THE STORY OF
WIRELESS TELEGRAPHY

BY

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WITH FIFTY-SEVEN ILLUSTRATIONS

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THE STORY OF WIRELESS TELEGRAPHY

INTRODUCTION

Fairy Tales of Science—Early Dreams of Wireless Telegraphy—The Conduction Method—Induction—The Magnetic Field—Electromagnetic Waves—Electricity and Light—Clerk-Maxwell's Theory—Researches of Hertz—First Hint of Etheric Telegraphy—Radiophony—Light Telegraphy.

THE past century witnessed the discovery and development of many (as they may be called) fairy tales of science; but none of them—wonderful as they on their first inception seemed—strike the imagination with such a sense of the wonder-worker at play as the marvels of Wireless Telegraphy. Electric telegraphy itself was in the days of its early trials and successes regarded as something almost necromantic; and when pioneers in science began to speculate about and to forecast its application to ocean telegraphy they were regarded somewhat as moonstruck dreamers and phantasiasts of the castle-in-the-air variety. But ocean telegraphy came, and then, before the century, of whose mid decades it was a triumph, reached its end, it was followed by the realization of another dream, and in the wonder-book of the nineteenth century was written another fairy tale of man's triumph over matter and over space in the achievement of electric telegraphy without wires.

As we shall see in the following pages, the anticipation, the forecast of such a triumph, was in men's minds from the very earliest days of telegraphy, and from that time to the present keen intellects and indomitable wills—one after another—never ceased to be turned to the solution of the problem. First they sought an answer in one direction, then in another. Ever there was a reply sufficiently alluring to keep the ball rolling—to keep the ranks of the investigators full; and the achievements of one generation of workers after another served as the stepping-stones over which their successors moved to more assured successes, until finally the goal was won, if we can consider anything as final when there is so much still to win from the unknown.

There were in the earlier half of the last century two methods familiar to men of science by which it was hoped that one day it would be possible to convey messages from place to place without the use of wires. One of these methods was that known as Conduction, by which the conductive properties of the earth and water are turned to account for conveying the electric force; the other is that known as Induction, by which is signified the property an electric impulse has, so to speak, of transferring itself from one place to another.

But toward the end of the century, a third principle was discovered, which suddenly and most unexpectedly took precedence of the other two, and with almost startling rapidity was turned to account as a means of electrically communicating between distant places without connection by wires. This third method is that known as the radiation of electromagnetic waves through space.

It will be convenient here, by way of preliminary statement, to give a brief explanation of these different principles of electrical action. To take Conduction first—this is the property certain bodies possess of allowing heat, sound, and electricity to pass through them. Thus the felled trunk of a tree is a good conductor of sound. Metal is a conductor of heat, as may be proved by putting one end of a metal rod in the fire and taking hold of the other end. Electricity finds its way through certain substances in the same manner, and in proportion to the ease of such passage is it a good or an indifferent conductor. The fact that copper wire was early found to be so good a conductor caused it to be selected as the best material for ordinary telegraphic purposes. It will be seen, before we have proceeded very far in our account of wireless telegraphy, that water and the solid ground also are conductors, and it was the discovery of this fact which turned the attention of investigators to the earth as a means of telegraphing without the connecting link of wires.

What Induction is may best be explained by a simple diagram (Fig. 1). Fig. 1 represents two circuits, in the first of which (A) represents a galvanic battery and (B) an interrupter, by means of which the current of electricity can be closed or broken at will; while in the other, which remains always closed, a galvanometer (C) is included. Every time that the inducing wire, that is the one containing the battery, is closed, a short, constant current is set up in the other, or induced, wire or circuit, and this secondary current has much the same duration as that in the inductive current. If the latter be broken there arises in the induced circuit, a current whose direction is opposed to that in the primary circuit, and this phenomenon is repeated

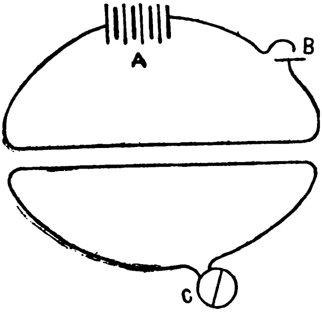

Fig. 1.

every time the current in the inducing wire is interrupted. The two wires may be a few feet or several miles apart, but whether the one or the other, induction takes place all the same. Another circumstance connected with this singular appearance is that directly the current in the primary wire begins to flow, as we say, what is called a magnetic field is set up all round it and, so far as we understand, is the cause of the induction. But the whole phenomenon is still involved in a good deal of mystery, and will require the genius of another Faraday, whose peculiar glory it is to have first discovered the principle, thoroughly to lay bare its secret.

The third method of telegraphing without wires, that based on the phenomenon known as electrostatic waves, is the most surprising of all, and up to the present time has produced the most wonderful results, although it is quite possible that they may be outdone in the future by other forms of electrical action. The existence of these electromagnetic waves has only been known since 1888, and the story of their discovery is one of the romances of science. We shall come to that epoch-making event in due course: all that it is necessary to say here is that by means of disruptive electrical discharges electromagnetic oscillations are set up in the ether with which all space is filled, and that upon these oscillations, or waves, by instruments properly adapted to that end, signals may be transmitted and received, as in ordinary telegraphy.

These waves move with a velocity equaling that of light, with which they are held to have an intimate connection, and vary in size according to the strength of the impulses which starts them on their course, some being, as it were, mere ripples while others stretch to hundreds and even thousands of miles in length. They are of course invisible to the unaided eye, though the eye of the camera has seen and transfixed them (Fig. 2).

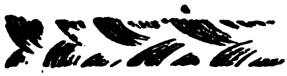

FIG. 2.

The first hint of the existence of these electromagnetic waves was given by Professor J. Clerk-Maxwell of Cambridge, who, struck by the value of a certain coefficient, very important in the study of electrical phenomena, and by its agreement with the figure which represents the velocity of the propagation of light, was one day strongly impressed with the extreme likelihood that light and electricity were essentially the same. Building upon this apparent identity, he worked out an hypothesis in regard to the constitution of the medium in which these phenomena exist, and in due course, as a French writer puts it, "gave to the world the edifice of his thought."

Part of that edifice consisted in the theory that electricity, like light, traverses space through the medium of the ether, and that if, by a disruptive discharge, a magnetic flux is created in any place it spreads outward or extends itself by an undulatory motion similar to what we see in a body of water when a stone is dropped into it. Twenty-five years later a German professor named Heinrich Hertz, deeply imbued with the teachings of Maxwell, and stimulated by a chance observation that has already become classic, conceived the idea of establishing his theories by practical experiment. To this end he devised an apparatus peculiarly adapted to his purpose, and with it not only succeeded in making a brilliant demonstration of the truth of Maxwell's conception, but, going still further in his researches, ended by giving to the world a means of communicating through space on the ether-piercing rays of electricity.

As already said, this magnificent discovery was given to the world in 1888. It was barely made public ere a German engineer named Huber questioned Hertz as to the possibility of making use of the electromagnetic waves as a means of telegraphing without wires. Hertz threw cold water on the idea. He had not grasped the full significance of his own discovery; and indeed other discoveries and inventions were necessary for the practical realization of the idea thus thrown out. But there were not wanting minds who perceived something of the scope and grandeur of the rôle this Maxwell-Hertz discovery was destined to play in the near future, and these, as we shall see, were soon at work moving, unconsciously for the most part, toward a certain end.

I have mentioned three methods of turning electrical energy to account for the production of wireless telegraphy. But there is still another which ought not to be passed over in such an account as this, the more especially as it is one that may yet play an important part in intercommunication between place and place. I refer to telegraphy by means of light rays. Radiophony, the discovery whereof is usually attributed to Professor Graham Bell, but the honor of which belongs as much to Mr. A. C. Brown, is based upon the phenomena, made known in 1878, that selenium possesses, under certain conditions, the property that when placed under a ray of light it opposes to an electrical current a less resistance than when it is in the dark. In other words, it is a better conductor in the light than in the dark.

The discovery appears to have been first made by one of Mr. Willoughby Smith's assistants; although Siemens lighted on the same fact almost contemporaneously. Bell, however, in collaboration with Sumner Tainter, continued and extended his researches with a view to ascertaining whether other substances possessed the like qualities, with the result that he found, among others, that gold, silver, iron, ivory, gutta-percha, paper, wood, mica, glass, etc., were similarly sensitive to light, although in a less degree than selenium.

On the basis of this observation Bell proceeded to devise an apparatus whereby a ray of light could be thrown upon a selenium cell. The cell was connected with a battery and a telephone in a circuit in such a way that every change in the resistance of the selenium, and the therewith associated change in the strength of the current in the telephone, could be at once detected. By shutting off the light rays at short regular intervals, signals could thus be transmitted, and these were distinctly repeated in the telephone. This delicate instrument, first made public in 1880, was originally designated the photophone, a name which was subsequently changed to radiophone. The same idea was further developed some years later; but of this invention we shall have something to say later in connection with Hertz and his investigations, and so need make no further reference to it at this point.

CHAPTER I

Steinheil's anticipation of Wireless Telegraphy—Conductivity of the Earth—Its use in place of a second wire—Telegraphing through the Earth—Anticipation of the Radiophone—Morse's experiments in Wireless Telegraphy—His results.

THE story of Wireless Telegraphy presents us with a number of names of men who may be said to have predicted the future triumph of such a form of communicating between place and place, if we may accept what appear to have been mere wide-awake dreams as prediction. Setting these aside, however, as not germane to our subject, we come, in the scientific records of 1838, to the name of one who may with truth be said to have laid the foundation of telegraphy without wires. This was Prof. C. A. Steinheil of Munich, who in the year named gave to the world a very clear and intelligent anticipation of this form of electric communication. Being associated with Gauss—who, along with Weber, had been the first to demonstrate the practicability of electric telegraphy—during the time that he was constructing his famous system of telegraphy in Bavaria, that distinguished scientist suggested to him the possibility of utilizing the two lines of a railway as telegraphic conductors. Steinheil was struck with the suggestion, and put it to the test of experiment on the line between Nuremberg and Fürth. The attempt, however, proved a failure because of the impossibility of so isolating the rails as to prevent the passage of the electric current from one rail to another through the ground.

But if Steinheil's researches turned out unsuccessful in this particular respect, they nevertheless led to a most important discovery. For he found that the conductivity of the earth was so great that it led him to believe that it might be turned to advantage for the return current in place of the second wire previously used. The experiments instituted to test the truth of this inference proved entirely successful, and he was thus enabled, by the introduction of this earth circuit, to make one of the most important contributions toward successful telegraphy.

In the account Steinheil gives of his discovery, and the practical use he made of it, he says: "It appeared of especial interest to inquire into the laws of dispersion, whereby the ground, whose mass is limited, is acted upon by the passage of the galvanic current. The galvanic current cannot confine itself merely to the portions of earth situated between the two ends of the wire, but must spread out indefinitely on every hand, and it only depends, therefore, on the relation in which this law as to the excitation of the ground stands to the distance of the exciting terminations of the wire, whether any metallic connection at all is necessary for carrying on telegraphic communication.

"I can here only briefly state that I have discovered a means of putting the law of this phenomenon to the test of experiment, with the result that it is seen that the excitation quickly declines as the distance from the exciting conductor is increased.

"Appliances can indeed be constructed (Steinheil goes on to say), in which the indicator, having no metallic connection with the multiplier, generates currents in that multiplier, through the excitation of the ground alone, sufficient to cause visible deflections of the bar. This is a hitherto unobserved fact, and may be classed among the most extraordinary phenomena that science has revealed to us. It only holds good, however, for small distances, and we must leave it to the future to decide whether it will ever be possible to telegraph to great distances entirely without metallic connection. For distances up to fifty feet, I have proved the possibility of such electric communication by experiment. For greater distances we can only conceive it possible by augmenting the power of the galvanic induction, or by appropriate multipliers constructed for the purpose, or, finally, by increasing the surface of contact presented by the ends of the multipliers. In any case the phenomenon is worthy of our best attention, and it may not perhaps be without influence upon the theoretic view we may form in regard to the nature of galvanism itself."

Thus was the possibility of wireless telegraphy first scientifically demonstrated. Steinheil's experiments, however, did not lead him in the end to any very sanguine anticipations in regard to the practical value of such telegraphy, and in referring to the subject in his Application of Electro-Magnetism,* he makes the following observation: "The spreading of the galvanic effect is proportional, not to the distance of the point of excitation, but to the square of this distance; so that, at the distance of fifty feet, only exceedingly small effects can be produced by the most powerful electrical effect at the point of excitation. Had we the means which could stand in the same relation to electricity that the eye stands to light, nothing would prevent our telegraphing through the earth without conducting wires; but it is not probable that we shall ever attain that end."

While Professor Steinheil's mind was thus intent upon the subject of wireless telegraphy he struck out another idea in connection therewith, and thereby curiously anticipated Graham Bell's radiophone. His proposed method was to direct

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* Die Anwendung des Electromagnetismus.

radiant heat upon a thermoelectric pile by means of condensing mirrors, thus calling a galvanic current into action, which in its turn could be employed to bring about declinations of a magnetic needle. Though Steinheil foresaw considerable difficulties in the working out of this principle, he held that they were not insuperable. Others since his time have given much time and thought to the subject; but it would take us too far away from the main line of investigation regarding wireless telegraphy to go into the matter here.

Following Steinheil, little beyond some scientific dreaming was done until Professor S. F. B. Morse, Superintendent of Telegraphs to the Government of the United States, inventor of the telegraphic alphabet known by his name, began to experiment with a view to seeing what could be done by way of dispensing with artificial conductors. His first experiments were made in the autumn of 1842, when, at the request of the American Institute, he undertook to give to the public of New York a demonstration of the practicability of his telegraph, and for that purpose laid wires between Governor's Island and Castle Garden, a distance of a mile. To his intense mortification, however, soon after he had begun operations, his purpose was frustrated by the accidental destruction of a part of his conductors by a vessel which drew them up with its anchor and cut them off. The accident, however, proved to be a fortunate circumstance, as it put into Morse's head the idea of arranging his wires along the banks of the stream, and so trying if the water itself would conduct the electricity across.

His first experiments according to this new method were made in December, 1842, across a canal at Washington, and proved eminently successful. These experiments were continued by Professor Gale on Morse's behalf, and in writing to the Secretary of the United States Treasury on the subject of his experiments, on December 23, 1844, Morse says: "The simple fact was then ascertained that electricity could be made to cross a river without other conductors than the water itself."

Morse repeated his experiments on a larger scale in the autumn of 1844, his aim then being, as he explains, to ascertain the law ruling the passage of electricity across a body of water. The nature of his experiment will be understood from the annexed diagram (Fig. 3).

A, B, C, D are the banks of the river; P, R is the battery; G is a galvanometer; *W, W* are the wires along the banks, connected with copper plates, *f, g, h, i,* which are placed in the water. According to Morse, the electricity, generated by the battery, passes from the positive pole P to the plate *h*, across the river through the water to plate *i*, and thence around the coil of the galvanometer to plate *f*, across the river again to plate *g*, and thence to the other pole of the battery R, to complete the circuit.

These experiments were made with different lengths of wire laid along the banks of the canal, and with batteries, the number of elements composing which were of different strengths. In the result it was found that the quantity of electricity which passed from one bank of the stream to the other stood in direct relationship to the size of the plates sunk in the water, as well as to the distance of the plates on the same side of the river from each other. From these and other experiments it was deduced that this distance should be three times greater than that from shore to shore. A greater distance than that did not give any increase of power.

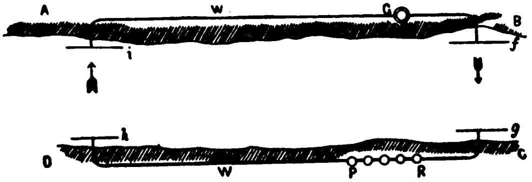

FIG. 3.

Similar experiments were carried out by Messrs. Vail and Rogers, two of Professor where the distance separating the two circuits Morse's assistants, across the Susquehanna River, was nearly a mile, and with complete success. It is curious to note that, in his communication to the Secretary of the Treasury, Morse remarks that "experience alone can determine whether lofty spars, on which wires may be suspended, erected in the rivers, may not be deemed the most practical."

A full account of these experiments is given in Alfred Vail's American Electromagnetic Telegraph, published in 1845, and reprinted in the Electrical World, June 29, 1895.

CHAPTER II

Wilkins' proposed method of wireless communication with France—Dering's experiments with conduction through water—Lindsay—His electrical researches—Proposal to telegraph across the Atlantic—His method—Experiments across the Tay and elsewhere.

THE next worker in the field of wireless telegraphy of whom we have any knowledge is Mr. J. W. Wilkins, whose experiments were begun in 1845. Wilkins was associated for many years with Messrs. Cooke and Wheatstone, the pioneers of electric telegraphy in Great Britain; and in a letter appearing in the Mining Journal, March 28, 1849, he clearly sets forth a method whereby, as he conceived, telegraphic communication might be established between England and France, which the submarine cable had not at that time joined. As this letter, from the suggestions it contains, is of great importance in the history of wireless telegraphy, it will be well to give almost entire the writer's description of the method by which he proposed to carry out his "theory upon which a telegraphic communication may be made between England and France without wires."

"I take for certain," he proceeds—"as experiments I have made have shown me—that when the positive and negative poles of a battery are dipped into or connected with any conducting medium, the electricity around the positive pole is positive, being diffused in radial lines, and the part around the negative pole is negative in radial lines converging toward it, supplying the electricity requisite for the decomposition of the substances composing the battery. This understood, it is evident that when a positive radial line sets out from the junction of the battery with the earth it makes its way to, or is attracted by the nearest negative portion of *earth,* at last meeting the negative pole of the battery, restoring the equilibrium. From this it appears that the first portion of electricity will pass in a straight line between the two poles, being the shortest between them, and the rays will then form curves between the poles until, by reason of increasing distance, they are no longer influenced by one another, without a better medium of conduction be interposed in their circuit.

" It is natural to suppose that all parts of the earth are not of one uniform density; if so, then some parts are positive, and others negative. Then from this it is easy to see that some of the electricity flowing from the positive pole is the means of restoring equilibrium to negative portions of the earth—not necessarily rendered so by the negative pole of the battery; and also positive portions, for the same reason, rendered neutral or negative.

"These rays of electricity may be collected in a certain quantity between the point whence they start, and where they are rendered neutral, and by the interposition of a metallic medium that shall offer less resistance than the water or earth —obviously the nearer the battery the greater the chance of collecting them. I do not anticipate the distance of twenty miles is at all too much (with the means we can use to compensate it) to collect a sufficient quantity of current to be useful for telegraphic purposes. Still, the quantity would be small, and with the present telegraphic instruments would not be detected at all. The current in the wire (of the instrument used) must be detected—not by its amount, but that it exists in *any quantity,* however small. If, then, electricity can be collected in France, simultaneously with a discharge from a battery in England, all that is required is, to find out what to do with it, so that it shall indicate its presence.

"I will now lay before you the arrangement I propose for carrying out this design.

"*No.* 1.—Upon one shore I propose to have a battery that shall discharge its electricity into the earth or sea, having a distance of some five, ten, or perhaps twenty miles—as the case may be—between the poles.

"*No.* 2.—Let a similar length of wire be erected on the opposite coast, as near to, and as parallel with it as possible; having its ends dipping into the sea or earth.

"*No.* 3.—Within the above circuit have an instrument consisting of about ten or twenty, or more, square or round coils of finest wire, of best conductibility, suspended on points or otherwise, being part of circuit No. 2. Suspend this coil before or between the poles of an electro, or permanent magnet or magnets, and in either case any current passing through the coil will be indicated by its moving or shifting position. This would then constitute the telegraph. It would now only depend upon the distance between the poles of the battery, in one case, and the ends of the circuit wire in the other, together with the lightness of the coils of wire used—having reference to their number—and the power of the magnet or magnets used to deflect it; although that would be easy of adjustment, and when once done, are certain to be of continuance—at all events, much more so than a submerged wire across the Channel.

"I hope some one will take up this suggestion, and carry it out practically, to a greater extent than my limited experiments have enabled me; for, of its truth, for long, as well as short distances, I am satisfied, and want of means only prevents me carrying it out at once. I venture to say what I have, on an experience in electricity of ten years, and a practical acquaintance with electric telegraphs of nearly five years."

This letter, and the theory it contained, appears to have been forgotten until, in a letter in the Electrician (July 19, 1895), Wilkins directed attention to it. "In 1845" (he writes) "while engaged on the only long line of telegraph then existing in England, my observation led me to question the accepted theory that currents of electricity, discharged into the earth at each end of a line of telegraph, sped in a direct course—instinctively, so to say—through the intervening mass of ground to meet a current or find a corresponding earth-plate at the other end of it to complete the circuit. I could only bring myself to think that the earth acted as a reservoir or condenser—in fact, receiving and distributing electricity almost superficially for some certain or uncertain distance around the terminal earths, and that according to circumstances only. A year later, while occupied with the installation of telegraphs for Messrs. Cooke and Wheatstone, a good opportunity offered of testing this matter practically upon lengths of wire erected on both sides of a railway.

"To succeed in my experiment, and detect the very small amount of electricity likely to be available in such a case, I evidently required the aid of a very sensitive galvanometer, much more so indeed than the long pair of astatic needles and coil of the Cooke and Wheatstone telegraph, which was then in universal use as a detector. The influence of magnetism upon a wire conveying an electric current at once suggested itself to me, and I constructed a most sensitive instrument on this principle, by which I succeeded in obtaining actual signals between lengths of elevated wires about 120 feet apart. This, however, suggested nothing more at the moment than that the current discharged from the earth-plates of one line found its way into the earth-plates of another and adjacent circuit, through the earth.

"Later on I had other opportunities of verifying this matter with greater distances between the lines of wire, and ultimately an instance [presented itself] in which the wires were a considerable distance apart, and with no very near approach to parallelism in their situation. Then it was that it entered my head that telegraphing without wires might be a possibility."

It is of interest to note that the instrument which Wilkins conceived as a means of detecting the current impulses anticipated the siphon recorder of Lord Kelvin, as well as the Deprez-D'Arsonval instrument so much used on the Continent, and others.

These researches on the part of Wilkins were followed in the earlier half of the next decade by two series of highly interesting experiments conducted respectively by George E. Dering and James Bowman Lindsay. It is perhaps impossible now to determine which of these investigators was actually first in the field, but as Dering was the first to take out a patent (August 15, 1853) for transmarine telegraphs he seems to claim priority of attention. In his specification Dering sets forth several alternative methods for effecting his purpose, one of which consists in establishing circuits composed of uninsulated or partially insulated conductors, and in part of the conducting property of the sea, across which communication is to be made, or of the earth or the moisture contained therein in the case of land telegraphs. "For this purpose the connections are effected at such a distance in a lateral direction that a sufficient portion of the current will pass across the water or earth space and enter the corresponding wire connection at the other extremity."

Dering tested his method across the river Mimram, at Locksley, Herts, with parallel wires of galvanized iron, laid at a distance of about thirty feet apart, and a small battery composed of two or three Smee cells, with which apparatus he was successful in obtaining understandable signals.

Lindsay was a man in many respects very different to the others that have been named. They were practical men and for the most part pioneers in the actual work of telegraph-laying and operating. Lindsay, on the contrary, was a scholar, a man deeply read in many branches of learning, and with a mind admirably adapted for scientific research. He seemed to possess the intellectual tentacles which are forever probing ahead on the borderland of the unknown and pushing forward lines of light into its dim and unfathomed spaces.

A linen-weaver by trade, he early showed such a devotion to books that his parents saw fit to send him to St. Andrews University. There, although hitherto self-taught, he soon distinguished himself by his abilities, and won, before his four years' course was concluded, the premier place in the mathematical and physical branches of science. It was his intention, apparently, to enter the Church, and he devoted himself very assiduously to theology with that object in view; but his mind appears to have run too much in the groove of science and investigation for him to be content in the restricted sphere of a minister, even if he had become one, which he never did.

For a time during his University career he appears to have resumed his occupation of weaving in the summer vacation; but later he devoted himself to teaching, and to that profession the remainder of his life was more or less given—for a time as mathematical lecturer at the Watt

Institution, Dundee, later as teacher in the Dundee Prison at a salary of £50 a year, a post which he held from 1841 to 1858. In the latter year he was, on the recommendation of Lord Derby, at that time Prime Minister, granted a pension of £100 a year in recognition of his great learning and extraordinary attainments.

Much of Lindsay's time seems to have been wasted on dead languages, and, if we may be permitted the comparative, "deader" chronology. But for that—and his poverty—his achievements in the field of electrical science, great as they were, might have been much more considerable. According to his own statement, he first turned his thoughts to electrical investigation in 1832, and was for a time undecided whether he should devote his attention to electricity as a source of power, of light, or of telegraphic communication. He decided in favor of light, and his success in that direction was, we are told, so undoubted that he was able (in 1835) to light his one little room by electricity. A year before that he had predicted in a public print that "in a short time houses and towns would be lighted by electricity," that they would be heated by it also, and that machinery would be driven by it "at a trifling expense."

Having gone thus far in his investigations with regard to electric lighting, Lindsay, after some years devoted to other and less illuminating labors, turned his attention to electric telegraphy. It is not necessary here to refer at length to his ideas regarding transatlantic telegraphy. Such a thing in 1845 was a dream, but it was such a dream as Lindsay had the prescience to see might one day be realized. His conception was that the thing could be done by means of a naked wire and earth batteries. According to his own statement he had "proved the possibility" of the method he suggested, "by a series of experiments." He was not, of course, the first to make such experiments; for, as we have seen, Steinheil in 1838, and Morse in 1842, to say nothing of others, had successfully tested the feasibility of signaling with uninsulated wire and without wire. But to him is apparently due the credit of having first suggested the possibility of telegraphing across the Atlantic by combining the two principles.

But Lindsay's "intellectual tentacles" led him a considerable step beyond this, although it was not until 1853 that he made his conception known to the world. In the month of March in that year he delivered a lecture in Dundee on the subject of telegraphic communication, and in the course of his remarks he made it perfectly clear that he had conceived the possibility of telegraphy without wires. By a peculiar arrangement of wires at the sides of rivers or seas (he said) the electric influence could be made to pass through the water itself. Thence submerged wires, such as those then used for telegraphic purposes between England and France, were no longer necessary. In June, 1854, Lindsay patented his method,* and in the opening clause of his specification, he describes his invention as consisting of "a mode of transmitting telegraphic messages by means of electricity or magnetism through and across water without submerged wires, the water being made available as the connecting and conducting medium."

The annexed diagram (Fig. 4) explains Lindsay's method. A, A show the position of a battery and telegraph instrument, to which are attached two wires terminating in metal plates or balls placed in the water *z*, at a certain distance apart, according to the width of the water to be traversed; B, B represent the battery and instrument on the opposite side of the water; C, E, D, F are metallic and charcoal terminators; C, H, I, K insulated wires connecting the terminators, batteries, and instruments, as indicated.

If it is required to send a message from A, it is evident that the current will have two courses open to it, the one being directly through the water from C to D, the other across the water from C to E, along the wires I, K, through the instrument B, and so back from F to D. "Now,

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* Lindsay's patent is numbered 1942, Dering's 1909.

I have found (says Lindsay) that if each of the two distances C D and E F be greater than C E and D F, the resistances through C E and D F will be so much less than that through the water between C and D, that more of the current will pass across the water, through the opposite wires, and recross at F, than take the direct course C D; or, more correctly speaking, the current will divide itself between the two courses in inverse ratio to their resistances."

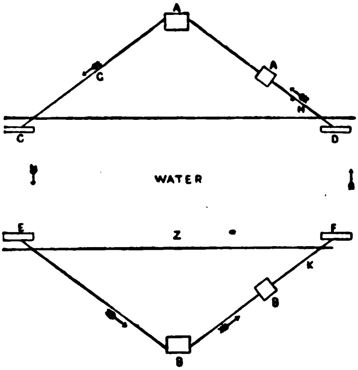

FIG. 4.

Lindsay's specification provides that the distance between the submerged plates shall, when practicable, be greater than that across the water; but when that is not possible, and there is danger, in consequence, of the current of electricity taking the shorter cut from C to D, in place of the longer one, as would thus be, from C to E, he proposes to increase the size of the plates and at the same time to augment the force of the batteries, "so as to compel a sufficient portion of the current to cross."

Lindsay made public trials of his method in one of the docks at Dundee, and subsequently at Glencarse on the Tay, where the river is nearly three-quarters of a mile wide, and where he was successful in getting deflections of the needle from one side to the other. These experiments were repeated at Woodhaven on the Tay, where the river is nearly two miles across, and at various other places, generally with equal success, although on one occasion, at Liverpool, he met with a signal and unaccountable failure.

In 1859, when the British Association held its annual meeting at Aberdeen, Lindsay read a paper before that body "On Telegraphing without Wires," which appears to have won the hearty approval of Lord Rosse, the president of the electrical section, as well as of Faraday, and other leading scientific men.

An abstract of the paper appeared in the Dundee Advertiser, in which it was stated that "Experiments had shown that only a fractional part of the electricity generated goes across, and that the quantity that thus goes across can be increased in four ways: (1) by an increased battery power; (2) by increasing the surface of the immersed sheets; (3) by increasing the coil that moves the receiving needle; and (4) by increasing the lateral distance of the sheets. In cases where lateral distance could be got he recommended increasing it, as then a smaller battery power would suffice. In telegraphing by this method to Ireland or France abundance of lateral distance could be got, but for America the lateral distance in Britain was much less than the distance across."

This devoted investigator's latest experiment with wireless telegraphy took place in 1860, when he again succeeded in strongly moving a telegraphic needle across the Tay at a point where it is more than a mile wide. Two years later he died, perfectly convinced to the last, as we are told, of the correctness of his views and of the ultimate triumph of his method of telegraphy.

CHAPTER III

Highton and his suggestions—Other experimenters in Wireless Telegraphy—A proposal to communicate with besieged Paris by telegraphy through the water—Its necessity obviated by the armistice—Wireless telegraphy in India—An American dentist's conception and experiments.

WHILE Lindsay thus occupied himself in Britain Bonelli was busy with similar investigations in Italy, just as Gintl (first inventor of duplex telegraph) was in Austria, and Bouchot and Donat in France. So little, however, is known about their experiments that it must suffice here simply to mention their names, going to show, as they do, that the idea of wireless telegraphy was, as we say, very much "in the air."

Of another investigator, who was at work at the same time, and whose researches, begun in 1852, extended over a period of twenty years, it is necessary to speak at greater length. This was Henry Highton, who, basing his suggestions upon numberless experiments designed with the view of finding out the best means of telegraphing between two places separated by water, described in a paper on Telegraphy without Insulation, read before the Society of Arts (May

1, 1872), three plans by which that end could be attained. The first is practically the same as the plan adopted by Morse. In the water near one bank are placed the copper plates A B (Fig. 5), which are connected by a wire, including the battery P. Near the opposite bank are submerged similar plates, C D, connected by a wire, in the circuit whereof is placed the galvanometer G. Between A and B the current will pass by every possible route, in quantities inversely proportional to their resistances; parts passing direct by A B, and other portions by A, C, D, B, and by A, C, G, D, B. If the plates be large, and A C and B D respectively comparatively near to each other, an appreciable current will pass from A C, through G, back to D B; but if the plates be small, the battery power small, and the distance from A to B, and from C to D, comparatively short, no appreciable amount will pass through the galvanometer circuit.

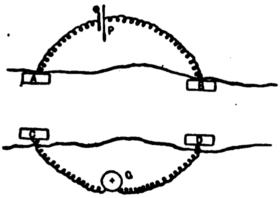

FIG. 5.

Mr. Highton held that it was possible, by erecting a very thick line wire from the Hebrides to Cornwall, by the use of enormous plates at each extremity, and by an enormous amount of battery power (as regards quantity) to transmit

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a current which would be sensibly perceived in a similar line, with equally large plates, on the other side of the Atlantic. "But," adds Mr. Highton, "the trouble and expense would probably be much greater than that of laying a wire across the ocean."

Highton's second plan was to lay across the water two wires kept from metallic contact with each other, and to work with that portion of the current which preferred to pass through this metallic circuit instead of passing through the liquid conductor, having currents of low tension from batteries of large surface. In certain cases, finally, this double line across the water might be dispensed with and a single imperfectly insulated wire used in its place, when the water itself would serve for the return current. Of these three plans Highton held the second to be the simplest and, on the whole, the most workable. It was, as a matter of fact, the one largely made use of by telegraph engineers in India for crossing large rivers, for which purpose it was found specially adapted, provided the two wires sunk in the water were a sufficient distance from each other.

There were many other workers in the same field in these mid-nineteenth century years, and a large number of patent specifications are to be seen at the office for that purpose in Chancery Lane, London, in which the subject of electric signaling is dealt with, chiefly on the lines laid down by one or other of the investigators whose experiments have been described. Their methods need not be described; but there was one projected plan of signaling which, both on account of its historical interest and its striking originality, is well worthy of a place in these pages. I refer to the method proposed by M. Bourbouze, a noted French electrician, for establishing telegraphic communications between Paris during the time it was invested by the German army and the French forces operating in the provinces. Bourbouze's proposal was, from a suitable place outside the German lines, to discharge a strong current into the river Seine, and to receive the same, or such portion of it as could be picked up by a metal plate sunk in the river and connected with a delicate galvanometer. Some preliminary experiments between the Hotel de Ville and the works of M. Claparède at St. Denis having proved successful, it was decided to put the plan in operation. With this object in view M. d'Almeida, on December 17, 1870, quitted Paris by balloon, and, after some perilous experiences, descended outside the German lines, and made his way by Lyons and Bordeaux to Havre. From that place the apparatus necessary for the experiment were ordered from England, and on January 14, 1871, M. d'Almeida arrived at Poissy on the Seine, where the contemplated operations were to be set in motion. Unfortunately, however, the river was found to be frozen over, and so the experiment had to be postponed until January 24. By that time, however, all need for it had gone in consequence of the arrangement of an armistice, which in due course was followed by the treaty of peace. Some years later, Bourbouze instituted some experiments by way of testing his proposed method of electric communication without wires, but to what extent they were successful, if at all, does not appear to have been made public.

Although the proposed experiments of M. Bourbouze, which were based on the same principle as those of Messrs. Dering and Highton, referred to above, came to nothing, yet it was not many years before the methods which they adopted, and worked at with such indifferent results, were put in operation with conspicuous success in India.

At a very early date in the annals of telegraphy a great want was felt in India for some form of wireless telegraphy, in order to carry the electric current across the many broad rivers that exist in that country, whose frequent flooding and other obstacles caused telegraphy by cable to be fraught with many difficulties. A large number of experiments, extending over many years, were made by different gentlemen connected with the Indian Telegraph Department, including Blisset, Schwendler, and W. P. Johnston, all resulting in but indifferent success, until, in 1889, Mr. W. F. Melhuish, continuing the operation of his predecessor, Mr. Johnston, finally triumphed over the difficulties that had baffled so many previous investigators. It is needless to go into the details of his experiments, which show the practical realization of the methods proposed by Highton and Dering. He made it clear that "at all river cable crossings where the cables are laid in separate alignments—the further apart the better—should the cables become interrupted, communication may still be maintained from bank to bank, by using vibrating sounds, thus avoiding the delay, inconvenience, and cost of a boat service."

Melhuish adds that, in the case of such a parallel cable crossing, "besides the circuits afforded by the copper conductors, when these are in working order, there is always an additional local circuit available by means of the iron guards between the opposite cable-houses, and that this circuit could be used by means of the vibrating sounder as a talking circuit, in case of necessity, without interrupting through working on either of the cables."

This reference to Melhuish's experiments in India, has, however, carried us a little too far forward in our story, and we must go back a few years in order to give a few particulars anent a scheme propounded, and to some extent tested, by an American who was much talked about in his day. This was one Mahlon Loomis, a dentist, who conceived the idea of utilizing the electricity known to exist in the atmosphere for the purpose of establishing electrical communications between distant places. In the description of his patent, taken out in 1872, he speaks of his discovery as a means of turning natural electricity to account for "establishing an electrical current or circuit for telegraphic or other purposes without the aid of wires, artificial batteries, or cables." By this method he hoped to be able to communicate "from one continent of the globe to another."

His plan was, to use his own words, "to seek as high an elevation as practicable on the tops of high mountains, and thus establish electrical connection with the atmospheric stratum or ocean overlying local disturbances." Upon these mountain-tops his plan was to "erect suitable towers and apparatus to attract the electricity, or, in other words, to disturb the electrical equilibrium, and thus obtain a current of electricity, or shocks or pulsations, which traverse or disturb the positive electrical body of the atmosphere between two given points by connecting it to the negative electrical body of the earth below."

The notion may seem vague and wild; but if we are to believe the reports, Loomis actually tested his idea by selecting two "mountain-tops" in West Virginia and sending up kites therefrom, the strings of which contained a fine copper wire. These conductors were provided with the necessary apparatus for sending and receiving messages, and though the two stations were ten miles apart, and the only "electro-motor" was "the atmospheric current between the kites," yet the attempt to communicate between the two summits was successful.

So successful indeed were these experiments said to be that there was talk of a tower being built on one of the loftiest peaks of the Rocky Mountains to correspond with a similar erection on some suitable Alpine summit. On the top of these towers a tall mast was to be placed to carry an apparatus for collecting electricity. Nothing appears to have come of the project beyond a good deal of journalistic talk, not unmixed with ridicule; but it is interesting to note that it is in connection with this scheme of Mahlon Loomis that we first hear of the application of vertical conductors, or antennæ, as they are sometimes called, for the transmission of signals to a great distance.

CHAPTER IV

Effect of improvements in cables—Invention of the telephone—Researches of Professor Trowbridge with—His experiments with Wireless Telegraphy—Professor Graham Bell's Investigations—Dolbear's working with etheric waves—His anticipation of Marconi.

THE various experiments which we have hitherto been considering had for the most part their origin in the great cost and the technical difficulties involved in the laying of completely insulated and externally well-protected cables, as well as in the obstacles to speedy repair which had to be contended with in case of injury. When these various difficulties and hindrances had in the main been overcome by the improvements which were gradually introduced in the construction of submarine cables, the attention of inventors and investigators became for the time being directed from wireless telegraphy to other problems connected with electric communication, and not without success.

One of the triumphs of research that signalized the interval between the project last referred to and the one next in importance, connected with telegraphy without wires, was the introduction of the telephone. This wonderful little instrument, the invention of Professor A. Graham Bell, was given to the world in 1876, and soon became, in a most accidental way, a potent means of advancing the study of electric communication without continuous wires. It was found almost from the first that the telephone was so sensitive that sounds being transmitted on adjacent lines could be heard in it. Various experiments were made to test this property of the telephone, among others by Edison, Prof. E. Sacher, of Vienna, M. Henri Dufour, and others.

Professor Trowbridge, of Harvard University, however, was the first to put the possibilities here indicated to the test of systematic experiments. Utilizing the wire which runs from the Observatory to Boston for the purpose of sending time signals, he was successful in obtaining the transference of these signals to another wire from 150 to 180 meters in length, which was something like 1,600 meters distant from the first. Trowbridge varied his experiments in many ways, and as the result came to the conclusion (1) "that a battery terminal discharging electricity to the earth is the center of waves of electrical energy, ever widening, and ever decreasing in strength or potential as they widen; and (2) that, on tapping the earth by means of a wire at two points of different potentials (not very distant if near the central source, but more removed the farther from that source) we can obtain in the telephone evidence of their existence."

Professor Trowbridge goes on to say, quoting Steinheil's dictum: "The spreading of the galvanic effect is proportional . . . to the square of the distance, so that at the distance of fifty feet, only exceedingly small effects can be produced. Had we the means which could stand in the same relation to electricity that the eye stands to light, nothing would prevent us from telegraphing through the earth without conducting wires." Trowbridge adds that the telephone, though far from fulfilling the conditions required by Steinheil, is the nearest approach thereto, and then proceeds:

"The theoretical possibility of telegraphing across the Atlantic without a cable is evident from the survey which I have undertaken. The practical possibility is another question. Powerful dynamo-electric machines could be placed at some point in Nova Scotia, having one end of their circuit grounded near them and the other end grounded in Florida, the connecting wire being of great conductivity and carefully insulated throughout. By exploring the coast of France, two points on surface lines not at the same potential could be found; and by means of a telephone of low resistance, Morse signals sent from Nova Scotia to Florida could be heard in France."

Professor Trowbridge adds that "theoretically, this is possible, but practically, with the light of our present knowledge, the expenditure of energy on the dynamo-electric machines would be enormous."

But although Trowbridge perceived that this difficulty would prevent his method from being utilized for transocean telegraphy, he thought it might be turned to account for the intercommunication of ships at sea. He devoted a great deal of thought to this subject, and suggested two plans by which ships at sea might be enabled to speak with each other. They do not differ very materially the one from the other. In each case the ships must be provided with a powerful dynamo, one terminal of the dynamo connecting with the water at the bow of the vessels, and the other to a long wire, insulated except at its extreme end, trailing over the stern, and buoyed so as not to sink. The current from the dynamo would by this means spread out over the water and, so to speak, saturate it with electricity. The idea is that an approaching vessel, suitably provided with a telephone, the ends of whose wires passed over the bow and stern respectively, would thus be able to pick up any sounds issuing from the dynamo of the first vessel, and so get into communication.

Professor Trowbridge's second plan was to use, in place of a telephone circuit, a sensitive galvanometer connected with a cross arm of wire, whose ends should dip into the sea on either side of the vessel. As in the first-named method, the water would be saturated with electricity, and when another vessel came within this area the galvanometer would show how the equipotential lines were disturbed, and if a map of those lines were carefully traced the position of the approaching ship could be fixed. The idea of this second method is, of course, to prevent collisions in times of darkness and fog, and Trowbridge throws out the further suggestion that it might be applied to saturating the water about a rock, so that a ship might take electrical soundings and ascertain its position from electrical maps carefully made out.

Another ingenious method devised by Professor Trowbridge for obviating collisions during fog is shown in the annexed diagram (Fig. 6); in which M is a microphonic contact in a water-tight box. The face A of the box constitutes a vibrating diaphragm, the vibrations of which are conveyed to the microphonic contact M. The wires from the microphone M are conveyed to a battery B, and then through the primary coil P of an induction coil. In the circuit of the latter is placed a telephone. The water-tight box was lowered into the water from the side of a boat. An assistant stationed on land made sounds under water by striking two stones together, and by various other means, while Trowbridge listened at the telephone from a point up the stream. When distant three or four hundred feet or more, the sounds were transmitted through the water to the telephone, and similar results were obtained when the sounds were made from another boat. With more powerful sources of sound, such as the noise produced by steam condensing in a pipe under water, signals were transmitted more than a mile under water.

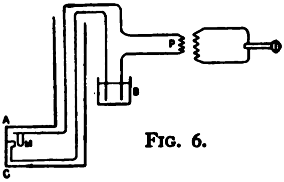

Fig. 6.

These investigations occupied Professor Trowbridge between the years 1880 and 1884. Subsequent to this he gave considerable attention to the question of aerial telegraphy, in these researches also having in view the practicability of establishing communications between ship and ship. He was led to the conclusion that electro-magnetic conduction would best serve this purpose, and devised a means whereby such process could be utilized. His apparatus consisted of two coils of copper wire of many convolutions, the ends of one whereof were attached to a telephone, while the other was connected with a battery through a key. If these were placed parallel to each other, and within a few feet apart, each time the current was made and broken in the battery coil, instantaneous currents were produced by induction in the coil attached to the telephone, as was attested by the clicks of the latter.

Making use of this principle, Professor Trowbridge proposed to stretch a wire ten or twelve times to and fro, from the yard-arms of a vessel's foremast, and connect it at the two ends with a powerful dynamo or battery, or with a telephone. When another vessel similarly provided approached the first, if the current on one of them were interrupted a great many times per second, a musical note would be heard in the telephone on the other. The sound would be strongest when the two coils were parallel the one to the other. If therefore the coils were movable, the position of greatest effect could soon be found, and so the direction in which the vessel was approaching be ascertained.

The method seems very simple, but for practical application the difficulties appear too great. To produce an audible note at the distance of half a mile would require a coil of wire or a strength of current beyond what was feasible. Such was Professor Trowbridge's conclusion, and, though others have worked in the same line of investigation, including Professor Henry and

Sir J. Oliver Lodge, the problem remains much as Trowbridge left it.

These investigations marked the beginning of a fresh attack upon the problem of wireless telegraphy, and were, during the next few years, followed by some remarkable achievements on the part of a number of workers in electrical science. The first in point of time was Prof. Graham Bell, who, basing his investigations on some experiments made with the galvanometer by Professor Adams, of King's College, turned the telephone to account in tracing equipotential lines and surfaces. The results of these experiments he communicated to the American Association for the Advancement of Science in 1884, and they are of so interesting a nature as to be worth quoting somewhat *in extenso.*

"In a vessel of water," he writes, "I placed a sheet of paper. At two points on that paper were fastened two ordinary sewing-needles, which were also connected with an interrupter that interrupted the circuit about one hundred times a second. Then I had two needles connected with a telephone: one needle I fastened on the paper in the water and the moment I placed the other needle in the water, I heard a musical sound from the telephone. By moving this needle around in the water, I would strike a place where there would be no sound heard. This would be where the electric tension was the same as in the needle, and by experimenting in the water you could trace out with perfect ease an equipotential line around one of the poles in the water."

Professor Bell goes on to say, respecting this experiment, that what was true on a small must also be true on a large scale, and that in this method a means might be found of communicating electrical signals between vessels at sea. He accordingly made some preliminary experiments in England, and succeeded in sending signals in this way across the river Thames. Then, urged by Professor Trowbridge, he made some further experiments, deriving therefrom some very valuable results. The first was on the Potomac River, and he thus describes it:

"I had two boats. In one boat we had a Leclanché battery of six elements, and an interrupter for interrupting the current very rapidly. Over the bow of the boat we made water connection by a metallic plate, and behind the boat we trailed an insulated wire, with a float at the end carrying a metallic plate, so as to bring these two terminals about one hundred feet apart. I then took another boat and sailed off. In this boat we had the same arrangement, but with a telephone in the circuit. In the first boat, which was moored, I kept a man making signals; and when my boat was near his I could hear those signals very well—a musical tone, something of this kind: tum, tum, tum. I then rowed my boat down the river, and at a distance of a mile and a quarter, which was the farthest distance I tried, I could still distinguish those signals.

"It is therefore perfectly practicable for steam-vessels with dynamo machines . . . to know of each other's presence in a fog when they come, say, within a couple of miles of one another, or, perhaps, at a still greater distance. I tried the experiment a short time ago in salt water of about twenty fathoms in depth. I used then two sailing boats, and did not get so great a distance as on the Potomac. The distance, which we estimated by the eye, seemed to be about half a mile; but on the Potomac we took the distance accurately on the shore."

Bell was so confident of the practicability of his method that he expressed a strong hope that steamships which had dynamo-engines and were electrically lighted would try it. The idea was that one of them should trail a mile-long wire electrically charged from the dynamo, and that the end on board should be attached to a telephone. The telephone or dynamo end would be positive, and the end trailing in the water negative. All the water next the ship, within a circle whose radius is one-half of the length of the wire would be positive, while the water within the same radius of the other or negative end of the wire would be negative. Such being the case, it would be impossible to approach within the radius of water so charged without the telephone making the fact known. If the ship so approaching were provided with a similar apparatus the two could communicate with each other by means of their telephones, and in case of fog would be able to keep out of each other's way.

Still another American, Professor Dolbear of Tuft's College, Massachusetts, was about the same time (1882) experimenting on lines similar to those which, as we have seen, had been occupying the attention of Trowbridge and Graham Bell, and so far did he push his researches that his friends claimed for him priority in the discovery of aerial telegraphy. He did actually send signals through space without wires, and came very near the achievement which is now so indelibly associated with the name of Marconi. In the early days of his investigation Dolbear put the distance at which he could make his sounds heard at half a mile, but later it was affirmed that he had obtained results as far as thirteen miles away.

There are some striking resemblances between his method and that of Marconi, and one can hardly doubt that, had Hertz then made his great discovery of the electric waves that bear his name Dolbear might have forestalled his younger rival.

Professor Dolbear read a paper descriptive of his method before the American Association for the Advancement of Science in the month of August, 1882, in which year he patented his apparatus in the United States. Fig 7 represents that apparatus, the left being the transmitting and the right

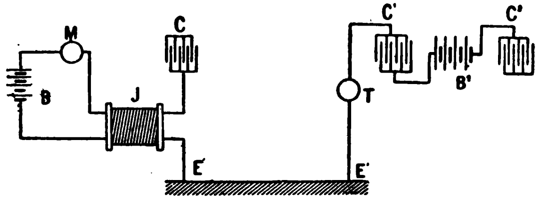

FIG. 7.

the receiving circuit. The induction coil J consists of a series of turns of wire which connect the primary and secondary coils. One twist of the coil is cut, and the four ends of the coil thus obtained are connected with the battery B, with the microphone transmitter M, with one end of the condenser C, and the earth. The battery consists of a large number of cells arranged in series in order to get between the condenser C and the earth a potential difference of at least 100 volts.

In the receiving circuit is a telephone T, which is connected with the earth, E^1, and one end of the condenser, C^1. The other end of the condenser, C^1, is connected with one pole of the battery, B^1, and through this with one end of the condenser, C^2. This arrangement is designed to charge the earth at E^1, with the opposing potential as at E. As, however, the condensers, C^1, C^2, possess only a small capacity their influence is an inconsiderable one, and they were considered by the inventor as not essential.

Fig. 8 represents in a simpler form what takes place when the resistance of the microphone M is subjected to changes by rapid vibrations of its membrane. J stands again for the induction coil, while C C^1 represent the ends of condenser of small capacity. Since, however, these condenser plates are near to earth they each represent a second complete condenser, the earth itself forming the second side. The capacity of these condensers is essentially greater than the capacity of the condenser C C^1, because the capacity of a condenser stands in reverse re-

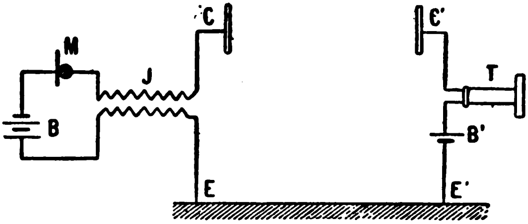

FIG. 8.

lation to the distance of the plates, and the distance between C and C¹ respectively and the earth is essentially less than the distance between C and C¹. If we consider the circuit E J B M J C C¹ T B¹ E¹ E, in which a changeable electromagnetic current is generated through the vibrations of M, it will be seen that there are figuratively two currents. The one begins at B, passes over the transmitter M, through the coil J to C, and so to the earth and thence over the second coil from J back to B. The second circuit runs in like manner, starting from B, over M, in the first coil from J C C¹ T B¹ E¹ E through the second coil from J back to B. This latter circuit serves for the transmission of the signals proceeding from the sender M to the receiver T. If the resistance, the self-induction, and the capacity of one of each of these currents are known, and likewise the total output of E M F through the battery and the variation in resistance from M be known, the strength of the current in each of the circuits can be reckoned. It is evident, however, that only a very small part of the current circulating in the circuit B C E B can be of any effect. The battery B¹, connected in series with B, increases the total E M F in the whole circuit and hence a change in resistance M will strengthen the current which goes through T.

Dolbear says that he obtained his first results from this apparatus with a large magneto-electric machine with one terminal grounded through a Morse key,. the other terminal being out in free air, and only a foot or two long. The receiver had one terminal grounded; the other was held in the hand, his body being insulated, and the distance between grounds being about sixty feet. Louder and better effects were obtained by using an induction coil having an automatic break, and with a Morse key in the primary circuit, one terminal of the secondary grounded, the other in free air, or in a condenser of considerable capacity, the other having an air discharge at its opposite terminal. At times a gilt kite was employed carrying a fine wire from the secondary coil. The discharges were then nearly as strong as if there was an ordinary circuit.

" Some very interesting results," says Dolbear, " were obtained when the static receiver with one terminal was employed. A person standing upon the ground at a distance from the discharging point could hear nothing; but very little standing upon ordinary stones, as granite blocks or steps; but standing on asphalt concrete, the sounds were loud enough to hear with the telephone at some distance from the ear. By grounding the one terminal of the induction coil to the gas or water pipes, leaving the other end free, telegraph signals could be heard in any part of a big building and its neighborhood without any connection whatever, provided the person be well insulated."

At the Electrical Exhibition held in Philadelphia in 1884, Dolbear exhibited an arrangement for wireless signaling which had been effective over limited distances. He used an induction coil as generator and a telephone as receiver. By connecting one terminal of the secondary of the induction coil to earth, and the other to one side of a condenser, the other terminal whereof had points for "discharging into the air," a telephone transmitter or Morse key, operating the primary circuit of the induction coil with a powerful battery, produced audible sounds in a telephone receiver one hundred feet away. One terminal of the telephone was connected to earth, the other through a battery to condensers arranged as at the transmitting end. Dolbear's idea was apparently the electrification of the two "ground" wires and the changing of their potential from positive to negative whenever a signal was transmitted. It was an original conception of the highest order, and in one feature furnished in advance a main requisite for long-distance telegraphy, that is, the vertical wire. There was a distinct approach, too, toward Marconi's method in the employment of condensers and the flying of gilt kites carrying a fine wire. Dolbear showed also that he was groping his way toward the real thing in attributing some of his results to the action of the ether.

That, however, is an entity which at the time referred to was little understood, and some of the most advanced minds as regards electrical science were inclined to attribute Dolbear's singular results as due to "an exceptional application of the principles of electro-static induction." There can be no doubt that Dolbear was working with Hertzian waves, although he did not know it, six years having still to elapse before their existence was discovered, and to that extent therefore he was anticipating Marconi.

CHAPTER V

Telegraphic communication with trains—A. C. Brown's method—Willoughby Smith and Phelps's suggestions—Successful application of the principle by Edison and Gilliland—Edison's method applied to ships—Sir William Preece's researches—His experiments on the Solent—Across the Severn—At Porthcawl—On the Bristol Channel—Loch Ness—The Island of Mull—His theory of the part played by the earth in electro-magnetic operations.

LIKE Trowbridge and Graham Bell, Professor Dolbear saw in his aerial method a valuable means of communication between vessels at sea. This idea and the cognate one of communication with trains in motion have been favorite subjects for investigation by scientific electricians since the earliest days of telegraphy. Many suggestions were thrown out, and a large number of experiments made, with a view to establishing such a system of communication with traveling trains; but as they were based on the principles of ordinary telegraphy they do not concern us here.

The first person to suggest an advance upon this method appears to have been Mr. A. C. Brown, who, in a letter published in the *Elec-*

trician for March 21, 1885, says that four years earlier (1881) he laid before the Managing Director of the United Telephone Company a paper in which he set forth a scheme by which signalmen might communicate directly with the guards or drivers of trains. He proposed to run a wire along the permanent way, parallel with the rails, and to wind a coil of wire round the engine or carriage to be communicated with, in such a way as to get as long a stretch of wire parallel to, and as near to the line wire as possible, so as to be well exposed to the inductive action thereof. He then proposed to place in the signal boxes a battery, signaling key, and rapid make-and-break instrument, or buzzer, and to signal thereby to the train, using a telephone in circuit with the train-coil as a receiver.

A similar suggestion was thrown out by Mr. Willoughby Smith in a paper read before the Institution of Electrical Engineers in November 1883, in which he says that one or more spirals might be fixed between the rails at any convenient distance from the signaling station, so that, when necessary, intermittent currents could be sent through the spirals. Another spiral could be fixed beneath the engine, or guard's van, and connected to one or more telephones placed near those in charge of the train. Then, as the train passed over the fixed spiral, the sound given out by the transmitter would be loudly reproduced by the telephone, and indicate by its character the signal intended.

Phelps, another experimenter in the same line, worked out a system which was a further development of that of Willoughby Smith. Along the whole length of railway line, between the rails, he proposed to lay an insulated wire, which was connected at the stations with sending and receiving apparatus. Beneath the guard's van or other carriage were several coils of wire, whose ends were connected with similar apparatus in the van or carriage. The sending apparatus consisted of, in addition to a battery and a key, an automatic interrupter, which was put in action the instant the key was depressed. From this resulted an intermittent stream of sounds which awoke a similar current of induced sounds in the coil beneath the train. The tympanum of the telephone, which, as the receiving instrument was connected with the end of the coil, would be set in motion by this current and so make known what was required. Or, in place of the telephone, a suitable relay might be added and in connection therewith an apparatus for giving the Morse alphabet, whereby communications could be sent to and from the transmitting stations.

In 1885 a further development of the principle herein set forth was patented by Edison and Gilliland. In their specification the invention is described as "an apparatus for telegraphing between moving trains, or between trains and stations, by induction, and without the use of connecting wires." The chief difference—although there are other important ones—consists in the fact that Edison and Gilliland made use of the ordinary telegraph wires running along the side of the railway in place of a wire specially laid between the lines. The details of a transmitting installation as arranged on a train is shown in Fig. 9. It consists of an induction apparatus, whose primary circuit, besides a battery and a Morse key, contains also an automatic current-breaker. The terminal of the second wire is carried to earth by means of the wheels of the train and the rails on which they run, while the other terminal conducts to a metallic condensing surface, properly insulated, which is stretched along the top or side of the car. This arrangement was later replaced by the metal roof of the car. When the Morse sounder in the primary circuit of the induction apparatus is depressed, and by this means the instrument is put in action, the secondary wires connected with the metallic condensing surface receive static impulses. These act inductively upon the telegraph wires, which receive and convey exactly equivalent impulses. These in turn affect the condensing surface upon the carriages of the other train, and cause impulses which are audible in the telephone.

Trains might likewise be supplied with receiving apparatus; and in order that it might be possible to telegraph thereto from a station, Edison and Gilliland erected between the telegraph wires a large metallic condensing surface connected with the station by a wire. The stations being thus connected inductively with the line wires, the same as the trains, signals could be received and transmitted by a station just as by a train, signals being sent by keys, circuit breakers, and induction coils, and received by telephones.

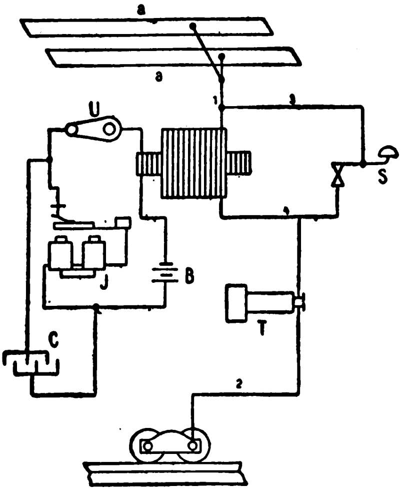

FIG. 9.

This system of train telegraphy was put in practical operation on the Lehigh Valley Railroad in 1887, and proved, so far as actual working was concerned, an undoubted success; but from a business point of view it turned out a failure. It had been thought that the traveling public would find it a great boon, and that messages to and from trains would be constantly flashing hither and thither. Such, however, was not found to be the case, and in a few months "train telegraphy" of this description was a thing of the past. Somewhat later Mr. Edison took out a fresh patent for the application of his method of aerial telegraphy on a scale that would adapt it for communication between vessels at sea, or between ships at sea and stations on land.

The apparatus he devised for the purpose is shown in Fig 10. In C C^1, elevated a considerable distance above the ground, we have two capacity surfaces which are connected by wire with the receiver and with the secondary coil of the induction apparatus. The receiving apparatus, called the "Electromotograph," consists of a rotating chalk cylinder, whereto is applied a metal brush, which through the resulting friction gives forth a sound of a certain height. By the passage of the electrical current over the brush through the chalk cylinder the strength of the position is altered, and a sound of a different quality is generated. This change of sound serves to distinguish the signals.

In the place of this receiver (represented in the diagram by R) any receiving apparatus depending on alternating currents may be employed, a rotating current-breaker U or U¹, closed respectively by the key T or T¹, is connected with the primary coil of the inductive apparatus. If the key be put down there ensues in the primary coil a series of rapidly successive current impulses, and corresponding alternating currents are called forth in the secondary coil, which spread over the surface of the elevated condensers, whereby the condensers are charged, discharged, in the opposing sense charged, and so on.

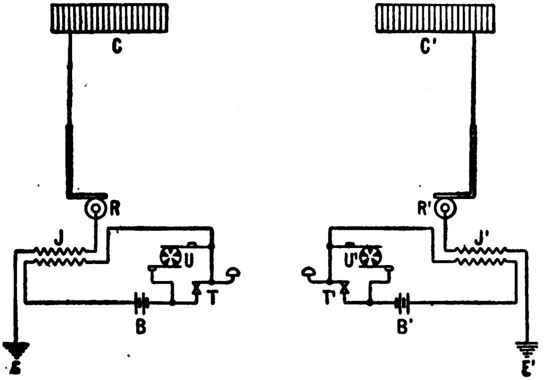

FIG. 10.

These electrostatic impulses are now transferred by way of the static induction to the condensers of the receiver and make themselves felt in the receiving apparatus itself. The air lying between the condensing plates forms the dielectric of the condensers thus created, and we have again the case of a circuit which contains resistance, self-induction, and capacity in series, and by which the alternating current is generated by a succession of impulses of relatively lower frequency.

In this patent Edison is shown to be the first who recognized the advantage of an elevated condenser. He foresaw the difficulties that would arise to the employment of his method between distant points on land, from the inductive absorbing effects of houses, trees, and hills. As a means of overcoming these impediments, he suggested increasing the height—" by using very high poles or captive balloons"—from which the signaling operations should be conducted. In these " high poles and captive balloons " we have, of course, another anticipation of Marconi, with his tall masts set on houses and high places.

We have seen how the experiments of Professor Trowbridge set a number of experimenters to work, and with what results. But there was still another inspired by his researches, whom we have not yet mentioned, and whose investigations were of the highest importance. I refer to Sir (then Mr.) William H. Preece, for many years engineer-in-chief to the British Postal Telegraph Department. Sir William had his attention drawn to the subject of wireless telegraphy very early in his professional career, having been witness of an experiment made by Lindsay at the York Road Stores of the Electric Telegraphy Company, London, in 1854. His own personal investigations, however, date from 1882, when (in the month of March) he tested the possibility of telegraphing without connecting wires across the Solent from Southampton to Newport in the Isle of Wight. The result of his experiment is told in a paper (on Recent Progress in Telephony) read before the British Association the same year. From some cause, he says, the cable across the Solent broke down, and as it was of great importance to know if by any means it was possible to communicate across, he thought the opportunity a good one to test the ideas which had been promulgated by Professor Trowbridge. He therefore put a plate of copper about six feet square in the sea at the end of the pier at Ryde. An overhead wire passed from there to Newport, and thence to the sea at Sconce Point, where was placed another copper plate. Opposite, at Hurst Castle, was a similar plate, connected with a wire which ran through Southampton to Portsmouth, and terminating in another plate in the sea at Southsea Pier. Thus there was a complete circuit, if the water be included, running from Southampton to Southsea Pier (twenty-eight miles), across the sea to Ryde (six miles), thence through Newport to Sconce Point (twenty miles), across the water again to Hurst Custle (one and a half miles), and thence back to Southampton (twenty-four miles).

The account goes on to say that loud-speaking Gower-Bell telephones were first connected in the circuit, but it was found that conversation was impossible. Then, at Southampton and Newport, a Theiler's sounder, or buzzer was tried, and with it, a Morse key, and thirty Leclanché cells at Southampton, it was possible to hear the Morse signals in a telephone at Newport, and *vice versa.**

Although, in consequence of the repair of the cable the next day, any further experimenting was unnecessary, Preece did not permit his interest in the subject to flag, and during the next few years no opportunity was neglected that might add to his knowledge in regard to wireless telegraphy.

This Solent experiment was, of course, one of conduction; but his attention was now to be

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* Major Cardew, R. E., introduced, in 1886, a similar system in connection with our military telegraphs, which is much used to bridge over broken or badly insulated wires.

drawn to communication by induction. Curious cases of telephones picking up telegraphic signals from distant circuits ever and anon occurred to give fresh stimulus to inquiring minds, and to act, as it were, as way-marks to investigation. One of the most striking instances of the kind is that known as the Gray's Inn Road case, which occurred in 1884. From insulated wires buried in iron tubes beneath the road it was found that messages in course of transmission could be read upon telephone circuits carried on poles over the roofs of houses eighty feet high.

Here there seemed to be a clear case of the operation of the principle or law of induction, as described in the opening chapter. It was not safe, however, to accept it as such without further evidence, as there was just the possibility that the phenomenon might have been caused by earth conduction. In order to put the matter to a thorough test, and also to discover to what distance the parallel wires could be removed from each other before the inductive influence failed to operate, Preece instituted a series of experiments on the town-moor of Newcastle (1885). Two quadrangles of insulated wire were laid down parallel to each other and quarter of a mile apart. When intermittent electrical currents were set up in one of these sets ot wires or circuits, they could be distinctly heard through a telephone in the other circuit. The sides of these squares were 440 yards in length, and, as in other experiments which followed, it was found that as soon as the distance between the parallel wires began to exceed the length of the wires the "induced" current in the second wire commenced to fall off.

One of the most interesting of Sir William Preece's experiments of this description took place in 1886 on the banks of the Severn, between Gloucester and Bristol, where for some fourteen miles, with an average distance apart of four and a half miles, there was an absence of intermediate lines that could have a disturbing influence. The experiments were conclusive, though unsatisfactory in so far as they showed that the "range of audibility" with the apparatus employed had been exceeded. Incidentally the interesting fact came out that the results were much the same whether the circuits were metallic throughout or earthed at the ends.

In the same year (1886) a similar series of experiments was conducted on a wide stretch of sand at Porthcawl, in South Wales, when the effect of suspending one circuit in the air above the other was tried. From these investigations the conclusion was drawn that the magnetic field permeates the earth as well as the air, and that if a circuit were arranged in a space beneath the surface of the ground a current could be induced in it from a superimposed circuit above ground. This inference was some months later put to a successful test at the Broomhill Colliery, by Mr. Heaviside, one of Mr. Preece's assistants. An equilateral triangle of insulated wire three quarters of a mile in length each side, was arranged in a horizontal plane at the bottom of the colliery, 360 feet below the surface of the ground. A similar triangle was placed above ground, exactly over and parallel to the former, and between the telephones in the two circuits communication was successfully established.

Similar and highly interesting experiments were conducted the same year (1886) across the Mersey at Liverpool, and between Shrewsbury and Much Wenlock.

It is unnecessary to go into details of all the investigations instituted by this indefatigable worker; but two or three sets of experiments carried out in Scotland and Wales respectively call for especial mention. The first of the series took place in 1892 between Lavernock Point on the Bristol Channel, and the two near-lying islands of Flat Holm and Steep Holm. The accompanying sketch-map (Fig. 11) shows the position of the two islands, the first named being 3.3 miles distant from Lavernock Point, and the other 5.35 miles distant. At the Point two thick copper wires, bound together so as to form one circuit, were stretched on poles for a distance of

1,267 yards, and then conducted to earth, which completed the circuit.

In addition to this three other wires were laid down, 600 yards from the first and parallel to it. Two of them were covered with gutta-percha, the third was left bare; the ends of all three were buried in the ground. One of the insulated lines was attached to an iron wire to represent a cable.

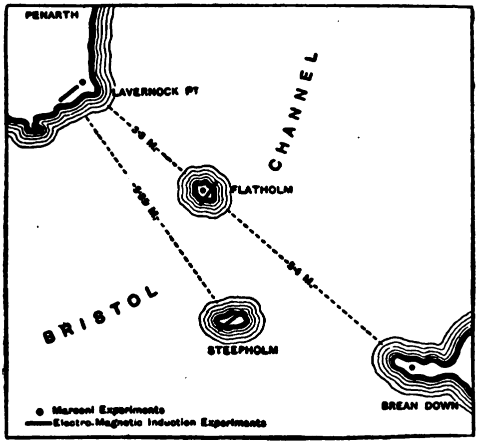

FIG. 11.

The current on shore was generated by a portable engine working an alternator transmitting 192 complete alternations per second of a maximum intensity of fifteen ampères. The receiving circuits on Flat Holm and Steep Holm consisted of gutta-percha covered wires 600 yards in length, laid parallel to the lines on shore, and ending in each case in the water. The alternating currents were broken up into Morse signals, and were received on the secondary circuit by a couple of telephones. The transmission to Flat Holm was perfect; to Steep Holm it was not so satisfactory: though the signals were perceptible, conversation was out of the question.

Other experiments were made by means of a steam launch carrying an insulated copper wire half a mile in length. One end of this wire was attached to a buoy in such a way that it could be stretched between the latter and the launch either above the water or for the most part submerged. Near the shore communication in both cases was good; but so soon as the secondary circuit was removed a mile from the transmitting station the signals were only received when the wire was out of the water.

The end aimed at in these experiments was two-fold: (1) To test the practicability of establishing a system of signaling without wires between the shore and the lighthouse situated on Flat Holm, and (2) to determine the effects due to earth conduction from those due to electromagnetic induction. In the result Preece came to the conclusion either that the electromagnetic waves of energy are dissipated in the sea-water, which is a conductor, or else that they are reflected from the surface of the water like rays of light. Later experiments, at Conway in particular, tended to prove that these waves are transmitted to considerable, though as yet unknown, distances through water.

Another important series of experiments made by the then chief engineer to the post-office took place on Loch Ness, which forms part of the waterway known as the Caledonian Canal, and has a telegraph on each side of it. Though these lines are about a mile and a quarter apart, it was found to be an easy matter to send messages across either by Morse signals or by means of the telephone. Somewhat later signals were passed between the Island of Arran and Kintyre, across Kilbrannan Sound, a distance of four miles (see Fig. 12).

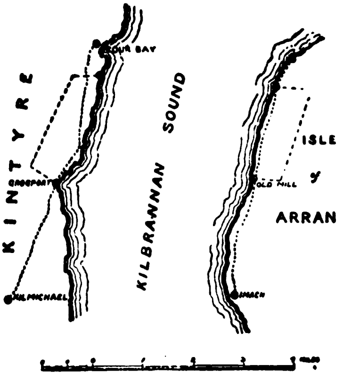

FIG. 12.

A similar success—and with Sir William Preece a success in these experiments always meant a commercial success—on the same lines was obtained in March, 1895. The cable connecting the Island of Mull with the mainland near Oban having been broken, it was decided, pending the arrival of the cable ship charged with repairs, to establish communication across the Channel by inductive means. The width of the Channel at the point selected for the experiment varied from one and a quarter to two miles. An overhead wire, well adapted to the object in view, existed skirting the coast of the island between Craigmore and Aros. On the mainland, parallel to this wire, another with gutta-percha insulation was laid along the ground for a distance of a mile and a half. One end of it was earthed in a running stream, the other end in the sea. A rheotome, or make-and-break wheel, an ordinary battery, a Morse key, and a telephone to act as receiver were included in each circuit. The installation was perfectly successful, the ordinary service being conducted by this means until the cable had been repaired.

As the result of his many and varied experiments in connection with wireless telegraphy, Sir William Preece arrived at definite conclusions in regard to the part played by the earth in electromagnetic operations. The earth, so he holds, acts simply as a conductor, and as a rule it is a very poor conductor, deriving its conducting property principally from the moisture it contains. On the other hand, the resistance of the "earth" between the two earth-plates of a good circuit is practically nothing. Hence it follows that the mass of earth which forms the return portion of a circuit must be very great indeed, for we know that the resistance of a circuit increases with its specific resistance and length, and diminishes with its sectional area. Now, if the material forming the "earth" portion of the circuit were, like the sea, homogeneous, the current-flow between the earth-plates would follow innumerable but definite stream lines, which, if traced and plotted out, would form a hemispheroid. These lines of current have been traced and measured. A horizontal plan on the surface of the earth is of the form illustrated in Fig. 13, while a vertical section through the earth is of the form shown in Fig. 14.

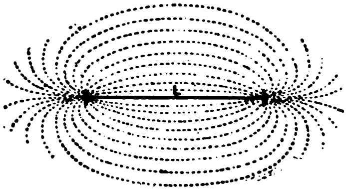

FIG. 13.

With earth-plates 1,200 yards apart these currents have been found on the surface at a distance of half a mile behind each plate; and, in a line joining the two, they are evident at a similar distance transversely at right angles to this line.

Now this hemispheroidal mass could be replaced electrically by a resultant conductor (R, Fig. 14) of a definite form, resistance, and position; and, in considering the inductive action between the two circuits having earth returns, it is necessary to estimate the position of the imaginary conductor.

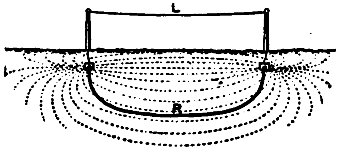

FIG. 14.

If the material of the earth be variable and dry the hemispheroid must become very much deformed and the section very irregular, the lines of current-flow must spread out further, but the principle is the same, and there must be a resultant return.* The general results of experiments at Frodsham indicate that the depth of the resultant earth was 300 feet, while those at Conway are comparable with a depth of 350 feet. In the case of Frodsham the primary coil had a length of 300 feet, while at Conway the length

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* "Signaling through Space," by W. H. Preece, C. B., F. R. S.

was 1,320 feet. At Loch Ness and between Arran and Kintyre, where the parallel lines varied from two to four miles, the calculated depth was found to be about 900 feet. The depth of this resultant must, therefore, increase with the distance separating the earth-plates, and this renders it possible to communicate by induction from parallel wires over much longer distances than would otherwise be possible.

CHAPTER VI

Willoughby Smith's experiments in conduction through water and earth—Smith and Granville's experiments at the Needles Lighthouse—Application of their method to the Fastnet Lighthouse—The investigations of C. A. Stevenson in electromagnetic conduction and induction—Preece and Stevenson's experiments awaken interest on the Continent—Professor Rathenau's investigations—Evershed's Experiments at the Goodwin Lightship—Preece's experiments at the Skerries and Rathlin Island—His views as to earth-conduction, etc.

REFERENCE has been made in the foregoing chapter to views enunciated by Mr. Willoughby S. Smith in 1883, in regard to signaling to and from trains, and the influence they undoubtedly had upon Edison's subsequent experiments in the same field. From the suggestions he then threw out it will be seen that Smith's investigations were at first directed more particularly to electromagnetic induction as a means of communicating between distant places; but not arriving at the results he desired by that means, he began to try what could be done by conduction through earth and water. The principle upon which he went to work is fully set forth in a communication he made to the Electrician (Nov. 2, 1888) in regard to the application of his method to lighthouses and to vessels within a certain distance of the shore. In the article in question he explains how a wooden bathing-hut on a sandy beach was utilized as a shore station. From it were laid two insulated copper wires 115 fathoms in length. " The ends of the wires, scraped clean," he says, " were twisted round anchors, their position being marked by buoys about one hundred fathoms apart, and in about six fathoms of water. Midway between the two a boat was anchored with a copper plate hanging fore and aft about ten fathoms apart, and consequently about forty-five fathoms from either end of the anchored shore wires. This boat, which represented the sea station, would," he continues, " have been much better for my purpose had it been of metal, for then I should have used it instead of one of the collecting plates, as the larger the surface of these plates the better the results obtained."

Messages by this means were passed with " distinctness and ease," and accordingly a patent for the method was secured in June, 1887. The diagram given herewith (Fig. 15) explains the *modus operandi.* A is a two-conductor cable proceeding from the signal station B on shore toward the rock C. A short distance from the shore the cable divides, one of the conductors going off at right angles to the submerged metallic plate D the other terminating in like manner at plate E. Opposite them are two other submerged plates, F F, connected by insulated conductors leading to a telephone of low resistance in the lighthouse H. Communication between shore and rock is carried on by means of an interrupter or reverser I and battery K at the shore end of the cable and a telephone in the lighthouse; and *vice versa* for communication between rock and shore. Smith's specification shows how the system may be equally well adapted for communication between passing vessels and the shore.

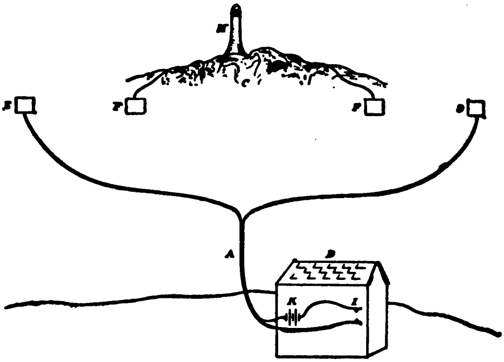

FIG. 15.

In collaboration with Mr. William P. Granville, Willoughby Smith subsequently considerably developed the method above described. They found that if the rock was at a considerable distance from the shore the transmission of signals was greatly facilitated by submerging as near as practicable to the rock a transformer

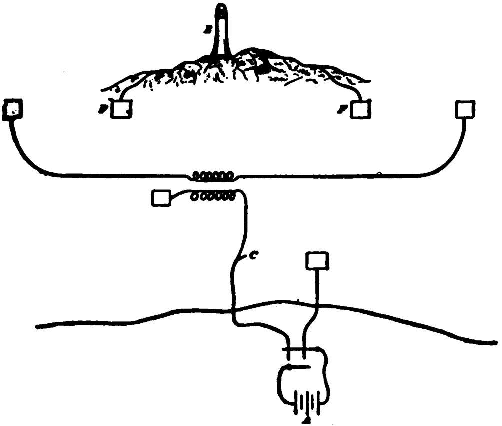

FIG. 16.

which has its primary or high resistance circuit coupled to the two insulated conductors from the shore, or to a single insulated conductor and earth-plate or metallic mass, as shown in Fig. 16, while the ends of the secondary or low resistance coil are coupled to other insulated conductors leading to two submerged earth-plates or masses in the vicinity of the rock. The arrangement provides also for the use of a transformer on the rock. This method, it will be seen, is

Preece's, as worked between Lavernock and Flat Holm, with a little modification.

By arrangement with the Trinity House authorities this system was, in 1892, put to a successful test at the Needles Lighthouse, and was subsequently applied to the lighthouse on the Fastnet Rocks, off the southwest corner of Ireland, one of the most inaccessible beacons on the British coasts, where it is still in operation.

Equally interesting, although hardly so successful as those just described, were the researches of Mr. Charles A. Stevenson, of the Northern Lighthouse Board, in much the same field—that is, between shore and ship, and shore and lighthouse, and *vice versa.* Stevenson's investigations began in 1892, and were continued for several years, the results arrived at being given in two papers read before the Royal Society of Edinburgh in January, 1893, and March, 1894, respectively. This experimenter struck out and tested two methods. In each he starts with a cable stretched and submerged from the shore seaward. When, in the first method, a ship, which is provided with a wire having a telephone in circuit, that is stretched from stem to stern and terminates in coils dipping into the water, approaches or crosses the cable at right angles, or nearly so, any currents set up in the latter from the shore end are audible in the telephone on board. This method was tested by means of a boat on a small lake, when the currents in the submerged wire could be plainly heard in the telephone at a distance of 300 feet.

Mr. Stevenson's second method consisted in letting down into the sea over a vessel's side, by means of a wire 200 feet long, a three-foot electromagnet. Interruptions in the current from six dry cells were audible on the telephone at a distance of forty feet in air, while with double the number of dry cells the sounds could be heard through sixty feet of water.

Stevenson subsequently changed his base of operations from electrostatic or electromagnetic conduction to simple induction, using insulated coils of wire, as being, according to his view, better. He made a large number of experiments, in the laboratory and elsewhere, with a view to working out a system that might be adopted for communication between the lighthouse on the island of Muckle Flugga, in the Shetlands, and the mainland. It is not necessary to weary the reader with details of those investigations. Suffice it to say that, though the Commissioners of Northern Lighthouses, being impressed by the experiments shown them by Mr. Stevenson (when it was proved that the distance between Muckle Flugga and the mainland could be satisfactorily bridged by means of a battery of 100 dry cells, with 1.2 ohms resistance each and 1.4

volts), decided on adopting the system for communication with the North Unst Lighthouse, yet, in the end, the idea, in consequence of financial difficulties, was abandoned.

Referring to his experiments in regard to the proposed Muckle Flugga installation in a communication to the Journal of the Institute of Electrical Engineers, Mr. Stevenson says: "Theory and formulæ give one the impression at first sight that a single outstretched wire is always the best . . . but formulæ, if they are to be practised, ought to take into account a limited area and workable amounts of resistance, current, etc., and then the fact is disclosed that the coiling of wires (whether condensers be used with them or not) becomes an advantage for most work which the engineer will be called upon to deal with.

"It is not necessary, as has been stated, that the coils should be identical in size and shape. Far from it; each case must be treated for size and configuration by itself. . . .

"I have made numerous trials of the coil *versus* the parallel wire system since 1891, and I have found—and other observers also seem to have found—that it is not practical to work the latter more than three or four times the length of base; whereas by coils I have found it possible to work many times this diameter. Thus in 1892, at the Isle of May Lighthouse, I signaled to a distance 360 times the diameter of an electromagnet coil with currents from a De Meriten's magneto-electric machine. Again, at Murrayfield, I signaled four times the base with five dry cells; and I have, in Edinburgh, a coil with iron cone seventeen inches diameter, which, with one cell, can easily signal through a space twenty-five times its diameter."

During these prolonged experiments Stevenson developed a method of wireless telegraphy for guarding a dangerous coast. This was by means of a wire many miles in length suitable for communicating warning signals to vessels on board of which were detectors of small dimensions. "This guarding of a dangerous stretch of coast," he says, in a discussion on Magnetic Space Telegraphy at the Institution of Electrical Engineers, Jan. 12, 1899, "appears to me to be the most important application of telegraphy by induction. There are two main systems, both of which I have tried. First, there is the principle of laying down a submarine cable along the line of coast (see Fig. 17).

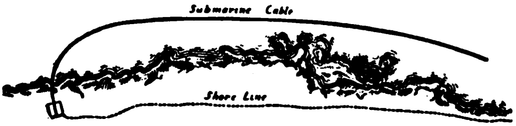

FIG. 17.

" In this case the currents set up in the cable have to be sent only through the sheet of water to the vessel—say twenty fathoms, or 120 feet, or, if an electromagnet be let down from the ship, only four or five fathoms. There are, however, certain objections to this system: for instance, the first cost of cable and maintenance of it are important considerations."

His second system consisted of the erection of a pole line on shore, either along the stretch of coast, or in the form of a coil on a peninsula. The main difference between this and the first method lay in the fact that the currents set up in the land line had to be sent several miles out to a ship in place of only a few yards, but the submarine cable was done away with. Stevenson says: " I have tried this system with two miles of pole line and a coil about a quarter of a mile off the line with perfect and never-failing success."

These experiments of Stevenson, together with those of Preece, and others, attracted so much attention on the Continent, and especially in Germany, that Prof. Emil Rathenau, of Berlin, at the request of the German Imperial Marine, undertook, with the assistance of Drs. Rubens and W. Rathenau, to make a thorough inquiry into the possibility of establishing telegraphic communication through the medium of water as a conductor. As regards method, those he employed did not differ materially from the double pair of metallic plates used by Morse, only in consequence of the technical improvements made in electrical apparatus in recent years, Rathenau was enabled to lay down a more perfect installation.

These experiments took place (in 1894) on a small lake near Potsdam, known as the Wannsee, on account of the facilities as regards apparatus afforded by the electric-light station at Alsen. The primary circuit contained a battery of twenty-five cells (A B in Fig. 18), an interrupter driven by a motor, a set of resistance coils R, an ampère-meter A, and a volt-meter V, as well as a Morse key T. The line ended in two zinc plates E E, fifteen square meters in surface measurement, sunk in the water, and 500 meters apart.

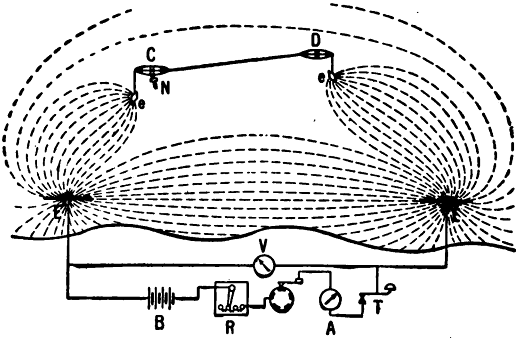

Fig. 18.

The receiving circuit consisted of two zinc plates (e, e), four square meters in surface measurement, which were suspended in the water from two boats, whose distance apart varied from 50 to 300 meters; the plates being connected the one with the other by means of a wire, to which was attached a telephone N, stretched above the water.

The primary current at disposal did not exceed three ampères in intensity, and it could only be broken 150 times per second, while the sensitiveness of the telephone is held to be the greatest for a frequence of 600 impulses per second. Yet in spite of these unfavorable conditions the transmitted signals were clearly audible to an unaccustomed ear from the sending station P P (Fig. 19) to the boat stationed off New-Cladow, a distance of 4.5 kilometers. Nor was the distinctness of the signals much interfered with when the receiving station was removed to the position marked 3 in the sketch-map, although the island (as indicated) stood in the way.

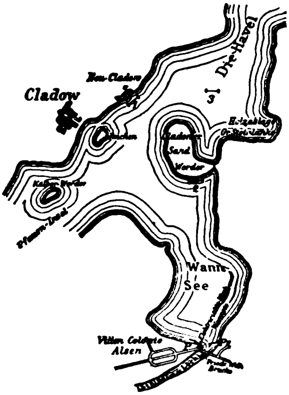

FIG. 19.

Professor Rathenau remarks that with more favorable conditions—that is, if the current in the primary circuit had been stronger, or there had been a greater distance between the plates of that circuit, as well as quicker interruptions, or a greater number of impulses in the primary circuit, and lastly, if a telephone had been employed which had been carefully timed to the number of current-breaks in the transmitting circuit—much better results would have been obtained.

It is worthy of note that, like Sir William Preece and others, Professor Rathenau found that when two conductors connected with the poles of a source of electricity are carried to earth, whether the earth be moist or dry, streams of electricity spread out on every side, just as in water; and he sees in this phenomenon a possible explanation of the inference so often noticed between near-lying telegraph and telephone wires, and attributed by many to the influence of induction. In these streams of electricity spreading in all directions through the solid earth, Professor Rathenau saw the possibility of a system of wireless telegraphy adapted for continental (as distinguished from intracontinental or transoceanic) use. The idea was taken up by Strechner, who somewhat later made a number of interesting and, so far as they went, successful experiments with a view to seeing how far earth conduction could be utilized. He had the satisfaction of getting results at the distance of seventeen kilometers; but the cost at which they were obtained rendered his method practically inoperative. He had not, of course, hit upon the right principle, which appears to have been reserved for Messrs. Orling and Armstrong (whose system we shall presently have to discuss) to discover.

While on this subject of communication with lighthouses and lightships it may be well to refer to two or three other experiments of the kind, although they take us a little too far ahead as regards date. In 1896 Mr. Evershed made trial of a method of using coils which he had patented several years before on the North Sand Head (Goodwin) lightship. One end of a cable was coiled in a ring on the sea-bottom, enclosing the entire area covered by the ship in swinging to and fro with the tide, the other end being connected with the shore. The ship itself was encircled by another coil above the water-line. The two coils were only about 200 fathoms apart; but for various reasons—the influence of the vessel's iron hull and the screening effect of the sea-water—effective signaling was out of the question.

A year or two later (1899) Preece conducted some careful experiments on the Menai Straits "which determined the fact that the maximum effects with telephones are produced when the parallel wires are terminated by earth-plates in the sea itself." It became desirable to establish communication between the lighthouse on the rocks known as the Skerries and the coastguard station at Cemlyn on the mainland of Anglesea, and it was decided to do this by means of wireless telephony. A wire 750 yards in length was stretched along the Skerries, and on the mainland one of 3½ miles from a point opposite the Skerries to Cemyln, the average distance between the two being 2.8 miles. Each line terminates by an earth-plate in the sea. The connections used are shown in the diagram (Fig. 20). Telephonic communication is easily maintained and the service is said to be excellent.

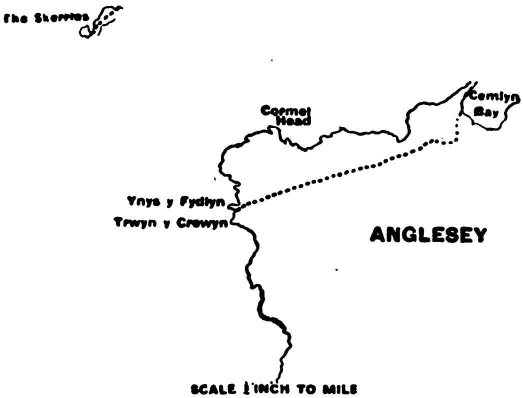

FIG. 20.

The same system was subsequently adopted for communication between Rathlin Island on the north coast of Ireland, and the mainland. The east and west portions of the island of Rathlin are about eight miles from the mainland, but a tongue of land projects southward to within a distance of four miles (Fig. 21). Communication was required between the lighthouse near the northeastern corner of the island and the mainland, and it was a question whether an overhead line across the neck of the southern peninsula would be sufficient. This proved to be the case, and thus wireless communication, both telegraphic and telephonic, was established across the sea.

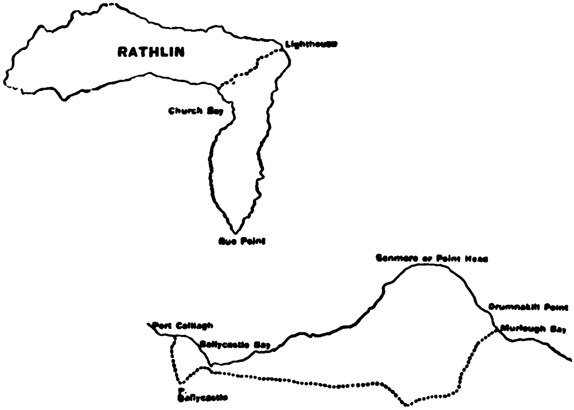

FIG. 21.

At this time Preece seemed to hold these experiments as conclusive that earth conduction had nothing to do with the results obtained. Other authorities, however, such as Sir Oliver Lodge, Charles A. Stevenson, Professor Rathenau, of Berlin (cognate researches by whom we shall shortly have to describe), and others, inclined to the opinion that the effect is partly inductive and partly conductive.

As the result of his many experiments Preece came to the conclusion that "although communication across space has thus been proved to be practical in certain conditions, those conditions do not exist in the case of isolated lighthouses and lightships, cases which it was specially desired to provide for." But after seeing what was subsequently done at the Fastnet Lighthouse, Sir William no doubt changed his opinion in this respect.

CHAPTER VII

Hertz's great discovery of electromagnetic waves—His apparatus—Clerk Maxwell's hypothesis—Sir Oliver Lodge on Maxwell and Hertz—The identity of electricity with light—Professor Hughes and his researches—Sir William Crookes's prediction—Hughes's account of his experiments—His wireless telegraphy—Discouragement by scientific experts.

THESE later installations of Sir William Preece—for the establishment of permanent communications at the Skerries, Rathlin Island, and Lavernock had gone beyond the experimental stage—did not at the time attract the attention they deserved, and would otherwise have excited, because of the sensation awakened, not only in 1897, when the new discovery first became known, but since, by Marconi's application of Hertzian waves to telegraphy. Up to this time, although Hertz's epoch-making researches were nearly ten years old, they were almost wholly unknown to the general public. Nor in all probability would the German professor's famous discovery, whereby Clerk Maxwell's mathematical deduction as to the existence of electromagnetic waves was lifted into the clear region of established fact, have become generally appreciated had not the foundation thus laid suddenly found a builder able to complete the edifice by the realization of its potentialities in aerial telegraphy.

Hertz has recorded how his interest was first awakened in regard to electrical oscillations through the offer of a prize for an experimental proof of a connection betwixt electro-dynamic forces and dielectric polarization in insulators. Although he soon relinquished the inquiry, which he took up at the suggestion of Von Helmholz, under whom he had studied, his mind was ever after on the lookout for phenomena that seemed to point in the direction indicated. Hence when making use of an old pair of coils or spirals of insulated wire for some experiments in the course of a lecture he was giving at Carlsruhe, he found that the discharge of a small Leyden jar, or of an induction coil, through one of the spirals resulted in the setting up of an induced current in the other, provided the first spiral had a small " spark-gap " in its circuit, he was not slow to perceive the importance of the fact. In short, in that casual observation lay the germ of the effective spark-gap, the " electric eye," as Lord Kelvin has called it, through which Hertz was led to his remarkable discoveries.

Those discoveries, and the apparatus by which he was enabled to make them, he described in a series of papers which was subsequently published in a collected form under the title of Electric Waves. His apparatuses were remarkable for their simplicity, and consisted in the main of an exciter or radiator and a receiver or detector. For the former he made use of wire rectangles, or simple rods to the ends whereof metallic spheres were attached, continuity in either case being broken, and the distracted ends fitted with round knobs (Fig. 22). This break in the wire forms the "spark-gap," the discovery of which was the starting-point of Hertz's investigations. The receiver consisted of either a rectangle or a simple circle of iron, having a spark-gap the same as the exciter.

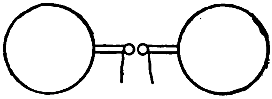

FIG. 22.

When through such a circuit as the exciter here described forms, a charge is sent by means of a condenser, like a Leyden jar or a small Ruhmhorff induction coil (as was Hertz's wont) an electrical discharge of short sharply defined duration is obtained. By such a discharge a sudden and infinitely rapid disturbance of electrical equilibrium is set up, causing an excitation of electrical vibrations of great velocity in the ether. Vibrations of this description are capable of creating in another circuit of similar construction, such as a Hertz detector, disturbances of a like nature and of such energy as to be perceptible when the two circuits, that is, the exciter and receiver, are far apart.

The proof that the rapid changes in the discharges are really vibrations Hertz established in the following manner: He placed opposite the exciter (Fig. 23) a second circuit a b c d, which returns upon itself as far as the short air-gap a d. The quick current changes in A A induce in the secondary circuit equally rapid changes, which announce themselves by sparks between a d. In these effects of induction Hertz was able under certain conditions to trace resonance. The conductor a b c d is a form in which the electricity can make oscillations whose period is given by self-induction and capacity. If the rapid changes of electricity are really oscillations, their inductive effects can only call forth electrical resonance in a b c d when the period number of the oscillations agree with the natural period number of the secondary circuit.

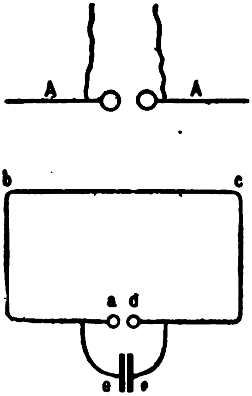

FIG. 23.

The proper oscillatory duration of the secondary conductor depends on its self-induction and capacity, and can be lowered therefore by changing the capacity. With this end in view Hertz bound the ends a and d with the changeable plates of a small condenser e e, whose variable capacity then determines the tone. By this means he was able to prove that strong sparks were only able to play between a and d when the plates were at a given distance from each other, while by the increase or diminution of the distance the sparks become considerably weaker. Thus it was shown experimentally that resonance takes place when the periods in the exciting and the receiving circuits are in harmony.

With such simple apparatus Hertz reproduced all the phenomena of light, including those of reflection and refraction, in corresponding electromagnetic effects, and, in accordance with Maxwell's hypothesis, he showed that light and electricity are in all essential particulars identical.

As to the existence of the electromagnetic waves, Sir Oliver Lodge tells us that " Maxwell and his followers were confident that the proof would come. They knew the rate at which they would go; they knew that they would go slower in glass and water than in air; they knew that they would curl round sharp edges, that they would be partly absorbed but mainly reflected by conductors, that if turned back upon themselves they would produce the phenomena of stationary waves, or interference, or nodes or loops. It was known how to calculate the length of such waves, and even how to produce them of any required or predetermined wave-length, from

1,000 miles to a foot. Other things were known about them which would take too long to enumerate; any homogeneous insulator would transmit them, would repeat or concentrate them if it were of suitable shape, would reflect none of a particular mode of vibration at a certain angle, and so on."

All this was known, but Hertz supplied the verification. "He inserted suitable conductors in the path of such waves, conductors adapted for the occurrence in them of induced electric oscillations, and to the surprise of every one, himself doubtless included, he found that the secondary electric surgings thus excited were strong enough to display themselves by minute electric sparks."*

Such was Hertz's contribution to exact science, and it would be extremely difficult to overestimate its importance. Sir Oliver Lodge, one of the brightest lights of contemporary science, whom we have just quoted, and who has done more than any one else in England to make Hertz and his work known, has said, speaking of the death of that investigator (which occurred in 1894), that he did not go until he had "effected an achievement which will hand his name down to posterity as the founder of an epoch in experimental physics"; and in that

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*Signaling through Space without Wires, by Prof. Oliver Lodge, F. R. S. (Third Edition).

high eulogy he in no wise exaggerates. Without Hertz's brilliant discoveries—and he proceeded from one to another with almost startling rapidity, measuring the waves and fixing the rate, proving that they might be a fraction of an inch or 1,000 miles in length, determining their periodicity to be about one hundred millionth of a second, waves of 2.8 meters in length having the velocity of light, or 186,000 miles a second, demonstrating that the waves could be reflected, deflected, and secured, and determining their nodal points and outline, all within the walls of his thirty-foot laboratory: without all this, aerial telegraphy, such as we know it, would have been an impossibility.

And yet Hertz died before that achievement had been reached. As already stated, a civil engineer of Munich put the question to him whether he thought telephonic communication would be possible by means of electromagnetic waves. He answered in the negative, because he found the alternations of current in the telephone too slow in comparison with the period of the electromagnetic oscillations. He could hardly at that time have answered the question otherwise than as he did; for then no sufficiently sensitive means was to hand for detecting electromagnetic waves of low intensity.

As a matter of fact the necessary apparatus for that purpose—subsequently rediscovered by others and as a "Coherer" or "Radioconductor" made public—had been invented and turned to practical account years before Hertz made his famous discoveries, by Professor D. E. Hughes, the inventor of the micrometer and the printing telegraph. Hughes had, by means of this apparatus, transmitted signals to a considerable distance, and had recognized the nature and cause of the phenomena by which he had done so. But he had given to the world none of his investigations, or the results he had thereby attained; although several of the leading lights of science of the day had witnessed some of the more striking of them. The facts only came to light in consequence of a remarkable forecast in regard to wireless telegraphy made by Sir William Crookes in an article entitled Some Possibilities of Electricity, which appeared in the Fortnightly Review for February, 1892, and in which reference was made to experiments he had witnessed made by Professor Hughes.

"Rays of light," he therein says, "will not pierce through a wall, nor, as we know only too well, through a London fog; but electrical vibrations of a yard or more in wave-length will easily pierce such *media,* which to them will be transparent. There is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfilment. At present experimentalists are able to generate electric waves of any desired length, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so to direct a sheaf of rays in any given direction. Also an experimentalist at a distance can receive some, if not all, of these rays on a properly constituted instrument, and by concerted signals, messages in the Morse code can thus pass from one operator to another.

"What remains to be discovered is—first, simpler and more certain means of generating electrical rays of any desired wave-length, from the shortest, say a few feet, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers which will respond to wave-lengths between certain defined limits and be silent to all others; and thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space, and fading away according to the law of inverse squares.

"At first sight an objection to this plan would be its want of secrecy. Assuming that the correspondents were a mile apart, the transmitter would send out the waves in all directions, and it would therefore be possible for any one living within a mile of the sender to receive the communication. This could be got over in two ways. If the exact position of both sending and receiving instruments were known, the rays could be concentrated with more or less exactness on the receiver. If, however, the sender and receiver were moving about, so that the lens device could not be adopted, the correspondents must attune their instruments to a definite wave-length, say, for example, fifty yards. I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw, or altering the length of a wire, so as to become receptive of waves of any preconcerted length. Thus, when adjusted to fifty-yard waves, the transmitter might emit, and the receiver respond to, rays varying between forty-five and fifty-five yards, and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for the most inveterate curiosity would surely recoil from the task of passing in review all the millions of possible wave-lengths on the remote chance of ultimately hitting on the particular wave-length employed by those whose correspondence it was wished to tap. By coding the message even this remote chance of surreptitious tapping could be rendered useless.

"This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly within the path of researches which are now being actively prosecuted in every capital of Europe, that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. Even now, indeed, telegraphing without wires is possible within a restricted radius of a few hundred yards, and some years ago I assisted at experiments where messages were transmitted from one part of a house to another without intervening wire, by almost the identical means here described."

The last sentence awakened a good deal of curiosity as to who the investigator could be who had succeeded in telegraphing without wires. Among others whose interest was thus excited was Mr. J. J. Fahie, who had for some time been engaged on his History of Wireless Telegraphy. He accordingly wrote to Sir William

Crookes for some particulars of the experiments alluded to in his Fortnightly article, and in answer to his request was advised to write to Professor Hughes, who was by this means induced to give a synopsis of his experiments and discoveries.

The full account as he wrote it, is given in an appendix to Mr. Fahie's admirable History as well as in Lodge's Signaling through Space, and may, in either work, be seen by all who desire to consult it. But, as Hughes's researches form an important part of the story of wireless telegraphy, it is necessary to give here a brief *resumé* of his investigations, which extended over the years from 1879 to 1886. In the former year, he tells us, being engaged upon experiments connected with his microphone and his induction balance, he remarked that at times he could not get a perfect balance in the induction balance, through apparent want of insulation in the coils; but investigation showed him that the real cause was some loose contact or microphonic joint excited in some portion of the circuit. He applied the microphone and found that it gave a current or sound in the telephone receiver, whether the microphone was placed direct in the circuit or several feet away from the coils through which an intermittent current was passing. After numerous experiments he found that the effect was caused by the extra current produced in the primary coil of the induction balance.

Further researches proved that an interrupted current in any coil gave out at each interruption such intense extra currents that the whole atmosphere in the room, or in rooms some distance away, would have a momentary invisible charge, which became evident if a microphone joint was used as a receiver with a telephone. This led him to experiment with a view to finding the best form of receiver for these invisible electric waves, which evidently permeated great distances, and through all apparent obstacles, such as walls, etc. All microphonic contacts or joints proved to be extremely sensitive. Those formed of a hard carbon such as coke, or a combination consisting of a piece of coke resting upon a bright steel contact, were very sensitive and self-restoring; while a loose contact between metals was equally sensitive, but would cohere, or remain in full contact after the passage of an electric wave.

After referring to Branly's "Radioconductor" and Lodge's "Coherer" as rediscoveries of his microphonic contacts, Professor Hughes goes on to say that the most sensitive and perfect receiver he had made did not cohere permanently, but recovered its original state instantly, and therefore required no tapping or mechanical aid to the separation of the contacts after momentarily being brought into close union. Still he soon found that, while an invisible spark would produce a thermo-electric current in the microphonic contacts (sufficient to be heard in the telephone in its circuit), it was far better and more powerful to use a feeble voltaic cell in the receiving circuit, the microphonic joint then acting as a relay by diminishing the resistance at the contact, under the influence of the electric wave received through the atmosphere.

Professor Hughes, after stating that he devised and experimented with numerous forms of transmitter and receiver in 1879 (particulars of which were written in books for the purpose), goes on to describe how he found that very sudden electric impulses, whether given out to the atmosphere through the extra current from a coil or from a frictional electric machine, equally affected the microphonic joint, the effect depending more on the sudden high potential effect than on any prolonged action. Thus, a spark obtained by rubbing a piece of sealing-wax was quite as effective as a discharge from a Leyden jar of the same potential—a fact independently verified by Lodge.

"The rubbed sealing-wax and charged Leyden jar had no effect until they were discharged by a spark, and it was evident that this spark, however feeble, acted upon the whole surrounding atmosphere in the form of waves or invisible rays, the laws of which," says Professor Hughes, "I could not at the time determine. . . . In 1879, while making these experiments on aerial transmission, I had two different problems to solve: first, what was the true nature of these electrical aerial waves, which seemed, while not visible, to spurn all idea of insulation, and to penetrate all space to a distance undetermined; second, to discover the best receiver that could act upon a telephone or telegraph instrument, so as to be able to utilize (when required) these waves for the transmission of messages. The second problem came easy to me when I found that the microphone, which I had previously discovered in 1877–'78, had alone the power of rendering those invisible waves evident, either in a telephone or a galvanometer, and up to the present time I do not know of anything approaching the sensitiveness of a microphonic joint as a receiver."

Professor Hughes here gives the names of a number of scientific men, including Sir W. H. Preece, Sir William Crookes, Professor Huxley, and Professor Dewar, who witnessed some of his results, and then says that they saw his experiments in regard to aerial transmission by means of the extra current produced from a small coil and received upon a semi-metallic microphone, the results being heard upon a telephone in connection with the receiving microphone. The transmitter and receiver were in different rooms, about sixty feet apart.

"After trying successfully all distances allowed in my residence in Portland Street," Hughes proceeds, "my usual method was to put the transmitter in operation and walk up and down Great Portland Street with the receiver in my hand, with the telephone to the ear. The sounds seemed slightly to increase for a distance of sixty yards, then gradually diminish, until at 500 yards I could no longer with certainty hear the transmitted signals. What struck me as remarkable was that opposite certain houses I could hear better, while at others the signals could hardly be perceived. Hertz's discovery of nodal points in reflected waves (in 1887–'89) has explained to me what was then considered a mystery. At Mr. A. Stroh's telegraph instrument manufactory, Mr. Stroh and myself could hear perfectly the currents transmitted from the third story to the basement, but I could not detect clear signals at my residence about a mile distant. The innumerable gas and water-pipes intervening seemed to absorb or weaken too much the feeble transmitted extra current from a small coil."

On February 20, 1880, Mr. Spottiswoode, the President of the Royal Society, together with Professors Huxley and G. Stokes, the honorary secretaries, called upon Professor Hughes to see his experiments on aerial transmission. The experiments shown were very successful, and at first they seemed astonished at the results; but toward the close of three hours' experiments Professor Stokes said that all the results could be explained by known electromagnetic induction effects, "and therefore he could not accept my view of actual aerial electric waves unknown up to that time, but thought I had quite enough original matter to form a paper on the subject to be read at the Royal Society.

"I was so discouraged," he continues, "at being unable to convince them of the truth of these aerial electric waves that I actually refused to write a paper on the subject until I was better prepared to demonstrate the existence of these waves; and I continued my experiments for some years, in hopes of arriving at a perfect scientific demonstration of aerial electric waves produced by a spark from the extra currents in coils, or from frictional electricity, or from secondary coils."

Thus, it would appear that, through the discouragement of three scientific men, an Englishman was robbed of the honor of being the first to announce the discovery of wireless telegraphy. Howbeit, the distinction remains his, as has been generally recognized, not only by his own countrymen, but by foreign scientists as well.

CHAPTER VIII

The imperfect means at Hertz's command—The coherer and its history—Guitard—Varley—Onesti—Professor Branly—His radioconductor—Sir Oliver Lodge and the coherer—His experiment at Oxford in 1894—Rutherford—Dr. Muirhead—Captain Jackson—Professor Bose—Professor Righi—Lodge's new coherer—Popoff's experiments.

THE attainment of a "perfect scientific demonstration of the existence of aerial electric waves," for which Hughes continued to work, but unfortunately failed to achieve, proved to be an almost easy conquest to the genius of Hertz, whose "strenuous and favored youth (as Sir Oliver Lodge puts it) was surrounded with all the influences that go to make an accomplished man of science." Truth, however, demands that full recognition should be accorded to others whose discoveries and inventions helped forward the final achievement which was the outcome of his labors. With the imperfect means which Hertz had at his command he would probably have held it impossible to obtain visible effects or to transmit signals by means of electric waves that would be audible at any but a very short distance from their place of origin; and yet the discoverer of the microphone had already actually obtained such results.

This could not have been done without the discovery of those wonderful instruments which are now so well known to the scientific world as sensitive "contacts," "coherers," or "radioconductors." Space forbids us to go very deeply into the history of these various contrivances, so essential to wireless telegraphy; but some little account of them is necessary to make the story we are telling complete. The principle of the coherer, or the radioconductor, lies in the sensitiveness of metal filings enclosed in an insulating tube to electric currents of low potential. Sir Oliver Lodge tells us that probably the earliest discovery of cohesion under electric influence was contained in an observation of Guitard in 1850, that when dusty air was electrified from a point the dust particles tended to cohere into strings or flakes.* Mr. S. A. Varley made a practical application of the same principle in the construction of his lightning protector for telegraph apparatus, which he told the British Association in 1870 had been in use several years. It consisted of two thick metal conductors terminating in points, the chamber containing the points being loosely filled with a powder consisting of carbon and a non-conducting substance in a minute state of division. "The lighting finds in its

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* Signaling through Space without Wires.

direct path a bridge of powder, consisting of particles of conducting matter in close proximity to one another; it connects these under the influence of the discharge, and throws the particles into a highly incandescent state. Incandescent matter . . . offers a very free passage to electricity, and so the lightning discharge finds an easier passage across the heated matter than through the coils."

In the action here described we have in rough the principle of the coherer (Fig. 24)—a principle which was independently observed in 1885, by an Italian professor, Signor Calzecchi-Onesti; who found that iron filings contained in a glass tube, placed between two metallic electrodes, became suddenly conductive when the electrodes were connected with the two poles of the secondary circuit of a Ruhmkorff coil. This discovery, although published in Il Nuovo Cimento, appears to have attracted but little attention, and was only remembered when, in 1890, Professor E. Branly, of Paris, discovered the change that takes place in the conductivity of metallic filings when a Leyden jar is discharged in its vicinity. The resistance of the metal suddenly falls from millions of ohms to hundreds. Its conductivity increases with the number and intensity of the sparks. If, therefore, an electric battery be con-

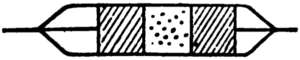
FIG. 24.

nected on to the tube a current is enabled to pass which will produce action of some sort: cause a deflection in the galvanometer needle, for instance, or put in operation an electromagnet. By the latter proceeding it is possible to work a registering apparatus, or to close a local circuit. The electromagnet will then become a relay similar to those used in ordinary telegraphy. It is possible, therefore, by this means to set free an electric current of any strength that may be desired, and thus to produce very considerable results.

The annexed diagram (Fig. 25) explains the principle and form of the Branly coherer, or radioconductor, as the inventor prefers to call it. A vertical ebonite cup containing aluminium powder (iron, brass, antimony, cadmium, zinc, or bismuth powder will do as well) is fixed between two metal plates A B; literally the powder is in contact with a couple of rods C D, which pass through the sides of the ebonite cylinder. A and B may be connected to two terminals of one of the arms of the Wheatstone bridge, C and D being free, and *vice versa*. Whatever arrangement be adopted, if a battery

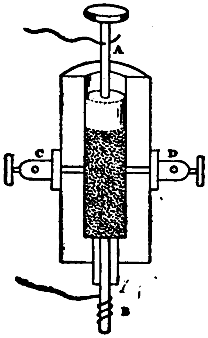

FIG. 25.

of a hundred cells be joined up for a few seconds with one or other of the pairs of terminals, the increase in the conductivity is immediately visible in that direction, and is found to exist also in the direction at right angles.

Sir Oliver Lodge appears to have been one of the first to recognize the importance of the Branly coherer, as he called it, and to apply it in his investigations in furtherance of the discoveries made by Hertz, using it in place of the receiver or resonator of the latter. He introduced certain improvements, and was thus enabled to procure greater sensitiveness to the electromagnetic waves.

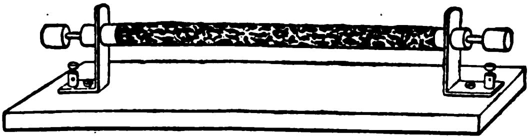

FIG. 26.

Lodge's first form of the instrument is shown in Fig. 26. It consisted of a glass or ebonite cylinder about seven inches in length and half an inch in external diameter, and was fitted at the ends with copper pistons, which could be so regulated as to press upon the metal filings with any degree of force that might be required. A mechanical "tapper," set in motion either by a clock-work arrangement or by a trembling electrical appliance, was added to shake back the filings into their normal non-conducting condition. This addition, as we shall see, was afterward done away with.

This form of the radioconductor, as Branly prefers to call it, Lodge exhibited before the British Association at Oxford in 1894, showing how by means of it signals could be transmitted to a distance of about 150 yards from the source of the oscillations; but, curious to relate, the idea never occurred to him that he was experimenting with an instrument that might be turned to account for long-distance telegraphy. Speaking of this afterward (in his Work of Hertz and his Successors), he says: "Stupidly enough, no attempt was then made to apply any but the feeblest power, so as to test how far the disturbance could really be detected. Mr. Rutherford, however, with a magnetic detector of his own invention, constructed on a totally different principle, did make the attempt (June, 1896) and succeeded in signaling across half a mile full of intervening streets and houses at Cambridge."

In his Signaling through Space without Wires, Lodge further tells us that Dr. Alexander Muirhead foresaw the telegraphic importance of this method of signaling immediately after hearing his lecture on June 1, 1894, and arranged a siphon recorder for the purpose. Captain Jackson, also, of the Royal Navy, made experiments for the Admiralty at Devonport, and succeeded in transmitting signals from one ship to another without wires, prior to the announcement of Marconi's discovery. Details of these experiments, however, have not been divulged—which seems rather unfair to Captain Jackson.

German investigators do not appear to have taken very readily to the coherer method of detecting electric waves, and so did not at first make such progress with etheric wave telegraphy as was made in England and elsewhere. Prof. Chunder Bose, of Calcutta, made a series of highly interesting experiments, and obtained results, especially in regard to the production of waves of exceedingly minute dimensions, of the highest importance. Professor Righi, of Bologna, also entered upon a series of exceedingly valuable researches in an optical direction, which he has since embodied in a treatise in Italian, entitled Opticé Elettrica. These are the more interesting to-day because it was from Professor Righi that Marconi had his first lessons, if not his chief inspiration, in regard to the employment of electromagnetic waves.

None of these, however, had done so much with the new power as Sir Oliver Lodge, and it is on that account the more astonishing, when, as it were, wireless telegraphy was within his grasp, that he should have missed it—missed it, as one imagines, by not having his eye on the commercial factor. In short, he failed to appreciate the full magnitude of the power—at all events from the practical side—which Hertz's researches had discovered to the world, and which he had done so much to develop and make known. In especial was his improving faculty manifested in regard to Branly's coherer, which he made ready to Marconi's hand. But he has done more than that. It was seen almost from the first that the coherer in its present form could not long remain as the receiver for aerial telegraphy, and now the principal of the Birmingham University has produced an instrument which bids fair—certainly until a better enters the field—to take the place of the old one.

The principle of the new coherer, which is not the invention of Messrs. Lodge and Muirhead, is that of two metallic bodies brought into contact with a thin film of mineral oil between them, the impulse of the electric vibrations breaking down the oil film and establishing a momentary cohesion between the two metallic surfaces, the one consisting of a steel disk and the other of a globule of mercury. It requires no tapper, but is kept perpetually sensitive by the rotation of the steel disk, with its razor edge, in close juxtaposition to the quicksilver button. This beautiful instrument is shown without its metal case, in Fig. 27, and its construction in Fig. 28, in which *a* is the rotating steel disk, and *b* the mercury in its trough *d*, with an amalgamated spiral of platinum wire *c*, connecting it to the terminal or binding screw *h*, *e* is a copper brush making connection with the steel disk *a*, through its axle *j*, *f* is a spring carrying a small cushion of felt *k*, which rests lightly on the steel disk for the purpose of keeping its edge clear and free from dust before and after contact with the mercury, *g* are ebonite wheels which gear the steel disk to the clockwork movement actuating the siphon recorder, to the side whereof the metal case containing the coherer is fixed.

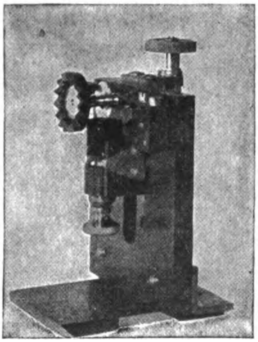

FIG. 27.

This is one of the most original distinguishing features of the Lodge-Muirhead system of wireless telegraphy, which, like that of Professor Fessenden, of Alleghany, like the Slaby-Arco method, and many others, embodies important modifications of, and it may be improvements upon, the Marconi system, of which it and the others are more or less natural outcomes.

Besides those already mentioned, a number of other investigators devoted much time and thought to the line of research wherein Hertz had won such brilliant results. Among these we must not omit to mention Professor Popoff, of the Military Academy of Cronstadt, and his apparatus for registering electrical discharges in the atmosphere. He described his invention in

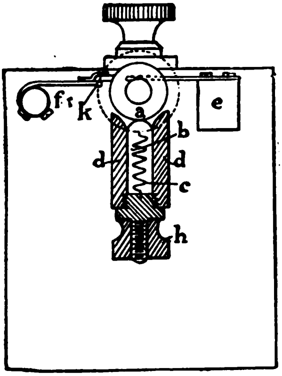

FIG. 28.

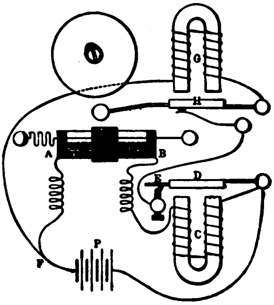

FIG. 29.

a paper communicated to the Physico-Chemical Society of St. Petersburg in 1895, and from it the following particulars are taken. Fig. 29 represents his apparatus, in which A B is a coherer or radioconductor, which together with the electromagnet of a relay C, is linked in the circuit of a battery D. If the contents of the coherer, under the influence of the electromagnetic waves, be rendered conductive, the electromagnet C draws down its armature D. By that means the contact E is closed, and the current conducted through the until now open circuit F G E, which contains the electromagnet of an electric bell. This now draws its armature, and the striker hits the bell.

At the same moment the circuit is interrupted, and the striker falls back into its original position, in doing which it shakes the coherer and thus restores its resistance. The apparatus therefore, after announcing by the ringing of the bell the passing of the electric waves, automatically restores the coherer to its normal condition, and so puts it in the position to be again influenced by the etheric waves. The relay actuates another circuit, not here shown, which contains a Richard's register for setting down in graphic signs the electric perturbations of the atmosphere.

Popoff tells us that by substituting steel for iron filings in his coherer, and using a Hertzian exciter of thirty centimeters diameter, with Siemens and Halske's relay, he was able to detect electric waves at a distance of one kilometer, while, with a Bjerknes exciter of ninety centimeters diameter, and a more sensitive relay, he had good results at a distance of five kilometers. Popoff's apparatus shows some striking analogies to that of Marconi, but more especially in respect to the use of vertical conductors, or antennæ, as they are sometimes called, for the reception of the waves.

In a later communication (December 5, 1895) Popoff gives expression to the confidence he has of being able, by means of the electric waves, of establishing a system of aerial telegraphy. To this end he looked chiefly to the perfecting of his apparatus by a more powerful exciter. He would, however, have attained the same result if he had provided his transmitter, as he had done his detector, with a vertical conductor. It remained for Marconi, however, to make this last important addition.

CHAPTER IX

Gradual evolution of Wireless Telegraphy—Marconi's beginnings—Studies at Bologna—Arrival in England and introduction to Sir Wm. Preece—His Indebtedness to Righi and others—His originality in seeing further than others—Description of his system—His oscillator—The coherer—The action of the whole apparatus.

We have now watched the gradual evolution of well-nigh all the elements necessary for the practical application of wireless telegraphy. There have been many workers in the field, all contributing their little—as is invariably the case in such matters—toward the as yet unrealized, and in some instances undreamed of, end, but all lacking, as it were, the broad synthetic grasp to comprehend and perfect the whole. For this it required the genius or the practical business talent of a Marconi. No one can take from the young Italian inventor the honor of having been the first to see the possibilities lying hidden in Hertz's discoveries, and at the same time to bring them to a practical realization. Yet granting this distinction, justice requires that due credit should be given to those who, by their researches and inventions, paved the way, or, we might say, raised the scaffolding that enabled him to put the crowning touch to the whole.

By way of introduction to a record of this remarkable man's invention, we may say that Guglielmo Marconi was born near Bologna, Italy, on April 25, 1874, of Italian-Irish parentage, and was consequently twenty-two years of age when he came to England with fortune in his hands. He had, as already stated, studied under Professor Righi at the Bologna University, and had made himself acquainted with all the latest developments in electrical science, and especially in regard to their bearing upon telegraphy. Righi was an enthusiastic disciple of Hertz and had contrived an improvement of his exciter. The latter's electromagnetic waves were many meters long, never, apparently, less than thirty centimeters; but the Bologna professor, by employing small spheres, obtained oscillations of 2.5 centimeters. Even this diminution, was still further reduced by Professor Chunder Bose, of Calcutta, who, employing little pellets of platinum, was able to produce vibrations of only six millimeters in length.

This familiarity with Hertz and his work created an "atmosphere" at Bologna, which, as we may say, gave an impulse to the study of etheric phenomena, and especially to that category thereof connected with the researches of Clerk Maxwell and Heinrich Hertz. Into this study Marconi threw himself with enthusiasm, and one day found himself wrestling with a new idea—the idea as to whether these Hertzian waves could not be utilized for the purpose of realizing in an easier and more complete manner than had heretofore been done, the old scientific dream of a wireless telegraphy. He made some experiments on his father's estate near Bologna, and then finding no one in Italy ready to take up his idea, set out for his mother's homeland to try his fortune.

His first step on reaching England appears to have been to apply for a provisional protection for his invention and then to get an introduction to Sir William (at that time Mr.) Preece. It has been well said by an American writer that Marconi "made no mistake when he wandered into Mr. Preece's office. He may have heard that no inventor with a meritorious idea on machine ever met with a discouraging reception from that far-seeing, scientific, and practical official, himself at the very time carrying on experiments for wireless communication across the British waters on the induction plan." The same writer goes on to say that "little or nothing has been said or written about the splendid help given to the new plan by the engineering branch of the British post-office; but it may be safely assumed that to the practical experience and great skill of the head and staff of that department belongs much of the credit for the rapid development of Marconi's system."

Marconi himself would probably be one of the last to deny such a statement; for like all great inventions or improvements in the arts and sciences, aerial telegraphy is the outcome of the labor, not of one man, but of a number. Let us see to what extent the steps had been laid down for Marconi's advance. It hardly requires two looks at the wave-exciter (Fig. 30) described by him in his first patent of June 2, 1896, and which we here reproduce from the English patent specification, for any one to see the practical identity of this apparatus with that of Professor Righi, as shown in Figs. 31 and 32. In both contrivances the waves arise from the discharge which takes place between the two or more brass balls or spheres by a short spark springing across through an insulating fluid, the requisite charges being conveyed to the two spheres by the sparks which leap betwixt the same and the two outer spheres that are connected with the poles of a

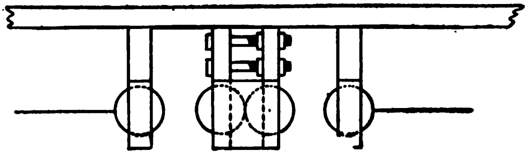

FIG. 30.

source of electricity. Fig. 31 is known as Righi's three-spark exciter.

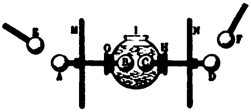

FIG. 31.

Again, the apparatus sensitive to the electric waves employed by Marconi as a receiver (Fig. 33) is no other than the filings-tube of Professor Calzecchi-Onesti, or the coherer of Sir Oliver Lodge. Further, the use of a relay for closing a local circuit, as well as the employment of the clapper of an electric bell for the automatic restoration of the resistance of the filings-tube, to say nothing of the vertical conductor, at any rate as part of the receiving apparatus, had already been, as we have seen, resorted to by other investigators, and notably by Popoff, who made known his method and the apparatus by which it was operated in 1895, while Marconi only applied for his patent in June, 1896. Nor has the latter any better title to be considered the originator of the idea of transmitting messages to a distance by means of the various apparatus for sending and receiving the electric waves which he combined together in so comprehensive a whole. The

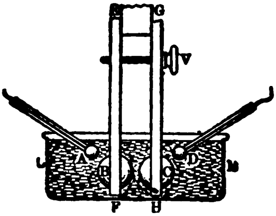

FIG. 32.

thought, as we have seen, had previously occurred to a number of investigators.

But when all these allowances have been made, it still remains Marconi's incontestable merit that he developed a far-seeing initiative where others had not gone beyond timid projects or tentative research. As Sir William Preece put it, "they all knew the egg, but Marconi had shown them how to make it stand on end." In short, he carried forward into the domain of practical reality what had only floated indistinctly before the minds of others, or had served them for modest experiments. This is the calm and discriminating judgment of men who have every means at command to enable them to arrive at a right conclusion,* and it will no doubt be acquiesced in by all who bring to the consideration an impartial mind, including Marconi himself. Judged,

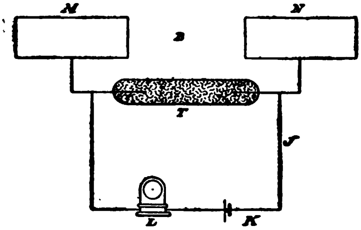

FIG. 33.

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* Augusto Righi and Bernhard Dessau in their work Die Telegraphie ohne Draht.

therefore, by its practical results, Marconi's service to science in this matter resolves itself into a victory over innumerable practical difficulties, involving many apparently insignificant details and minor improvements, the successful dealing with which demanded the exercise of a gift that has been characterized as genius itself.

Into all the details distinguishing Marconi's system we can not pretend to enter here; nor is it necessary in a popular work of this description. Suffice it, therefore, to give some of its leading features. For generating the electromagnetic waves, Marconi in his early experiments, employed, as we have seen, a Righi's oscillator, charged by a Ruhmkorff induction coil. In the primary circuit of the latter, besides a galvanic battery of a few cells and an interrupter, is included a Morse key, which has to effect for longer or shorter periods the closing of the circuit and the transmission of the waves corresponding to the dots and dashes of the Morse alphabet. As interrupter an automatic tapper is employed, and in order that it may work properly (which is not always the case) a nickel plate is fixed to the end of a cylinder which is kept revolving by means of a small electrical motor actuated by the current which works the coil, or by another current.

With an induction coil capable of giving sparks of about eight inches in length, the two middle spheres of the oscillator, with diameters of four inches each, are only from $\frac{1}{25}$ to $\frac{1}{30}$ of an inch apart, while the distance between each of these and the outer spheres is one inch. The length of the waves generated by this apparatus is, according to Marconi, ten inches.

In his earlier experiments the inventor, following Righi, used an oscillator mounted in the focal line of a metallic reflector, preferably of brass or copper, whose surface formed a parabolical cylinder. The receiver also was supplied with a similar reflector. But when it was desired to telegraph to great distances, Marconi found that an arrangement like that represented by t^2 t^2 (Fig. 34) produced better results than reflectors. These are what he calls his "capacity areas," and consist of metal plates joined on to the oscillator. Two similar plates also formed part of the receiver. Marconi's idea at the time was that the carrying power of the apparatus was increased with the size of these capacity areas, and the distance of the same from each other and from the earth. In the case of stations separated from each other by elevations of the ground or by buildings Marconi preferred the arrangement depicted in Figs. 35 and 36.

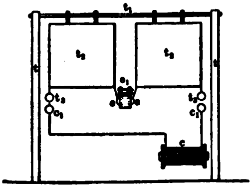


FIG. 34.

Here a single metal plate was hung by means of an insulator to a tall mast and connected with one end of the exciter or the receiver respectively, while from the other end a wire conducted to earth.

In some cases these metal plates are bent into the form of cylinders, covered in at the top, and so hung on the summit of the posts like hats. The higher above the earth these plates or cylinders are placed, the greater is the distance, according to Marconi's view, to which a message can be sent. In the long run, however, he came to the conclusion that the deciding factor does not lie in the capacity area connected by means of a long wire with the exciter or receiver, but in the wire itself; and thus he finally did away with the plates altogether and employed for his vertical conductor a long wire alone, which can

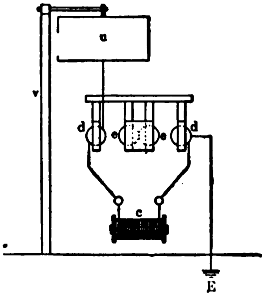


Fig. 35.

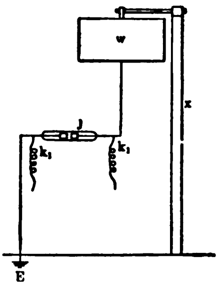


Fig. 36.

be carried by a mast, or when great height is required, by a balloon or kite.

Another form of oscillator, consisting of similar spheres mounted in an ebonite tube, is shown in Fig. 37. The space between the two inner spheres was at first, as in the one already

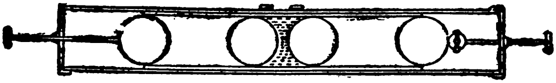


FIG. 37.

described, filled with vaseline oil stiffened with solid vaseline. The use of oil, however, was after a time given up, experience showing that it did not offer the advantages which it had been thought it would, or indeed in any way improve the action of the apparatus as regards the generating of electromagnetic waves. At the same time the apparatus was in other respects greatly simplified.

The most important part of the receiver is the coherer. If the waves are received by a reflector it has to be carefully brought into focus. Marconi, however, only used a reflector in his first experiments and in special cases. Later it was done away with, and the coherer was connected on one side with the vertical conductor, and on the other side with a wire conducting to earth. In each case the coherer is included in the circuit of a sensitive relay and a very weak battery.

The relay is required to close the circuit of a stronger battery, in which the telegraphic receiver proper, that is, a Morse key, and an electric tapper are inserted parallel to each other. The latter serves to give light taps to the filings-tube, whereby its resistance, lowered by the waves, is again restored to its normal condition.

Marconi gave special care and attention to the perfecting of his coherer. In his hands it grew not only into an uncommonly sensitive, but also into a very trustworthy instrument, with little of the capriciousness which characterized its original condition. Moreover, the dimensions of the coherer were greatly reduced. Its improved form is represented in Fig. 38. In a glass tube of from four to six centimeters in length and from three to four millimeters in diameter are two closely fitting silver cylinders, whose even and parallel ends, turned the one toward the other, are about half a millimeter apart. The space between the two is filled with metal filings. Different metals may be employed, although Marconi favors, as best suited to the purpose, a mixture of 96 per cent of nickel to 4 per cent of silver filings. The latter are held greatly to heighten the sensitiveness of the whole to the Hertzian waves. A larger proportion of the silver filings still further

FIG. 38.

increases the sensitiveness, but the reliableness of the instrument is thereby impaired. A slight trace of quicksilver contributes in like manner to heighten the effectiveness of the whole.

The breadth of the space between the cylinders may vary within certain limits; the wider it is made the larger must the single filings be. In general, however, a greater sensitiveness is attained with a narrow space; half a millimeter proving, as a rule, to be the most appropriate measurement. Two platinum wires let into the glass tube and soldered to the outer end of the cylinders serve as external connections. Finally, by means of a lateral addition the coherer is connected with an air-pump and exhausted to about one-thousandth of an atmosphere.

The prepared coherer must still be proved for its sensitiveness, and according to Marconi it is only fitted for wireless telegraphy when it answers to the inductive effect of an ordinary electric bell a yard or two from the tube.

In order to keep the sensitive tube in the best possible condition, Marconi holds it to be advisable never to allow the strength of the current to exceed the limit of one milliampère. If a stronger current be required he considers it better to use several parallel tubes, care being taken to have each shaken by the tapper; this arrangement, however, is not quite so satisfactory as the single tube. When using sensitive tubes of the type here described it is preferable not to insert in the circuit with it more than one cell of the Leclanché type, as a higher electromotive force than 1.5 volt is apt to pass a current through the tube; even when no oscillations are transmitted.

Another form of tube, however, provides for working with a higher electromotive force. In this tube, instead of one space or gap filled with filings, there are several spaces separated by plugs of tightly fitting silver wire. Such a tube will work satisfactorily if the electromotive force of the battery in circuit with the tube be equal to about 1.2 volts multiplied by the number of gaps; but here also it is well not to allow a current of more than one milliampère.

The united action of the different parts of this somewhat complicated apparatus is not difficult to understand. When the telegraph instrument at the sending station is depressed the induction apparatus is set in motion, and the discharge of it generates electromagnetic waves which, when the oscillation is in the focal line of a reflector, proceed in a converging manner in a given direction; on the other hand, when the secondary wire of the induction apparatus leads to a vertical conductor they are spread out from it in all directions. In the first case the waves must be directed to the reflector of the receiver; in the other case a portion of the oscillations will be taken up by the vertical conductor of the receiver. In either case they strike upon the coherer and reduce its resistance.

In the coherer circuit a current is thus set up which brings the relay into action; the so-called local battery is then closed and sends a correspondingly strong current through the electromagnet of the telegraph apparatus, which draws down its armature and begins to give a signal. At the same time the tapper yields to the pressure of its electromagnet and gives the filings-tube a light tap, which at once restores its resistance. The current in the delay disappears and along with it the local current which had set the receiver and the tapper in motion.

If the transmitting station had sent but a momentary electric impulse the matter would have ended there; but if further electrical oscillations are forwarded to the coherer, the operation of the same begins afresh and the process described is repeated so long as the telegraph key is kept going, the signals being reproduced at the receiving station just as in ordinary telegraphy. Of course every transmitting station is also a receiving station, the same vertical conductor being enough for both purposes.

In addition to the apparatus already described a station for wireless telegraphy must have a number of other appliances, some of which—too much matters of detail to mention here—are described in Marconi's patent, while others have been the outcome of later experiences. In his first experiments the inventor connected two strips of copper with the coherer in order to tune it to the waves generated by the oscillations; they were attached to a glass tube in the focal line of the receiving reflector, but were afterward discarded, Marconi finding it better to connect the coherer on one side with the vertical conductor and on the other with the earth.

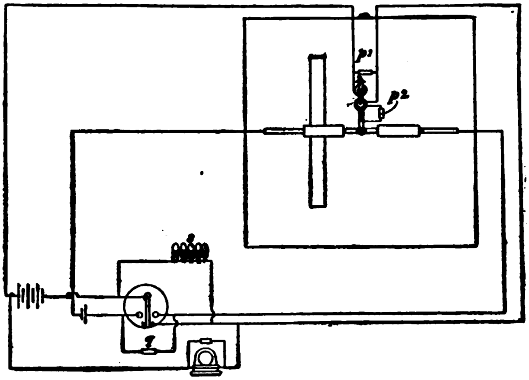


FIG. 39.

Other alterations and improvements have for object the prevention of electrical disturbances set up by the trembler or tapper and other apparatus near to or in circuit with the tube from themselves restoring the conductivity of the filings-tube immediately after the tapper has destroyed it. This purpose is effected by introducing into the circuit at the places marked p^1 p^2, q, s (in Fig. 39), high resistances having as little self-induction as possible. The action of the high resistances is that, while preventing an appreciable quantity of the current from passing through them when the apparatus is working, they nevertheless afford an easy path for the currents of high tension which would be formed at the mount when the circuit was broken, and thus prevents sparking at contacts or sudden jerks of currents, which would restore or maintain the conductivity of the sensitive tube. Similar resistances or condensers are provided at other points for the like purpose, as, for instance, to prevent the high resistance oscillations set up across the plates of the receiver by the transmitting instrument, which should pass through the sensitive tube, from running round the local battery wires and thereby weakening their effect on the sensitive tube or contact.

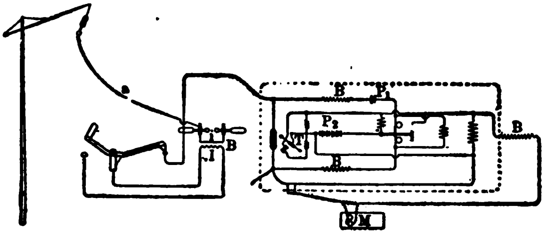


FIG. 40.

Fig. 40 represents a complete transmitting and receiving station. When working the apparatus it is necessary either that the local transmitter and receiver at each station should be at a considerable distance from each other, or else that they should be screened the one from the other by metal plates. The usual method is to have the apparatus, with the exception of the sending key and the reading instrument, enclosed in a metal box which is connected to earth.

CHAPTER X

Marconi's first experiments in England—Trials on the Bristol Channel—Also between the Needles and Bournemouth—Experiments at Spezia—Valuable results obtained—Professor Slaby's investigations at Potsdam and elsewhere—Further experiments by Marconi—Wireless telegraphy on board the Royal Yacht—Aerial communications between England and France—British and French Associations for the Advancement of Science—Wireless telegraphy at the Naval Maneuvers—Experiments of the Brothers Lacarme—Communication with balloons—Trials by the United States Navy Board, etc.

MARCONI'S first experiments in England took place in the General Post-Office building itself, under the supervision and with the able assistance of Sir William Preece. These having proved successful, his system was submitted to a more critical test on Salisbury Plain, with a clear distance of two miles between the sending and receiving stations. In these experiments parabolic reflectors and resonance plates were used.

These trials having proved successful, Marconi's apparatus were subjected to a more searching trial, along with Preece's own method. The experiments took place between Lavernock Point and Flatholm (3.3 miles), and also between

Lavernock Point and Brean Down (8.7 miles) on the opposite side of the Bristol Channel. Here the reflectors were done away with and vertical wires employed in their stead. The receiving station was fixed at Lavernock Point, twenty yards above the level of the sea. A mast thirty yards high was erected and on the top of it placed a cylindrical cap made of zinc, two yards long and one in diameter. Connected with this cap was a copper wire leading to one electrode of the coherer, the other electrode being attached to a wire that descended into the sea.

The sending apparatus was placed on Flatholm where the vertical wire and the zinc cap resembled those at Lavernock Point. A Ruhmkorff coil giving twenty-one inch sparks, with an eight-cell battery, was used for generating the Hertzian waves. After some experiments had been made with Preece's method (already described), which were entirely successful, Marconi's apparatus was put to the test. At first the trials were anything but satisfactory—indeed they were little short of utter failures. Next day, however, May 12, the vertical wire having been lengthened by twenty yards, the results, though still unsatisfactory, were better; while on the 13th, when the receiving apparatus was taken down from the cliff to the beach and a further length of wire added, the success achieved was beyond doubt.

The experiments which followed betwixt Lavernock Point and Brean Down were equally satisfactory, as were also similar trials that took place in the following November between the Needles, Alum Bay, Isle of Wight, and Madeira House, Bournemouth.

These experiments attracted so much attention that the Italian Ministries of War and Marine caused a series of trials to be made at Spezia between July 11 and July 18, 1897, under Marconi's direction. The first three days were devoted to trials on land, when excellent results were obtained at a distance of 3.6 kilometers. On the 14th the scene of operations was transferred to the water. The sending apparatus, which was installed in a tent upon a tongue of land near the arsenal of St. Bartholomew on the eastern side of the Gulf of Spezia, consisted of an oscillator with two central spheres of ten centimeters and two outer spheres of five centimeters diameter and an induction coil with sparks twenty-five centimeters in length, supplied by an accumulator battery. The vertical wire was twenty-six yards in length and terminated in a zinc plate.

The receiving apparatus was set up on a tugboat, and had a vertical wire running to the top of a mast sixteen yards high and terminating in a zinc plate, while another wire led from the coherer into the water. Transmission was successful up to four kilometers. On July 15 the experiments were continued with the same apparatus, only the "antenna" of the sender was lengthened to thirty yards. At first the trials were unsuccessful, the receiver giving signals, through the presence of thunder-clouds, before the transmitter had began to work. When, however, these atmospheric disturbances had ceased and the tug began, as on the previous day, to move out further and further from the sending station, the signals continued intelligible until a distance of 5.5 kilometers had been reached. But when the vessel became hidden from the sending station by a stretch of land the signals stopped altogether.

On the 16th the tug-boat kept the sending station continually in sight, and up to a distance of thirteen kilometers the messages sent were legible. When, however, the steamer turned about and began to make its way back, it seemed as though the receiver had lost some of its sensitiveness, and only at a much less distance than before were the signals intelligible.

These unfavorable results were attributable in part to the fact that the vertical wires of the two stations did not rise perpendicularly, but obliquely and with irregular bends. When the tug was steaming outward they were fairly parallel to each other, but on the return journey they were in a much less favorable position the one to the other. Another unfavorable circumstance was that in steaming back the mast carrying the "antenna" came betwixt the sending station and the receiving wire, and must have received or turned aside some of the electromagnetic energy which would otherwise have reached the coherer.

These influences entered still more unfortunately into the concluding experiments on July 17 and 18. The length of the vertical wire at the transmitting station was increased to thirty-four meters, while that connected with the received apparatus, placed on these days on the ironclad S. Martino, was at first seventeen meters and then twenty-eight meters in length. On the outward run messages were successfully transmitted up to a distance of eighteen kilometers; but on the return journey, when the masts and funnels of the steamship came between the receiving wire and the sending station, the same unfavorable results were experienced as on the previous day, and in a more marked degree.

The cause of these unfortunate appearances was not to be mistaken. On the ironclad the straight course between the sending station and the receiving wire was barred by a still greater mass of metal than on the tug. On the other hand the placing of the coherer and its auxiliary apparatus on the ironclad appeared to have little influence upon the transmission; the legibility, although not so good as usual, was still passable, even when the coherer was installed beneath the armor-plated deck, where it was surrounded on almost every side by thick masses of metal. Yet in these experiments again it was found impossible to get signals through when the line between the vessel and the sending station was broken by a point of land or by an island.

In these investigations an important consideration, which Marconi had previously observed, and the law in regard to which he now believed he had confirmed, was the influence of the height of the vertical conductor on the distance to which transmission can be effected. According to Marconi's view the limit of transmission increases with the square of the height of the wire. Thus if the height of the vertical wire at both stations were doubled the limit of transmission would be quadrupled. Hence it having been ascertained that a wire twenty feet high is sufficient to carry a message a mile, a simple calculation gives the height that would be required to telegraph to a distance of twenty miles, and so on. But whether the law be so simple as that or not (which there is reason to doubt), it at any rate appears to hold good for water only. On land, especially where there are elevations of the ground, or buildings or trees, a greater length of vertical wire is required for a given distance than when the telegraphing is done over a simple water surface. Hertz found that the electromagnetic waves went through doors and walls and indeed through all non-conducting substances, being only stopped by conductors; but the rule has its exceptions in actual practice—that is, when the wood of doors is translated into trees, and so forth.

These observations were confirmed by Professor Slaby, of Charlottenberg. Slaby had witnessed the trials at Lavernock Point, and had been so struck by them that on his return to Germany he set about making similar experiments himself. These took place first between his own laboratory and a neighboring house, and then in the grounds of the Imperial Palace at Potsdam. His apparatus was not essentially different from Marconi's; although, having found the latter's

FIG. 41.

coherer too sensitive to atmospheric disturbances, he used coarser filings. His sending apparatus was set up in the portico of the church at Sakrow, as shown in Fig. 41, the vertical conductor being suspended from the end of a pole on the top platform of the tower, twenty-three meters above the ground, while the receiving apparatus was stationed on the bridge at Glienick, 1.6 kilometers distant. Transmission was perfect except when, in order to protect the sending apparatus from the rain, it was pushed too far within the entrance of the church, thereby making it necessary to run the wire for a short distance parallel with the earth. Similarly unfavorable results followed where trees stood in front of or too near the transmitting wire.

According to Slaby the vertical conductors of both stations should be in sight the one of the other. Even the sail of a boat or the smoke of a small steamer coming between the two stations, or even a strong wind, were sufficient at times to turn the signals aside. He holds, too, that for distinctness of transmission the two conductors should be of equal height. As at the Spezia trials, so Slaby, at Berlin, found that any considerable unevenness of the ground between the two stations influenced the signaling.

In October, 1897, Professor Slaby instituted a series of experiments on a still larger scale. On this occasion his receiving apparatus was set up on the shooting-range at Schöneberg, near Berlin, while the sending station was on the military parade ground at Rangsdorf, twenty-one kilometers distant. Captive balloons, at a height of from 200 to 280 meters, were employed in place of masts for carrying up the wire conductors. At first it was thought that the steel ropes which held the balloons might serve as conductors; but no good came of the attempt; and it was only when a copper wire was employed independently of the steel tethering rope, that faultlessly distinct messages were received. Perfect transmission, however, was sometimes prevented by electrical disturbances in the atmosphere, at which times it was found to be extremely dangerous to work the instruments.

It is worthy of note that the distance at which Professor Slaby got successful signals was the longest which had at that time been attained. These experiments were published by Professor Slaby in a work entitled Funken Telegraphie (i. e. Spark Telegraphy). Many of the leading achievements in aerial telegraphy which followed upon the formation of the "Wireless Telegraph and Signal Company," formed to work Marconi's patent, will be well within the recollection of most people, and need not be referred to here, except in so far as they brought out or emphasized new developments in connection with aerial telegraphy.

In July, 1898, on the occasion of the Kingstown Regatta, the Flying Huntress, which was provided with a sending apparatus, followed the races and reported the results through a receiving station set up on shore for the Dublin Daily Express. This was regarded at the time as a great achievement; but a still more surprising exhibition of the power of the new telegraphy was given in the following month, when for sixteen days the royal yacht Osborne, with the King, then Prince of Wales, on board, was kept in uninterrupted communication with Osborne House. The vertical conductor on board had a height of eighty-three feet and the pole at Ladywood Cottage 100 feet.

The royal yacht was usually anchored in Cowes Bay, nearly two miles from Osborne House: but on August 12 she ran out to the Needles, and telegraphic communication was kept up with Osborne until off Newton Bay, a distance of seven miles, although the two places were separated from each other by considerable elevations of ground. During the same month successful communications were carried on between Alum Bay and the Haven Hotel, Poole, a distance of eighteen miles.

Important experiments were conducted in March, 1899, between the South Foreland Lighthouse and a station fixed up at Wimereux, on the French coast, near Boulogne. The two places are forty-five kilometers distant the one from the other. The vertical conductors, which were at first forty-five meters in height, but afterward reduced to thirty-seven meters, consisted of cables formed of seven strands of copper wire 0.9 millimeters in thickness with gutta-percha insulation. Aloft each cable terminated in a spiral, which was fastened to its mast by means of two ebonite cylinders.

Signals were also exchanged between the South Foreland and the East Goodwin Lightship, which was provided with a vertical conductor twenty-four meters in height, as well as with the dispatch boat Ibis, and the transport La Vienne, with conductors of twenty-two and thirty-one meters length respectively.

Fog, rain, and storm notwithstanding, messages were sent to and fro between the South Foreland, and between the latter place and the East Goodwin Lightship, without the least difficulty. The same success attended the experiments between the land stations and the Ibis and La Vienne, whether they lay at anchor or were moving from place to place. The greatest distance at which messages were exchanged between one of these vessels and the South Foreland was fifty-two kilometers. If the direct line between the two signaling stations happened to be broken by intervening objects the signals were naturally legible at a less distance. Nevertheless the Ibis, with an antenna of twenty-two meters, was able to exchange messages with Wimereux, whose vertical conductor on the occasion of this experiment had a height of forty-five meters, although the direct line between the two stations (nineteen kilometers in length) was broken by the lofty promontory, Cape Gris-Nez.

In the month of September, 1899, the British Association for the Advancement of Science held its annual meeting at Dover, while at the same time the "Association Française pour l'Avancement des Sciences" met at Boulogne. An apparatus (as shown facing title) was set up in the town hall at Dover, and messages between that place and Wimereux were successfully sent and received, despite the masses of cliff that interpose between the two places. Wimereux was also put into direct communication with a Marconi station at Dovercourt, near Harwich, and with Chelmsford. Both places are 136 kilometers from Wimereux; the line between the last-named place and Dovercourt, however, is entirely over the sea, except at one point, where it is cut by the point of the North Foreland, while the distance between Wimereux and Chelmsford is half over land, and therefore offered less favorable conditions for telegraphy without wires. Nevertheless the experiments, for which conductors forty-five meters in height were used, were entirely successful.

A series of exceedingly interesting trials of the Marconi system at sea was conducted during the British naval maneuvers of the same year (1899). Three ships were fitted up with the apparatus: the Alexandra (flag-ship), and the cruisers Juno and Europa. The two latter exchanged signals at a distance of sixty nautical miles, the Juno and the Alexandra at a distance of forty nautical miles. Signals were obtained at a still greater distance (seventy-four nautical miles), but the former were held at the time to indicate more truly the limit of clearness and legibility. The special point of interest in these experiments consisted in the fact that, in consequence of the rotundity of the earth, a great mass of water intervened between the ships, and hence the electric waves must either go right through it or find their way over its surface. Sir Oliver Lodge, I believe, holds that the electric oscillations leap from wave to wave.

The experimenters in the field of wireless telegraphy had by this time become almost numberless, and scarcely a week passed without one success or another being announced. One of the most interesting of these trials was that of the brothers Lecarme, who set up apparatus at Chamounix and at the observatory on the summit of Mont Blanc, erected by Vallot. The importance of these experiments lies not so much in the distance reached (12 kilometers only), as in the difference of elevation, between the two points, Chamounix being 1,000 meters and Mont Blanc 4,350 meters above the sea-level The experiments were completely successful, being interrupted neither by clouds nor by atmospheric disturbances; but at night, when Chamounix was electrically lighted, wave telegraphy became an impossibility.

The transmission of messages from the earth to balloons by wire telegraphy was made the subject of experiment in the Austrian and French armies during the same year (1899). The sending station in each case was on terra firma, the vertical conductor, whose length in the Austrian trials was 150 and in the French forty meters, being carried up by captive balloon. The antennæ of the receiving apparatus, which in the first case was twenty meters and in the second fifty meters long, hung from the balloon, in the basket whereof the apparatus was placed. The greatest distance to which signaling could be effected by the French experimenters was six kilometers, the balloon being at the time 200 meters from the ground. The Austrian officers, in consequence (it was thought) of better weather conditions and a longer conductor, succeeded in transmitting messages to a distance of ten kilometers with the balloon at a height of 1,600 meters. Similar experiments had already taken place in the German army; but nothing very explicit was made known respecting them further than that signals were successfully transmitted from the earth to the balloon when the latter was forty-five kilometers from the sending station.

In October, 1899, the progress of the yachts in the international race between the Columbia and Shamrock was successfully reported by aerial telegraphy, as many as 4,000 words having been (as is said) despatched from the two ship stations to the shore stations. Immediately afterward the apparatus was placed by request at the service of the United States Navy Board, and some highly interesting experiments followed under Marconi's personal supervision. The instruments were set up on board the cruiser New York and the battleship Massachusetts, and although those vessels were not provided with all the improvements which had then been made, the Massachusetts was nevertheless successful in transmitting intelligence to the New York at a distance of thirty-five miles. When messages were sent the other way only about half the distance was reached. On another occasion the very opposite occurred. Nevertheless the report of the Navy Board was in general favorable, and recommended the adoption of the system " on all vessels in the navy, including torpedo-boats, and small vessels, as patrols, scouts, and despatch-boats."

In the month of March, 1900, the Marconi system was adopted by the Nordeutscher Lloyd Steamship Company, and by agreement with that company apparatus was installed in the Borkum Riff Lightship and in Borkum Lighthouse, as also on board the L.M.S. Kaiser Wilhelm der Grosse. From the commencement of the service about the middle of May until the end of the year the station on the lightship received 582 telegrams from passing ships, fifty-three telegrams were sent from the lightship to passing vessels, while twenty telegrams went from ships direct to the lighthouse station, totaling in all to upward of 8,000 words.

It need hardly be pointed out what an important service to commerce this represents. But the immense utility of the system was shown on more than one occasion during the same period in a strikingly dramatic manner. The Borkum Riff Lightship, for instance, one day at the height of a storm was torn from its anchors and driven out to sea, and the probability is that all on board would have been lost but for the fact that they were, by the Marconi system, enabled to send a report to Borkum of what had happened.

In July of the same year (1900) a contract was entered into with the British Admiralty for the installation of the Marconi apparatus on twenty-six of H. M. ships and at six coast stations. The contract contained the condition that the apparatus should render possible the exchange of signals between two ships of which the one should be stationed at Portland and the other at Portsmouth, sixty-two miles distant and separated from the former place by the Devonshire hills—a condition which was satisfactorily fulfilled.

CHAPTER XI

The American Navy Board and "interference"—Wireless telegraphy experiments at Calvi, Corsica—Syntony imperfectly attained—Sir Oliver Lodge and syntony—Signals received at St. John's Newfoundland, from Cornwall—The influence of sunlight upon sending wires—Experiments on the Carlo Alberta—The apparatus on board and at Poldhu—Report on the results—Marconi's detector—Criticisms on the report—Tapping the messages—Syntony again—Achievements of transatlantic telegraphy without wires.

In the report of the United States Navy Board, already referred to, reference is made to a very important point in regard to aerial telegraphy. " When," says the report, " two transmitters are sending at the same time, all the receiving wires within range receive the impulses, and the tapes although unreadable, show unmistakably that such double sending is taking place. In every case, under a great number of varied conditions, the interference was complete. Mr. Marconi, although he stated to the board, before these attempts were made, that he could prevent interference, never explained how, nor made any attempt to demonstrate that it could be done."

This criticism goes to the root of one of the weak points of wireless telegraphy. A great deal has been made of the possibility, by syntony, of so "tuning" the transmitter to the receiver as to render a message going from one to the other not only illegible to a receiver not tuned to the proper pitch or key, but inappreciable thereto. In other words, if we have understood Marconi aright, he entertains the belief that he can send a signal in such a way that all receivers not specially tuned to the sending instrument shall, as we may say, be deaf thereto. Up to the present, however, so far as we are aware, little or nothing has been done to justify the promise.

One of the most important series of experiments instituted by the Marconi International Marine Communication Company was that carried out between Biot on the coast of Provence, and Calvi, Corsica, the two stations being 175 kilometers apart. According to the testimony of witnesses, the results obtained were most satisfactory. Messages passed to and fro in a most faultless manner; the dots and dashes of the Morse alphabet were all clearly distinct one from another; but the much-desired, and apparently greatly aimed at, syntony, was only imperfectly attained. Sometimes the receiving apparatus would innocently pick up and register messages that were being exchanged between battle-ships thirty kilometers distant.

The same thing has happened again and again, and we are in consequence driven to the conclusion that, though resonance or syntony has much to do with the clear transmission of messages by the aerial path, it has not yet been found possible by its means to prevent interference or the interception of messages. Indeed, it is an open secret that the despatches going to and from Poldhu are read on the post-office instruments at Penzance, as well as Porthcurno, the Eastern Telegraph Company's station.

So far, therefore, it may be said that the attempt to individualize signals by resonance or syntony has not proved a conspicuous success. Whether such will always be the case is another matter. The idea has given rise to a great deal of ingenuity, especially on the part of Sir Oliver Lodge and his coadjutor Dr. Muirhead, and it may be that their efforts will in time be crowned with complete success. In the pamphlet recently published, describing their system of wireless telegraphy, reference is made to the adjustable nature of the inductance coil and the condenser as being a means of tuning the radiator to any desired frequency or pitch, and thus rendering syntony possible in the receiver. This adjustability, it is contended, makes it feasible so to attune the two circuits that they shall be secure from certain kinds of outside interference. It is admitted that "for very close tuning of this kind more elaborate devices are necessary," and in Mr. Marillier's description of their method in Page's Magazine it is claimed that "with the close screening devices" which the inventors have introduced into their system, all "outside interference from other stations outside a ten-mile radius" can be satisfactorily eliminated.

The matter, however, is one of detail, of which perhaps, more has been made than it deserves; because whenever secrecy becomes a thing of vital importance codification is always possible. Many hold—Sir William Preece, I believe, among the number—that etheric wave telegraphy is by its nature a universal system, and will continue to be such in spite of efforts to the contrary. The electromagnetic waves travel in every direction through the ether from the point of excitation, like radiations from the center of a sphere, and are only stopped or turned from their course by matter of different degrees of inconductivity. But for this the oscillations would radiate through the earth in the same way that they radiate through the air. It is supposed, however, that when the electromagnetic waves impinge upon the earth they are stopped or deflected. But it must be confessed that our knowledge in the matter is very imperfect.

This discussion on syntony, however, has carried us a little too far ahead, and it is necessary to go back a little and record the surprise with which the announcement was made on December 12, 1901, that Marconi had at St. John's, Newfoundland, received signals from Poldhu, Cornwall, a distance of 1,800 miles across the Atlantic. These "signals" were explained to be nothing more than a letter of the alphabet several times repeated, and the public were incredulous. The feat was believed to be impossible; but the following month brought most surprising confirmation of the wonder. The American liner Philadelphia, fitted with the Marconi apparatus, and with Marconi himself on board, on her way to New York, received legible messages from the Poldhu station up to a distance of 1,551½ miles, and weak signals up to 2,099 miles.

These experiments brought out one very remarkable phenomenon; for while, by night transmission was possible to upward of 1,500 miles, during the daytime the utmost limit of legibility was 700 miles. This difference Marconi attributed to the discharging influence of the sunlight upon the electricity-laden vertical wire of the transmitter.

Further investigations into this phenomenon were made during the voyage of the King of Italy to St. Petersburg in July, 1902, in the Carlo Alberta. The vessel was fitted up with wireless telegraphy apparatus, and under Marconi's direction, signals and messages were received daily from Poldhu. The noteworthy thing about these experiments was not merely the greatness of the distance to which messages were transmitted, but the circumstance that so much of that distance was overland. A detailed report on these investigations was made by Lieutenant Solari, of the Italian Navy, and from it, as given by Righi and Dessau in their work Die Telegraphie ohne Draht, I take the following particulars:

The receiving station on board the Carlo Alberta comprised two Marconi coherers, which carried the signals coming from Poldhu by means of a relay to an ordinary telegraph apparatus, which repeated them in the Morse alphabet, and three of Marconi's new magnetic wave detectors, which were connected with a telephone. The waves acted upon the coherers by means of a transformer, which was tuned to the period of the oscillations radiated from the sending apparatus at Poldhu. These were received at first by an arrangement of four isolated parallel wires, which were stretched from the peak of the foremast (forty-five meters in height) to the peak of the mizzen-mast, and thence down to the receiving apparatus. The attachments of the wires were carefully insulated by chains of porcelain insulators, and the mast wire was perfectly insulated by means of an ebonite tube.

Later, however, while the Carlo Alberta lay off Cronstadt, this arrangement was replaced by a combination of fifty thin tinned copper wires, supported between the two masts by a steel rope (Fig. 42). This fan-like contrivance was set up in order to bring the oscillatory period of the receiver more closely in unison with that of the sender. It should be added that the height of the masts was, during the return voyage, increased to fifty-two meters.

Messages were, as a rule, sent from the Poldhu station, erected for transatlantic communication, which differs from the other stations of the Wireless Telegraphy & Signal Company in possessing more powerful engines for generating the electric waves and for the effective directions of the same. For this latter purpose the station is furnished with four sections of 100 thin bare conductors of tinned copper, which are suspended from four steel ropes stretched between four open-work wooden towers seventy meters in height and sixty meters distant the one from the other. Above the wires are about fifty centimeters apart, while the lower ends are so bound together on the roof of the station buildings that the whole resembles a four-sided pyramid with its apex reversed.

The potential to which these conductors were charged during transmission was sufficient to cause sparks thirty centimeters long to leap between one of the conductors and a copper wire connected to earth.

It was arranged that each midday between the hours of twelve and one and every night between the hours of one and three, the first ten minutes of each quarter of an hour should be occupied at the Poldhu station in sending the initial letters of Carlo Alberta and the letter S, and that afterward the most interesting items of the day's news should be telegraphed. The experiments began under Marconi's direction at midday on July 7, at which time the Carlo Alberta was near Dover, 500 nautical miles from Poldhu, going in a northeasterly direction. Signals which were received on a magnetic detector were, in consequence of the imperfect syntony and the disturbing influence of the sunlight, not very strong, although they were, notwithstanding, clearly distinguishable. Telegrams were also

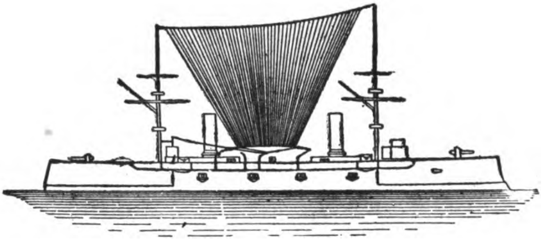


FIG. 42.

received from the Cornwall station by means of the coherer and the Morse alphabet.

During the ensuing night the Carlo Alberta was 900 kilometers from Poldhu; nevertheless, the magnetic detector distinctly repeated the signals from the Cornish station, while the Morse apparatus worked without interruption. Transmission was better than during the day, because of the absence of the disturbing influence of the sunlight. The following midday, when the battle-ship was 1,000 kilometers from Poldhu, the disturbing influence of the light was again experienced, and it was only on the telephone, which was connected with the detector, that the signals of a few S's were appreciable. During the night of July 8 and 9, however, although the distance had considerably increased and the whole breadth of England, as well as the northern portion of Denmark, lay between the vessel and the sending station, the signals again arrived in sufficient strength not only to act upon the telephone, but to set the Morse alphabet in activity.

Before Cronstadt the signals were at first difficult to make out even during the night. This circumstance was attributed to the fact that the water, with its smaller admixture of salt, formed a poor conductor to earth in comparison with the salt water of the ocean. However, the alteration in the arrangement of vertical wires, already described, had the effect of restoring the signals to their former distinctness.

On the return voyage from Cronstadt, during the night of July 22 and 23, the Carlo Alberta being at the time to the northeast of the island of Gothland, the signals in the telephone were so distinct that, as the report says, those who heard them could scarcely believe that 8,000 kilometers of land and water separated them from the sending station. Later, through atmospheric disturbances, transmission became difficult, and about 2.30 the signals altogether ceased, although at 2.45 the closing signal again became quite distinct.

From July 24, when the Carlo Alberta lay in the inner harbor of Kiel, till England was again reached, the signals from Poldhu arrived with such regularity and so clearly that the magnetic detector and the telephone were dispensed with, and the messages constantly received by means of a coherer and the Morse apparatus. Equally remarkable results were obtained during the homeward run from England to Italy, but it must suffice to give one striking fact out of many. When the Carlo Alberta was lying in the harbor of Cagliari, over 1,580 kilometers from Poldhu, signals from the latter place were received, while at a little smaller distance complete messages were registered.

Lieutenant Solari sums up the results of the experiments on board the Carlo Alberta as having established the following points: (1) that there is practically no limit to the distance to which the electric waves can be sent if the expenditure of energy be proportioned to the distance to be spanned; (2) that stretches of land between the sending and receiving stations are no hindrance to transmission; (3) that sunlight has the effect of diminishing the carrying power of the waves and that therefore while it lasts a greater expenditure of force is necessary; (4) that as during electrical disturbances in the atmosphere, it is essential that less sensitive receiving instruments should be used, a greater amount of electrical energy must be expended, and (5) that the magnetic detector, as regards sensitiveness and reliability, is superior to every form of coherer.

As regards the last item it may be that the detector is all that Solari says it is; but on that point we shall know more when it has stood the test of longer experience. It is believed by many, however, that Marconi possesses some special secret which enables him to do so much more by means of his system than others can do with theirs, and it may be that it lies, in part, at least, if not wholly, in this detector, of which it has been said in the Monthly Review, by Mr. Worthington, that it raises Marconi "to the foremost rank of scientific inventors," and removes from wireless telegraphy a stumbling-block in the way of speed.

Much discussion has arisen over this "magnetic detector," which is nothing more than the "mercury coherer" previously referred to in speaking of Lodge & Muirhead's improved receiver. Mr. Marconi, before the Royal Society, mistakenly attributed the invention to Lieutenant Solari. The editor of the journal L'Elettricita, published at Rome, intending to correct the error, committed a fresh one by quoting Señor Castelli as the inventor of the new method. It appears, however, that neither of these gentlemen have any claim to be the originator of the mercury coherer, the merit of the invention really belonging to Professor Thomas Tommasina, of Geneva, who brought it before the notice of the Physical Society of that city in 1899, and published an account of it in the Comptes Rendus de l'Académie des Sciences for May 1 of that year.

Some rather sharp criticisms were passed on Lieutenant Solari's performance by Mr. Nevil Maskelyne, superintendent of the wireless telegraph station at Porthcurno, erected by the Eastern Telegraph Company for the purpose of signaling to vessels fitted with wireless installations. These strictures were not so much upon what Lieutenant Solari put in his report as upon what he left out. The imputation appears to be that the naval officer was not let into all that was going on in connection with the experiments between Poldhu and the Carlo Alberta, and hence that his account was not a full and complete one. The gravamen of the charge is that, despite the allegations of the Marconi Signal & Telegraph Company that they could prevent their messages from being "tapped," pretty nearly all that was sent from Poldhu to the Carlo Alberta *en voyage* was intercepted and read by the staff at the Porthcurno station, 18 miles distant; and this was done even when the attempt was apparently being made to prevent such interception by sending two messages, or sets of signals, at the same time. Mr. Maskelyne interprets the fact as "an attempt to prevent stations nearer than the Carlo Alberta from reading the message transmitted by Poldhu," and he asks what had become of the Marconi syntonic apparatus? Many have been asking since what has become of it.

But, as already said, this question of syntony is a detail which will settle itself one way or another in course of time. Meanwhile there are other matters of moment calling for record, one of which is that the King of Italy was so gratified by the "wireless" experiments conducted on board the Carlo Alberta during the voyage to St. Petersburg and back that he placed that vessel at the disposal of Marconi for his projected run to America to test the long-distance stations of his company at Cape Breton, Canada, and Cape Cod, Massachusetts. The stations at those places are similar to the one erected at Poldhu, of which we have given a description above. Of the one at Glace Bay, Cape Breton, we are enabled to give a view in Fig. 43.

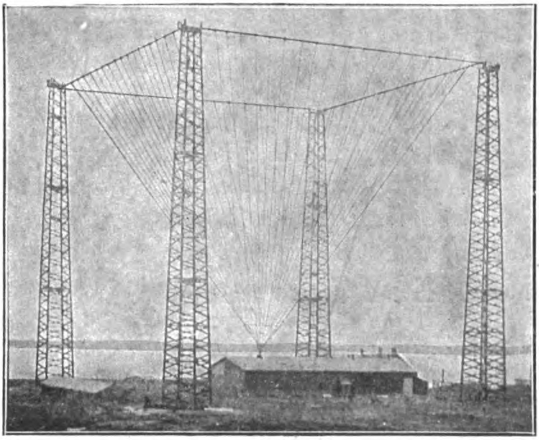


Fig. 43. (From *The Electrician.*)

It is needless to give a detailed account of the events that led up to the achievement of wireless telegraphy across the Atlantic. Suffice it to say than on December 22, 1902, the famous Italian inventor was enabled to telegraph, "through free space," to King Edward, as follows:

> "To Lord Knollys, Buckingham Palace, London.
> "On occasion of first wireless telegraphic communica-

tion across Atlantic Ocean may I be permitted to present by means of this wireless message transmitted from Canada to England my respectful homage to his Majesty the King?
"MARCONI."

At the same time the following telegram was sent to the King by Lord Minto:

"To His Majesty the King, London.
"May I be permitted by means of this wireless message to congratulate your Majesty on success of Marconi's great invention connecting England and Canada? MINTO."

The King's reply to Marconi was as follows (although it is understood that it was not transmitted to Canada by the wireless method):

"To Marconi, Canada.
"I have had the honor of submitting your telegram to the King, and I am commanded to congratulate you sincerely from his Majesty on the successful issue of your endeavors to develop your most important invention. The King has been much interested by your experiments, as he remembers that the initial ones were commenced by you from the royal yacht Osborne in 1898. KNOLLYS."

A wireless message was also sent to the King of Italy, who replied as follows:

"I have learned with great pleasure of the results you have obtained, which constitute a triumph for yourself, to the greater glory of Italy and of science."

The next important step in the history of the new telegraphy was taken on Monday, March

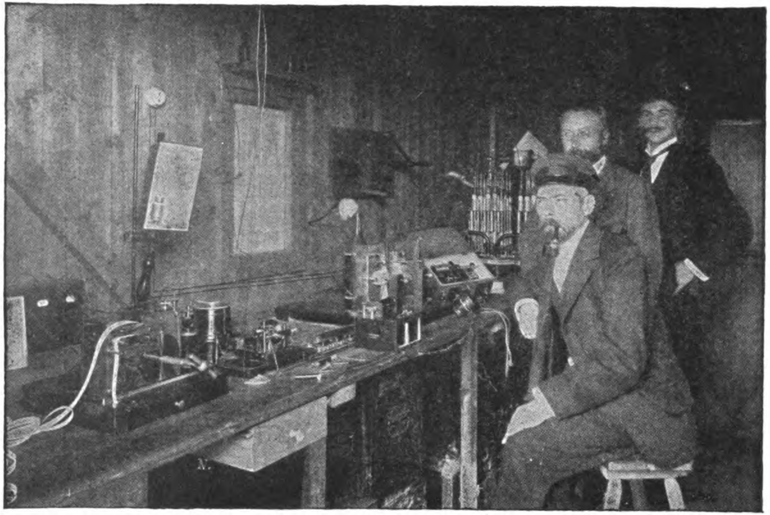
30, 1903, when the Times announced that it had entered into an arrangement with the Marconi Telegraph Company for the regular transmission of news from the other side of the Atlantic. This announcement was accompanied by the publication of about twenty lines of news from the leading journal's New York correspondent, by "Marconigraph," partly on Saturday and partly on Sunday. An article in the same issue stated that a day-to-day transmission of news between the New and the Old World had been undertaken on a contract basis. After that first specimen, however, no other "Marconigrams" appeared, and the director of the company had to explain that the interruption of the service was due to a breakdown of the apparatus at Cape Breton. This he felt confident would be repaired very shortly.

CHAPTER XII

The system of Professor Braun—The Orling-Armstrong method—Further particulars of the Lodge-Muirhead system—Two American wireless methods—That of Dr. Lee de Forest, Professor Fessenden's Discoveries —His system—The future of wireless telegraphy.

Having given as complete an account of the Marconi system of wireless telegraphy, and of the marvelous results which it has achieved up to the present time, as is possible, it remains to refer with some detail to several rival methods that are competing for public recognition. One of the most important of these is that of Professor Ferdinand Braun, of Strasburg.

Professor Braun early came to the conclusion that the Hertzian waves penetrate the earth and water and spread out therein on every side, just as they do in the air, and that it was possible to turn them to account for the transmission of signals through earth and water. But his hopes of success in this regard were based upon the fact that, while slow currents of electricity penetrate and fill the whole diameter of a conductor, like a wire, rapidly alternating currents, or Hertzian waves, which we know, are of great velocity, only skim, as it were, along the surface,



Professor Braun in his Laboratory.

or, at any rate, enter into the substance of the conductor to an extremely slight extent. Moreover, this penetration is the less the more quickly the alternations of current follow one after another.

Putting this law to the test in water, Professor Braun found that there are no electric waves of any noteworthy intensity at a depth of under two meters from the point at which they enter. He accordingly devised a series of experiments to see what results he could obtain from the action of electric waves in the water. His first experiments were made in the disused moats of the old fortifications of Strasburg. One of these moats had the form shown in Fig. 44. The transmitting station was placed at one end of the moat, at the point marked *a b*, close to a

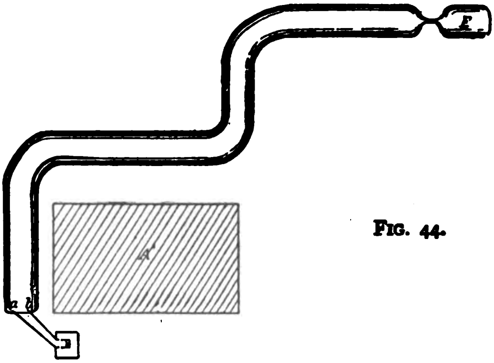


Fig. 44.

quadrangular space covered with buildings, by reason of which Braun held that direct transmission by electric waves through the air was next to impossible. The receiving station—with its two wires dipping in the water—was removed farther and farther from the sending station, transmission remaining perfectly distinct so long as the experiments were confined to the main sheet of water. But immediately the receiving wires were transferred to the basin *E*, which was connected with the larger body of water by a shallow channel hardly a meter in breadth, the intensity of the signals dropped off considerably, and was only restored by a corresponding strengthening of the induction coil.

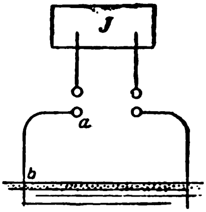


FIG. 45.

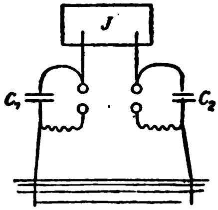


FIG. 46.

In these experiments Professor Braun made use of variously contrived wave-generators, of which Fig. 45 is the simplest form. By sparking between the spheres, oscillations are excited which are transferred to the surface of the water, whence, according to Professor Braun, they pass in part into the water and in part are reflected. Another form of exciter is depicted in Fig. 46. This was found very effective. The condensers, C^1 C^2, consisted of two Leyden jars of about 2,000 centimeters capacity, the self-induction coil of spirals of from ten to a hundred and more turns of copper wire, the diameter of the coils being from three to fifteen centimeters. The right selection of these coils was found to be very essential to favorable working.

Braun was satisfied that in these experiments the results obtained were: (1) not the effect of waves through the air, and (2) that they were not produced by induction in the sense of Preece's experiments.

Other experiments were subsequently conducted on the Rhine, and with equally favorable results. In the summer of the following year (1899) Professor Braun tested his method in the sea at Cuxhaven, when, with a Bunsen battery of eight cells and a medium-sized induction coil, and under conditions generally unfavorable, transmission to a distance of three kilometers was completely successful.

Notwithstanding this success, however, Professor Braun appears to have pursued these investigations no further, but directed his efforts in the remainder of this and a considerable portion of the ensuing year to experiments with aerial telegraphy. In these researches, as in those through the water, he made the sender or exciter, not the receiver, as with others, his chief consideration. During the summer of 1899 attention was chiefly given to testing the distance for which messages could be sent from incoming or outgoing vessels to the lighthouse Kugelbake (Fig. 47), at the mouth of the Elbe, not far from Cuxhaven. The result reached was that, with the apparatus used, perfect messages could be transmitted to a distance of thirty-two kilometers, while legible signals could be sent to a distance of fifty kilometers.

The experiments were continued during the winter of 1899–1900, and through the following summer, when wireless connection was successfully made with Heligoland, a distance of sixty-three kilometers.

In the methods previously described the chief aim of the investigators has been to turn water and the air to account as *media* for the transmission of electrical impulses. But in the method which it is now necessary to give, some account of transmission is effected through the earth itself. It is given out as the joint invention of Mr. Axel Orling, a Swedish electrician, and Mr. J. T. Armstrong, a London engineer, and according to one account, a patent was taken out for it before that of Marconi. As a matter of fact, however, the Orling-Armstrong method is based upon a number of patents, and it may be that one or another of them are of earlier date than that of Marconi, but all the same the fact remains that it was not made public until 1902. In any case, this like all other methods, has to be judged by results, and these, so far as we know, have not yet gone beyond the experimental stage.

The Orling-Armstrong invention differs from other wireless systems in that, as already said, the earth is utilized as the conductor, and the currents discharged are of a very low potential, a current of eight volts being more than sufficient to transmit a message twenty miles. It differs from its rivals also in its simplicity, the "Armorl" system, as its inventors call it, dispensing with induction coils, coherers, high masts, and the like, of which we hear so much in connection with other methods.

The leading feature of the invention consists of an apparatus which, after the manner of a telegraph relay, is designed to close the circuit of a telegraphic receiver or some other arrangement operated by a stronger current. This apparatus must, in accordance with its character, answer to a very weak current. It is based on the observation that, in a sufficiently narrow, funnel-shaped tube, of which one part is filled with mercury and the rest with sulphuric acid, by the passage of an electric current from the mercury to the acid, or vice versa, the two fluids

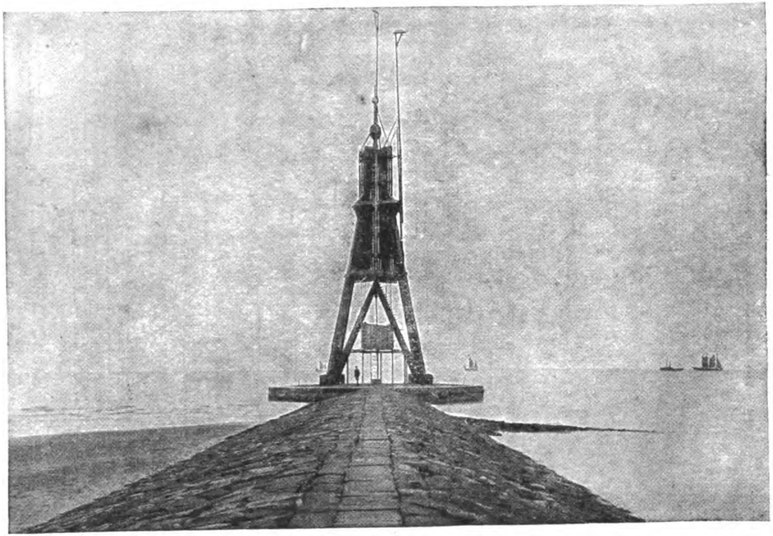


FIG. 47.—Kugelbake at the mouth of the Elbe.

are caused to move in the direction of the current. This phenomena, which has its origin in an alteration in the capillary attraction of the mercury, has long been known and has been turned to account in the construction of an extremely delicate electrometer.

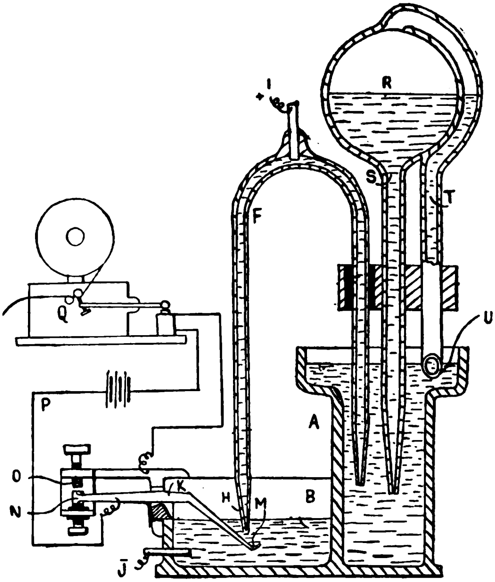


FIG. 48.

The simplest form of the Orling-Armstrong apparatus consists in the main of a siphon F (Fig. 48), whose shorter shank dips into the mercury contained in the chamber A, while the longer shank, which ends in the chamber B, below the acid, is constricted to a fine point. By this means the siphon is kept in a state of inactivity and the mercury prevented from flowing from the chamber A to the chamber B. If, however, between the two contacts I and J, of which one leads to the mercury in the siphon, the other to the acid in the chamber B, a potential difference is caused in the direction, so that I receives a positive charge, then the mercury, which before had reached to the summit of the siphon, makes its way out of the same and falls in minute drops on to the lever K. This is set in motion thereby and establishes a contact at O, which closes the circuit of a battery and a telegraph receiver. The reservoir R keeps the mercury in A at a uniform height.

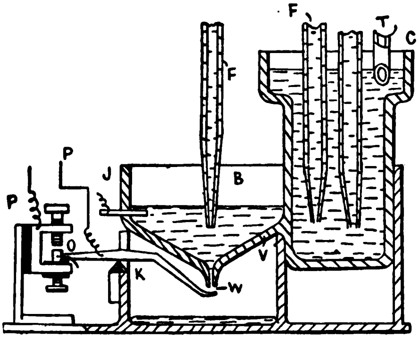


FIG. 49.

A modification of the arrangement before described is shown in Fig. 49, according to which the chamber B is provided with a funnel-shaped bottom V, having a perforation W of such dimensions as will only allow fluid to pass when under pressure. In practice the chamber B is first supplied with mercury until the pressure due to the weight causes it to begin to drip through. The chamber is then supplied with dilute acid as previously described. When, however, more mercury is delivered by the siphon from the chamber C, the excess of pressure causes an equal quantity of the mercury that was already at the bottom of the chamber B to fall through the perforation W, whereupon it comes in contact with a delicately poised lever K, by means of which a relay circuit is closed. Or, according to the further modification shown in Fig. 50, the drop of mercury during its descent is caused to bridge a "break" X, and so close the relay circuit P.

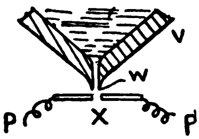


FIG. 50.

Another form of the invention is shown in Fig. 51, wherein a scale-beam, Y, is delicately poised on a knife edge in suitable standards. The scale-beam consists of a glass tube, which rests in a suitable cradle, 2, and is provided with two upwardly inclined limits, 3. The tube contains a small quantity of sulphuric acid at the point D, where the two limbs meet, while the limbs themselves are filled with mercury. To the ends of the scale-beam are secured conductors, 4, which maintain electrical connection between the mercury in the limbs, 3, and the mercury in the cups, 5, into which the conductors dip. If a potential difference is caused between the mercury cups, the enclosed drops of acid in the glass tube, Y, will be moved to one side, the balance of the scale-beam will be destroyed, it will incline to one side, and the tongue, 7, will be brought in touch with one of the contacts 8 and 9, whereby a local circuit will be closed.

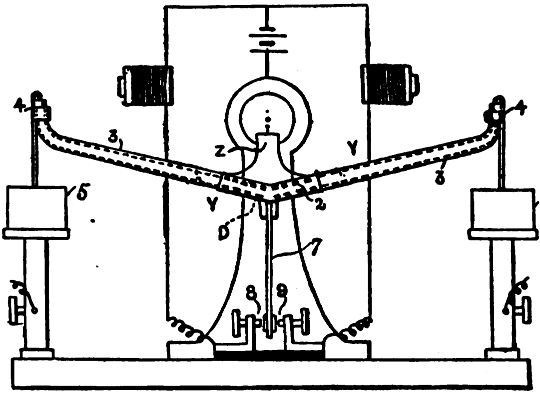


FIG. 51.

By means of these various devices the inventors claim that electric currents which the most sensitive galvanometers can not record, and by which the telephone receiver is unaffected, are detected. The apparatus comprises a receiver, a small battery of eight volts, packed in a case provided on the outside with two contact screws, and two pointed iron stakes to be driven into the ground to a depth of about eighteen inches and about twelve feet apart. To each of them a wire is attached connecting the positive and negative poles of the instruments. The current thus set up flows through these wires into the ground and so finds its way to the corresponding station, where similar iron stakes are planted in the ground to receive the impulses. Each station is provided with a key, similar to that employed for sending Morse signals, together with a telephone receiver. The operator holds the telephone to his ear with one hand while he transmits in the ordinary way with the other. If necessary the receiver may be connected to a Morse tape printing machine and thus the messages be printed as received.

Up to the present time the "Armorl" system has not been worked to a distance of more than twenty miles. Beyond that distance the inventors are compelled to have recourse to relays, or else to avail themselves of aerial transmission. For this purpose they require a special installation, with high poles, etc., just like Marconi and others; but they claim as an advantage over their rivals the fact that their poles are only one-tenth the height of those of Marconi. They claim a further advantage in respect of speed of transmission.

There can be no doubt that Messrs. Orling and Armstrong are the inventors of a very ingenious system of wireless telegraphy, although its full capabilities have yet to be tested by practical experience. Features greatly in its favor are its portability and its cheapness. The system lends itself to purposes other than those of telegraphy, as, for instance, to the firing of mines, the guidance of torpedoes, etc.; but into these matters it is not necessary to enter here.

Reference has already been made to the Lodge-Muirhead wireless system, and to the delicate contrivance by which the old-fashioned filings-tube coherer has been replaced. It remains to give some particulars of other leading features of the system, which, as the inventors claim, is based on patents taken out for the most part in 1897. These provide for the following essentials:

1. The combination in the transmitting and receiving circuits of two capacity areas and an inductance coil as a vital element in a syntonic system of wireless telegraphy. Between these areas, which may be regarded as the two coats of a Leyden jar spread out in space, is placed

the spark-gap, and between this and the lower, or earth-capacity area is the adjustable inductance coil (Fig. 52). Sometimes an adjustable condenser is inserted between the lower or earth-capacity area and the adjustable inductance coil. The purpose of these is to prolong the electrical oscillations, and by means of their adjustment to tune the radiator or exciter to any desired frequency or pitch, and thus render syntony possible in the receiver. As has already been stated, Sir Oliver Lodge's main idea, as regards transmission, has always been to obtain a succession of waves of definite frequency, the cumulative effect of which would be to produce a perceptible effect upon a tuned receiver, no matter how feeble the waves might be, on the well-known principle of sympathetic resonance.

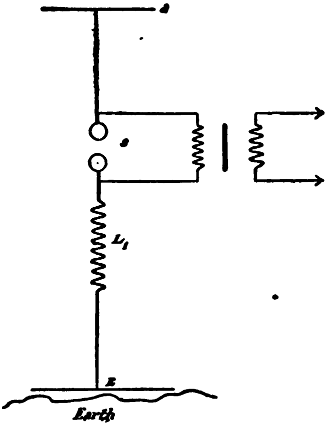


FIG. 52.

a, E the two capacity areas, s spark-gap, L_1 an adjustable self-inductance coil for adjustment of syntony.

2. The second point of importance laid claim to by the inventors is the use of a transformer,

or ironless induction coil, in the receiving circuit (tp, ts, Fig. 53). The purpose of this device is, briefly stated, to magnify the electromagnetic force, and to put the coherer into a second circuit, instead of in direct series with the vertical collecting wire and the lower capacity, or earth-plate.

3. The third distinctive feature of the Lodge-Muirhead system is the use of a condenser shunt (see Fig. 53) in the coherer circuit, which enables that circuit to have a definite time period. This condenser shunt eliminates the battery and receiving instrument so far as oscillations are concerned, and is regarded by the patentees as an addition of great importance.

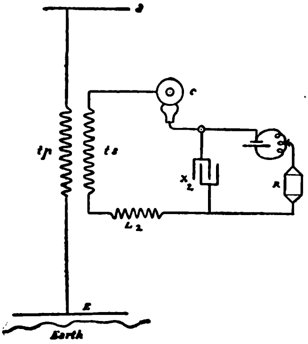


FIG. 53.

a, *E* the two capacity areas, *tp* the primary (adjustable) circuit of the Lodge transformer (or jigger), *ts* the secondary circuit (adjustable) of the transformer, L_2 an additional adjustable inductance coil to assist in the accurate tuning of the coherer circuit, *c* the steel mercury coherer, X_2 adjustable condenser (*N.B.*—This condenser is one of the characteristics of Lodge's system), *R* siphon recorder.

The disk coherer is placed directly in circuit with a siphon recorder, without the interposition of any relay, and is connected also with a potentiometer for the purpose of regulating the P.O. at its terminals from 0.03

to 0.5 volt, according to circumstances. The coherer is so sensitive, when the disk is rotating with moderate speed, that the application of a whole volt is sufficient to break down the film of oil and establish coherence.

The transmitting circuit consists of an elevated capacity, in the form of a globe, a wire-cage arrangement, or a framework of wires (as offering as little resistance as possible to the wind), from which is suspended the vertical wire, connected at its lower end to one knot of the spark-gap. The inductance coil and condenser (when one is employed) are connected in series with the other knob, and a lead is taken thence to the earth-plate or to the center of a second capacity lying on the ground. The system also includes a Ruhmkorff coil for generating the sparks and a battery of five cells, more or less, which is replaced for long-distance work by an alternator.

The signaling apparatus consists either of a specialized Morse key, worked by hand, or, what is a distinctive feature of Dr. Muirhead's improvements, an automatic signaling machine used in conjunction with a perforator of special pattern. In either case the local signaling circuit contains a transmitter designed to open and shut at a definite rate the primary of the inductive coil. This instrument (shown in Fig. 54) is made up of two telegraphic sounders cross-connected in such a way as to act reciprocally.

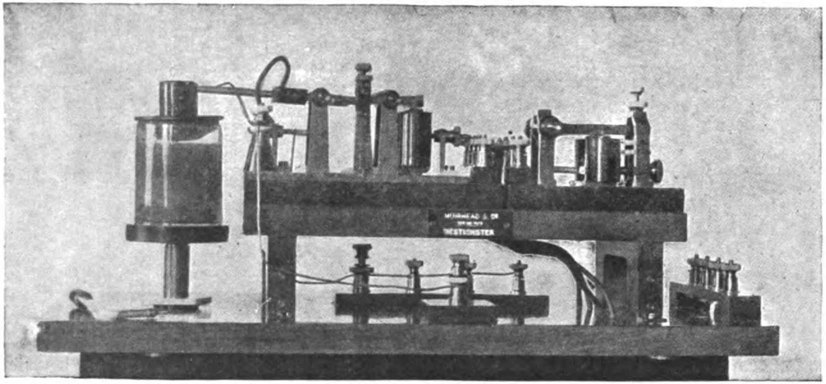


FIG. 54.—The Lodge-Muirhead Buzzer.

An aluminium arm fitted with a copper rod dipping into mercury is attached to the armature of the second sounder, and the rapid make-and-break between the copper rod and the mercury (about 600 times per minute) serves to fix the frequency of the sparks. The function of this apparatus, or "buzzer," as it is called, is, during the holding down of the Morse key, to cut up the long-continued contact into a rapid succession of sparks, without any attention on the part of the operator, so that all he has to do is to signal shorts and longs in the usual telegraphic manner. These are translated by the "buzzer" into the requisite mode of disturbance for spark-signaling, and are transmogrified by the receiver into the dots and dashes of the siphon script.

This application of ordinary telegraphic signaling apparatus is due chiefly to the ingenuity of Dr. Muirhead, and how perfectly it works may be seen by a visit to the inventor's experimental range between Elmers End and Aldershot, a distance of thirty-four miles, which, owing to the insulating nature of the Kentish chalk formation is held by the inventors to be equivalent to several times that distance over sea. The system has been tested also over the official range of sixty-two miles between Portland and Portsmouth, and with satisfactory results.

As already stated, the inventors are satisfied that they can eliminate interference beyond a radius of ten miles. Within that distance the problem is more difficult. For ordinary seagoing work, and for communication between ship and shore, they hold that a simple open-tuned system is at present almost necessary, because of the complication that would arise if every ship had to tune both a closed oscillating condenser circuit and its attached aerial specially for each station.

While the number of vessels sending wireless signals or messages at one time is small the risk of confusion is not very great. But what will be the condition of things when the wireless equipment of ships becomes general, unless some close system of syntonic signaling be devised, it is not difficult to foresee. Sir Oliver Lodge and his coadjutor, Dr. Muirhead, have for some time been pressingly alive to the imminence of this contingency, and they have in consequence been turning their attention to the working out of a contrivance to meet the need, rather than to the covering of great distances by their "wave" system.

They will achieve a great thing if they can adapt their apparatus to this purpose, and so make theirs the premier system as regards safety and effectiveness, if only for short distances. It is some reward for their tireless labors in this direction that the first installation of "wireless" telegraphy adopted by one of the cable companies, that on board the two new repairing ships of the Eastern Extension Telegraph Company, should have been allotted to the Lodge-Muirhead "Wireless" Telegraphy Syndicate, after a careful consideration of the different competing systems at present in vogue.

It remains to give a brief description of two other systems of aerial telegraphy, the inventors whereof are both Americans. The first is that of Dr. Lee de Forest, of which much has been heard in connection with the Russo-Japanese war, the most interesting part of whose invention centers in the "responder," the device by which he replaces the coherer of other methods. This apparatus, according to the description of the company working the system, depends for its action upon an electrolytic principle. Between two electrodes of soft metal is fixed a paste containing some electrolizable fluid, metallic particles, and some viscous material. Under the action of the local battery, minute conducting particles are torn off from the electrodes and made to bridge the gap. The resistance of the device is therefore ordinarily very small, but under the action of the electric waves electrolysis is set up, and minute hydrogen bubbles are generated at the cathode. This suddenly disrupts the conducting chains and greatly increases the resistance of the responder. The oxygen appears to combine with the anodic metal, while the hydrogen amalgamates with a depolarizing agent mixed with the paste. The action is thus instant and automatic, and allows the use of a telephone as receiver. As a proof of the sensitiveness of the responder, it is said that it will respond to a $\frac{1}{64}$ inch spark 45 feet away with antennæ only 2 feet in height.

The receiving apparatus includes also an adjustable inductance, an adjustable capacity, a potentiometer, a telephone, and a fixed capacity. The adjustable inductance and the adjustable capacity serve for varying the time constant of the oscillating circuit, in order that the circuit may be put as nearly as possible in tune with the transmitted waves. The object of the potentiometer is to obtain the loudest possible sound in the telephone receiver.

As regards the sending apparatus, an ordinary alternating current is used in place of interrupters or coils. A special key is employed for breaking the current, and with it a speed of upward of 48 words per minute is said to have been reached.

One of the more salient features of the De Forest method is a "reactance regulator," the true function of which is to prevent the formation of an arc across the spark-gap in case the energy of delivery to the circuit becomes excessive. Should a tendency to arc at the gap arise, the handle of the reactance regulator may be so worked as to bring in more turns of wire and thus reduce the excess of energy. Another feature of interest is a helix, consisting of four turns of quarter-inch nickel-plated copper tube, and having a diameter of about eighteen inches. By means of a movable contact the self-induction in the circuit is readily variable, while owing to the very high oscillating frequency, the slightest movement effects a difference in the nature of the waves thrown off. This helix forms a most important part of the apparatus, as by its means an approach to syntony is said to be attained.

Another feature of the De Forest system is the five-wire antennæ attached to both the transmitter and receiver. In transmitting the whole of the five wires are in parallel, while in receiving only four are parallel, though they are in series with the remaining one. By this arrangement the spark-gaps on the receiving side act as insulators.

The De Forest method has frequently been worked, and with every satisfaction, in connection with the American army and navy operations; while in the month of December, 1903, Dr. de Forest made a series of successful experiments in the transmission of aerial signals and messages between Holyhead and Howth, a distance, as the crow flies, of 65 miles, when a speed of from 20 to 30 words per minute was obtained. It is worthy of note that the inventor makes no claim to having achieved perfect syntony, which he holds to be impossible at present.

The other system of wireless telegraphy whereof, before concluding, it is necessary to give some account, is that of Professor Fessenden, a brief reference to whom has already been made. Professor Fessenden was until recently connected with the teaching staff of the Alleghany University, and it was while there that he worked out his remarkable system. It is entitled to the distinguishing adjective because, as was observed in a descriptive article in the Electrical World of New York, the inventor "has not only evolved apparatus entirely different from that of his contemporaneous workers abroad, but has discovered new phenomena separate and distinct from those of Hertz, 'in that they are not complete waves, but only half waves, and in that they travel on the surface of a conductor, and, hence, unlike Hertz waves, can be deflected from a straight line.'" These waves are described as "semi-free ether waves," but are "different from those investigated by Lodge in metal conductors, in that they are not current waves."

Fessenden, in one of his patent specifications,* thus refers to these electromagnetic waves: "In

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* No. 706,746.

the Lodge waves the electric energy is maximum when the magnetic energy is minimum, and all energy not absorbed by resistance losses is recoverable, while with the form investigated by me the electric energy is a maximum at the same time as the magnetic, and none of the energy radiated is recoverable except by deflection. I have found that it is essential for the proper sending and receipt of these waves that the surface over which they are to travel should be highly conducting, more especially in the neighborhood of the point where the waves are generated."

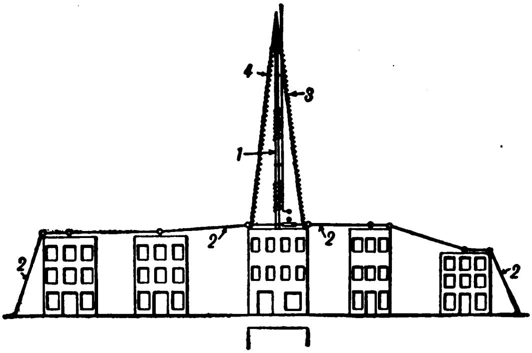

FIG. 55.

The salient features of Professor Fessenden's system may be seen from the accompanying diagrams (Figs. 55 and 56). Fig. 55 represents what the originator designates a "wave-chute," wherein 1 is the antenna or sending conductor, and 2 the grounded conductor leading across buildings and other obstacles to a $\lambda/4$ or more, beyond the limits of obstructions, when the terminals are earthed, as shown. The coils 3 and 4, forming guys from the mast, have a natural period of oscillation, different from that of the sending conductor, and this, with the grounded conductor or wave-chute, eliminates outside interference of wave-lengths not in tune, and dissipates atmospheric potentials which ordinarily produce untoward effects in the reception of wireless messages.

Another novel feature of the antenna and oscillator system, says the account to which we are chiefly indebted for these facts,* "is due to the inventor's discovery that, if electromagnetic waves were produced in a medium having a specific inductive capacity and permeability to electromagnetic waves greater than air, the height of the antenna may be considerably reduced, since 'the periodicity of oscillation is decreased compared with that of the same antenna in air; and the radiation is therefore increased, giving the effect of a long conductor.'" In order to accomplish this end the conductor with the oscillator is placed within a second conductor of tubular form, which is immersed "in water or other liquid having an electric constant

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* The Electrical World and Engineer of New York.

greater than that of air, and on which the emitted wave length depends."

At his transmitting station Fessenden uses a vertical wire with large capacity and low induction. The capacity can be regulated by increasing the area of the antenna and the induction by adding to the turns of wire connecting the vertical wire with the source of energy.

One of the strongest points claimed for Fessenden's apparatus is that by its means messages may be sent at a much higher rate of speed than is possible by the ordinary method of making and breaking the primary circuit. Another point in its favor is that signals can be sent by it to a much greater distance with a slighter expenditure of power than by other systems. Still another advantage claimed for it is the accuracy of its message delivery, being equal, as is said, in this respect to transmission by wire.

In Fig. 56 the complete sending and receiving apparatus is diagrammatically shown; 1 being a conductor, connected to one of the terminals of the induction coil 2, the other terminal being grounded. A switch, 3, is arranged in the controlling circuit of the generator (induction coil), so as to permit of the generator being rendered inoperative when the apparatus is employed as a receiver. When transmitting, it is preferred that the generator should be kept constantly in action. When the generator is thus in operation a key, 4, is employed to throw the antenna out of tune with the station to which signals are being sent. This is effected, as already said, not by making and breaking, but by short circuiting, more or less, the tuning device, which is arranged in series with the conductor 1, and preferably between the generator and the ground.

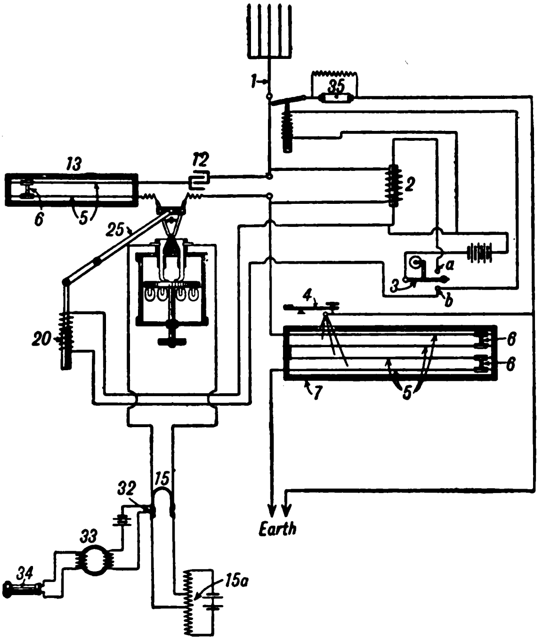

FIG. 56.

In the receiving circuit the conductor, 1, the condenser, 12, and a combined capacity and inductance forming a tuning gird, 13, are connected in series; but the condenser and combined inductance and capacity are in shunt to the spark-gap, and hence in parallel with the transmitting conductor.

For the sake of speed Fessenden uses the telephone receiver, and as this necessitates the employment of some form of detector more rapid than the ordinary coherer, the inventor has contrived an instrument somewhat on the principle of the bolometer. But in place of having a large radiating or absorbing surface in proportion to its mass, the reverse obtains, with the result that conductor losses exceed those by radiation.

The heat capacity is so small that an infinitesimal amount of energy is sufficient to heat it. These effects are obtained by a short loop of silver wire, having a diameter of 0.002 inches, and having a platinum core of 0.00006 inches in diameter, fastened to the leading-in wires, which are sealed in a glass bulb. The tip of the loop is immersed in nitric acid and the silver dissolved so as to expose the platinum. In order further to reduce loss of radiation by heat the loop is enclosed in a silver shell. The sensitiveness of the detector may be heightened by exhausting the bulb.

An earlier form of Fessenden detector consists of a silver ring resting on two knife edges of silver, and a third edge of carbon. This forms a microphonic contact, and may be employed as converter of electromagnetic waves into Morse signals. It is only necessary to add to this brief account that the numbers 32, 33, and 34 (Fig. 56) refer to the call apparatus, 32 being a coherer, 33 a transformer, and 34 a telephone bell or other alarum-like mechanism. Another coherer, 35, connects the antenna with the ground—this to protect the apparatus from possible injury by atmospheric electricity.

It will be seen from these brief details that Professor Fessenden's system is a very novel and original one. It is claimed, indeed, on its behalf* that "it differs so widely from the systems previously used that it may be considered of a different class," and such in truth it is. It differs wholly from the coherer methods employed by other investigators, although some of the contrivances characteristic of Fessenden's system appear to have been simultaneously hit upon by other experimenters. One of the most recent additions to the system is a device called by the inventor a "barretter." It is thus named because of its property of "exchanging a given amount of single frequency energy for continuous-current energy." A small column of liquid

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* The Electrical World and Engineer of New York.

is employed in place of the platinum wire already described. It may take the shape of a diaphragm with a minute hole in it, connected to a body of liquid; or a minute wire may be immersed in the liquid so as to concentrate its resistance about the point. The sensitiveness of this form is said to be much greater than that of the hot-wire barretter, as well as greater than that of the mercury coherer.

The use of this "current-operated constantly receptive receiver" in place of the voltage-operated coherer is one of the leading features of the Fessenden system. It is affirmed that by its use alone can sharp tuning be accomplished. In this respect Professor Fessenden claims to have gone further than any of his competitors in wireless telegraphy. His system, like that of Dr. de Forest, has been severely tested in the United States and has come successfully out of its trials. It is now being worked by a company, and bids fair to have an important future.

The same, indeed, may be said of most of the systems here briefly described. They are scoring fresh achievements daily, making wireless communication surer at every step, and making it more and more a necessity to the world's business and pleasure. As to the larger question of the meaning and, as we may say, the origin of the electromagnetic waves which render possible this aerial telegraphy, that is another story and can not be gone into here, although like Newton's law of gravitation, it opens up a new era in the realm of cosmic research and discovery.

THE END.

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