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ELECTRICAL SECTION.

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Electrolytic Receivers in Wireless Telegraphy.

BY DR. LEE DE FOREST.

With the form and nature of the ordinary filings-tube coherer as applied to-day in wireless telegraphy the public has become fairly familiar.

Branley, the distinguished French physicist, discovered in 1891 that the effect of electrical oscillations upon a body of metallic filings, or dust, was to produce a sudden increase in the conductivity of the mass, a conductivity which persisted until the particles were broken apart again by mechanical jar.

Although the American, Varley, the English scientist Hughes, and especially Onesti, the Italian, had previously noted this phenomenon, none of these investigators had fully appreciated the causes involved, or given to the world of science the benefit of their researches in thorough published reports.

The discovery of the "coherer" therefore is rightfully attributed to M. Branley; but to Professor Popoff, of St. Petersburg, and to Sir Oliver Lodge, of England, must be given the credit of applying the relay and mechanical tapper to the filings tube, the addition of antennæ wings, of upright wire and earth connection, and the first steps towards refinement and an appreciation of the possibilities of the new detector as applied to an unborn branch of human enterprise and progress.

With the notable work of Marconi in still further adapting the Popoff-Lodge arrangement to commercial requirements, the gradual increase of distance on which aerographic communication was established, the ingenious improvements in coherers by such men abroad as Tissot, Ducretet, Castelli, then by Lodge and Branley themselves, and in this country by Shoemaker, the audience is more or less familiar.

Enormous is the bulk of research matter published regarding the coherer. Theories of the action involved have been numerous, but divided chiefly into two schools: First, that of Lodge, who demonstrated an actual *welding* together of metallic filings, after the same had been drawn into contact by the electro-static attraction of the opposite charges induced upon the faces of the filings; and, second, that of Branley, who ascribed the action to a breaking down or puncturing by minute sparks of the dielectric film (either gaseous or a metallic oxide), which he held must exist between opposing surfaces of the filings.

The result of the years of investigation which have followed the early work of these two pioneers proves that in a measure both were right. The Branley effect undoubtedly exists, and affords a satisfactory explanation of the self-decohering phenomena observed in the microphone type of auto-coherers. These insulating oxide or gaseous films inevitably form and cling to the surface of any metallic particles not enclosed in absolute vacuum, and where strictest care is not taken to prevent. They are, moreover, elastic, self-healing; and unless the electric impulses are of excessive violence, so that adjacent particles are actually welded firmly together, the original high resistance is automatically

restored upon cessation of the electric impulse. This is notably the case when the elements of the radio-conductor are of carbon, hardened steel, carbon-mercury, aluminum, etc., where the formation of this resisting film is easily accomplished, or where amid the minute roughnesses of the carbon surface the adhesion of a gaseous film is made more easy.

If, however, the coherer consists of filings of some soft metal of relative low fusing point—silver, gold, lead—the Lodge cohering effect through actual welding follows upon the Branley action; making the final fall of resistance far more marked, and necessitating a vigorous mechanical jar to break up the cohered filings and restore sensitiveness.

It is on account of this enormous change in conductivity of the filings-tube coherer that this form has been the standard used almost exclusively in the coherer systems of wireless telegraphy.

For the filings-tube frequently shows a change from hundreds of thousands of ohms down to a few ohms under the influence of exceedingly weak electrical impulses.

This readily allows the use of a relay, operating a Morse inker and the tapping-back device; and in the old country, where the coherer systems have been chiefly developed, reading by sight has ever been deemed a necessity, especially in the navies, where, until recently, wireless telegraphy has enjoyed its most cordial reception.

The result of all this has been necessarily a system employing delicate relays, tapping-back adjuncts, complications of apparatus, requiring frequent and careful adjustments, a skill and delicacy on the part of the receiving operator seldom found outside of the physics laboratory, least of all upon a man-of-war, where the hands of Jack Tar, of the wig-wag and gundeck school, are all thumbs and of Cyclopic dimensions.

Despite many extravagant claims for high speeds of word transmission by coherer systems, I have yet to see proof of anything exceeding twelve to fifteen words the minute in genuine commercial working, while the actual every-day speed attained seldom exceeds half that amount.

For commercial applications of wireless telegraphy this pathetic speed limitation of itself renders the filings-tube systems to-day an impossibility; regardless of any other considerations, such as uncertainty of their action, ill-adaptability to electrical tuning, liability to interference (notably from atmospheric electricity), harmful effects from mechanical vibrations, etc., etc.

It has been stated by its early champions, and more recently by those prominently interested in *wire* telegraphs, that wireless telegraphy is destined to fill a place where existing methods of wire communication are impossible, such as from ship to ship and ship to shore. And their point was well taken; for, with the best tape-recording coherer systems developed to-day, after eight years of elaborate effort, no sane man would think of employing wireless telegraphy, with its six words and as many guesses per minute, its treacherous adjustments and its moody dispositions, where a wire system could possibly be used.

With the auto-coherer, or so-called microphonic contact, the case is better. Here, since no tapping-back is required, a relay is superfluous, although, to speak frankly, the changes of resistance in the auto-coherer are generally so slight and the *normal* resistance such a shifting quantity that no relay capable of operating reliably with the auto-coherer has been devised. A telephone, the most sensitive indicating instrument known, is invariably used to-day in place of the relay and inker; and, inasmuch as the auto-coherer is usually a quantitative instrument, possessed of no critical voltage, its combination with the telephone affords an extremely sensitive wave detector, the range of which is limited by the sensitiveness of the human ear.

With this arrangement one obtains a speed of word reception limited only by the ability of the operators to send dots and dashes with the transmitter spark, and to translate these into words. Consequently, in America one finds the alternating current of relatively high frequency and excellent regularity of action employed, with an ordinary Morse key obtaining a speed of twenty-five to thirty-five words per minute, instead of the antiquated induction

coil with its spluttering sticking hammer interrupter, or its messy, explosive mercury-brake and the pump-handle *Zeichengeber*, which is considered abroad as a fitting accompaniment to the coherer receiver, and is so well designed to hold down the impatient sender to a sloth sufficient for that form of receiver. As we frequently see in the daily press, the spark-coil coherer systems are excellently adapted to the trying requirements of a "chess game by wireless telegraphy!"

The auto- or microphonic coherer is, however, poorly adapted to the nice requirements of close syntony or electrical tuning. This is on account of its variable normal resistance and its normal capacity. Moreover, this device is liable to "close up" under the effects of severe static discharges, requiring readjustment by tapping, and rendering difficult its employment during time of severe atmospheric disturbances and lightning storms.

Furthermore, its inability to reliably operate by a relay, a bell for calling purposes often necessitates the addition of a filings-tube for that purpose.

I feel justified in saying while on this subject that the type of auto-coherer invented by Mr. Harry Shoemaker, until recently of this city, together with the special antenna which he employs therewith, is the most practical and satisfactory form which has come to my attention.

Having briefly reviewed the field of cohering indicators of electric waves, I wish now to call attention to an entirely distinct line of investigation leading up to forms of receivers which I believe may well be set in a class by themselves as regards sensitiveness, simplicity and general adaptability to most of the demands which can be made to-day in the field of wireless telegraphy. I refer to the electrolytic principle, one which has until recently attracted little investigation from experimenters generally, but which, notwithstanding, has to its credit performances which are rapidly compelling study and research in various sources here and abroad.

In 1898 the German, Neugschwender, performed the following experiment: The silver plating of a strip of mirror

glass was divided into two parts by a sharp razor cut, leaving a narrow gap between two silver edges, completely insulating the two sections. Each of the sections was now connected to the terminals of a dry battery, and a telephone and galvanometer inserted in series in the circuit.

No current was observed to pass until a film of moisture was deposited upon the slit, either by blowing the breath thereon or by placing a saturated sponge nearby or by placing a drop of water directly upon the slit. After a brief period the galvanometer began to show violent and irregular deflections. In the telephone a scratching, bubbling sound was heard, followed shortly by comparative quietness and a stable position of the galvanometer needle, indicating that the resistance of the gap in the silver mirror had been broken down until it measured but a few ohms.

If, now, electric waves were generated in the neighborhood, as from the spark of an induction coil, the galvanometer showed an increase of resistance in the circuit, while the listener in the telephone heard a purring sound, reproducing with singular fidelity the sound of the induction-coil spark.

Upon cessation of the electrical impulses the conductivity of the gap in the mirror instantly reasserted itself; the sound in the telephone ceased.

A year after Neugschwender discovered this strange action of the Hertzian waves, Aschkinass independently noted the same phenomena, the publication of which in *Wiedemann's Annalen* led the former to further pursue his researches, and to examine the action at the moist edges of the silver electrode under a powerful microscope. His observations thereon and my own investigations in 1899 coincide in all essentials, and clearly demonstrate that the phenomenon is one of electrolysis, due to the combined action of the Hertzian and local currents. They demonstrate, however, several features new to the generally accepted idea of electrolytic action; and open up lines of speculation and research of unusual interest to the physicist, and rife with suggestion.

The phenomenon noted above exist to a more prominent degree with tinfoil electrodes in place of silver, and these I shall now attempt to describe.

With the telephone to the ear and the eye at the microscope the action thus doubly observed affords in fact one of the most fascinating, most beautiful pastimes (as I may well term it) ever granted to the investigator in these fields.

When the local E.M.F. is first applied to the gap, minutest metallic particles, all but invisible even with a 1,000-power lens, are seen torn off from the anode, under the stress of the electric forces, apparently mechanical in action; and these dust-like particles, floating in the fluid, move across to the cathode, some rapidly, some slowly, by strange and grotesque pathways, or directly to their goal.

Tiny ferry-boats, each laden with its little electric charge, and unloading its invisible cargo at the opposite electrode, retrace their journeyings, or, caught by a cohesive force, build up little bridges, trees, with branches of quaint and crystalline patterns.

During this formative period (lasting perhaps for half a minute) the ear hears an irregular boiling sound, and the average deflection of the galvanometer indicates a gradual decrease of resistance, until one or more of these tin trees or tentacles has been built completely across the gap.

Then silence ensues until the current across this bridge is suddenly increased as by the Hertzian oscillations from an electric spark made in the neighborhood, or even from a source of so low frequency as the ordinary 60-cycle alternating current.

Instantly all is commotion and change among the tentacles, and especially where these join the cathode. Tiny bubbles of hydrogen gas appear, and enlarging suddenly break or burst apart the bridges, while the click in the telephone indicates the rupture of the current's path.

Yet they are persevering, these little pontoon ferrymen, and instantly re-form, locking hands and hastening from their sudden rout back to build new paths and chains. So the process continues, the local current re-establishing, the electric oscillations breaking up, its highways of passage, with furious bubblings and agitations—a veritable tempest in a microscopic tea-pot.

The hydrogen gas, having, of course, twice the volume of the oxygen, is most in evidence, and therefore the rupture of the tentacle occurs chiefly at its cathodic terminal. And where segregated branches of the tin trees are broken off, the bubbles of gas are generally noticed at the cathodes.

Moreover, the oxygen to a large extent enters into chemical combination with the tin, and after the slit has been used for some time a greyish deposit of stannous oxide may be scraped from the anode.

A peculiar feature of this phenomenon is the rapid disappearance of the gas bubbles. The hydrogen, and what oxygen does not combine with the tin, seems to be absorbed by the liquid ; or the two, being nascent, may recombine to form water.

One fact must be borne in mind, that the fine tentacles (whose diameter, by the way, is of the order of some hundred-thousandths of an inch) do not come into actual metallic contact with the anode terminal. A film of electrolyte of almost molecular thickness must exist between the two, conducting normally by electrolytic ionization and conduction, yet easily decomposed and transformed by a sudden *increase* of current into an insulating gaseous film, the expansion of which still further increases the resistance of the gap.

The character of the electrolytic action when soft metals, such as tin, silver, lead, are used as anode, and when the distance to the cathode is decreased to the order of $\frac{1}{100}$ -inch or less, is quite surprising. For example, the electro-motive forces needed for electro-deposition from anode to cathode are extremely small, nowhere approaching the critical E.M.F. of polarization of the electrolyte.

Moreover, distilled water, so-called chemically-pure glycérine, oils, etc., contain enough of impurities (such as acid traces) to enable them to act here like our ordinary electrolytic solution. I have in ten minutes plated a firm deposit of tin on a gold cathode, using distilled water only, and a potential difference not exceeding $\frac{1}{10}$ of a volt.

For the same reasons it is possible to decompose the water films interposed between branches of these tin trees

by a very minute difference of potential there-between. The result is that this electrolytic responder does not necessarily possess a "critical potential," as is common to a *coherer*; and it does not, therefore, cease to respond to electric impulses the potential of which is less than the E.M.F. of polarization of the electrolyte, as commonly understood.

This receiver is in fact a *current*-operated device, as distinguished from potentially-operated forms such as the *coherer*, as I have proved in a variety of ways.

Returning to the silver-mirror slit experiment of Neugschwender, my investigations soon showed me that the device was altogether unreliable as a practical wave-responding detector. In the slit form above described the tearing off of metal from the anode and the building up of conducting bridges and tentacles across the gap was found to continue until the whole gap became clogged with an agglomeration of crystalline formations, affording so many short-circuiting paths in parallel that very soon the auto-cohering could be obtained only in response to powerful sparks.

Again, an accumulation of hydrogen gas may obtain, completely preventing the reforming of a water film between tentacles and electrodes or between sections of the tentacles. There results thereupon the regular *coherer* arrangement, and at the first electric impulse permanent welding of the chain ensues, so that the device becomes inoperative until cleaned out or readjusted.

Systematic and painstaking experiments extending over two years were required before the electrolytic "responder," as I have termed it, assumed a commercial form.

As described in U. S. Patent 716,000, a viscous supporting medium, such as glycerine, heavy oil, or one mixed with an absorbent such as lycopodium powder, may be inserted between the electrodes to prevent the agglomeration of conducting paths, to confine the action to a few only and to prevent the permanent formation of gas among the tentacles.

In addition a depolarizer was added to chemically dispose of the hydrogen bubbles. This last factor has proved of greatest value, rendering the responder of extreme sensitiveness and reliability.

Other electrolytes, such as dilute acids, alkalies, alcohols, ammonia, etc., were early tried, but I found generally that such lead to a too violent disintegration of the metals in the responder.

It has frequently been asserted that the Marconi coherer when connected directly between the foot of an upright aerial conductor, of about 60 meters height, and the earth, failed to respond to impulses from a typical 12-inch induction-coil transmitter set at distances exceeding twenty miles. For longer distances it was necessary to insert a "jigger" or transformer, by means of which the potential difference across the terminals of the coherer could be stepped up to that required by the so-called "critical potential" of the coherer.

A carbon microphone auto-coherer is a current-operated device. It can, therefore, be inserted without a step-up transformer directly at the foot of the aerial wire, and shows no such failure to respond for the distances above mentioned.

If high-frequency electric oscillations from a distant source be impressed upon a vertical conductor grounded at its lower end, current oscillations will be induced in the surface of the conductor, traversing it from top to bottom. At the upper extremity the electro-static components of the oscillations will be reflected without change of sign, and at the base reflected *with* change of sign. The exact converse holds for the electro-magnetic or current components of the oscillation. The result is a loop of electro-static force at the upper end of the wire, and a current loop at its base. A current-operated device, therefore, will respond best when inserted in the base of the aerial at a point where the *coherer* is at its greatest disadvantage.

The extreme distances from which messages have been received on the electrolytic responder of the types just described, as compared to records with the coherer under similar conditions, afford a practical proof that it is a current-operated device, in addition to the consideration of the electrolytic principles involved in its action.

As an interesting instance of the work done by the re-

sponder under such conditions, I may cite the following aerogram received at the Coney Island Station of the de Forest Company, March 14, 1903, and addressed to President Schurman, of Cornell University. The message was sent by Charles De Garnio, professor of pedagogy in that institution, from on board the S. S. "Coamo," bound to Porto Rico, using a 10-inch coil and an antenna of only 90 feet, the distance being 110 miles: "Greetings from Old Ocean, who no longer sunders friends. Courtesy de Forest wireless telegraph system." Signed.

I call your attention now to a remarkable fact which I have discovered in connection with the electrolytic action of Hertzian waves.

The sensitive cell, as above described, shows nothing of a counter electro-motive force of polarization, although the electrodes may be of a great variety of shape and materials.

The locally applied electro-motive force may range from a few millivolts to 3 volts or more, but always with a proportionate increase of indicated current-flow.

If, however, the electrodes be slowly separated from one another, with one or more of the minute tentacles clinging thereto, a counter electro-motive force of polarization may be observed when the distance between the nearest electrodes exceeds a certain small limit. This counter E.M.F. exists whether the electrodes be of like or unlike material or shape.

Now, upon the first application of the local battery to the terminals of this cell, a temporary flow of current is observed, the resistance of the cell being at first slight, especially if a dilute alkali or acid form the electrolyte. Immediately thereafter, however, the current flow falls almost to nothing; the counter E.M.F. of the cell asserts itself. This, as is well known to the science of electro-chemistry, is due to the formation of a layer of gas insulating the faces of the electrodes. This requires that, unless some depolarizing means be added, the local applied electro-motive force must be raised above the opposing electro-motive force of the cell; that is to say, above the critical voltage required for the decomposition of the electrolyte.

This counter E.M.F. of the cell exists whether the fine tentacles be attached to the anode or cathode.

Now, when the cell is placed in the path of the high-frequency electrical oscillations the effect is found to be a temporary, more or less complete, annulment of the counter electro-motive force of polarization. This effect is scarcely noticeable when the tentacles are made the cathode; but when made the anode, so that oxygen is the gas surrounding and insulating the fine tentacles, the effect of the Hertzian oscillation is to decrease to a marked degree the apparent resistance of the cell.

The sensitiveness of the electrolytic cell to this second action of the Hertzian oscillations is nearly inversely proportional to the exposed area of the anode. It can be obtained even for such coarse anodes as are furnished by a 1 millimeter platinum wire; but the diameter of these is 100 times that of the fine tentacles or trees previously described.

Last year a German experimenter, Schloemilch, reported the independent discovery of this same effect in what he called "polarization cells." Anodes having diameters sufficiently small to give great sensitiveness to the responder are now obtained by mechanical means, using the Wallaston wire having gold or platinum core and a silver sheath; wherewith, after drawing the whole to a fineness of 2 or 3 millimeters, the silver sheath is dissolved in concentrated acid in the manner long known to the arts. The order of diameter thus obtained is comparable to that of the metallic trees built up by electrolytic deposit; but the wire anodes are more stable and better suited to the work in this second type of the electrolytic responder.

To recapitulate these points :

Electrolytic effects of the Hertzian oscillations are available in a practical detector whenever extremely fine tentacles or wires are used for one of the electrodes :

(1) When such tentacle is brought into close proximity of the other electrode, preferably the anode. The normal resistance of the cell then becomes very small, generally a few hundred ohms. The cell offers no counter E.M.F. of polarization. A minute film of liquid intervenes, conduct-

ing by ionization. The passage of the Hertzian oscillation will now decompose this film, insulating the fine electrode, and causing a temporary and marked decrease in the local current flow. This is a current-operated device, and is extremely sensitive when inserted as a potential node, directly at the base of the receiving antenna.

(2) When the anodic tentacle is withdrawn from proximity with the other electrode, of whatever shape or material. The normal apparent resistance of the cell now becomes very great, 30,000 or 50,000 ohms, due to the counter E.M.F. of polarization.

A minute film of oxygen gas normally envelopes the submerged surface of the fine cathode tentacle, practically insulating it. The passage of the Hertzian oscillation will now cause a temporary dissipation of this gas, apparently into the liquid, causing a marked increase in the local current flow. This is a potential-operated device, and is best located where can exist potential loops of opposite sign at its two electrodes.

One investigator, prominent for his inventions in the wireless field, maintains that the phenomenon observed in this second form of the electrolytic responder is a *heat* effect. I have been unable, however, to find a single fact warranting such a view.

First of all, the fact that the device is a valve-effect, not indifferent to the direction of applied local potential, but practically inoperative if the tentacle be made negative, shows that the results obtained are not chiefly C^2R effects, as would be required were the action a heat phenomenon due to the amount of current flowing. Second, that it is a potential-operated and not a current-operated device, possessing a capacity, and normally insulating the fine anode. Third, that its action is sensibly unaffected by extremes of temperature, high or low. Many other considerations; based upon theoretical calculations as well as practical experiment, upon which I cannot dwell at this time, point to the correctness of the explanation of the action involved, based entirely upon electrolytic phenomena.

The electrolytic responders which I have described seem

to possess in the highest degree the qualities necessary to place the art of aerography on a basis to compete with existing telegraphic service, by land as well as by sea. They are extraordinarily sensitive, regular in response, strictly quantitative, automatic in action, having approximately constant normal factors as regards resistance and capacity, allowing thus a speed of word-transmission limited only by the ability of operators to send and receive. By such means the problems of electrical tuning, or syntony, are enormously simplified ; for heretofore the erratic nature of the coherer has rendered it impossible to closely regulate the constants of the tuned electrical circuits in which they are placed ; thus making syntonization by their employ at best crude and uncertain.

In regularity of action the responder is strictly comparable with the Rutherford magnetic detector as developed by Wilson, Shoemaker, Marconi and Ewing, while as regards relative sensitiveness there is to-day no comparison between that of the magnetic detector and the electrolytic receiver. Moreover, the device is practically indestructible, while its syntonizing qualities enable me to so cut out foreign signals and electric disturbances as to render wireless communication by this means practically immune from interruption.

In corroboration of these statements allow me to call attention to the service which the American De Forest Company has now established between Cleveland and Buffalo. The distance here is 180 miles, extending, as the two stations are located, almost entirely overland. During the recent severe weather, when this land was frozen to a depth of several feet, and Lake Erie a mass of ice extending from the shore for miles (conditions which afford the greatest difficulties for aerographic transmission), the daily exchange of messages at high rates of speed has been continuous. The loudness and clearness of the signals are most surprising, originating, one might suppose, from some station less than 30 miles distant. Tuning here is so close that the addition or subtraction of 6 to 8 inches of wire in the syntonizing coils cuts out the signals altogether and enables the operator to dispose entirely of atmospheric disturbances

arising from severe lightning storms in the close neighborhood of the stations.

During a recent test to Lockport, 36 miles overland from the Buffalo station, messages were received on two small wires extending to the roof of a building but 85 feet above the earth, with the utmost clearness and accuracy.

Again, the recent excellent record which the United States Signal Corps has made between Fort Schuyler and Fort Wright, 98 miles apart, concerning which so much has recently appeared in the daily press, was made with receivers, tuning devices and oscillator sets purchased from the de Forest Companies. As a result of this work, following upon the failure of several coherer systems to cover the distance, the apparatus is to be installed next summer in Alaska between Nome and St. Michaels, over a range which the Signal Corps has sought in vain for several years to cover.*

The exact nature of the electro-magnetic waves by which wireless signals are transmitted has afforded field for a great amount of speculation and theory among scientists and laymen. Considerable interest has attached to the discussion of this subject, which has recently been running in the columns of the *Electrical World and Engineer*.

Unfortunately the classic work in exploration of the field of force and the nature of propagation from the dumb-bell oscillator, by which Professor Hertz immortalized his name, is not entirely applicable to the case; but the analogy is very close. When the lower half of the Hertz oscillator is substituted for a connection of that side of the spark-gap to a conducting or semi-conducting medium of unlimited extent (such as sea water or the earth's surface), the laws of electrical images do not strictly hold.

This was, however, the view taken by Abraham in his mathematical investigation of the subject; by Blondel, at least until recently, and others.

Mr. J. E. Taylor, engineer of the British General Post

* Since this paper was written these Alaskan stations have been opened. Capt. Wildman reports the system as giving complete satisfaction.

Office, and a zealous pioneer in wireless work, was, I believe, first to apply in a clear and lucid manner the theory and diagrams of Hertz to the case of the grounded oscillator. Taylor pointed out that we had in practice the sliding wave, following in general the shape worked out by Hertz; but with the feet of the lines of force which form the polarized wave-front gliding over the surface of the earth or sea, following the contour of hill and dale; and scaling such obstacles as do not absorb portions of the wave energy and cast thereby more or less serious shadows.

The Hertzian field of force does not call for approximately spherical radiation of energy, as seems to be taken for granted by some; and my own experience goes to show that the falling off in the strength of received energy does not follow anything like the law of the inverse squares of the distance, as this assumption would require.

The electrolytic responder is quite exactly a quantitative instrument, and with it I find, at distances far from the course of oscillations, a decrease in strength of received signals approximately proportional to the first power of the distance.

One fact is certain, that the propagation is not by hemispherical waves. One searches in vain the writings of Hertz for anything suggesting such a theory there. Hertz points out that even with the free polarized wave in space the force diminishes continuously with the inverse distance; at first rapidly, as the inverse cube, but later slowly, as the inverse of the distance itself. So at great distances will the effect of oscillation be marked only in the equatorial plane; that is, in our case, in the region nearest the earth's surface. On the other hand, the electric force in the direction of the axis of the oscillator, or vertically above the radiating antenna, falls off very rapidly, at first as the cube, later as the square of the distance.

Thus, at great distances, an appreciable effect from the Hertzian waves sliding over the earth's surface need not be expected at distances far above the surface. This does not require an hypothesis of the reflecting power of a highly-conducting stratum of rarified air, at an elevation of several

miles, as has been ingeniously suggested to account for the departure of the phenomena from the law of the inverse squares.

Possibly such strata may influence the radiation outwardly into space to some extent. But an exact knowledge of the actual field of force, both on the earth's surface and in the ether surrounding the transmitting station, can only be had by a thorough exploration with detecting oscillators, and under conditions such as obtain in practical, long-distance working; an exploration such as Hertz conducted in the laboratory at Karlsruhe, in that masterly way which so characterized his work.

Such work must obviously be undertaken in a captive balloon or air-ship, and will be attended with obvious and costly difficulties. A beginning was made several years ago by Captain Ferrie, of the French Artillery, but has never been pursued.

With the unequalled facilities offered this summer at the World's Exposition at St. Louis, both as regards a transmitting station of unusual power, or others of lesser range, and as regards vehicles for aerial navigation, it is to be earnestly hoped that more light may then be thrown upon this subject, so full of academic and practical interest.

The results of years of patient experiment, careful research, accompanied often with disheartening failures, on the part of the investigators in the wireless field, frequently fail to meet the full expectations of the public. The difficulties to be overcome can of necessity not be realized by those unacquainted with the exact details of development. Such, alas, has been the history of all invention, all progress. It is gratifying to know that the fundamental obstacles at least are in so large a measure overcome, that development in this, the field possessing perhaps the most popular interest exhibited in any age towards any invention, any discovery, has yet been steady, although at many times slow and faltering.

The difficulties remaining are manifold and great. The development of the past is an earnest of the greater things

which are so surely in store for this new and humanitarian art.

DISCUSSION.

PROF. GEO. A. HOADLEY:—I understand that the Hertzian waves decrease the resistance of the coherer in the Marconi system to such an extent that it is possible to use a local circuit and Morse instrument as a receiver. In this system, since the Hertzian waves increase the resistance of the electrolyte, such an instrument cannot be employed. What is to be used, a telephone receiver?

DR. DE FOREST:—In reading we always employ the telephone with the electrolytic receiver. This combination is the simplest and most sensitive possible and requires no attention or adjustment from the operator. The result is a speed and accuracy of reading impossible by relay; and the trained ear of the operator enables him to instinctively discard false or interfering signals, atmospheric or otherwise, and to attend exclusively to the signals having the distinctive sound of his transmitter spark. We can thus, with two telephones in series, and two operators, read two distinct messages without any other tuning.

A relay can, however, be used with the electrolytic receiver. On account of its sensitiveness and regularity of normal, I use this merely to ring a calling signal. But the records which my system has to its credit, often in competition with tape-register systems, justify, I think, this policy of simplifying the apparatus to the greatest possible extent.

MR. E. A. SCOTT:—In consideration of the fact that the earth, as a mass, is a conductor without resistance, would it not be practicable to make a ground connection with the two stations of sufficiently low resistance to use the earth as a current chute as the water is now used?

DR. DE FOREST:—While the conductivity of the earth as a mass may be considered as infinite, yet only that of the surface lying in the zone of influence from any transmitter station can enter into the question. This conductivity of course varies with the locality, and the quality and dampness of the soil intervening between the two stations. If this chanced to be especially better than the conductivity

of the surrounding country we would find the conducting strip acting in a measure as a "wave-chute," leading a greater portion of the wave energy in that direction than was propagated in other directions of the compass.

Such a condition would be offered in an arid country where the conducting surface was confined largely to the neighborhood of a river or its valley, lying in the line between the two aerograph stations.

A system of railroad tracks would act in this manner, and if both transmitter and receiver instruments were connected to these tracks transmission along the line would be especially good.

MR. CARL HERING:—Would not the presence of large quantities of telegraph wires, or large metal masses, interfere with transmission of your messages?

Would not the submarine cables play a part in transatlantic wireless?

DR. DE FOREST:—A mass of horizontally extending telegraph wires would have little effect on the transmission of "wireless" signals if the wires extended at right angles to the direction of propagation.

The lines of static displacement in the wave are vertical, and hence it is only the vertical components in the telegraph wires which would cause a reflection or absorption of the wave energy.

In the case, however, of large vertical masses of metal, such as elevators, gas reservoirs, steel-framed buildings, etc., a very considerable shadow effect of the waves is observed.

This is in accordance with the experiments of Hertz and Lodge on the polarized properties of the Hertzian waves.

On the other hand, if the line of telegraph wires extend in the direction of propagation, they afford a conducting path for the waves, and we find the propagation actually aided, with a tendency to confine or concentrate the energy propagated along that line.

The same thing is noticed in the laboratory, where a simple wire lying along the floor, and not connected either to transmitter or receiver, will greatly aid the transmission, if it lie in the proper directions.

I have noticed the same thing to a marked degree at one of my stations, where a single telephone wire leading into stations extended for several miles in a straight line towards the transmitting station.

It was possible to obtain the messages by connecting the receiver between this wire and earth fully as well as from the 180 feet antenna, although the distance to the transmitter was some 15 miles.

If this wire were extended at right angles to the line of propagation, we would expect no such action from it.

DR. E. GOLDSMITH asked the lecturer whether the earth or the water was not necessary for the transmission of aerial messages; and also whether the high poles built into the ground did not assist to help the transmission; how high have the poles to be in order to send messages across the Atlantic Ocean? It seemed to him that iron ships floating on the water helped in a measure the transmission of the waves.

DR. DE FOREST:—The conductivity of the earth or water surfaces over which the sliding waves are propagated enters very greatly into the phenomena. Therefore is it that we are enabled to operate over greater distances by sea than by land with a given quantity of transmitted energy, other conditions being the same. Moreover, overland the vertical wave-fronts are more or less cut into by obstacles which they there meet—forests, precipitous hill-sides, buildings, metal structures, etc. Every such obstacle absorbs or reflects a greater or less amount of the energy of the waves, depending on the dimensions, conductivity and shape of the obstruction.

It is necessary to extend the vertical transmitting and receiving wires to a certain height, roughly depending upon the distances to be covered. The commonly-accepted law is that with a parity of other conditions, the distances attainable are proportionate to the square of the height of the aerial conductors. But to-day a great number of other conditions and arrangements modify this rule.

Signals have been sent across the Atlantic using antenna 225 feet in the vertical, although the length of these

wires is much greater. That height is about the limit to be obtained in practice.

Obviously it is not necessary that the tops of the two masts, or towers, should lie in a line not cut by the curvature of the earth, for reasons already explained.

The distances attainable are nearly proportionate to the amount of energy transmitted, although the length of wave used plays a considerable part. Roughly speaking, the greater the energy the longer the period of oscillation of the radiator circuit, and the greater must be the length and the capacity of the antenna to be in resonance with such periods.

No better grounding conditions can be afforded than those found on an iron-hull vessel floating in sea water. Hence the long distances which are often attained under such circumstances.

ELECTRICAL TRANSMISSION OF PICTURES AND SCRIPT.

A correspondent of (London) *Nature* refers as follows to a method and apparatus for this purpose lately described by Dr. Arthur Korn:

The problem of distant electrical vision is one to which much speculation and experimenting have been devoted. Before this problem can be attempted with any hope of success, however, the preliminary one of the electrical transmission of photographs over a distance has to be solved. This problem, it may be stated at once, has been mastered, and it is now possible to transmit photographs in this manner, and successful results have been obtained over telegraph and telephone lines 800 kilometers long.

It does not need much consideration to see how important such a process would be for journalistic and police work if it could be industrially exploited, and it were possible simply to hand a sketch or photograph in at the telegraph office and send the same as one now sends an ordinary telegram. The evening papers would be able then to publish photographs taken at the seat of war in Korea on the same day. Unfortunately, with the apparatus at present to be had, the time taken to transmit a half-plate photograph is half an hour. The cost of the use of a telegraph line of any length for half an hour would be, it is needless to point out, prohibitive. The lessening of the required time of transmission is, however, simply a matter of further development, and no good reason can be seen why in a few years' time the process should not be an adjunct to every existing telegraph line.

The method shortly consists of the following: A ray of light is made to pass systematically all over the transparent film to be transmitted. After passing through the film it impinges upon a selenium cell the resistance of which varies proportionately to the amount of light which passes through the pho-