the watchword of Realism, in season and out of season, and is therefore bound to be veracious.

Meanwhile one of the prettiest and most characteristic features of Curzola, an extensive ship-yard overshadowed by venerable trees, where half the trading-boats that ply in these waters are constructed, seems to have escaped the notice of the guide-book makers altogether. Nor have they cared to let their fancy "play" to any great extent about either Lissa or Meleda, though each of these islands has interesting associations. It was off the former that the first proud navy of United Italy sustained so crushing a defeat at the hands of Admiral Tegetthoff in 1866, the bodies that were recovered after that fierce engagement having been all interred in the peaceful Campo Santo there; while Meleda, the southernmost of the four islands, prefers a plausible claim to have been the scene of St. Paul's shipwreck. For are we not explicitly informed that the island to which he escaped was called Melita? And our hearts will henceforth swell with a new sympathy for the apostle to the Gentiles whenever we read that the disaster took place after he had been "driven up and down in Adria."

(To be continued.)

Harriet Waters Preston.

TESLA'S OSCILLATOR AND OTHER INVENTIONS.

AN AUTHORITATIVE ACCOUNT OF SOME OF HIS RECENT ELECTRICAL WORK.[1]

SKOBELEFF, the great Russian general, once said of the political conditions in Central Asia, that they changed every moment; hence the necessity for vigilance, no less the price of empire than of liberty. Thus changeful, also, is the aspect of that vast new electrical domain which the thought and invention of our age have subdued. They who would inform themselves expertly about it, in whatever respect, must ever keep up an attitude of strained attention. Its theoretical problems assume novel phases daily. Its old appliances ceaselessly give way to successors. Its methods of production, distribution, and utilization vary from year to year. Its influence on the times is ever deeper, yet one can never be quite sure into what part of the social or industrial system it is next to thrust a revolutionary force. Its fanciful dreams of yesterday are the magnificent triumphs of to-morrow, and its advance toward domination in the twentieth century is as irresistible as that of steam in the nineteenth.

Throughout this change there has prevailed a consistency of purpose: a steady aim has been leveled at definite goals; while useful arts in multitude attest the solidity of the work done. If, therefore, we find a tremendous outburst of activity at the very moment when, after twenty-five years of superlative productiveness, electricians were ready, with the reforming English statesman, to rest and be thankful, we may safely assume that electricity has reached another of those crucial points at which it becomes worth the while of the casual outside observer to glance at what is going on. To the timid and the conservative, even to many initiated, these new departures have indeed become exasperating. They demand the unlearning of established facts, and insist on right-about-faces that disregard philosophical dignity. The sensations of a dog attempting to drink sea-water after a lifetime spent on inland lakes are feeble compared with those of men who discover that electricity is quite other than the fluid which they have believed it to be from their youth up, and that actually there is no such thing as electricity or an electric current.

Electricity has, indeed, taken distinctively new ground of late years; and its present state of unrest — unsurpassed, perhaps, in other regions of research — is due to recent theory and practice, blended in a striking manner in the discoveries of Mr. Nikola Tesla,[2] who, though not altogether alone, has come to be a foremost and typical figure of the era now begun. He invites attention to-day, whether for profound investigations into the nature of electricity, or for beautiful inventions in which is offered a concrete embodiment of the latest means for attaining the ends most sought after in the distribution of light, heat, and power, and in the distant communication of intelli-

[1] The photographs reproduced in this article were taken, under the special direction of the inventor, by Tonnele & Co.

[2] A biographical sketch of Mr. Tesla, by the present writer, with portrait, appeared in THE CENTURY for February, 1894.—EDITOR.

gence. Any one desirous of understanding the trend and scope of modern electrical advance will find many clues in the work of this inventor. The present article discloses a few of the more important results which he has attained, some of the methods and apparatus which he employs, and one or two of the theories to which he resorts for an explanation of what is accomplished.

By a brief preliminary survey, we may determine our historical longitude and latitude, and thus ascertain a little more precisely where we are. It is necessary to recapitulate facts known and accepted. Let it, then, be remarked that aside from the theories and interpretations that have beset the science, electricity as an art has for three hundred years been directed chiefly to securing an abundant, cheap, efficient, and economical supply of the protean agency, be it what it may. Frictional machine, Leyden jar, coil, battery, magnet, dynamo, oscillator,— these are but the steps in a process as regular and well-defined as those which take us from the aboriginal cradling of gold out of river sands up to the refining of ore with all the appliances of modern mechanism and chemistry. Each stage in electrical evolution has seen the conquest of some hitherto unknown art — electrotherapy, telegraphy, telephony, electric lighting, electric heating, power transmission; yet each has had limitations set on it by the conditions prevailing. With a mere battery much can be done; with a magnet, still more; with a dynamo, we touch possibilities of all kinds, for we compel the streams, the coal-fields, and the winds to do us service: but with Mr. Tesla's new oscillator we may enlist even the ether-waves, and turn our wayward recruits into resistless trained forces, sweeping across continents of unimagined opportunity.

The dynamo, slowly perfected these fifty years, has rendered enormous benefits, and is destined to much further usefulness. But all that we learn now about it of any intrinsic value is to build it bigger, or to specialize it; and the moment a device reaches that condition of development, the human intellect casts about for something else in which the elements are to be subtler and less gross. Based upon currents furnished by modern dynamo-electric machines, the arc-light and the trolley-car seek to monopolize street illumination and transportation, while the incandescent lamp has preempted for exclusive occupancy the interiors of our halls and homes. Yet the abandonment of gas, horses, and sails is slow, because the dynamo and its auxiliaries have narrow boundaries, trespassing which, they cease to offer any advantage. We can all remember the high hopes with which, for example, incandescent lighting was introduced some fifteen years ago. Even the most cynical detractor of it will admit that its adoption has been quick and widespread; but as a simple matter of fact, to-day, all the lamps and all the lighting dynamos in the country would barely meet the needs of New York and Chicago if the two cities were to use no other illuminant than electricity. In all England there are only 1,750,000 incandescent lamps contesting for supremacy with probably 75,000,000 gas-burners, and the rate of increase is small, if indeed it exceeds that of gas. Evidently, some factor is wanting, and a new point of departure, even in mere commercial work, is to be sought, so that with longer circuits, better current-generating apparatus, and lamps that will not burn out, the popular demand for a pure and perfect light can be met. In power transmission, also, unsatisfied problems of equal magnitude crop up. "Is there any load that water cannot lift?" asked Emerson. "If there be, try steam; or if not that, try electricity. Is there any exhausting of these means?" None, provided that our mechanics be right.

It must not be supposed that the new electricity is iconoclastic. In the minds of a great many people of culture the idea prevails that invention is as largely a process of pulling down as of building up; and electricity, in spreading from one branch of industry to another, encounters the prejudice that always rebuffs the innovator. The assumption is false. It may be true that in the gladiatorial arena where the principles of science contend, one party or the other always succumbs and drags out its dead; but in the arts long survival is the law for all the appliances that have been found of any notable utility. It simply becomes a question of the contracting sphere within which the old apparatus is hedged by the advent of the new; and that relation once established by processes complex and long continued, capable even of mathematical determination, the two go on together, complementary in their adjustment to specific human needs. In its latest outgrowths, electrical application exemplifies this. After many years' use of dynamo-electric machinery giving what is known as a "continuous current," the art has reached the conclusion that only with the "alternating current" can it fulfil the later duties laid upon it, and accomplish the earlier tasks that remain untouched. With the continuous current we have learned the rudiments of lighting and power distribution. With the alternating current, manipulated and coaxed to yield its highest efficiency, we may solve the problems of aërial and marine navigation by electricity, operate large railway systems, transmit the energy of Niagara hundreds of miles, and, in Mr. Tesla's own phrase, "hook our machinery directly to that of Nature."

THE GENERATION OF CURRENT.

Let us see wherein lies the difference between these two kinds of currents. In all dynamos the generation of what we call electric current is effected by the whirling of coils of wire in front of magnets, or conversely. The wires that lead away from the machine and back to it to complete the necessary circuit, may be compared to a circle of troughs or to a pipe-line; the coils and magnets are comparable to pump mechanism; and the lamps or motors driven by the current, to fountains or faucets spaced out on the trough circle. This comparison is crudity itself, but it gives a fairly exact idea. The current travels along the surface of the wire rather than inside, its magnetic or ether whorls resembling rubber bands sliding along a lead-pencil. A machine that produces continuous current, dipping its wire coils or buckets into the magnetic field of force, has all its jets, as they come around to discharge themselves, headed one way, and complicated devices called "commutators" have been unavoidable for the purpose of "rectifying" them. A machine that produces alternating currents, on the contrary, has its jets thrown first into one end of the trough system, and then into the other, and therefore dispenses with the rectifying or commutating valves. On the other hand, it requires peculiar adjustment of its fountains and faucets to the streams rushing in either way. It is an inherent disadvantage of the continuous-current system that it cannot deliver energy successfully at any great distance at high pressure, and that therefore the pipe-line must be relatively as bulky as were the hollow wooden logs which were once employed for water-conduits in New York. The advantage of the alternating current is that it can be delivered at exceedingly high pressures over very slender wires, and used either at that pressure or at lower or higher ones, obtained by means of a "transformer," which, according to its use, answers both to the idea of a magnetic reducing valve, and to that of a spring-board accelerating the rapidity of motion of any object alighting on it. Obviously a transformer cannot return more than is put into it, so that it gives out the current received with less pressure but in greater volume, or raised in pressure but diminished in the volume of the stream. In some like manner a regiment of soldiers may be brought by express to any wharf, and transferred, Indian file, to a sailing barge or an ocean liner indifferently; but throughout the trip the soldiers will constitute the same regiment, and when picked up by another train across the ferry, the body, though there be loss by desertion and sickness, will retain its identity, even if the ranks are broken in filling the cars, and are reformed four abreast at the end of the journey.

ALTERNATING CURRENTS.

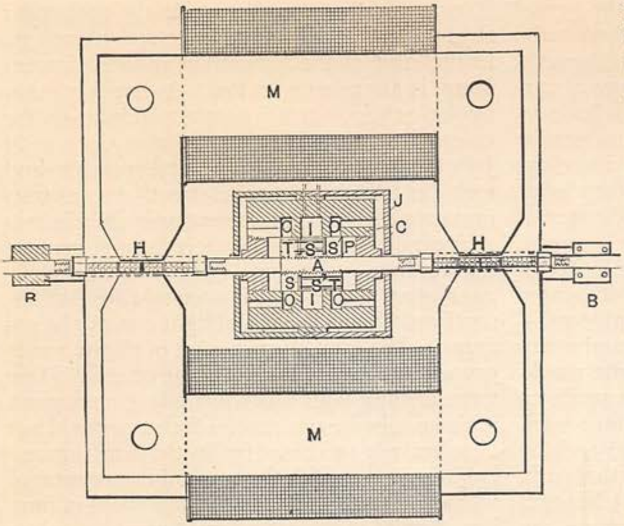
Let us, still recapitulating familiar facts, make the next step in our review of what is involved in the resort to alternating currents. It was stated above that the current-consuming devices such as motors, likened to fountains, needed peculiar adjustments to the inflow first from one side and then from the other. Not to put it at all too strongly, they would not work, and have largely remained inoperative to the present time. Lamps would burn, but motors would not run, and this fact limited seriously the adoption and range of the otherwise flexible and useful alternating current until Mr. Tesla discovered a beautiful and unsuspected solution of the problem, and thus embarked on one part of the work now revealing grander possibilities every day. The transmission of the power of Niagara has become possible since the discovery of the method. In his so-called "rotating magnetic field," a pulley mounted upon a shaft is perpetually running after a magnetic "pole" without ever being able to catch it. The fundamental idea is to produce magnetism shifting circularly, in contrast with the old and known phenomenon of magnetism in a fixed position. Those who have seen the patient animal inside the treadmill wheel of the well at Carisbrooke Castle can form an idea of the ingenuity of Mr. Tesla's plan.

Ordinarily, alternating-current generators, such as are now in common use, have a great number of projecting poles to cause the alternations of current, and hence their "frequency" is high — that is, the current makes a great many to-and-fro motions per second, and each ebb-and-flow in the circuit is termed the "period" or "frequency," one alternation being the rise from zero to maximum value and down to nothing again, and the other the same thing backward. If we ruled a horizontal straight line, and then drew a round-bellied Hogarth curve of beauty across it, the half of the curve above the line would be illustrative of the positive flow, the lower half of the negative flow; the top of one oval and the bottom of the other oval would be the positive and negative maxima respectively; and the point where the curve crossed the straight line would mark the instant when the current changes its direction. A swinging pendulum is an analogy favored by scientists in their endeavors to illustrate popularly the process of the generation of the alternating current. Each time the copper wire in the coils on the dynamo armature is rotated past the pole of the dynamo field, the currents in each coil follow this rise and fall; so that the number of the magnets and coils determines the period or frequency, as stated. The more numerous the magnets, and the faster the rotation of the coils, the quicker will be the ebbs and flows of current. But the character of the work to be done, and existing conditions, govern the rate at which the current is thus to be set vibrating; and no small amount of skill and knowledge enters here. The men who can predicate the right thing to do are still few and far between. The field has as yet been little explored. Moreover, in one of the deepest problems now engaging the thought of electrical engineers,—namely, the production of cheap light and cheap power by these new means,—opposite conditions pull different ways. Mr. Tesla made up his mind some time ago that for motor work it was better to have few frequencies; and the whole drift of power transmission is on that path, the frequency adopted for the work at Niagara being only twenty-five. But, as was natural, he ran through the whole scale of low and high frequencies, and soon discovered that for obtaining light, one great secret lay in the utilization of currents of high frequency and high potential. Some years ago, after dealing with the power problem as above described, Mr. Tesla attacked the light problem by building a number of novel alternating-current generators for the purpose, and attained with them alternations up to 30,000 per second. These machines transcended anything theretofore known in the art, and their currents were further raised in pressure by "step up" transformers and condensers. But these dynamos had their shortcomings. The number of the poles and coils could not be indefinitely increased, and there was a limit to the speed. To go to the higher frequencies, therefore, Mr. Tesla next invented his "disruptive discharge coil," which permitted him to reach remarkably high frequency and high pressure, and, what is more, to obtain these qualities from any ordinary current, whether alternating or continuous. With this apparatus he surprised the scientists both of this country and of Europe in a series of most interesting demonstrations. It is not too much to say that these experiments marked an epoch in electricity, yielding results which lie at the root of his later work with the oscillator in an inconceivably wider range of phenomena.

THE TESLA OSCILLATOR.

Up to this point we have been considering both continuous-current and alternating-current dynamos as driven by the ordinary steam-engine. Perhaps nine tenths of all the hundreds of thousands of dynamos in the world to-day are so operated, the remainder being driven by water-wheels, gas-engines, and compressed air. Now, each step from consuming the coal under the boilers that deliver steam to the engines, up to the glow of the filament in an incandescent lamp, is attended with loss. As in every other cycle that has to do with heat transformation, the energy is more or less frittered away, just as in July the load in an iceman's cart crumbles and melts in transit along the street. Actual tests prove that the energy manifesting itself as light in an incandescent lamp is barely five per cent. of that received as current. In the luminosity of a gas flame the efficiency is even smaller. Professor Tyndall puts the useful light-waves of a gas flame at less than one per cent. of all the waves caused by the combustion going on in it. If we were dealing with a corrupt city government, such wretched waste and inefficiency would not be tolerated; and in sad reality the extravagance is but on a par with the wanton destruction of whole forests for the sake of a few sticks of lumber. Armies of inventors have flung themselves on the difficulties involved in these barbaric losses occurring at every stage of the calorific, mechanical, and electric processes; and it is indeed likely that many lines of improvement have already been compelled to yield their utmost, reaching terminal forms. A moment's thought will show that one main object must be the elimination of certain steps in the transfer of the energy; and obviously, if engine and dynamo both have large losses, it will be a gain to merge the two pieces of apparatus. The old-fashioned electric-light station or street-railway power-house is a giddy maze of belts and shafting; in the later plants engine and dynamo are coupled directly together on one base. This is a notable stride, but it still leaves us with a dynamo in which some part of the wire wound on it is not utilized at every instant, and with an engine of complicated mechanism. The steam-cylinder, with its piston, is the only thing actually doing work, and all the rest of the imposing collection of fly-wheel, governor-balls, eccentrics, valves, and what not, is for the purpose of control and regulation.

In his oscillator Mr. Tesla, to begin with, has stripped the engine of all this governing mechanism. By giving also to the coils in which the current is created as they cut the "lines of force" of the magnets, a to-and-fro or reciprocating motion, so that the influence on them is equal in every direction, he has overcome the loss of the idle part of the wire experienced in rotating armatures; and, moreover, greatest achievement of all, he has made the currents regulate the mechanical motions. No matter how close the governing of the engine that drives the ordinary dynamo, with revolving armature, there is some irregularity in the generation of current. In the Tesla oscillator, if its inventor and the evidence of one's eyes may be



This form of oscillator has been used for experimental purposes, with air as the propelling force. It illustrates the principle of operation further developed in the machine shown in perspective in Fig. 2, in which steam is used as the propelling force. Outermost of all is seen the magnetic frame M M, built up of thin sheet-iron. This frame is wound with energizing coils of wire (indicated in hatchwork), as in ordinary electromagnets, and thus an intense magnetic "field of force" is concentrated on each side in the vicinity of H H, where are seen in dotted line two pairs of armature coils moving between the jaws of the inclosing electromagnets formed by M M. These armature coils, at H H, are supported on the shaft A, which runs through the piston P, and they, with the shaft, have additional bearings in the boxes B B at each end of the mechanism. The piston P is fitted into the hollow of the cylinder C, which in turn is inclosed by a jacket J, the latter serving chiefly to deaden the sound caused in working. The piston P is provided with channel-ports O O and I, which extend all around its inside surface. I is the inlet for the propelling compressed air, and O O are the outlets for the expanded air after its work is done at each stroke. In the piston P there are also two slots S S′, while tubes T T are screwed into holes drilled in the piston. These tubes T T establish communication between the slots S S′ and the chambers seen on each side of the piston, each chamber being thus connected with the slot which is remote from it. Now, the compressed air being brought through a delivery-pipe to the inlet I, with the piston P in the position it occupies in the diagram, and the shaft A being slightly touched so as to slide it a little to the left, the compressed air rushes through the slot S′ and its communicating tube T, out into the chamber on the left of the piston. The pressure thus encountered by the piston on the left, from the expanding air, drives it back toward the right. Owing to its inertia, the piston thus impelled overshoots the position of equilibrium, allowing in this way the next supply of compressed air to rush from the inlet I into slot S and its tube T, and from them into the chamber on the right of the piston. Meantime the communication to the left-hand chamber is cut off, and the now expanded air there, having instantly done its work, escapes through the channel-port outlet O. As the piston now travels back from the right on the return stroke, a precisely similar operation takes place on the right-hand side of it, due to the expanding of the compressed air there and its subsequent quick escape as exhaust. In this manner, so long as compressed air is supplied, oscillation of the piston P is maintained at a very high rate, and with highest accuracy. The coils of fine wire mounted on shaft A, to which the piston P is firmly attached, are thus rapidly thrust to and fro by the shaft across the faces of, and in the space inclosed by, the jaws of the electromagnets at H H. In this manner they cut the so-called "lines" of the intense "field of force" at those two points, and currents are thus engendered in them, which are led off to the exterior circuit for use. These currents are "alternating" in their character, and are of high regularity. The maintenance of constancy of oscillation on the part of the piston P is also due to the reaction and steadying effect of this electromagnetic part of the combination. The "fitting-boxes" at the ends of the cylinder C inclosing the piston project a carefully determined distance into the cylinder, thus setting limits to the length of the stroke. It will be obvious to those familiar with such matters that steam could also be used in this type of oscillator, with slight adjustments.

FIG. I. DIAGRAM OF WORKING PARTS OF EARLY FORM OF TESLA OSCILLATOR, AS IF SEEN FROM ABOVE, IN SECTION. (FROM "THE ELECTRICAL ENGINEER," BY PERMISSION.)

believed, the vibrations of the current are absolutely steady and uniform, so that one could keep the time o' day with the machine about as well as with a clock. It was this superlative steadiness of the vibration or frequency that Mr. Tesla aimed at, for one thing. The variations caused by the older apparatus might be slight, but minute errors multiplied by high rates of occurrence soon become perceptible, and militate against desirable uniformity and precision of action. Back of the tendencies to irregularity in the old-fashioned electrical apparatus were the equal or greater tendencies in the steam-engine; and over and above all were the frightful losses due to the inefficient conversion in both of the power released from the fuel under the boiler generating the steam.

Gain in one direction with a radical innovation usually means gain in many others, through a growing series. I confess I do not know which of the advantages of the oscillator to place first; and I doubt whether its inventor has yet been able to sit down and sum up all the realities and possibilities to which it is a key. One thing he does: he presses forward. Our illustration, Fig. 2, shows one of his latest forms of oscillator in perspective, while the diagram, Fig. 1, exhibits the internal mechanism of one of the early forms. Fig. 2 will serve as a text for the subsequent heads of discourse. The steam-chest is situated on the bed-plate between the two electromagnetic systems, each of which consists of field coils between which is to move the armature or coil of wire. There are two pistons to receive the impetus of the incoming steam in the chest, and in the present instance steam is supplied at a pressure of 350 pounds, although as low as 80 is also used in like oscillators, where steam of the higher pressure is not obtainable. We note immediately the absence of all the governing appliances of the ordinary engine. They are non-existent. The steam-chest *is* the engine, bared to the skin like a prize-fighter, with every ounce counting. Besides easily utilizing steam at a remarkably high pressure, the oscillator holds it under no less remarkable control, and, strangest of all, needs no packing to prevent leak. It is a fair inference, too, that, denuded in this way of superfluous weight and driven at high pressure, the engine must have an economy far beyond the common. With an absence of friction due to the automatic cushioning of the light working parts, it is also practically indestructible. Moreover, for the same pressure and the same piston speed the engine has about one thirtieth or one fortieth of the usual weight, and occupies a proportionately smaller space. This diminution of bulk and area is equally true of the electrical part. The engine-pistons carry at their ends the armature coils, and these they thrust reciprocatively in and out of the magnetic field of the field coils, thus generating current by their action.

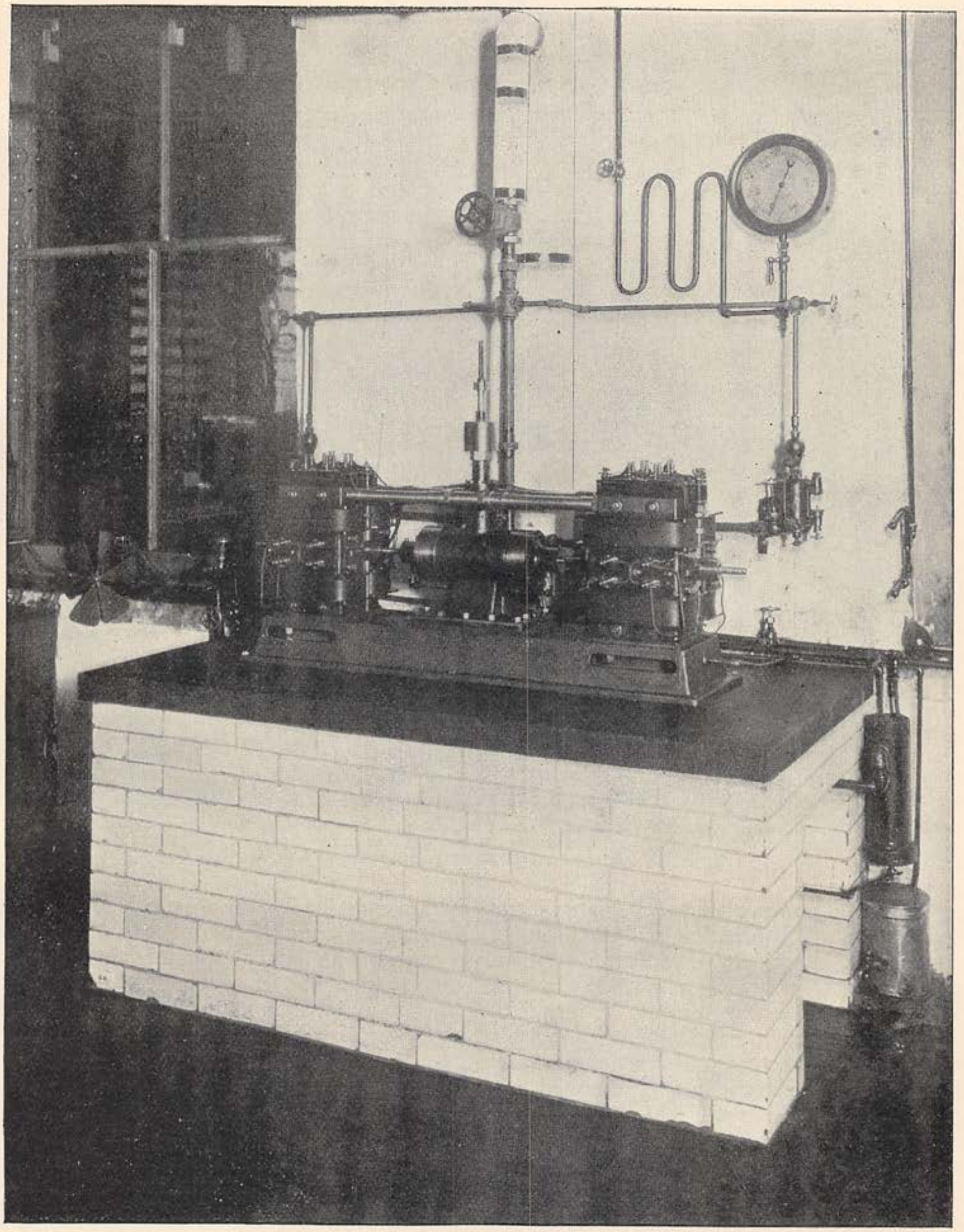


FIG. 2. LATEST FORM OF TESLA OSCILLATOR, COMBINING IN ONE MECHANISM DYNAMO AND STEAM-ENGINE.

If one watches any dynamo, it will be seen that the coils constituting the "armature" are swung around in front of magnets, very much as a turnstile revolves inside the barricading posts; and the current that goes out to do work on the line circuit is generated inductively in the coils, because they cut lines of influence emanating from the ends of the magnets, and forming what has been known since Faraday's time as the "field of force." In the Tesla oscillator, the rotary motion of the coils is entirely abandoned, and they are simply darted to and fro at a high speed in front of the magnets, thus cutting the lines of the "field of force" by shooting in and out of them very rapidly, shuttle-fashion. The great object of cutting as many lines of an intense field of force as swiftly, smoothly, regularly, and economically as possible is thus accomplished in a new and, Mr. Tesla believes, altogether better way. The following description of remarkable new phenomena in electricity will justify him in regard-

FIG. 3. FIRST PHOTOGRAPH EVER TAKEN BY PHOSPHORESCENT LIGHT. THE FACE IS THAT OF MR. TESLA, AND THE SOURCE OF LIGHT IS ONE OF HIS PHOSPHORESCENT BULBS. TIME OF EXPOSURE, EIGHT MINUTES. DATE OF PHOTOGRAPH JANUARY, 1894.

ing the oscillator as an extremely valuable instrument of research, while time will demonstrate its various commercial and industrial benefits.

Incidentally it may be remarked that the crude idea of obtaining currents by means of a coil or a magnetic core attached to the piston of a reciprocating steam-engine, is not in itself an entire novelty. It may also be noted that steam-turbines of extremely high rotative velocity are sometimes used instead of slow-moving engines to drive dynamos. But in the first class of long-abandoned experiments no practical result of any kind was ever reached before by any sort of device; and in the second class there is the objection that the turbine is driven by means of isolated shocks that cannot be overcome by any design of the blades, and which frustrate any attempts to perform work of the kind now under survey. What we are dealing with here is a dual, interacting machine, half mechanical, half electrical, of smallest bulk, extremely simple, utilizing steam under conditions unquestionably of the highest efficiency, its vibrations independent of load and pressure, delivering currents of the greatest regularity ever known for practical work or research. That such a combination should produce electricity for half the consumption of steam previously necessary with familiar apparatus in equivalent results, need not surprise us; yet think how much a saving of that kind would mean in well-nigh every industry consuming power!

THE OSCILLATOR AND THE PRODUCTION OF LIGHT.

HAVING obtained with the oscillator currents of high potential, high frequency, and high regularity, what shall be done with them? Mr. Tesla having already grappled successfully with the great difficulties of long distance power transmission, as narrated above, has first answered that question by boldly assailing the problem of the production of light in a manner nearer, perhaps, to that which gives us sunshine than was ever attempted before. Between us and the sun stretches the tenuous, sensitive ether, and every sensation of light that the eye experiences is caused by the effect of five hundred trillions of waves every second impressed on the ether by the molecular energy of the sun traveling along it rhythmically. If the waves have a lower frequency than this 500,000,000,000,000, they will chiefly engender heat. In our artificial methods of getting light we imitatively agitate the ether so poorly that the waves our bonfires set up rarely get above the rate at which they become sensible to us in heat, and only a few waves attain the right pitch or rapidity to cause the sensation of light. At the upper end of the keyboard of vibration of the ether is a high, shrill, and yet inaudible note,—"light,"—which we want to strike and to keep on striking; but we fumble at the lower, bass end of the instrument all the time, and never touch that topmost note without wasting the largest part of our energy on the intermediate ones, which we do not at all wish to touch. Light (the high note) without heat (the lower notes) is the desideratum. The inefficiency of the gas flame has been mentioned. In the ordinary incandescent lamp the waste is not so great; but even there the net efficiency of any one hundred units of energy put into it as electric current is at the most five or six of light, the waste occurring in the process of setting the molecules of the filament and the little air left in the bulb into the state of vibration under which they must work before they can throw out energy-waves on the ether, which will be conveyed to us through the glass of the bulb by the ether as light rather than as heat. The glass is as unconfining to the ether as a coarse sieve is to water.

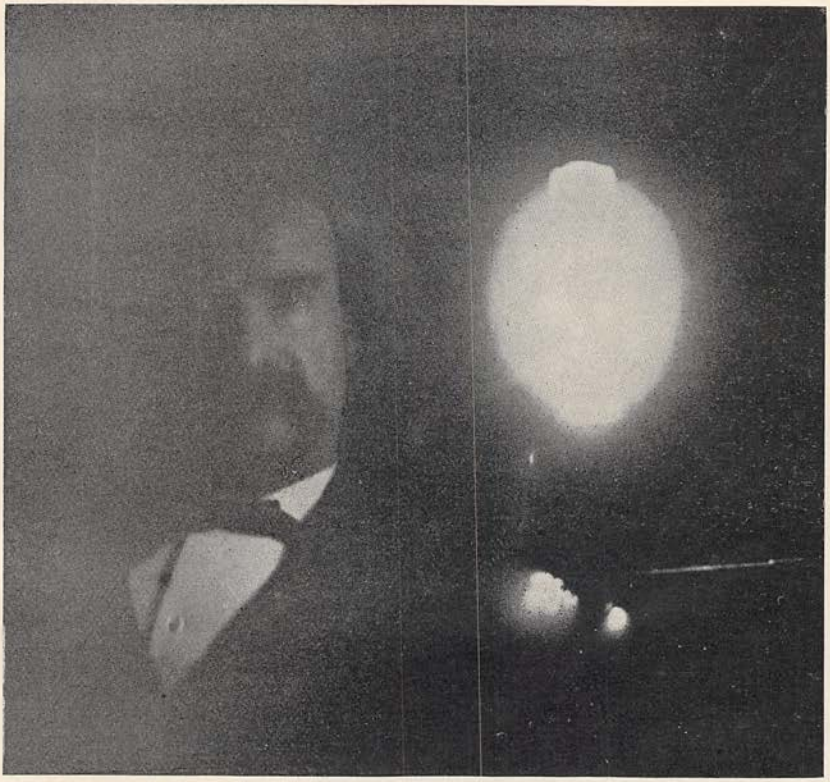


FIG. 4. PHOSPHOGRAPH OF MR. CLEMENS (MARK TWAIN), TAKEN IN THE TESLA LABORATORY JANUARY, 1894. TIME OF EXPOSURE, TEN MINUTES.

Now Mr. Tesla takes his currents of high frequency and high potential, subjects the incandescent lamp to them, and, skipping some of those intermediate wasteful heat stages of lower wave vibration experienced in the old methods, gets the ether-charged molecules more quickly into the intensely agitated condition necessary to yield light. Using his currents, produced electromagnetically, as we have seen, to load each fugitive molecule with its charge, which it receives and exercises electrostatically, he gets the ether medium into a state of excitement in which it seems to become capable of almost anything. In one of his first lectures, Mr. Tesla said:

Electrostatic effects are in many ways available for the production of light. For instance, we may place a body of some refractory material in a closed, and preferably in a more or less air-exhausted, globe, connect it to a source of high, rapidly alternating potential, causing the molecules of the gas to strike it many times a second at enormous speeds, and in this way, with trillions of invisible hammers, pound it until it gets incandescent. Or we may place a body in a very highly exhausted globe, and by employing very high frequencies and potentials maintain it at any degree of incandescence. Or we may disturb the ether carried by the molecules of a gas, or their static charges, causing them to vibrate or emit light.

These anticipatory statements are confirmed to-day by what Mr. Tesla has actually done in one old way revolutionized, and in three new ways: (1) the incandescence of a solid; (2) phosphorescence; (3) incandescence or phosphorescence of a rarefied gas; and (4) luminosity produced in a gas at ordinary pressure.

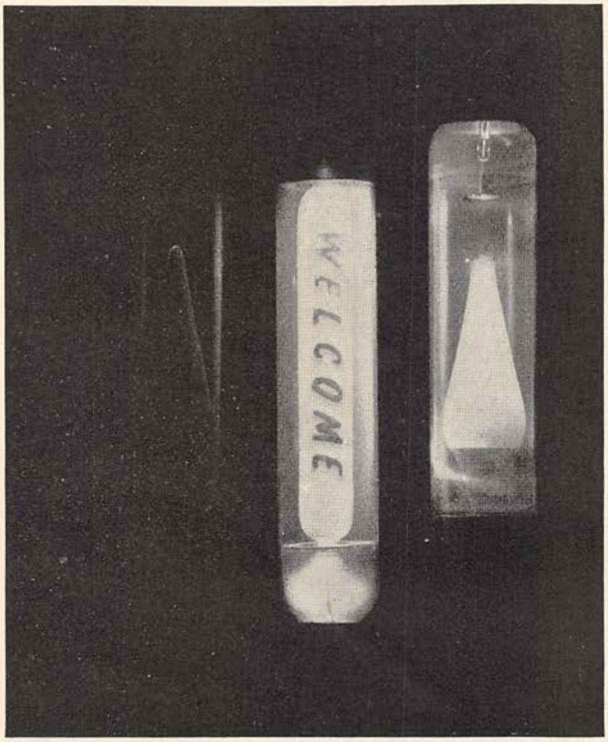


FIG. 5. THREE PHOSPHORESCENT BULBS UNDER TEST FOR ACTINIC VALUE. PHOTOGRAPHED BY THEIR OWN LIGHT.

LAMPS WITH BUTTONS OR BARS IN PLACE OF FILAMENTS.

Taking lamps in the first category, it may be stated that it had been commonly supposed that the light-giving conductor in the lamp, to be efficient and practical, should be fine; hence the name "filament" given to the carbon loop in such lamps. But with the Teslaic currents the resistance or friction of the filament to the flow of current does not count for anything: the filament may just as well be short and thick, for it will rapidly reach and steadily maintain proper incandescence by the passage of a small current of the right high frequency and potential. An action is set up as the result of which the filament is hit millions of times a second by the bombardment of the molecules around it in a merciless ring of tormentors. The vibrations of the current in similar manner will cause the infinite jostling of the molecules of solid and gas against a small polished carbon or metallic button or bar in a lamp, and brilliant light is also obtainable in this way.

LIGHT AND PHOTOGRAPHS WITH TESLA PHOSPHORESCENT BULBS.

In the field of lighting by phosphorescence we reach hitherto untrodden ground. Phosphorescent light has been associated with the idea of "cold light," or the property of becoming luminous with the omission of the intermediate step of combustion, as commonly understood. As a physical action, we know it in the light of the firefly, which Professor S. P. Langley rates at an efficiency of 100 per cent., all its radiations lying within the limits of the visible spectrum. By means of the Teslaic currents phosphorescent light strong enough even to photograph by has been obtained; and Fig. 3, representing the inventor himself, is the first portrait or photograph of any kind ever taken by phosphorescent light. A bulb whose light-giving member is coated with sulphide of zinc treated in a special way was rendered phosphorescent by means of current obtained from a high-frequency transformer coil. The current used was alternated or oscillated about 10,000 times per second. The exposure was about eight minutes.

Fig. 4, of Mr. Clemens (Mark Twain), was taken a few weeks later — early in 1894 — with the aid of the same bulb, and with an exposure of about ten minutes. In order to test more closely the actinic value of phosphorescent light, some bulbs subject to high-frequency currents were photographed, or, if we may coin a new word, "phosphographed," with a somewhat longer exposure. They are shown in Fig. 5. The right-hand, bright pair utilize sulphide of zinc in some form for luminosity. The third bulb, seen faintly to the left of them, has a coating of sulphide of calcium. Although, judged by the eye, it glowed with a brightness fully equal to that of the other two, the actinic value was

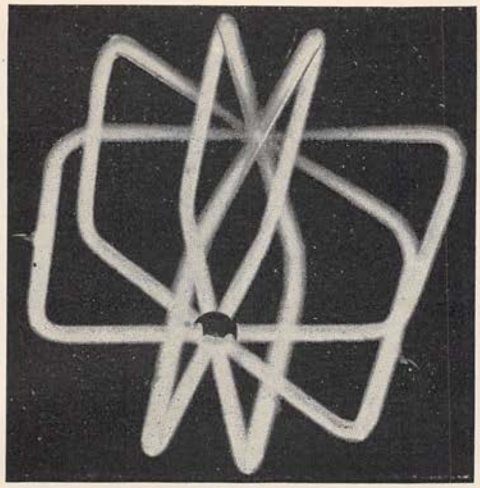


FIG. 6.

FIGS. 6, 7, AND 8 ARE TESLA TUBES OF DIFFERENT FORMS IN WHICH LIGHT IS OBTAINED WITHOUT FILAMENT OR COMBUSTION. (PHOTOGRAPHED BY THEIR OWN LIGHT.)

evidently much less. It is, perhaps, needless to say that these demonstrations invite to an endless variety of experiments, in which investigators will find a host of novel phenomena awaiting them as to phosphorescence and fluorescence produced with electrical currents.

LIGHT FROM EMPTY BULBS IN FREE SPACE.

THE third and fourth classes of lighting enumerated above as obtained by Teslaic currents are those caused by the incandescence or phosphorescence of a rarefied gas and the luminosity of a gas at ordinary pressure. We get pure, beautiful light without any filament or any combustion. In Figs. 6, 7, and 8 we have tubes or bulbs by means of which some of these interesting phenomena are obtained and illustrated. The bulbs shown are more or less exhausted of air. In the case of Figs. 6 and 7 the glass of the tubes is the ordinary German glass. In Fig. 8, uranium glass—green—was employed. This last was held in the hand while a photograph was taken of it by its own light; whence the unsteadiness of the negative. To obtain the beautiful illumination seen in all three, the bulbs were simply approached within a few inches of the terminal of a high-frequency coil or transformer. Just here it may be pointed out that the lamps are spoken of as unattached, in free space. Ordinary incandescent lighting is done, as everybody knows, with the lamps' bases firmly attached to the two current-bearing wires. Even where the lamps have been used on the ordinary alternating circuits in which the transformer is employed to "step down," or reduce, for safe use, the higher-tension current brought to it by the wire from the dynamo, the lamps have to be attached to the "secondary" wires of the coil so as to make a closed circuit for them. But as we rise in the frequency of the current, as we leave behind the electrodynamic conditions for the electrostatic ones, so we free ourselves from the restrictions and limitations of solid wires for the conveyance of the effects sought, until at last we reach a point where all the old ideas of the necessity of a tangible circuit vanish. It is all circuit if we can properly direct the right kind of impulses through it. As Mr. Tesla long ago pointed out, most of the experiments usually performed with a static machine of glass plates can also be performed with an induction-coil of wire if the currents are alternated rapidly enough; and it is in reality here that Mr. Tesla parts company with other distinguished workers who have fixed their attention merely on the results attainable with electrodynamic apparatus. Before passing on, let us quote the inventor himself:

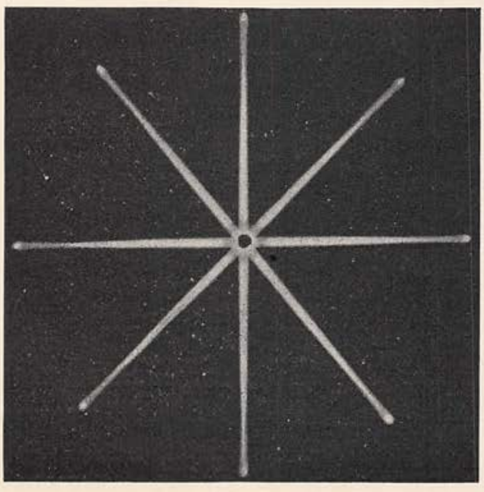


FIG. 7.

FIG. 8.

Powerful electrostatic effects are a *sine quâ non* of light production on the lines indicated by theory. Electromagnetic effects are primarily unavailable, for the reason that to produce the required effects

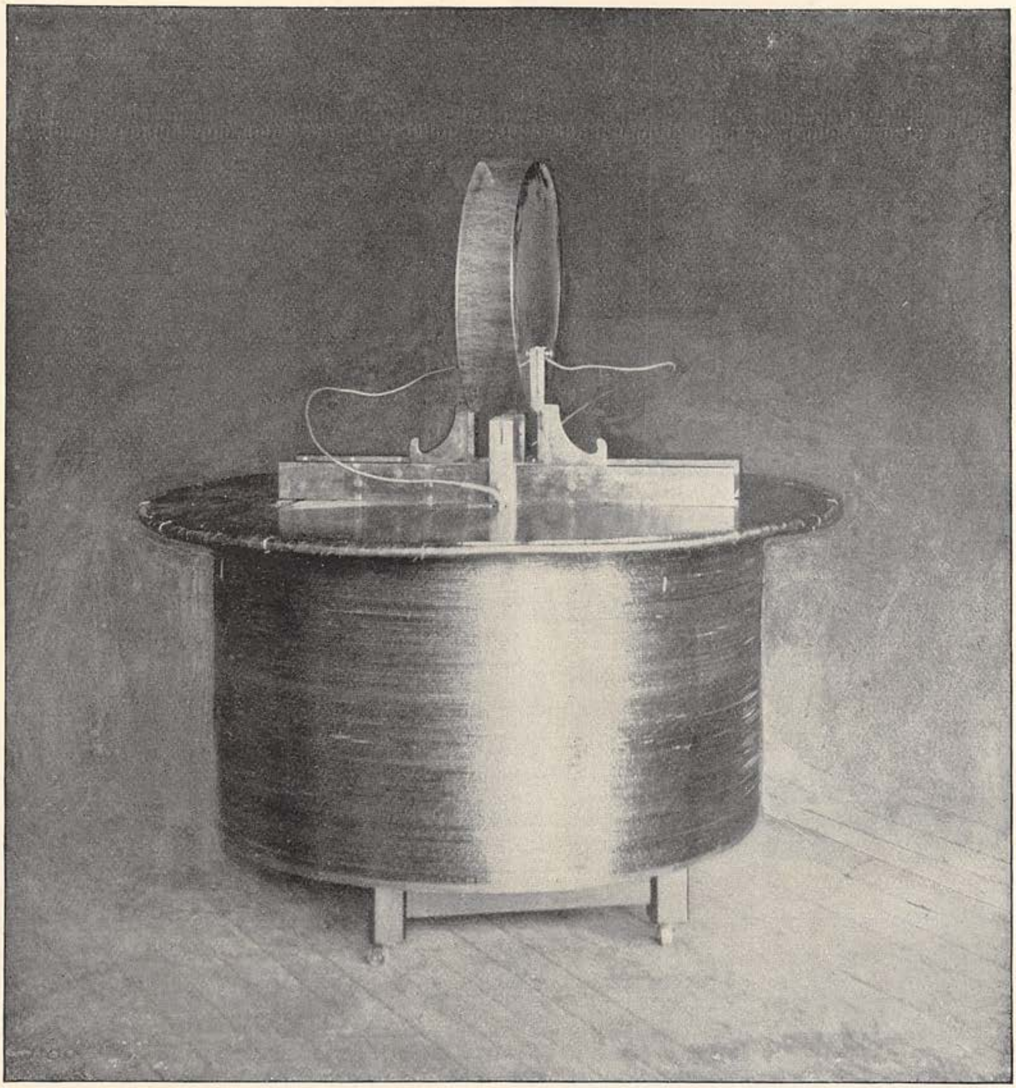


FIG. 9. EXPERIMENT SHOWING PLAY OF ELECTRIC SPARKS BETWEEN CONDENSER PLATES, PRODUCED BY ELECTRIC CHARGE. THE COIL, STANDING IN THE CENTER OF A LARGE ROOM, IS UNCONNECTED WITH THE ENERGIZING CIRCUIT. (FROM FLASH-LIGHT PHOTOGRAPH.)

we would have to pass the current impulses through a conductor which, long before the required frequency of the impulses could be reached, would cease to transmit them. On the other hand, electromagnetic waves many times longer than those of light, and producible by sudden discharge of a condenser, could not be utilized, it would seem, unless we availed ourselves of their effect upon conductors as in the present methods, which are wasteful. We could not affect by means of such waves the static molecular or atomic charges of a gas, and cause them to vibrate and to emit light. Long transverse waves cannot, apparently, produce such effects, since excessively small electromagnetic disturbances may pass readily through miles of air. Such dark waves, unless they are of the length of true light-waves, cannot, it would seem, excite luminous radiation in a Geissler tube, and the luminous effects which are producible by induction in a tube devoid of electrodes, I am inclined to consider as being of an electrostatic nature. To produce such luminous effects straight electrostatic thrusts are required; these, whatever be their frequency, may disturb the molecular charges and produce light.

EFFECTS WITH ATTUNED BUT WIDELY SEPARATED CIRCUITS.

A FEW experiments performed in Mr. Tesla's laboratory workshop afford an idea of the flexibility of the methods by which powerful electrostatic effects are produced across many feet of intervening space. The workshop is a room about forty by eighty feet, and ten or twelve feet high. A circuit of small cable is carried around it from the terminals of the oscillator. In the center of the clear, open space is placed a coil, wound drum fashion, three or four feet high, and unconnected with the current source save through the medium of the atmosphere. The coil is provided, as shown in the picture, with two condenser plates for adjustment, standing up like cymbals. The plates act after the manner of a spring, and the coil is comparable to an electromagnetic weight. The system of apparatus in the middle of the room has therefore a certain period of vibration, just as though it were a tuning-fork, or a sheet of thin resonant glass. Around the room, over the cable, there are sent from the oscillator electrical current vibrations. By carefully adjusting the condenser plates so that the periodicity or swing of the induced current is brought into step with that of the cable currents, powerful sparks are made to pour across between the plates in the dense streams shown in Fig. 9. In this manner it is easy to reach tensions as high as 200,000 and 300,000 volts.

No one who has witnessed these significant experiments can fail to be impressed with the evidence of the actuality of a medium, call it ether or what you will, which in spite of its wonderful tenuity is as capable of transmitting energy as though it were air or water. Still more impressive to a layman, perhaps, is the confidence and easy precision with which these fine adjustments are brought about.

In Fig. 10 there is a similar coil, in the middle of the same room, which has been so adjusted to the vibrations sent around the shop that an ordinary sixteen-candle-power incandescent lamp is well lighted up.

Fig. 11 pursues this a little further. Above the coil a circle of wire is held by an observer, and an incandescent lamp is attached to the circle. As before, the vibration of the ether in the coil is brought into harmony with the vibrations emitted from the cable. The inductive effect upon the circle held loosely in free space by the observer is so pronounced that the lamp is immediately lighted up, though it may be connected with but one terminal wire, or with two. A 100-volt lamp is used, requiring when employed ordinarily more than one tenth of a horse-power right off the connecting circuit wires direct from the dynamo to bring it up to proper illuminating value. Hence, as will be seen, there is actual proof here of the transmission of at least that amount of energy across a space of some twenty feet and into the bulb by actually no wire at all. This need not surprise us when we remember that on a bright day the ether delivers steadily from the sun a horse-power of energy to every seven square feet of the earth's

FIG. 10. EXPERIMENT SHOWING THE LIGHTING UP OF AN ORDINARY INCANDESCENT LAMP, AT A DISTANCE, THROUGH THE INFLUENCE OF ELECTRIFIED ETHER-WAVES. (FROM FLASH-LIGHT PHOTOGRAPH.)

surface toward it: so great is its capacity for transmitting energy. Mr. Tesla with his "electrostatic thrusts" has simply learned the knack of loading electrically on the good-natured ether a little of the protean energy of which no amount has yet sufficed to break it down or put it out of temper. We may assume either an enormous speed in what may be called the transmitting wheelwork of the ether, since the weight is inconceivably small; or else that the ether is a mere transmitter of energy by its well-nigh absolute incompressibility.

CURIOUS "IMPEDANCE" PHENOMENON.

IN Fig. 12 we have another remarkable experiment illustrated. Standing over the coil in the center of the room, the observer holds a hoop of stout wire in his hand. One or more lamps are connected with two points on the wire, so that the lamps are "short-circuited" by the short bar of wire. The vibrations are, however, so extremely rapid that in spite of the opposite terminals being united in this way, the current does not flow past them neglectfully, in the apparently easier path, as it should, but brings them to a bright incandescence. We have here an example of what is known as "impedance" phenomena, in which the current is oddly choked back at certain points and not at others. Under the conditions of "impedance," the best electrical conductor loses its property of conducting, and behaves like a highly resisting substance. Elaborating further these experimental results, Mr. Tesla shows that a gas — a perfect non-conductor under ordinary circumstances — may be more conductive than the best copper wire, provided the currents vibrate rapidly enough. The fantastic side of this phenomenon he touched on playfully once by suggesting that perchance in such wise we might some day utilize gas to convey electricity, and the old gas-pipe to insulate it.

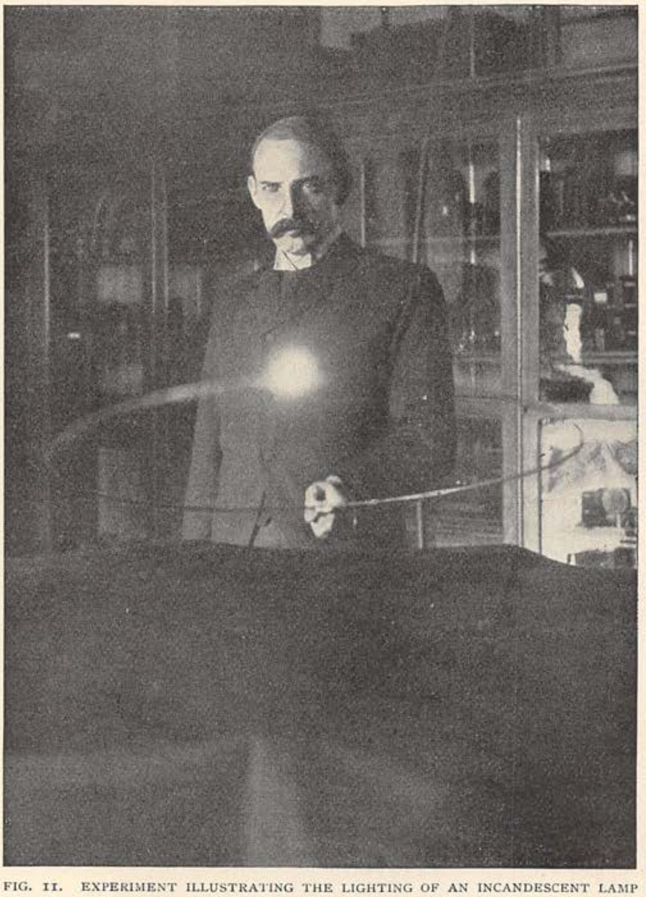


FIG. 11. EXPERIMENT ILLUSTRATING THE LIGHTING OF AN INCANDESCENT LAMP IN FREE SPACE BY INDUCTION FROM COIL BELOW, ENERGIZED BY DISTANT CIRCUIT AROUND THE ROOM. THE LOOP OF WIRE CARRYING THE LAMP IS HELD BY MR. MARION CRAWFORD. (FROM FLASH-LIGHT PHOTOGRAPH.)

LAMPS LIGHTED BY CURRENTS PASSED THROUGH THE HUMAN BODY.

IN Fig. 13 a most curious and weird phenomenon is illustrated. A few years ago electricians would have considered it quite remarkable, if indeed they do not now. The observer holds a loop of bare wire in his hands. The currents induced in the loop by means of the "resonating" coil over which it is held, traverse the body of the observer, and at the same time, as they pass between his bare hands, they bring two or three lamps held there to bright incandescence. Strange as it may seem, these currents, of a voltage one or two hundred times as high as that employed in electrocution, do not inconvenience the experimenter in the slightest. The extremely high tension of the currents which Mr. Clemens is seen receiving prevents them from doing any harm to him.

TRANSMISSION OF INTELLIGENCE BY ATTUNED OR "RESONATING" CURRENTS.

REFERENCE has been made to the "resonating" quality of the circuits and coils. It would be

FIG. 12. SIMILAR EXPERIMENT, ILLUSTRATING THE PHENOMENON OF IMPEDANCE. THE LOOP OF WIRE, CARRYING TWO LAMPS, IS HELD BY MR. JOSEPH JEFFERSON. (FROM FLASH-LIGHT PHOTOGRAPH.)

wearisome, and indeed is not necessary, here to dwell on the difficulty often experienced in establishing the relation of "resonance," and the instantaneity with which it can be disturbed. It may be stated, in order to give some idea of the conditions to be observed in these experiments, that when an electric circuit is traversed by a rapidly oscillating current which sets up waves in the ether around the wire, the effect of these waves upon another circuit situated at some distance from the first can be largely varied by proper adjustments. The effect is most pronounced when the second circuit is so adjusted that its period of vibration is the same as that of the first. This harmonizing is deftly accomplished by varying either of the two elements which chiefly govern the rapidity of the vibration, viz., the so-called "capacity" and the "self-induction." Whatever the exact process may be, it is clear that these two quantities in their effect answer almost directly to what are known in mechanics as pliability and as weight or inertia. Attach to a spring a weight, and it will vibrate at a certain rate. By changing the weight, or modifying the pliability of the spring, any period of vibration is obtainable. In very exact adjustments, minute changes will completely upset the balance, and the very last straw of fine wire, for example, in the induction-coil which gives the self-induction will break the spell. As Mr. Tesla has said, it is really a lucky thing that pure resonance is not obtainable; for if it were, all kinds of dangers might lie in store for us by the increasing oscillations of every kind that would be set up. It will, however, have been gathered that if one electrical circuit can be tuned to another effectively, we shall need no return wire, as heretofore, for motors or for lights, the one wire being, if anything, better than two, provided we have vibration of the right value; and if we have that, we might get along without any wires or any "currents." Here again we must quote Mr. Tesla:

In connection with resonance effects and the problem of transmission of energy over a single conductor, I would say a few words on a subject which constantly fills my thoughts, and which concerns the welfare of all. I mean the transmission of intelligible signals, or perhaps even power, to any distance without the use of wires. I am becoming daily more convinced of the practicability of the scheme; and though I know full well that the majority of scientific men will not believe that such results can be practically and immediately realized, yet I think that all consider the develop-

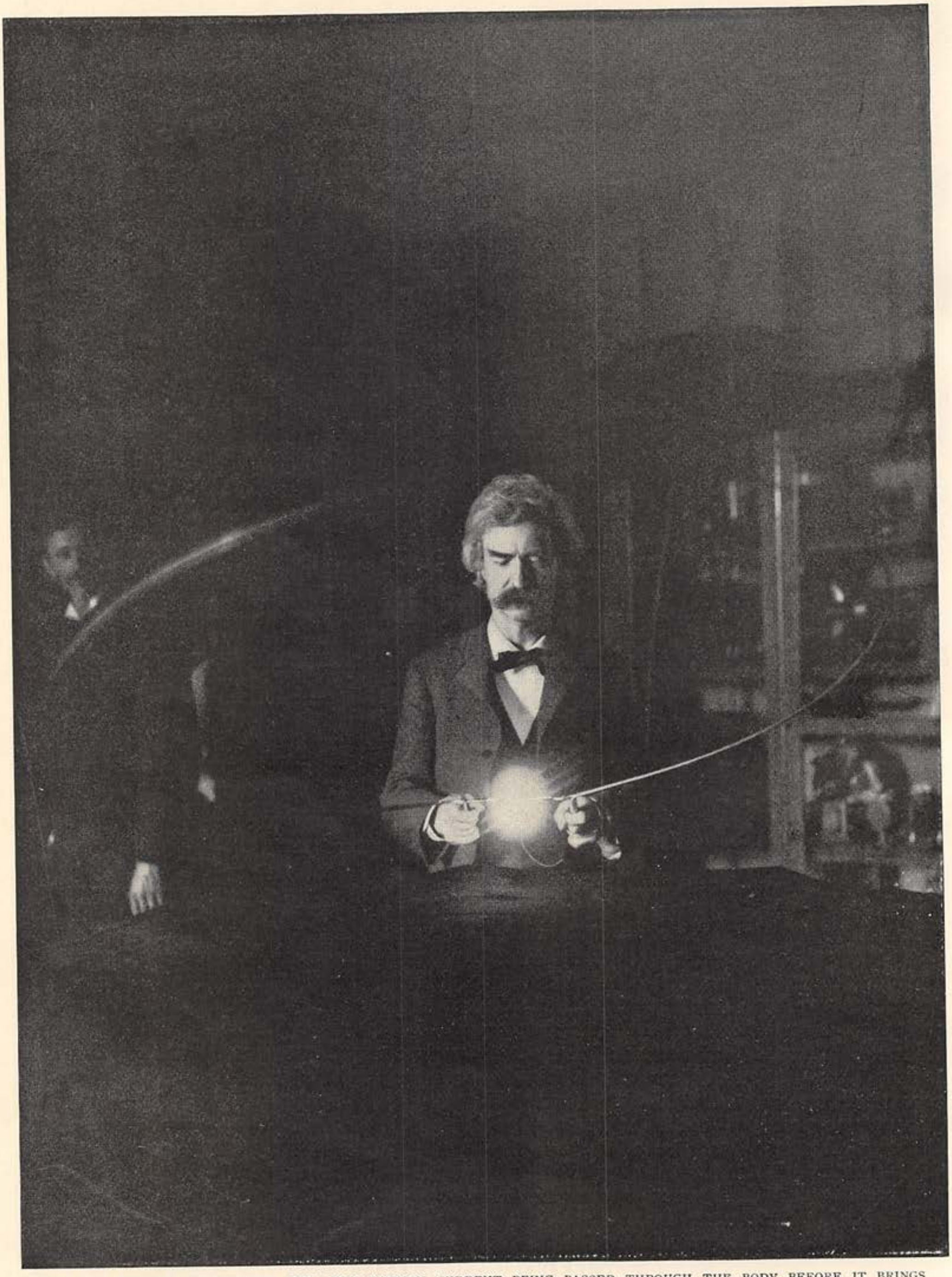


FIG. 13. SIMILAR EXPERIMENT, THE HIGH-TENSION CURRENT BEING PASSED THROUGH THE BODY BEFORE IT BRINGS THE LAMPS TO INCANDESCENCE. THE LOOP IS HELD OVER THE RESONATING COIL BY MR. CLEMENS (MARK TWAIN). (FROM A FLASH-LIGHT PHOTOGRAPH.)

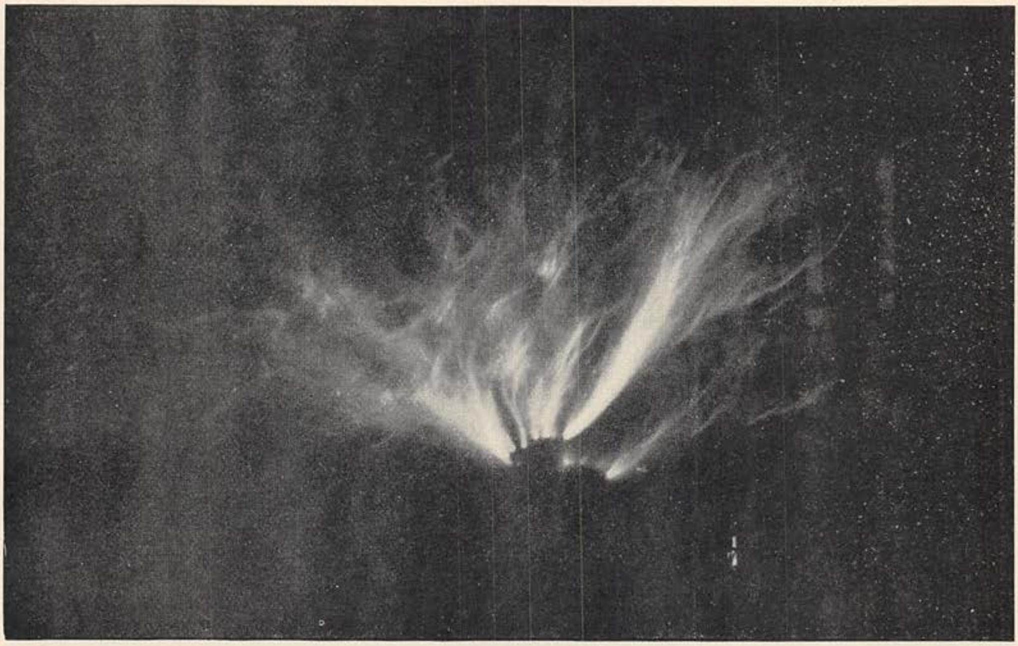


FIG. 14. EFFECT OF ELECTRICAL DISCHARGE FROM THE EARTH BY TESLA COIL. (PHOTOGRAPHED BY ITS OWN LIGHT.)

ments of recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering which must be carried out some day. The idea of transmitting intelligence without wire is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far; but I do firmly believe that it is practicable to disturb by means of powerful machines the electrostatic condition of the earth, and thus transmit intelligible signals and perhaps power. In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why, then, not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile-posts the earth may appear very large; but to that happiest of all men, the astronomer, who gazes at the heavens, and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician; for when he considers the speed with which an electric disturbance is propagated through the earth, all his ideas of distance must completely vanish. A point of great importance would be first to know what is the capacity of the earth, and what charge does it contain of electricity.

DISTURBANCE AND DEMONSTRATION OF THE EARTH'S ELECTRICAL CHARGE.

PART of Mr. Tesla's more recent work has been in the direction here indicated; for in his oscillator he has not simply a new practical device, but a new implement of scientific research. With the oscillator, if he has not as yet actually determined the earth's electrical charge or "capacity," he has obtained striking effects which conclusively demonstrate that he has succeeded in disturbing it. He connects to the earth, by one of its ends, a coil (see Fig. 15) in which rapidly vibrating currents are produced, the other end being free in space. With this coil he does actually what one would be doing with a pump forcing air into an elastic foot-ball. At each alternate stroke the ball would expand and contract. But it is evident that such a ball, if filled with air, would, when suddenly expanded or contracted, vibrate at its own rate. Now if the strokes of the pump be so timed that they are in harmony with the individual vibrations of the ball, an intense vibration or surging will be obtained. The purple streamers of electricity thus elicited from the earth and pouring out to the ambient air are marvelous. Such a display is seen in Fig. 14, where the crown of the coil, tapering upward in a Peak of Teneriffe, flames with the outburst of a solar photosphere.

The currents which are made to pass in and out of the earth by means of this coil can also be directed upon the human body. An observer mounted on a chair, and touching the coil with a metal rod, can, by careful adjustments, divert enough of it upon himself to cause its manifestation from and around him in splinters of light. This halo effect, obtained by sending the electricity of the earth through a human being,—the highest charge positively ever given in safety,—

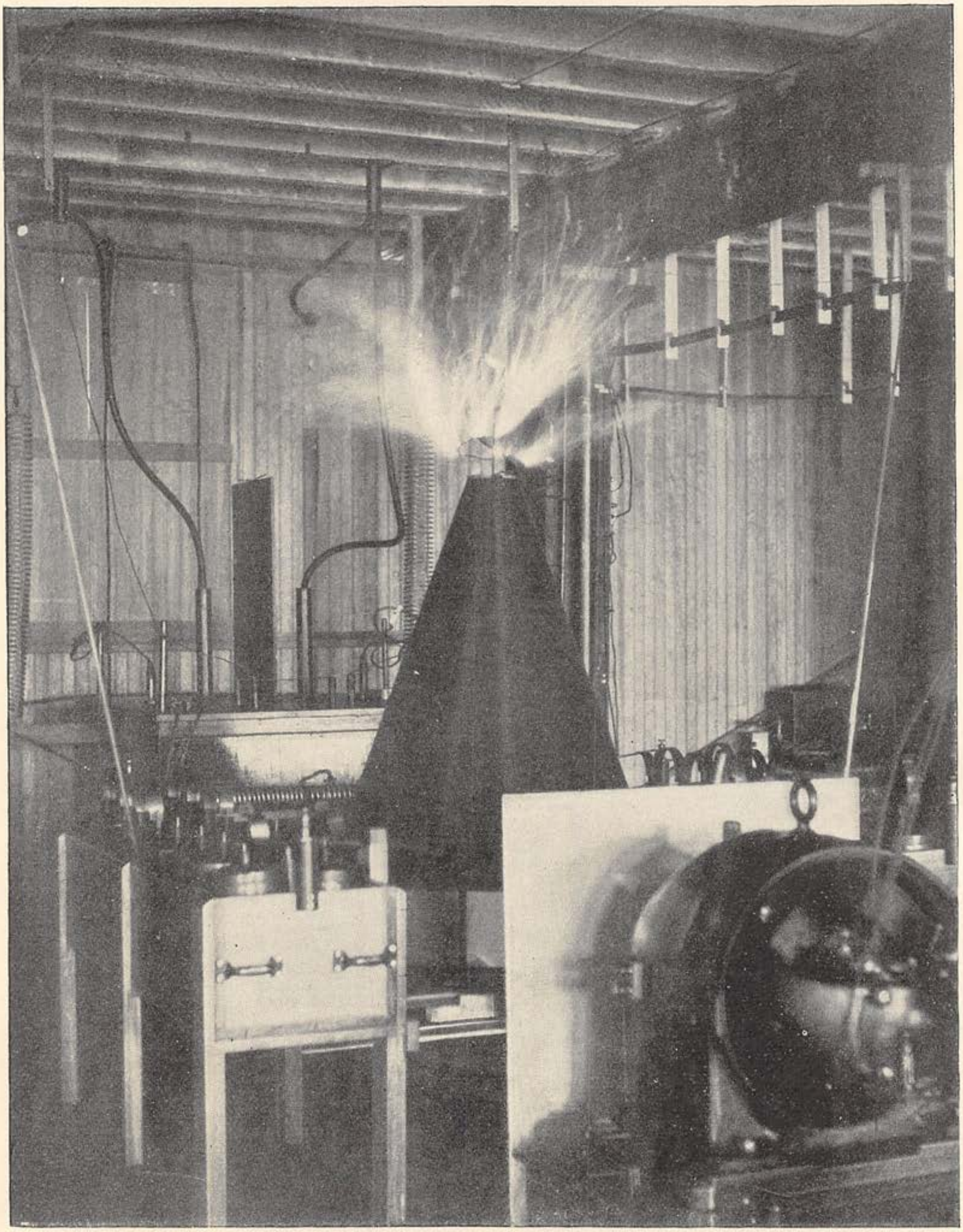


FIG. 15. TESLA COIL FOR ASCERTAINING AND DISCHARGING THE ELECTRICITY OF THE EARTH. THE STREAMERS AT TOP OF COIL ARE OF PURPLE HUE, AND IN FORM RESEMBLE FILAMENTS OF SEAWEED, THE EFFECT OF MASS BEING CAUSED BY PROLONGED EXPOSURE OF FLASH-LIGHT NEGATIVE.

is, to say the least, curious, and deeply suggestive. Mr. Tesla's temerity in trying the effect first upon his own person can be justified only by his close and accurate calculation of what the amount of the discharge from the earth would be.

Considering that in the adjustments necessary here, a small length of wire or a small body of any kind added to the coil or brought into its vicinity may destroy entirely all effect, one can imagine the pleasure which the investigator feels when thus rewarded by unique phenomena. After searching with patient toil for two or three years after a result calculated in advance, he is compensated by being able to witness a most magnificent display of fiery streams and lightning discharges breaking out from the tip of the wire with the roar of a gas-well. Aside from their deep scientific import and their wondrous fascination as a spectacle, such effects point to many new realizations making for the higher welfare of the human race. The transmission of power and intelligence is but one thing; the modification of climatic conditions may be another. Perchance we shall "call up" Mars in this way some day, the electrical charge of both planets being utilized in signals.

Here are great results, lofty aims, and noble ideas; and yet they are but a beggarly few of all those with which Mr. Tesla, by his simple, modest work, has associated his name during recent years. He is not an impracticable visionary, but a worker who, with solid achievements behind him, seeks larger and better ones that lie before, as well as fuller knowledge. I have ventured to supplement data as to his late inventions by some of his views as to the ether, which throughout this presentation of his work has been treated familiarly as the maid-of-all-work of the universe. All our explanations of things are but half-way houses to the ultimate facts. It may be said, then, in conclusion, that while Mr. Tesla does not hold Professor Oliver Lodge's ingenious but intricate notion of two electricities and two ethers, and of the ether as itself electricity, he does belong to what Lord Kelvin has spoken of as the nineteenth-century school of plenum, accepting one ether for light, heat, electricity, and magnetism, outward manifestations of an inward unity whose secret we shall some day learn.

Thomas Commerford Martin.

IN TESLA'S LABORATORY.

HERE in the dark what ghostly figures press!—
No phantom of the Past, or grim or sad;
No wailing spirit of woe; no specter, clad
In white and wandering cloud, whose dumb distress
Is that its crime it never may confess;
No shape from the strewn sea; nor they that add
The link of Life and Death—the tearless mad,
That live nor die in dreary nothingness:

But blessèd spirits waiting to be born—
Thoughts, to unlock the fettering chains of Things;
The Better Time; the Universal Good.
Their smile is like the joyous break of morn;
How fair, how near, how wistfully they brood!
Listen! that murmur is of angels' wings.

Robert Underwood Johnson.

OLD DUTCH MASTERS.

FERDINAND BOL (1616–1680).

FERDINAND BOL was the oldest student in Rembrandt's house in Amsterdam. He was one of the first, and by many is considered to have been the best. Very little is known of his life. He was born at Dort, in June, 1616, and became a pupil of Rembrandt toward 1630, when about fourteen years of age, and is not known to have had any other instructor. In 1652 he became a citizen of Amsterdam, and died there, on July 24, 1680, a rich man. Bol is considered chiefly as a portrait-painter, though he executed many historical works, and his etchings are highly esteemed. In his early pictures he adheres to the manner of his master, as may be readily observed in his portrait of Saskia, Rembrandt's wife, in the Brussels Museum, and in other of his works prior to 1642, in which he comes very near his master. After this he endeavors to strike out for himself, becomes different from Rembrandt in every way, and does not succeed very well, until finally we have a mas-