were "flitted" from end to end. An important desideratum was the shortening to as fine a point as possible of the wagoning of the coal from the face to the haulage rope. In conclusion, he might safely claim that they had attained such definite objects as: (1) More output per man employed; (2) coal economically worked which previously had been unworkable to a profit by hand; (3) more systematic working; (4) better round coal in three out of four mines; (5) greater area exposed in same time in two out of four seams; (6) premium per ton for risk of life reduced by one-third. It was scarcely possible to say how far the effect of coal-cutting reached. The official had to keep better vigilance than before, not only as regards safety, but also to keep the machine "forging ahead," as the next day's output depended largely upon it. The collier had been disturbed in his nest at the face. He now met the mechanic and the electrician on his own private preserve, and no doubt considered them interlopers; work of a higher class, such as the mechanical and electrical, was displacing, say, 33 per cent of the colliers' work, and that the most laborious. Therefore, having installed the coal-cutters, the Hulton Colliery would certainly consider that a return to the hand labor would be a step back into the older and darker times.

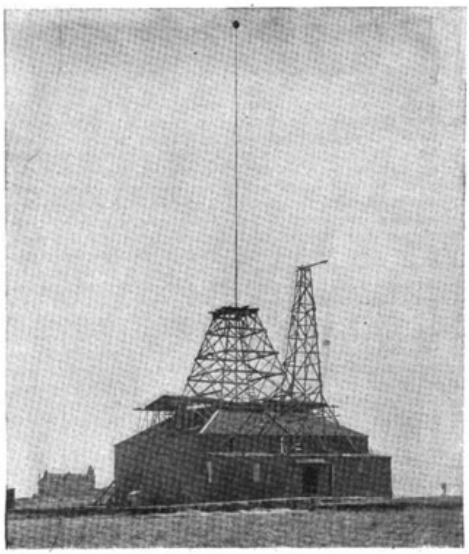

FIG. 1.—TESLA EXPERIMENTAL LABORATORY IN COLORADO, ERECTED DURING THE SUMMER OF 1899.

(The discovery by Mr. Tesla of the stationary waves in the earth was made here.)

THE TRANSMISSION OF ELECTRIC ENERGY WITHOUT WIRES.*

By NIKOLA TESLA.

TOWARD the close of 1898 a systematic research, carried on for a number of years with the object of perfecting a method of transmission of electrical energy through the natural medium, led me to recognize three important necessities: First, to develop a transmitter of great power; second, to perfect means for individualizing and isolating the energy transmitted; and, third, to ascertain the laws of propagation of currents through the earth and the atmosphere. Various reasons, not the least of which was the help proffered by my friend Leonard E. Curtis and the Colorado Springs Electric Company, determined me to select for my experimental investigations the large plateau, two thousand meters above sea level, in the vicinity of that delightful resort, which I reached late in May, 1899. I had been there but a few days when I congratulated myself on the happy choice, and I began the task for which I had long trained myself, with a grateful sense and full of inspiring hope. The perfect purity of the air, the unequaled beauty of the sky, the imposing sight of a high mountain range, the quiet and restfulness of the place—all around contributed to make the conditions for scientific observation ideal. To this was added the exhilarating influence of a glorious climate and a singular sharpening of the senses. In those regions the organs undergo perceptible physical changes. The eyes assume an extraordinary limpidity, improving vision; the ears dry out and become more susceptible to sound. Objects can be clearly distinguished there at distances such that I prefer to have them told by someone else, and I have heard—this I can venture to vouch for—the claps of thunder seven and eight hundred kilometers away. I might have done better still, had it not been tedious to wait for the sounds to arrive, in definite intervals, as heralded precisely by an electrical indicating apparatus—nearly an hour before.

In the middle of June, while preparations for other work were going on, I arranged one of my receiving transformers with the view of determining in a novel manner, experimentally, the electric potential of the globe and studying its periodic and casual fluctuations. This formed part of a plan carefully mapped out in advance. A highly sensitive, self-restorative device, controlling a recording instrument, was included in the secondary circuit, while the primary was connected to the ground and an elevated terminal of adjustable capacity. The variations of potential gave rise to electric surgings in the primary; these generated secondary currents, which in turn affected the sensitive device and recorder in proportion to their intensity. The earth was found to be, literally, alive with electrical vibrations, and soon I was deeply absorbed in this interesting investigation. No better opportunities for such observations as I intended to make could be found anywhere. Colorado is a country famous for the natural displays of electric force. In that dry and rarefied atmosphere the sun's rays beat the objects with fierce intensity. I raised steam, to a dangerous pressure, in barrels filled with concentrated salt solution, and the tinfoil coatings of some of my elevated terminals shriveled up in the fiery blaze. An experimental high-tension transformer, carelessly exposed to the rays of the setting sun, had most of its insulating compound melted out and was rendered useless. Aided by the dryness and rarefaction of the air, the water evaporates as in a boiler, and static electricity is developed in abundance. Lightning discharges are, accordingly, very frequent and sometimes of inconceivable violence. On one occasion approximately twelve thousand discharges occurred in two hours, and all in a radius of certainly less than fifty kilometers from the laboratory. Many of them resembled gigantic trees of fire with the trunks up or down. I never saw fire balls, but as a compensation for my disappointment I succeeded later in determining the mode of their formation and producing them artificially.

In the latter part of the same month I noticed several times that my instruments were affected stronger by discharges taking place at great distances than by those near by. This puzzled me very much. What was the cause? A number of observations proved that it could not be due to the differences in the intensity of the individual discharges, and I readily ascertained that the phenomenon was not the result of a varying relation between the periods of my receiving circuits and those of the terrestrial disturbances. One night, as I was walking home with my assistant, meditating over these experiences, I was suddenly staggered by a thought. Years ago, when I wrote a chapter of my lecture before the Franklin Institute and the National Electric Light Association, it had presented itself to me, but I had dismissed it as absurd and impossible. I banished it again. Nevertheless, my instinct was aroused and somehow I felt that I was nearing a great revelation.

It was on the third of July—the date I shall never forget—when I obtained the first decisive experimental evidence of a truth of overwhelming importance for the advancement of humanity. A dense mass of strongly charged clouds gathered in the west and toward the evening a violent storm broke loose which, after spending much of its fury in the mountains, was driven away with great velocity over the plains. Heavy and long persisting arcs formed almost in regular time intervals. My observations were now greatly facilitated and rendered more accurate by the experiences already gained. I was able to handle my instruments quickly and I was prepared. The recording apparatus being properly adjusted, its indications became fainter and fainter with the increasing distance of the storm, until they ceased altogether. I was watching in eager expectation. Surely enough, in a little while the indications again began, grew stronger and stronger and, after passing through a maximum, gradually decreased and ceased once more. Many times, in regularly recurring intervals, the same actions were repeated, until the storm which, as evident from simple computations, was moving with nearly constant speed, had retreated to a distance of about three hundred kilometers (186 miles). Nor did these strange actions stop then, but continued to manifest themselves with undiminished force. Subsequently, similar observations were also made by my assistant, Mr. Fritz Lowenstein, and shortly afterward several admirable opportunities presented themselves which brought out, still more forcibly, and unmistakably, the true nature of the wonderful phenomenon. No doubt whatever remained—I was observing stationary waves.

FIG. 2.—TESLA CENTRAL POWER PLANT AND TRANSMITTING TOWER FOR WORLD TELEGRAPHY, AT WARDENCLYFFE, LONG ISLAND, N. Y.

(The tower is a pyramid having eight sides; smallest dimensions across base, 95 feet; height, 154 feet; total height from ground to top, 187 feet; cupola on top, 65.62 feet in diameter.)

* Electrical World and Engineer.

As the source of disturbances moved away, the receiving circuit came successively upon their nodes and loops. Impossible as it seemed, this planet, despite its vast extent, behaved like a conductor of limited dimensions. The tremendous significance of this fact in the transmission of energy by my system had already become quite clear to me. Not only was it practicable to send telegraphic messages to any distance without wires, as I recognized long ago, but also to impress upon the entire globe the faint modulations of the human voice, far more still, to transmit power, in unlimited amounts, to any terrestrial distance and almost without any loss.

With these stupendous possibilities in sight, with the experimental evidence before me that their realization was henceforth merely a question of expert knowledge, patience, and skill, I attacked vigorously the development of my magnifying transmitter, now, however, not so much with the original intention of producing one of great power, as with the object of learning how to construct the best one. This is, essentially, a circuit of very high self-induction and small resistance which, in its arrangement, mode of excitation, and action, may be said to be the diametrically opposite of a transmitting circuit typical of telegraphy by Hertzian or electromagnetic radiations. It is difficult to form an adequate idea of the marvelous power of this unique appliance, by the aid of which the globe will be transformed. The electromagnetic radiations being reduced to an insignificant quantity, and proper conditions of resonance maintained, the circuit acts like an immense pendulum, storing indefinitely the energy of the primary exciting impulses and impressing upon the earth and its conducting atmosphere uniform harmonic oscillations of intensities which, as actual tests have shown, may be pushed so far as to surpass those attained in the natural displays of static electricity.

Simultaneously with these endeavors, the means of individualization and isolation were gradually improved. Great importance was attached to this, for it was found that simple tuning was not sufficient to meet the vigorous practical requirements. The fundamental idea of employing a number of distinctive elements, co-operatively associated, for the purpose of isolating energy transmitted, I trace directly to my perusal of Spencer's clear and suggestive exposition of the human nerve mechanism. The influence of this principle on the transmission of intelligence, and electrical epergy in general, cannot as yet be estimated, for the art is still in the embryonic stage; but many thousands of simultaneous telegraphic and telephonic messages, through one single conducting channel, natural or artificial, and without serious mutual interference, are certainly practicable, while millions are possible. On the other hand, any desired degree of individualization may be secured by the use of a great number of co-operative elements and arbitrary variation of their distinctive features and order of succession. For obvious reasons, the principle will also be valuable in the extension of the distance of transmission.

Progress, though of necessity slow, was steady and sure, for the objects aimed at were in a direction of my constant study and exercise. It is, therefore, not astonishing that before the end of 1899 I completed the task undertaken and reached the results which I have announced in my article in the Century Magazine of June, 1900, every word of which was carefully weighed.

Much has already been done toward making my system commercially available, in the transmission of energy in small amounts for specific purposes, as well as on an industrial scale. The results attained by me have made my scheme of intelligence transmission, for which the name of "world telegraphy" has been suggested, easily realizable. It constitutes, I believe, in its principle of operation, means employed, and capacities of application, a radical and fruitful departure from what has been done heretofore. I have no doubt that it will prove very efficient in enlightening the masses, particularly in still uncivilized countries and less accessible regions, and that it will add materially to general safety, comfort, and convenience, and maintenance of peaceful relations. It involves the employment of a number of plants, all of which are capable of transmitting individualized signals to the uttermost confines of the earth. Each of them will be preferably located near some important center of civilization and the news it receives through any channel will be flashed to all points of the globe. A cheap and simple device, which might be carried in one's pocket, may then be set up somewhere on sea or land, and it will record the world's news or such special messages as may be intended for it. Thus the entire earth will be converted into a huge brain, as it were, capable of response in every one of its parts. Since a single plant of but one hundred horse-power can operate hundreds of millions of instruments, the system will have a virtually infinite working capacity, and it must needs immensely facilitate and cheapen the transmission of intelligence.

The first of these central plants would have been already completed had it not been for unforeseen delays which, fortunately, have nothing to do with its purely technical features. But this loss of time, while vexatious, may after all prove to be a blessing in disguise. The best design of which I knew has been adopted, and the transmitter will emit a wave complex of a total maximum activity of ten million horse-power, one per cent of which is amply sufficient to "girdle the globe." This enormous rate of energy delivery, approximately twice that of the combined falls of Niagara, is obtainable only by the use of certain artifices, which I shall make known in due course.

For a large part of the work which I have done so far I am indebted to the noble generosity of Mr. J. P. Morgan, which was all the more welcome and stimulating, as it was extended at a time when those who have since promised most were the greatest of doubters. I have also to thank my friend, Stanford White, for much unselfish and valuable assistance. This work is now far advanced, and though the results may be tardy, they are sure to come.

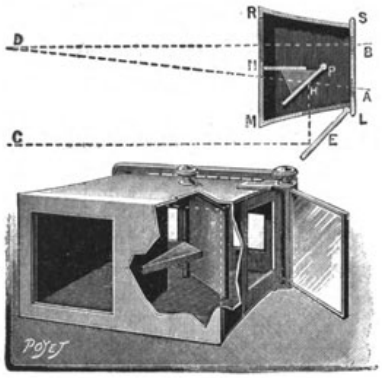

FIG. 1.—BELLIENI'S APEDIOSCOPE FOR OBSERVING STEREOSCOPIC PROJECTIONS.

Meanwhile, the transmission of energy on an industrial scale is not being neglected. The Canadian Niagara Power Company have offered me a splendid inducement, and next to achieving success for the sake of the art, it will give me the greatest satisfaction to make their concession financially profitable to them. In this first power plant, which I have been designing for a long time, I propose to distribute ten thousand horse-power under a tension of one hundred million volts, which I am now able to produce and handle with safety.

The energy will be collected all over the globe, preferably in small amounts, ranging from a fraction of one to a few horse-power. One of its chief uses will be the illumination of isolated homes. It takes very little power to light a dwelling with vacuum tubes operated by high-frequency currents, and in each instance a terminal a little above the roof will be sufficient. Another valuable application will be the driving of clocks and other such apparatus. These clocks will be exceedingly simple, will require absolutely no attention, and will indicate rigorously correct time. The idea of impressing upon the earth American time is fascinating and very likely to become popular. There are innumerable devices of all kinds which are either now employed or can be supplied, and by operating them in this manner I may be able to offer a great convenience to the whole world with a plant of no more than ten thousand horse-power. The introduction of this system will give opportunities for invention and manufacture such as have never presented themselves before.

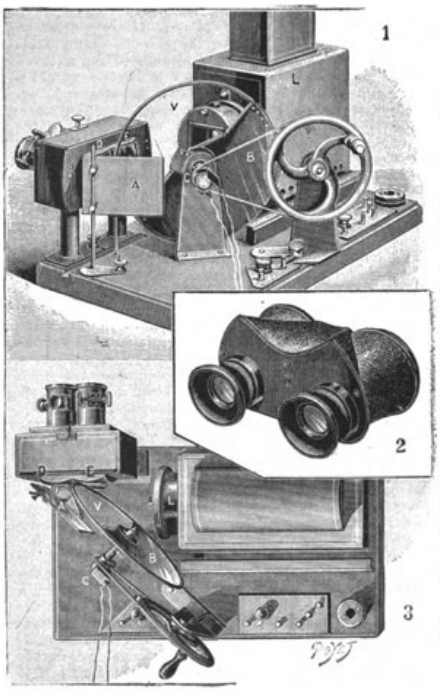

FIG. 2.—THE SCHMIDT AND DUPUIS APPARATUS AND OPERA GLASS FOR OBSERVING STEREOSCOPIC PROJECTIONS.

Knowing the far-reaching importance of this first attempt and its effect upon future development, I shall proceed slowly and carefully. Experience has taught me not to assign a term to enterprises the consummation of which is not wholly dependent on my own abilities and exertions. But I am hopeful that these great realizations are not far off, and I know that when this first work is completed they will follow with mathematical certitude.

When the great truth accidentally revealed and experimentally confirmed is fully recognized, and this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball, and that by virtue of this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment; when the first plant is inaugurated and it is shown that a telegraphic message, almost as secret and non-interferable as a thought, can be transmitted to any terrestrial distance, the sound of the human voice, with all its intonations and inflections faithfully and instantly reproduced at any other point of the globe, the energy of a waterfall made available for supplying light, heat or motive power, anywhere—on sea, or land, or high in the air—humanity will be like an antheap stirred up with a stick. See the excitement coming!

STEREOSCOPIC PROJECTIONS.

IN order that images may be seen in relief by stereoscopic projections, it does not suffice to project upon the screen the two images emanating from a stereoscopic negative, but it is also necessary that it shall be possible for each eye of the spectator, through an appropriate arrangement, to receive only that one of the two images that is designed for it. There exists a stereoscope for images of large dimensions, and that is the mirror apparatus of M. Cazes; but this is not easily manipulated and cannot be employed by the spectators at an ordinary exhibition of stereoscopic lantern slides. Other inventors, and M. Knight especially, have indicated the possibility of constructing portable apparatus on the same principle. We do not know whether or not the idea was ever carried out, but it appears, at all events, to have fallen into oblivion. Quite recently, M. Bellieni, taking up the same idea, and without knowing anything at all about the work of M. Knight, has succeeded in constructing the apedioscope, a small and easily portable apparatus of moderate price, with which each spectator may provide himself when a lecture, for example, is illustrated with stereoscopic projections. Experimented with recently at a meeting of the French Photographic Society, in which the inventor placed thirty of these apparatus at the disposal of the members, it gave excellent results.

Use is made of the stereoscopic positive upon glass, such as is found in the collections for the ordinary stereoscope (care being taken to remove the ground glass if any exists). This is passed into a single-objective lantern. A 6-inch condenser suffices for 3¼ x 6½-inch slides, and a 4¾-inch one for 2¼ x 5-inch slides.

The two images are thus projected upon the screen, one alongside of the other. In order to answer the requirements of the principle mentioned above, the spectator's apparatus consists of a small box, *M R S L*, containing two apertures, *A* and *B*, situated at the normal distance apart of the eyes (Fig. 1). Through one of these, *B*, we see directly with the right eye, for instance, one of the two images, *D*, which is the one intended for that eye. The other image, *C*, is concealed from the right eye by a wooden partition, *N P*, placed in the apparatus. But this other image is reflected in a small mirror, *E*, situated upon the other side of the box, and capable of being set in the proper position by means of a button. After the image, *C*, is properly perfected by this mirror, it is received by a second mirror, *H*, placed in the interior of the apparatus. It is here that the right eye, placed at *A*, sees it appear, and instinctively transfers it to *D*, beyond the mirror superposing it upon the first image. This gives the effect of reliefs, as in the ordinary stereoscope.

The slight regulation necessary for the proper reception of one of the images in the mirror is done once for all at the beginning of the lecture or other entertainment by means of a geometrical figure, for example, of which only a part need be projected on each side, but of which the superposition must be made to appear complete. It is to be remarked that this system occasions no loss of light.

There are still other methods of viewing stereoscopic lantern slides in relief. This question was discussed by us thirteen years ago, when M. Molteni projected the two images one upon the other, after having colored one of them red and the other green, by means of colored glasses placed before them. The spectators had to be provided with eye-glasses having the same colors. It is evident that, under such circumstances, each eye can see only the image that is designed for it, and the relief is easily perceived. But these multicolored screens upon the lantern and the eyes absorb too great a quantity of light, and that is what has prevented the development of this system of stereoscopic projection.

The idea has been taken up under another form by various persons, and, among others, by M. Rateau; and we have recently seen it carried out in a very complete manner by MM. Schmidt and Dupuis. The process consists in projecting the two images successively. If the spectator opens but one eye at a time—the left