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AND

HERTZIAN WAVES

BY

S. R. BOTTONE

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2 WHITE HART STREET, PATERNOSTER SQUARE, LONDON

NEW YORK : 66, FIFTH AVENUE

1900

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PREFACE

In the following pages will be found an attempt to set forth, in simple language, the principles on which those phenomena known as "electric waves," "signalling through space without wires," etc., are dependent. No mathematical formulæ will be introduced; those who desire to investigate the mathematics of the subject are referred to Dr. Heinrich Hertz's classical work, *Electric Waves.* The subject will be divided into four portions, viz. a brief outline of what electricity is; a short historical sketch; a description of the phenomena themselves, with an account of the appliances needed for their production; and lastly, constructional details of the various pieces of apparatus required.

As electricians generally, with regard to their views of the nature of the medium through which the electrical disturbance takes place, are pretty equally divided into two camps, we shall not favour any particular hypothesis, but simply refer to the *space* between the body setting up the wave and that receiving it, as the *medium.*

S. R. Bottone.

Wallington, Surrey,
February 1900.

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WIRELESS TELEGRAPHY AND HERTZIAN WAVES

CHAPTER I

PRELIMINARY NOTIONS

§ 1. A CERTAIN amount of knowledge of the laws which govern electrical and magnetic actions is essential to the proper comprehension of the phenomena under consideration. Without pretending to write a treatise on electricity, we give here a brief outline of the principal facts bearing on the subject. Those readers who possess a fair acquaintance with electrical science can skip this chapter.[1]

§ 2. Electricity appears to be a vibratory motion in the ultimate molecules of bodies—of this we have no positive proof, but can judge only by analogy. The name is derived from *Elektron*, the Greek for amber, this being

[1] Those desiring fuller information are referred to the author's work, *Electricity and Magnetism.*

the substance in which electrical manifestations were first noticed. The principal phenomena which are of interest to us in connection with the study of electric wave action are—excitation, attraction, repulsion, transference, induction, and magnetic effects. When by any means we are able to set up an electrical condition in a body, that body is said to be *excited.* The means are several: for instance, friction, cleavage, change of temperature, chemical action, motion in a magnetic field, etc. As examples of these, we may take the following—

(1) If we rub briskly a stick of sealing-wax with a dry flannel, we shall find that it acquires the property of attracting light bodies, and of giving feeble sparks if the knuckle be presented to it.

(2) If a roll of brimstone be broken across the middle, the broken surfaces will generally be found to attract strongly light bodies; and many natural crystals, if riven along the line of cleavage, will exhibit similar properties.

(3) If some melted sulphur be poured into a dry egg-cup, a stick being held centrally to serve as a handle, it will be found on withdrawing the sulphur, when it has set and is cold, that the under surface is strongly electrified.

(4) If a plate of zinc and one of copper be immersed in a vessel containing dilute sulphuric acid, or any other fluid capable of acting on the zinc, and the two plates be connected together outside by a wire, a current of electricity will flow along this wire, from the copper to the zinc, and in the fluid from the zinc to the copper; and the existence of this electrical flow may be shown by appropriate means which will be described later on.

(5) If we coil a few hundred feet of cotton-covered copper wire round a bobbin, in the same manner as cotton is wound on a reel, and bring the free extremities of the wire very close to one another, and then move this bobbin sharply before the poles of a powerful horseshoe magnet across the imaginary lines of force, connecting the two poles, this motion will set up an electrical disturbance in the wire, which will be evidenced by the occurrence of bright sparks at the gap between the two ends of the wire, every time the bobbin is moved to or from the magnet.

Not all bodies allow electricity to pass freely along them. Some offer very little resistance to its passage, and hence are called *conductors.* Others, on the contrary, present great resistance to its passage, and are therefore called *non-conductors* or *insulators.* As in all probability electricity, like light and heat, is simply a vibratory motion in the ultimate particles of matter, we can well liken the electrical conductivity of certain bodies to the facility which many elastic bodies have in transmitting *sound.* For instance, nearly all the hard and elastic bodies are sonorous and transmit sound easily—a stretched steel wire, a hard dry road, etc., are examples of this; while bodies which do not enter into vibration freely, as moist clay, sawdust, cotton-wool, etc., as they cannot take up the sound vibrations, are practically non-conductors of sound. The best conductors of electricity are the metals; among the worst are dry air, resinous bodies, such as shellac, gutta-percha, indiarubber, and its congeners, also sulphur, etc. Of the metals, silver is the best conductor; while paraffin wax is one of the solid bodies which presents the highest resistance. If we express the resistance offered by silver to the passage of electricity as 1, the resistance of paraffin wax and of shellac is certainly not less than 1,500,000,000,000. It must be borne in mind, however, that there is no *perfect* conductor and no *absolute* insulator; in other words, the best conductor we have presents *some* resistance to the passage of electricity, while, on the other hand, the best insulator will permit the passage of some electricity; in the same way, as if we stuff our ears with cotton-wool, or insert sawdust between our walls, in the hopes of deadening a sound, *some* vibrations still reach our auditory nerves and some sound is still heard. A short table of the principal conductors and non-conductors, beginning with the former and ending with the latter, the indifferent ones taking the middle place, is here inserted:—

All metals, as—	Metallic salts
Silver	Linen
Copper	Alcohol
Gold	Ether
Aluminium	Dry wood
Zinc	Dry ice
Brass	Metallic oxides
Platinum	Ice at 25° cent.
Iron	Fats and oils
Nickel	Indiarubber
Lead	Gutta-percha
Antimony	Dry air
Bismuth	Wool
Graphite	Ebonite
Acids	Diamond
Metallic sulphides	Silk
Water	Glass

Wax	Amber
Sulphur	Shellac
Resin	Paraffin wax

§ 3. It will be evident from this, that if we attempted to excite a metal rod held in one hand, by rubbing it with a piece of flannel or silk, we should obtain no manifestations of electricity, because, both the metal and the hand being good conductors, what electricity was evoked by friction would flow away through the rod and the body to the earth. To obtain any evidence of the electrical disturbance set up in the metal rod, it will be necessary to "insulate"[1] it and cut it off from connection with any other conductor, by fitting to it a handle of some non-conductor such as a rod of glass or ebonite. *Then* on rubbing the metal rod the usual manifestations of electricity can be obtained. With insulators or non-conductors this precaution is not necessary, since the electricity elicited on friction cannot escape to the hand. If we excite a stick of sealing-wax by rubbing with a piece of dry flannel, we shall find on presenting it to any light bodies, such as small bits of paper, pith, or straw, that it will first attract these strongly, and after having been in contact with them for a short time will as strongly repel them. In like manner a rod of glass rubbed with silk, will first attract and then repel light bodies. If, however, in performing these experiments we place the pieces of paper on a sheet of ebonite or a pane of glass, which, being *insulators*, will prevent the pieces of paper, etc., from losing any charge they may have taken up, we shall

[1] From *insula*, an island, "cut off from all other land by the sea."

notice a very peculiar fact, namely, that a piece of paper that has been *repelled* by the excited sealing-wax, will be attracted by the excited glass, while, on the other hand, that piece of paper which has been repelled by the excited glass, will be attracted by the excited sealing-wax. From this we gather that although both the sealing-wax and the glass are electrified, yet there must be some difference in the electrification; and if we agree to call the electricity of the glass *positive*, and that of the sealing-wax *negative*, we can lay down the following law:—Bodies charged with electricity of like name repel one another, while those charged with electricity of different name attract one another; or we may put the matter more briefly, though perhaps not so exactly, by saying "like electricities repel, unlike attract."

§ 4. It must be noticed here that when by any means we set up a charge of electricity of either name in any given body, we always call forth a similar charge, but of contrary name in the body which produces excitation. Thus on rubbing the sealing-wax rod with flannel we call forth negative electricity on the sealing-wax and positive on the flannel, and in the case of glass rubbed with silk, the former becomes positively and the latter negatively electrified.

§ 5. By *transference* is meant the actual passage of electricity from one charged body to another. It can only occur between bodies that are conductors. When transference occurs *suddenly*, it is generally spoken of as a "*discharge*"; when it is effected slowly and with more continuity it is termed a "*flow*," or a *current*. When it is desired to make use of a *current*, it is usual to employ *wire* to effect the connection between the positive and negative bodies, as the wire, being a good conductor, and presenting but little resistance, wastes but little electric energy. In the last section we pointed out, that whenever we set up an electrical condition (either positive or negative) in one body, we also produce an opposite condition in another body: so, for the sake of illustrating what relation the two phenomena of excitation and transference bear to one another, we may liken excitation to the pumping up of water from a pond, into a vessel standing at a higher level. The vessel will then be positive, and the pond negative. We have not produced any water, but simply altered its level. If now we knock the bottom out of the vessel, so that the water, finding no appreciable resistance to its passage, suddenly returns to its original level, we have an example of "discharge" or rapid transfer; but if instead we open a small hole in the vessel, the contained water again finds its level, but slowly, as a fine stream; and this exemplifies an electrical current. In every case, then, transference, whether it take the form of a sudden discharge, or of the slower and steadier current, always indicates that a levelling up of a difference in electrical condition is taking place. There is one point which it is important to notice with regard to the more sudden forms of discharge, and that is, that just in the same way as when, if we raise a body of water from a pond to some height, and then let it suddenly fall back again, the water does not immediately come to a dead level, but rebounds, splashing up again to some extent, producing surging waves, which only gradually die away, so a sudden electrical discharge does not immediately result in a dead electrical level, but sets up electrical "surgings," of infinitesimally short duration, as compared to those set up in the case of water, nevertheless not only capable of measurement, but also endued with far-reaching powers.

§ 6. The phenomenon of *induction* is the one to which particular attention must be directed, with a view to obtaining a clear insight into the principles which underlie electric wave signalling.

The French name for induction is *influence,* and this really gives us a very fair idea of what the effect is. We may define induction as being "the action which an *electrified insulated body* has upon all other bodies." This action (like all others dependent on radiating forces) will diminish inversely as the square of the distance. The inducing body must be insulated from the body induced, otherwise transference or "discharge" will take place instead of induction. A medium of some kind *must* exist between the inducer and the induced; but provided it be a non-conductor sufficiently resistant to prevent direct transference, induction will take place. We are not able to produce a *perfect* vacuum; but the highest vacuum we can produce, or of which we have any cognizance, permits inductive effects to take place through it. From our knowledge of other phenomena, it is, however, highly probable, that were it possible to produce a *perfect vacuum,* id est, a space with *nothing* in it, induction would not take place across that space. Hence, as induction is found to take place across every known space, the modern theory is that a subtle, weightless, and highly elastic medium, to which the name of *ether* has been given, pervades *all space.* Now for facts. If we take a large metal ball, and suspend it by a silken thread, we can charge it with positive electricity, either from a rubbed glass rod, or the positive conductor of any electrical machine. If now we bring near it (not touching) another insulated brass ball, we shall find that this second brass ball acquires and retains, so long as it is near the first one, certain electrical properties. In the first place, we shall notice that the surface of the second ball which is nearer the first or charged ball, is negatively electrified; while the further side is in a positive condition. This can be shown even more strikingly by using *two* suspended balls instead of only one for the second ball. In this case the two balls are kept together by their silken suspensions while approaching the charged ball, and in a line with the direction of approach. If they now be separated before they are withdrawn from the influence of the charged ball, it will be found, on testing, that the ball that was nearer the charged ball will have acquired a negative charge, while the further ball will be charged positively. No matter at what distance the charged or inducing ball shall be placed from the others, this effect will always take place provided no good conductors intervene; but of course as the distance increases, so the effect rapidly diminishes. What is this action? Does it really take place without any intermediary? A little consideration will show that *action at a distance* without any medium to convey that action is a physical impossibility. The air, we know, is a non-conductor, so there can be no transference; and even if it permitted the slow passage of the charge from the inducer to the induced, this would not account for the opposite condition of the nearer surface of the induced body. Clearly then the air or other surrounding medium must play a part, and a very important part, in this action. It will be remembered that we have noticed that "like electricities repel, and unlike attract." Now if we have a positively charged insulated body, it acts upon the molecules of the air or other surrounding medium, polarizing them, and causing them to present their negative faces to the charged body (by the attractive effect of the positive for the negative), while the positive faces are turned the opposite way under the repulsive influence of the positive upon positive. No discharge can take place, since, as we have seen, air is a non-conductor, but each molecule of air in like manner puts a strain on its neighbour, until the surface of the induced body is reached; forming as it were a chain (or a number of chains) of polarized air molecules, reaching from the inducer to the induced body. This strain in its turn puts a stress upon the conductor, which constitutes the induced body, and *its* molecules can part with their strain, being conductors; the final effect is that the face of the induced body becomes negatively charged, the positive electricity flowing to the opposite extremity, and this condition of things obtains as long as the charged inducing body is in its vicinity. As soon as the charged body is removed, or in any way discharged, the strain on the medium, being relieved, things return (after a few surges, so rapid as to be almost imperceptible except by the most delicate appliances) to their original condition. Of course if the induced body consists of a number of parts originally in contact but afterwards separated from one another, before the removal of the inducing body, then the nearer parts will be in an opposite electrical condition to that of the inducer, while the further portions will be found charged with electricity of like name. And this latter statement holds good whether the inducing body be charged negatively or positively.

§ 7. It is not within our province here to give an account of the many pieces of apparatus or divers applications to which this property of electrical induction can be put; we wish, however, to emphasize in the reader's mind, that the presence of a charged body immediately reacts on all surrounding bodies, by putting a strain on the molecules of the circumambient medium, which strain in its turn reacts on the molecules of the bodies subjected to its influence.

§ 8. Another property of electricity which must be noted in this connection is that every current, nay, every manifestation of electricity, is accompanied by magnetic effects. In point of fact we may lay down broadly that magnetism is but one aspect of electricity; and that whenever a current of electricity is set up, magnetic conditions exist at right angles to the direction of flow. It is easy to verify this statement. A piece of copper wire in its ordinary condition has no attractive influence on iron filings or magnetic bodies; the same wire when traversed by a current will be found to attract iron filings and to behave magnetically. If we coil some insulated wire round a small ruler or pencil so as to produce a long helix (from which the pencil, etc., may be afterwards removed), a current being sent through this helix will impart to it strong magnetic properties, precisely similar to those of a bar magnet. This magnetism lasts as long as the flow of electricity is stronger in proportion as the current is stronger, and ceases with its cessation. Lastly, if we place some iron filings in a tube around which we have loosely coiled some insulated copper wire, on sending a current through the wire the iron filings will be seen to arrange themselves in lines at right angles to the flow of the current, while the entire tube under the influence of the current will exhibit all the properties of a magnet.

The main facts we have to bear in mind are, that electricity appears to be a species of wave motion in the molecules of bodies; that we have many means of setting up this wave motion. That not all bodies convey this wave motion equally well; those that transmit it freely are called conductors; those that present great resistance are termed insulators, or non-conductors; that induction is the result of strain or stress put upon the molecules of the medium by the presence of a charged (rapidly vibrating) body, which strain or stress sets up a similar vibrating motion (electrified condition) in bodies in contact with the medium; and that this strain or stress is always accompanied by magnetic effects, and often affects largely the conductivity of the bodies themselves.

CHAPTER II

HISTORICAL CONSIDERATIONS

§ 9. THE action of a charged conductor on other bodies in its vicinity was known in the early part of the eighteenth century; the Leyden jar was described by Kleist, Cuneus, and Muschenbroeck about 1727, and from the notices given by several experimenters of that period there is no doubt that the phenomenon of the lateral discharge, which is in itself an evidence of the influence which a disturbance in the electrical condition of a given body produces on that of the surrounding bodies, was also well known. We have an illustration of the apparatus required to produce this effect in a work entitled *An Essay on Electricity*, by Geo. Adams, published in 1780, at Fig. 66, plate 4, where a series of conductors not touching one another, and at a certain distance from a charged Leyden jar, are shown to allow a spark to pass between them, at the instant that the jar is being discharged by a separate discharging rod. How far this disturbing effect influenced the surrounding medium does not appear to have occupied the attention of these early experimenters, and although the possibility of producing inductive effects by means of the sudden discharge of so-called "static" charges has been shown experimentally by Matteucci, yet the bearing of this important fact on the problem of transmitting a signal through space not connected by any other medium but the intervening air does not appear to have struck any one of them. In 1853 J. B. Lindsay proved the possibility of transmitting a message across water at points 500 yards apart, without continuous wires; and he patented this invention in 1854. But this can hardly be classed with the phenomena which we now understand by "wireless telegraphy"; and even the results obtained by Mr. Preece between 1884 and 1894, and that culminated in his induction system, which consists virtually in the inductive effect of a wire carrying a momentary current of electricity on a similar wire at a distance from the first, but parallel to it, has but little affinity with the methods at present adopted. Riess and Henry, in 1842, had pointed out that the discharge of a Leyden jar was not a sudden and complete levelling up of the difference of potential between the coatings of the jar, but rather partook of the nature of a principal discharge in one direction, and then a series of surgings backwards and forwards, until equilibrium was obtained. Feddersen, Paalzow, and others, notably Oliver Lodge, proved experimentally the existence of these surging waves during the discharge; and showed that as the resistance of the circuit increases, the number of these alternating discharges decreases, but at the same time their duration is greater. It was also known to Henry the great distance to which the inductive effect of these surging discharges could extend, for he calls attention to the fact that a single spark of about an inch in length from the prime conductor of a machine passing to the end of a circuit of wire placed in an upper room, produced an induction sufficiently powerful to magnetize needles in a parallel circuit of iron placed in the cellar beneath, at a perpendicular distance of 30 feet, with two floors and ceilings, each 14 inches thick, intervening. This discovery of Henry's, important as it was, lay dead and without practical application, until the attention of Dr. Heinrich Hertz, of Carlsruhe and Bonn, was directed to this subject, in consequence of a prize which had been offered by the Berlin Academy of Science for the elucidation of the relation which exists between dielectric polarization and electro-magnetic induction. By means of a series of masterly experiments, following upon careful reasoning, Dr. Hertz, between the years 1886 and 1891, placed our knowledge of these electric waves and their effects on surrounding bodies on so firm a basis as to have enabled us to put them to practical use. The author has ever been of opinion that no knowledge is so easily acquired or can be so thoroughly retained, as that following actual experiment; and for that reason he reproduces here illustrations of the principal experiments leading up to our present knowledge of electric waves, and strongly recommends those of his readers who have not hitherto performed these experiments, to make practical acquaintance with them now, as by this means they will obtain a grasp of the subject that no amount of mere book knowledge will ever give them.

§ 10. The phenomenon of the *lateral discharge,* as illustrated in George Adams' work, is easily demonstrated by apparatus arranged as shown in our Fig. 1. A charged

Leyden jar is placed on an insulating slab (a sheet of glass or ebonite will do), and in close proximity to it and each other, but not actually touching, are two elongated conductors, the last of which may be connected to earth. On discharging the jar by means of the discharging rod, and more especially if a chain intervene between the outer coating of the jar and the discharging-rod, a bright spark will be seen to pass along the gaps between the two con-

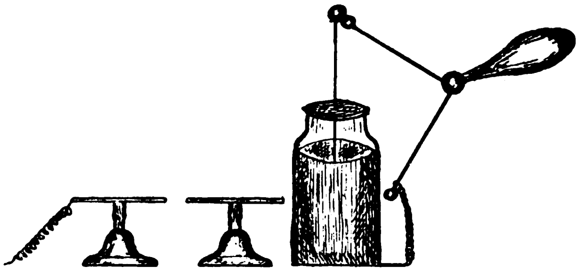

Fig. 1. Lateral Discharge.

ductors, and also between the outer coating of the Leyden jar, at the instant that the jar is discharged.

Another mode of producing an electrical disturbance in a neighbouring body and of giving evidence of this disturbance, is that devised by Matteucci; in which a disc of glass about one foot in diameter is supported on an insulating stand in a vertical position. On the face of this disc is coiled, from the centre to the circumference, a spiral of well insulated copper wire, starting from a perforation in the centre of the plate and terminating in its circumference. Each turn of the wire, besides being

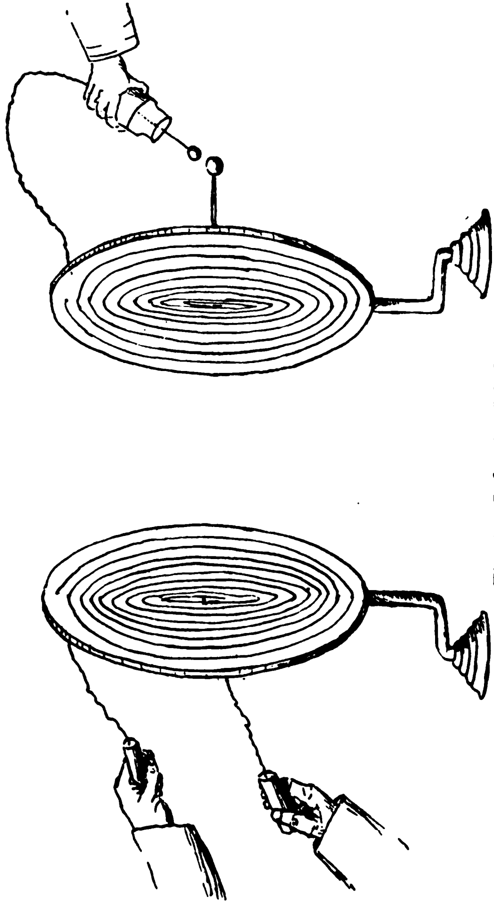

Fig. 2. Induction Discharge.

insulated by its silken covering, is imbedded in shellac, applied in the form of thick varnish, in many coats; each being allowed to dry before the next is applied. The size of this wire may be No. 20 or 22 B.W.G. The extremities of this wire are brought out at the back of the disc, and made to terminate in brass balls. A precisely similar disc, wound with finer wire (No. 34 or 36), terminating in brass handles, is placed facing the first disc. On discharging a Leyden jar through the coarse spirals, an experimenter, holding the handles connected to the fine wire spirals, receives a distinct shock, which is greater or less according to whether the discs are near together, or far apart. Fig. 2 illustrates this apparatus, and the mode of using it. Preece's method of telegraphing without wires is very similar to this, and depends, like it, upon the induction set up by a momentary current along a wire through the air, or other intervening dielectric and another wire lying parallel to it, but at a considerable distance. The nature of the apparatus to be used is shown in our Fig. 3, in which *A* represents a battery or other source of electricity; *B*, a tapping-key, or similar means of making or breaking contact rapidly; while *C*, *C′*, and *C″* constitute a triangle formed of a length of wire suspended horizontally at the points *P P′*. It is evident that on closing the key *B* and releasing it, a momentary current will flow along the triangle. If facing this triangle, at a distance not exceeding the length of the wire *C* between *P P′*, there be a similar wire triangle *D D′ D″* connected to a galvanometer, or any other current detector, each time that contact be made or broken at *B*, the induction set up through the medium will induce a momentary current in the opposite direction along the wire *D*, and give evidence of its presence by a deflection of the needle of the galvanometer *G*. This is illustrated in our Fig. 3. As it is not very easy to perform an experiment demonstrating satisfactorily the oscillating nature of the Leyden jar discharge, we do not illustrate here the means by which this can be effected; but refer

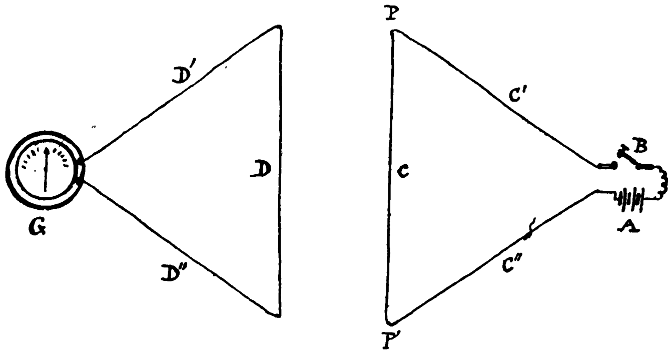

Fig. 3. Preece's system.

our readers to the very clear explanation of this subject given under the heading of "The discharge of a Leyden jar," in Oliver Lodge's work, *Modern Views of Electricity*. Here we need only mention that it is in our power to modify the rate of the oscillations which take place during the discharge by altering the size of the jar, and that we can in like manner control the duration of these oscillations by inserting better or worse conductors in circuit.

§ 11. The fact that iron-filings enclosed in a tube would take up a set position on the approach of a magnet or of a magnetic field, set up by a wire carrying a current in its proximity, has been known for nearly a century, but the discovery of the power which a static discharge has of producing a somewhat similar effect (accompanied by a great increase in conductivity) in metal-filings, and, in fact, in almost any small metallic bodies in close proximity to each other, though, of course, at a distance from the discharging body, is of recent date, and is due to M. Branly and Sig. Righi. Advantage was taken of this by Chunder Bose to effect the explosion of powder and the ringing of a bell by a local current at the time that the resistance of the filings, etc., enclosed in the tube was lowered by the impact of the electric waves.

Branly has quite recently shown that a tube containing a number of small, well-polished balls, similar to bicycle bearing-balls, has its resistance greatly lowered on the reception of these electric waves. To Oliver Lodge is due the merit of the discovery that this newly imparted conductivity is impaired if the particles, be they filings, small metal balls, or simply metallic surfaces in loose contact, be mechanically agitated; or in other words, that the electric agitation appears to cause the particles to cohere, and thus allow the electric current to flow freely, whereas mechanical agitation seems to separate the particles, or "decohere" them, thus rendering the passage of the current more difficult. To show the effect of a magnetic field on iron-filings, it will be sufficient to procure a piece of glass tube about 3″ long and a ½″ bore, fitted with a cork at each end. Having nearly fitted the tube with rather coarse iron filings, a helix of about half-a-dozen turns of No. 20 cotton-covered wire is wound tightly round the extremity of the tube. If now the tube be laid flat on the table, and contact be made between the free ends of the helix and the poles of a single bichromate battery, or a dry cell, at the instant of making contact the filings will be seen to take up an end to end position. The same effect will result if, instead of using the helix and battery, the pole of a magnet be drawn over the tube longitudinally. To show the effect of a static discharge taking place at some distance from the tube containing filings, the following simple experiment may be made. A short piece of glass tube is fitted as before with a cork at each end. The size of this tube may be $1\frac{1}{2}''$ long by $\frac{3}{8}''$ bore. Through the centre of each cork is pushed a piece of No. 16 copper wire, bared and cleaned. The tube is then nearly filled with iron-filings,[1] the corks put in and the wires adjusted so as to nearly, but not quite, touch each other in the tube. This tube, which we shall henceforth call a "coherer," is now attached in a horizontal position to one terminal of an ordinary electric bell by one of the protruding wires. The bell is connected to one pole of a battery by its free terminal, the other pole of the battery being placed in contact with the free wire of the coherer. The wires, passing through the tube of the coherer, are now approached to each other by gently pushing through the cork, until the bell just rings, and then as gently separated, until the bell *just does not* ring. Things being thus arranged, a charged Leyden jar

[1] These filings must be perfectly clean and free from grease.

of about one pint capacity is brought within six or eight inches of the coherer, and discharged at this distance by means of an ordinary discharging-rod. The electric waves set up by the discharge of the jar will be found sufficient to cause the particles in the tube to cohere, thus allowing

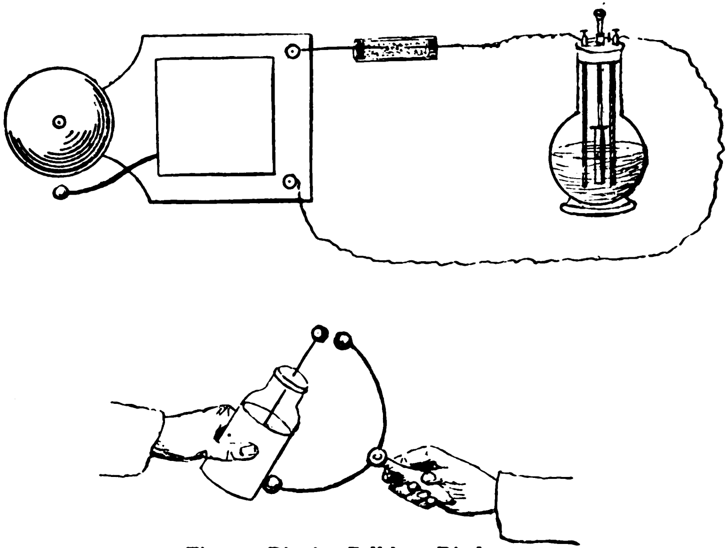

Fig. 4. Ringing Bell by a Discharge.

the current to pass from the bottom to the bell, which will ring and continue ringing until the filings are "decohered" by tapping the tube. Fig. 4 gives a good idea of the arrangement required.

§ 12. The importance of having the "receiver" syntonized or "put in tune" with the vibration rate of the electric waves set up by the transmitter, was early recognized by Hertz (*Sitzungsber. d. Berlin. Akadem.*, Nov. 10, 1887). Oliver Lodge (1890) described a form of receiver consisting simply of two long copper rods, suitably supported; and these may be taken as the prototypes of the "wings" or wave collectors of the more modern forms of electric wave telegraphs or signalling appliances. Robinson at about the same time devised an instrument, which he designated the "electric harp," consisting of about fifty strips of tinfoil, each about 12″ in length and ⅜″ wide, fastened down in parallel rows on a sheet of glass by means of any well-insulating varnish. The edges of the strips, at both ends of the plate, are connected together by a long strip of tinfoil, and then the strips are separated by a diagonal razor-cut, so as to divide them into lengths varying from ⅜″ to 12″. Owing to the varying capacities of these different lengths of the tinfoil strips, Robinson's "harp" responds to vibrations extending over a very considerable range of wave lengths, as is shown by the production of minute sparks along the gaps produced by the razor-cut, on the discharge of almost any charged body in its vicinity; and the author has taken advantage of this property (of varying resonance by varying the length of receivers) to perfect a very delicate form of coherer, which will be described in the sections dedicated to constructional details. To Hertz we are indebted for our knowledge of the capability of these electric waves being reflected like those of light and of sound (1888); and Oliver Lodge (1892) has arranged a simple form of parabolic mirror, with suitable vibrator and receiver, to prove the possibility of emitting and receiving a parallel beam of these Hertzian waves by reflection. To both Oliver Lodge and Hertz are due our cognizance of the fact that good conductors (metals, etc.) interposed in the path of these waves, annul their inductive influence, while insulators oppose little or no obstruction.

Quite recently (January 1900), Sig. Emilio Guarini, of Trani, has shown that it is possible to extend greatly the useful range of the Marconi form of receiver, by using in conjunction with it a peculiar form of "relay," or, as Guarini calls it, "repeater." This would appear to consist essentially in a very delicate form of relay (see § 30, Fig. 30), in conjunction with a coherer (§ 18, Fig. 8), which, on receiving the impact of the wave or waves from the transmitter, automatically closes the circuit with another coil battery and transmitter, and thus retransmits the message to a greater distance.

§ 13. We gather then, from the foregoing *résumé*, that to no one man alone is due the merit of having placed a new means of signalling at a distance within our grasp; but, rather, that the intelligent application of isolated discoveries by such men as Nollet, Faraday, Henry, Righi, Preece, Bezold, Hertz, Branly and Lodge, has enabled Marconi to perfect that system now known as "Wireless Telegraphy."

CHAPTER III

ON THE HERTZIAN WAVES

§ 14. THE subject under consideration has much in common with ordinary wave motion, as we see it exemplified in the ripples on the surface of a pond, or become cognizant of it as **sound**, a form of wave motion in the air, or other bodies. In order to render the matter as clear as possible, attention will be first directed to those waves with which we are most familiar, and thence, by analogy, we will pass on to other manifestations of wave motion, which, not being so easily grasped by the eye or the ear, are not so readily recognized as belonging to the same category.

§ 15. If we throw a stone into a pool of water, the motion of the stone translates itself into a wave movement on the surface of the water, and this motion is propagated in all directions from the place at which the water was struck, in ringlike waves, or ripples, which decrease in height until the undulation reaches the edges of the pool, where, as the material against which the waves strike is incapable of taking up the **same kind** of wave or vibration, the effect apparently ceases. These waves are, however, capable of doing some work, as is rendered evident by the bobbing up and down of a piece of cork, of leaves, or any other light substances which chance to be floating on the surface of the water. If, as at the seaside, these waves happen to strike against a material which is capable, even in a small degree, of taking up this undulatory motion, such as the shifting sand, the waves expend their energy in rippling up the sand, as all familiar with the seashore will have noticed when walking on the sands and following the retreating tide. These waves are very sluggish, and take so long a time to travel, that the eye can easily follow their motion and readily count how many waves follow one another per second, or per minute. It is in our power, using a more elastic medium than water, to set up other waves, which follow one another in very much more rapid succession. For instance, if a gong be struck, the blow causes it to vibrate, and in turn to set up waves in the surrounding air, and as we are provided with a beautifully delicate arrangement of nerves in our ears, which nerves are capable of taking up these waves, and vibrating in unison with them, provided they be not fewer than sixteen nor more than 44,000 per second, we become cognizant of a something which we call **sound**, which is the work done by the impact of these waves on the tympanum of our ears, and thence transmitted by suitable nerves to the brain. Of the actual energy or power to do work, which even these comparatively speaking sluggish sound-waves possess, provided they impinge upon a body or bodies capable of entering into the *same rate of vibration*, the following examples may be given:—A singer with a powerful voice, if he or she sing loudly near a wine-glass a note corresponding in pitch to the vibration rate or note given by the said wine-glass, will cause that glass to enter into vibration; and in many cases the waves set up in the glass will be so violent as to cause the glass to shiver to pieces. But in order to succeed with this experiment it is absolutely necessary that the pitch, or vibration rate of the glass and that of the note sung by the operator, should be precisely the same, or, in other words, that they should be in tune with one another.

Some time ago one of the rocking-stones at Stonehenge was known to be poised in a position of tottering equilibrium, and those to whose care it was entrusted, had noticed that it vibrated to low notes, and were accustomed consequently to warn visitors not to make sudden loud noises in the vicinity. A certain lieutenant, disregarding this injunction, or perhaps desirous of testing experimentally the truth of the statement, discharged his pistol at some little distance from the rocking-stone, with the result that the huge mass came to the ground, and cost the lieutenant £500 to replace it.

If a flame of hydrogen gas, or even of ordinary coal gas, be adjusted so as to be just on the point of roaring, it lengthens out considerably, not giving much light. While in this condition, if a long tube be placed vertically over it, it will be found to give a musical note, owing to the rapid vibration set up by the current of heated air rushing up the tube. If a similar note be now sounded with an organ-pipe or other instrument in the vicinity of the singing flame, the two sets of sound waves meeting each other cause the flame to bob down, and sometimes to be entirely extinguished. It must be borne in mind that these waves, although recurring with much greater frequency than those which we see on the surface of water, are still, comparatively speaking, slow; the most rapid of which the human ear can take cognizance, being at the rate of about 44,000 complete vibrations per second.

But if we pass from sound to that rapid vibratory motion which we shall call **heat**, we find that we can no longer measure the waves by thousands per second, nor yet by millions, but that, that degree of heat which corresponds to bright red, requires the atoms of the body giving out this heat to vibrate no less than 400 billion times per second! Except by comparison, the mind is unable to grasp the meaning of these figures, but it will assist matters if we suppose that a man were to set himself to count, at the rate of 240 a minute, one, two, three, four, etc., without stopping night or day until he had counted 1,000,000. This would take him just upon three days and three nights; and since our billion is one million millions, it follows that our indefatigable counter would have to go on counting for about 8000 years before he would have completed his task of counting *only one billion.* And yet, whenever we see a glowing coal, or anything else that is at the temperature which we usually call "red hot," waves are being given out by that body at the rate of about 400 billions per second.

Now the particular waves to which our attention is directed, and which are known as Hertz waves (from the name of the scientific man who devoted much time to the elucidation of their properties), do not undulate quite so rapidly as heat waves; in fact, as far as we have been able to measure them, their vibrations take place at the rate of about 230 millions per second. These Hertz waves are set up by any sudden electric discharge, such as that of a Leyden jar, an induction coil, a lightning flash, or even a mere electric spark, such as can be got from an electric gas-lighter. As in the case of sound, in order that these waves may become evident to our senses, they must be received by something which is capable of taking up the same rate of vibration, or, as we should say in the case of sound, "in tune" with them.

Very similar, but not precisely identical, effects, are produced when a momentary current is caused to pass along a wire, upon another similar wire, quite separated from it, but parallel to it, and of the same length. Of this peculiar property advantage has been taken by Mr. Preece in his earlier attempts to transmit messages across space. The apparatus employed by him in 1885, as shown in Fig. 5, consisted virtually of two triangles of insulated wire, one at the sending end, and the other at the receiving, the former connected to any source of electricity whereby short, powerful, intermittent currents could be made to complete their circuit along the triangle, as, for example, a number of cells and a tapping-key, while the receiving triangle was connected to a very delicate galvanometer, or, better still, to a sensitive telephone. By means of the induction wave set up in the triangle *B* under the influence of the momentary current or currents sent through *A*, it is found possible to transmit intelligible signals to considerable distances, and even through a great thickness of solid earth. Owing, however, to the fact that the best results are obtainable only when the bases of the triangles are of equal lengths, and not separated from each other by a distance greater than this length, it is evident that the application of this method of signalling through space, though possibly of service under some circumstances, must be limited. For example, if it were desired to communi-

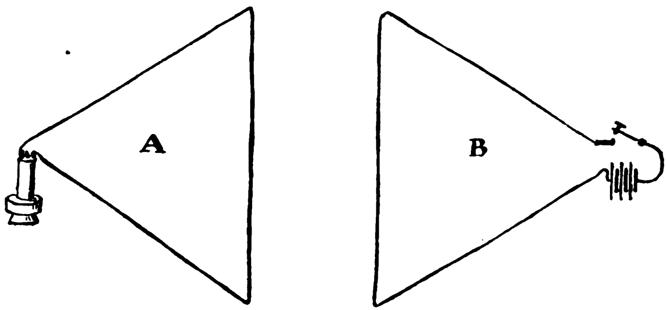

Fig. 5. Preece system, another form.

cate in this manner between Dover and Calais, as the distance is about twenty-two miles, it would be necessary to stretch a line on the Dover side twenty-two miles long, and another precisely similar, and parallel to it, on the Calais shore.

§ 16. In 1876, Prof. Oliver Lodge, and then again, in 1888, the late Dr. Hertz of Carlsruhe and Herr von Bezold showed experimentally that the discharge of a Leyden jar is not such a simple process as it was long believed to be, a mere instantaneous levelling up of the difference of potential between the two coatings of the jar, but rather that it took the form of a series of surging waves (inconceivably rapid), oscillating until balance was obtained. Moreover, he proved that these surging waves were capable of setting up similar waves in bodies in their vicinity, *provided these bodies were of such electrical capacity as to be able to vibrate electrically, at the same rate as the body which emitted them.* This noticeable fact has its exact parallel in the case of *sound;* if a given tuning-fork be caused to vibrate in the proximity of a second tuning-fork of precisely the same pitch; when, under the influence of the sound wave propagated by the air, this second tuning-fork enters into vibration, and emits a musical note. In both these experiments exact similarity in the vibration rate, or "syntony," is a necessary condition to success. One of the simplest methods of showing this effect of a sudden discharge is that originally employed by Dr. Hertz and slightly modified by Prof. Lodge. It consists in arranging two precisely similar Leyden jars, as shown at Fig. 6; one, *A*, in connection with any source of electricity of high E.M.F. and furnished with a discharging circuit *A′*, and the other jar *B*, also furnished with a similar circuit *B′*, along which, at *C*, is placed a sliding piece, that by being moved backwards or forwards enables the second circuit to be syntonized or "tuned" to exactly the same vibration rate as the first. Besides this "syntonizing" or "tuning" arrangement, the jar *B* is fitted with a strip of tinfoil *D*, which, starting from the inner coating of the jar, passes over the mouth, and reaches down very nearly to the edge of the outer coating. Now if we charge the first jar with electricity, and then discharge it in the vicinity of the second jar, although the second jar be entirely separated from the first one, we shall find that at the instant that the first jar is discharged a minute brilliant spark is visible on the second jar, between the edge of the strips coming from the inner coating and the outer coating of the jar. This effect, like that of one tuning-fork setting another in vibration, or one glass causing another to ring, is due

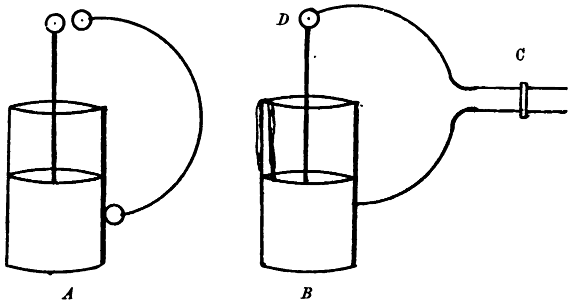

Fig. 6. Syntonic Jars.

entirely to the surging waves set up during the discharge of the first jar disturbing the electrical condition of the second jar and causing similar but feebler waves to respond to them. Owing to the small capacity of these jars, the waves are necessarily very short and their duration extremely limited; hence the spark, though brilliant, is excessively minute. By increasing the size of the jars, and yet more by removing the coatings farther from one another, it was found possible to intensify these effects largely. By making the two coatings of the jar quite separate from one another, and of considerable size, it is evident that we can influence a larger volume of the surrounding medium, and thus produce these effects at longer distances. This constitutes the original and typical form of Dr. Hertz's wave-starter, or oscillator, as he named it. The enthusiastic amateur can easily and cheaply construct for himself such an apparatus, by procuring two sheets of stout zinc about 16″ square, and mounting these in a light wooden frame; at the centre of the edge of each plate a little zinc strap should be soldered, into which is to be inserted a 4″ length of brass wire about $\frac{1}{8}$″ in diameter, bent at right angles. The free end of this brass wire or rod is fitted with a brass ball of about 1″ in diameter. The zinc straps and the brass balls are so arranged that when the plates stand in a line with one another the balls shall face each other. The zinc plates with their frames should each be fitted with two ebonite feet, raising them off the level about 2″ or 2$\frac{1}{2}$″. This very simple form of oscillator, if placed on a table with the plates in line with one another, and the balls separated by a distance of from $\frac{1}{4}$″ to 1″ according to circumstances, will, when connected to the inner and outer coatings of a Leyden jar, which is kept charged by means of a Wimshurst or an induction coil, set up powerful electrical disturbances or Hertz waves in the surrounding medium, at the instant that the discharge takes place between the balls of the "oscillator" plates. To take up and render evident these waves, the very simple form of receiver known as Hertz's Resonator is well adapted. This consists in a rod of $\frac{1}{4}$″ brass bent into shape of a nearly complete circle, 18″ in

D

diameter. At the gap the two ends of the incomplete ring should terminate in two 1″ brass balls, capable of adjustment so as to allow the proper sparking distance to be obtained. "Tuning" is secured by adding to this ring metallic extensions or "wings," placed on its sides either in permanent contact, or merely temporarily in juxtaposition. Fig. 7 gives a general idea of the disposition of the parts required to secure this result. *A* is the Leyden jar, *B* and *B′* the oscillator, *C* and *C′* the balls between which the discharges of the Leyden jar take place. The waves set up by these discharges, on impinging on the ring *D*, set up sympathetic surges in it, and these overflow at the spark-gap between the two balls *E* and *E′*. The addition of the extensions or wings *F F′* (more especially if one of these be "earthed") greatly conduces to the success of these results. The apparatus just described, of the dimensions given above, will show a minute but brilliant spark between the balls of the receiver *D*, when placed eight or ten feet from the oscillator *B B′*, even when a brick wall intervenes, if a sharp clean discharge be caused to take place from the jar *A*, between the balls *C* and *C′*. This discharge need not exceed for this purpose ¼″ in length (say roughly 12,000 volts), but it must be *clean* and *snappy*, not brushing; hence it is well to insulate carefully the oscillator plates *B B′*. Many other forms of emitters, oscillators, and of receivers or resonators have been devised by experimenters.

§ 17. We will now pass on to consider a peculiar effect which takes place in the receiver, at the point where, and at the time when, the echoing spark set up by the wave flows. This peculiar effect is known as *coherence*. Let us suppose that we place there two balls practically in contact. We shall find that the mere pressure-contact is not perfect, and that either very minute particles of dust, or that a thin layer of air intervenes between the two. That this actually occurs can be well seen by placing an ordinary needle flat on the surface of water, when although steel is nearly eight times as heavy as water,

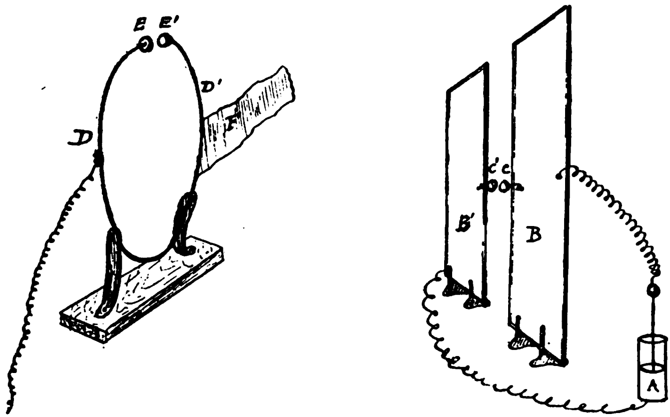

Fig. 7. Hertz's Apparatus.

yet the needle floats, sustained by the thin stratum of air which surrounds it. Now if we test the resistance presented to the passage of a current of electricity by those two balls thus *apparently* in contact, we shall find that it is considerable; but after having caused a Hertz wave to strike the balls, and set up its minute echoing spark, the resistance to the passage of a current of electricity falls enormously, and *remains permanently* *lowered*, unless the balls be disturbed, either by actual separation, by a jar, or other jolting. It must be noted, that after the passage of the little spark set up by the surging Hertz waves, the two balls do *actually cohere* slightly, with a measurable force, but that sound waves, or other mechanical vibration, will break down this coherence. Had we to depend solely on the observation of the minute sparks set up by the Hertzian waves in the receiver, as a method of transmitting messages to a distance without wires, it is to be feared that such a system of wireless telegraphy would not have satisfied our requirements. But, fortunately, this peculiar property of *coherence* enables us to make use of the difference of resistance set up, to allow a current of electricity to pass from a local battery along the cohering points and thus ring a bell, deflect a needle, or otherwise make clearly evident, either to the eye or to the ear, of the advent of the Hertz wave sent by the transmitter (§ 9). It has long been a well-known fact, that if a current of electricity be sent round a tube containing iron-filings, the filings which originally appeared as a confused mass, without order, or as children say were all "higgledy-piggledy," immediately take up a symmetrical position, the individual particles arranging themselves in lines transversely to the direction of the flow of the current. This effect may be likened to the result produced on a company of soldiers standing "at ease" when the officer gives the command, "Fall in." This effect is due to the fact that every manifestation of electricity is accompanied by a magnetic effect; in fact, that magnetism is simply one aspect of electricity, so that an electric current or wave is always evincing magnetism at *right angles* to its own direction. Hence the current passing *across* the tube magnetizes the contained filings in the *direction of the length of the tube*, thus causing them to adhere together end to end. The same thing, or something very similar, occurs, if a tube, containing metallic filings, and furnished with projecting wires, be placed in the path of the Hertzian waves set up by a transmitter. The effect is not so distinctly visible to the eye as when a current is passing actually over the tube, but still *coherence* does take place, and the resistance of the filings to the passage of a current is greatly lowered. According to Prof. Oliver Lodge, who experimented with an 8″ tube containing iron-filings, he found that the resistance fell from 2500 ohms before, to 2000 ohms after, the reception of the wave by the tube; and in the most modern arrangement, with suitable filings, the difference in conductivity is much more marked. It follows from this, that if a battery be connected up in series with such a tube, and with a current detector, the resistance presented by the filings (in their ordinary conditions) may be so great as to prevent sufficient current passing to the detector, to give any sensible indication of its flow; whereas, immediately on receiving the impact of an electric wave, the resulting coherence so greatly lowers the resistance of the filings, that the current flows freely, and gives a very sensible deflection on the current detector, or galvanometer. Such an arrangement, of a tube with projecting wires and containing filings, is called a "coherer." A very simple form of coherer, known as the "Branly Tube," is illustrated at Fig. 8.

§ 18. We can now profitably consider how the practical application of the knowledge of the facts we have just studied will assist us in solving the problem of transmitting a signal without the aid of wires, and depending only on the medium around us. Let us summarize these facts—(1) We can set up electrical waves of different lengths, in the medium, by means of *clean, sharp* discharges, the length and the velocity of these waves depending on the capacity of the bodies between which

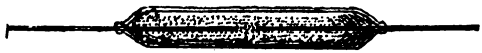

Fig. 8. The Branly Tube.

the discharges take place and the resistance in the circuit. (2) These waves travel with an enormous velocity (about 200,000 miles per second), and to very great distances, their intensity becoming less as the distance becomes greater. (3) These waves, on striking other bodies, are able to set up electrical disturbance in these other bodies, provided these latter are capable of vibrating at the same rate, or, as a musician would say, are "in tune" with the body emitting the waves. This electrical disturbance manifests itself by the production of sparks responding to those of the emitter, and also by lowering the electrical resistance between points in the receiving body which are not in absolute contact, but altering their molecular condition. (4) That we can take advantage of this lowered resistance to allow a current of electricity, too feeble to overcome the resistance of the imperfect contacts, to pass and to give sensible evidence of its flow, *at the time when the* waves propagated by the emitter strike the receiving body. So far good, but there is this disadvantage, that when once the receiving body has been struck by the wave, the new condition of coherence, by means of which it allows an extraneous current of electricity to pass, is maintained, so that a current would continuously flow, thus doing away with the power of transmitting any intelligible signals. Fortunately, however, it has been found that the slightest agitation, a slight tap, or any other purely mechanical vibration, or even a loud noise in its vicinity, is sufficient to destroy this coherence, and to prevent the local current (which is used to give the signal) from passing.

In one of the most common forms of receiver, we have an ordinary electric bell, which, as all are aware, will ring when an electric current of suitable strength is caused to flow round its magnet coils. In the path between this bell and the battery a *coherer* is placed. This coherer, in its ordinary state, presents so much resistance to the passage of the current from the battery, that the bell will not ring. If now the coherer be "put in tune," or syntonized with the apparatus destined to emit the waves, at the sending station (which can be done by attaching to it rods or wires of suitable lengths), *then* on a spark being caused to pass at the transmitter, waves are set up, which waves, on striking the receiver, break down the resistance of the coherer, and allowing the battery current to flow, cause the bell to ring. But unless some means are taken to restore the particles in the coherer to their original non-conducting state, the current would continuously flow, and the bell as continuously ring; a state of things that would be useless for our purpose. It is quite true that sometimes the mere jarring or vibration set up by the ringing of the bell itself, is sufficient to shake up, or "decohere," the particles of filings in the coherer, and thus stop the flow of the local battery current. In fact, in some of Oliver Lodge's experiments with an ordinary glass tube coherer containing filings, he found he could not without discohering the filings shout to his assistant (who was situated about forty yards off), to cause him to press the key of the coil and make a spark, but was obliged to show him a duster instead, this being a silent signal which had no disturbing effect on the coherer or tube of filings. But it would evidently be unsafe to depend on such uncertain means of decohering; especially as in many cases a bell is not used to render the signal perceptible.

In Marconi's arrangement, as originally devised, the decoherence of the filings is effected by a little tapping-hammer striking the tube. The hammer is itself actuated by an electro-magnet which is thrown into circuit with a small battery every time the Hertzian wave allows the current from the main battery to pass through the coils of the Morse receiver, which serves at once to receive the message and to close the circuit between the small electro-magnet and its battery. In order to render this clear to the reader, we give, at Fig. 9, an illustration of Marconi's original apparatus both for transmitting and for receiving; the left-hand group being the transmitter, and the right-hand one the receiver. At *A* we have an ordinary tapping-key connected to the primary of a coil *C C'*, through the battery *B*. The secondary *C'* of this

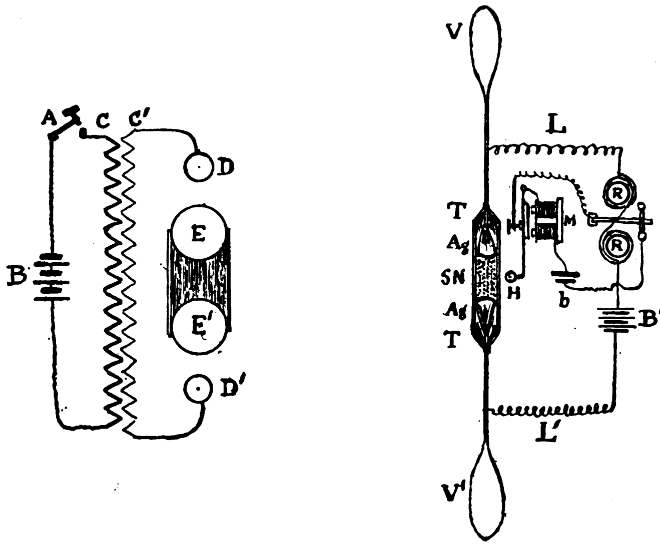

Fig. 9. Marconi's original arrangement.

coil is connected to two brass balls, *D* and *D'*, which are placed at the two opposite diameters of two larger brass balls, *E* and *E'*, that are half inserted in a glass tube filled with vaseline oil. The distances between *E* and *E'* and between *D*, *E*, as also between *D'* and *E'*, admit of adjustment to suit the length of the spark employed, and the distance at which the receiver is placed from the transmitter. The receiver proper consists in a coherer *T T*, constructed as follows:—In the centre of a glass tube is placed a small quantity of a mixture of silver and nickel filings, to which the merest trace of mercury has been added. The position of this is shown at *S N*. These filings lie loosely between two conical silver plugs, *Ag*, *Ag*, having wires which pass to the outside of the tube at each extremity. Before the tube is sealed up, it is exhausted of air. This is to prevent oxidation of the filings. The wires which come from the silver plugs are connected either directly or indirectly to the wings or resonators, *V* and *V′*. These in turn have branch wires attached to them, which, passing to the spirals *L* and *L′*, called "self-induction coils," complete the circuit through the battery *B′* and a delicate Morse telegraph instrument *R*, the lever of which is arranged between two studs, so that when it is drawn down to the lower stud at the instant a wave impinges on the coherer *T T*, it also closes the circuit of the little battery *b* through the electro-magnet *M*, thus causing the hammer *H* to strike the coherer and decohere the filings; and in this manner to restore to the coherer its capacity of taking up a fresh impression. Many ingenious devices have been employed to bring about this shaking up or decoherence; perhaps one of the simplest, and at the same time a very efficient mode, is that used by Mr. Leslie Miller, which consists in attaching a wire on the surface of which a fine screw-thread has been cut, as a prolongation to the hammer-shank of the bell that is used for giving evidence of the signals, and causing the wire to lie crossways upon one of the wires proceeding from the coherer itself. As a result, every time the inflowing wave causes the bell to ring, the bell, in ringing, draws its wire like the bow of a violin across the wire of the coherer, and the vibration thus set up in this wire is sufficient to shake up the particles in the coherer, stopping any farther flow of

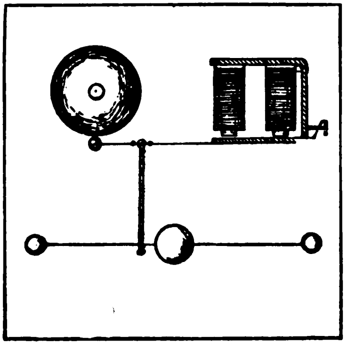

Fig. 10. Miller's Decoherer.

current or any more ringing until the next wave sent shall have again set up the conducting condition in the coherer. This arrangement is shown in our Fig. 10, which represents the coherer, bell, and decoherer portion of one of Leslie Miller's very ingenious wireless telegraphy sets.

In the form of bell-signalling apparatus devised by the author, the hammer of the bell is made to strike on the coherer itself. This device does away with all complication, but of course it is limited in its application, owing to the position in which the bell must be placed in relation to the coherer. Fig. 11 gives a general idea of a lecture-table apparatus arranged according to this plan. (The receiver alone is illustrated.) In this, *A* is the relay, *B* the coherer, and *C* the bell, the hammer *D* of which serves at once to strike the bell, and on falling back to agitate

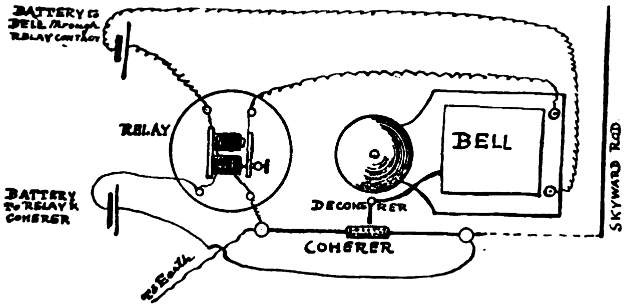

Fig. 11. General arrangement of Receiver.

the coherer, and decohere its filings. *E* is a dry cell, of which one pole is connected to one magnet coil of the delicate relay *A*, the other pole being connected to the coherer at *F*, whence the current passes (when coherence is set up) to the other magnet-coil of the relay. The battery *G* is in circuit with the bell *C*, through the armature of the relay *A*, when the armature is attracted by the electric magnet.

§ 19. Extraordinary as are these results which can be obtained from the practical application of our knowledge of these peculiar properties of the electric waves, yet they by no means exhaust the subject or its possibilities. When a spark-gap is arranged between the balls of a Hertz resonator (see Fig. 7, *E E′*) at such a distance that a spark will just not flow between them when influenced by the oscillator *B B′*, it will be found that if those rays of the

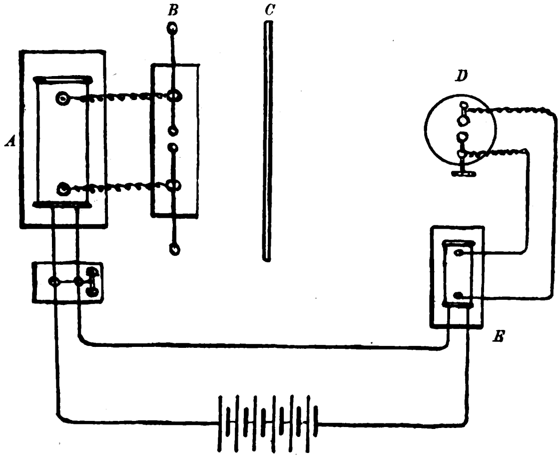

Fig. 12. Hertz's device to show effect of Light.

spectrum which are known as ultra-violet are allowed to fall on the space between the two balls of the resonator *E E′*, the spark can now be made to pass, which goes to prove that the vibration rate of the ultra-violet rays must in some way assist that of the electric waves themselves. In Hertz's original experiments in this direction, which were instituted with the aid of an induction coil (*A*) giving sparks between two balls (*B B*), and shielded by any opaque screen (*C*), or even a sheet of glass, from the spark-gap of another smaller coil (*E*) similarly arranged, but with its balls (*D*) so far apart that they would *only just* allow a spark to pass, he found that the presence of the shield, which cut off the ultra-violet rays emanating from the spark of the larger coil, prevented the smaller coil from sparking. This arrangement is shown at our Fig. 12, in which the larger coil is to the left, and the smaller to the right; it was afterwards found that the light given by an electric discharge was not the only one that would thus modify the distance over which the induced spark could be made to bridge, but that the electric "brush," and, in fact, any source of light rich in ultra-violet rays, such as the light of burning magnesium, etc.—would give similar results. It may be noted that although a screen of glass seriously interferes with the passage of these ultra-violet rays, transparent though it be to ordinary light, a screen of quartz does not impede their passage. Prof. Oliver Lodge has somewhat modified the arrangement to produce this effect, and we illustrate, at Fig. 13, the apparatus he employed. *A* are balls proceeding from the prime conductors of a Holtz or Wimshurst machine. These are respectively connected to the inner coatings of two insulated Leyden jars (*B* and *B'*), the outer coatings of which are connected together by a suitable metallic loop (*C*), and also to a pair of discharging balls (*D D'*), the distances between which can be adjusted at will. It will be seen that when the jars are fully charged they can discharge themselves through *A*, while the outer coatings will have their equilibrium restored through *C*. An "overflow" discharge, however, will always take place between *D* and *D′* if these balls are near enough to one another, but if over the opening of the screen *S* a sheet of glass be placed, these overflow sparks will cease; to recur on the removal of the glass or other obstacles to the passage of ultra-violet rays. From the experiments of Elster and Geitel it would appear that this effect is to some extent

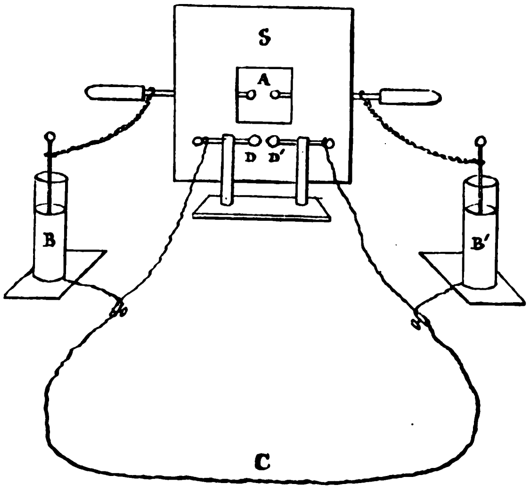

Fig. 13. Oliver Lodge's arrangement.

dependent on the nature of the discharge at the transmitting end (the oscillator). The subject of the influence of light on any discharge is full of interest, and may lead to very important applications, and for this reason we make no apology for reproducing here an abstract of their Papers, which can be found in full in *Wiedermann's Annalen* 38, pp. 40, 497 *et seq.*:—" With a view to verifying Arrhenius' theory concerning atmospheric electricity, we arranged experiments on the photo-electric power of sunlight and diffuse daylight at Wolfenbüttel, from the middle of May to the middle of June 1889.

"Hoor alone had observed the effect of sunlight; other experimenters had failed to observe it, but we find a discharging effect even in diffuse daylight.

"We take an insulated zinc dish 8″ in diameter connected to a quadrant electrometer, or an Exner's electroscope, and expose it in the open, so that it can be darkened or illuminated at pleasure.

"Sunlight makes it lose a negative charge of 300 volts[1] in about 60 seconds. If the charge be positive it is retained. The dissipation of negative electricity ceases in the dark, and is much weakened by the interposition of glass. But light from the blue sky has a distinct effect. Fill the dish with water, or stretch a damp cloth over it, and the action stops. A freshly-scrubbed plate acquires a positive charge of 2½ volts, which can be increased by blowing. With freshly cleansed wires of zinc, aluminium, or magnesium attached to the knob of the electroscope, a permanent negative charge is impossible in open sunlight. Indeed magnesium shows a dissipating action in diffuse evening light. Such wires act like glowing bodies. Exposing an electroscope so provided in an open space, it acquires a positive charge from the atmosphere. No abnormal dissipation of positive electricity has been observed.

[1] A volt is the unit of electrical pressure, equal to about one Daniel cell.

"Our success last time was largely due to the great clearness of the sky in June, and we wished to see if we could get the same effect at the beginning of the winter. The following is our summary of results:—

"Bright fresh surfaces of the metals zinc, aluminium, and magnesium were discharged by both sun and daylight when they were negatively charged, and they spontaneously acquired a positive charge whose amount could be increased by blowing.[1] A still more notable sensitiveness to light is shown by the amalgams of certain metals, viz. in the order of their sensitiveness, K Na Zn, Sn; since pure mercury shows no effect, the hypothesis is permissible that the active agent is the metal dissolved in the mercury. If so, the following are the most active metals:— K, Na (Mg, Al), Zn, Sn.

"All other metals tried, such as Sn Cd Pb, Cu, Fe Hg Pt and gas carbon, show no action. The same is true of nearly all non-metallic bodies; but one of them—namely, the powder of *Balmain's luminous paint*[2]—acted remarkably well in sunlight. Of liquids, hot and cold water, and hot and cold salt solution were completely inactive; consequently wetting the surface of metals destroys their sensibility to light. The illumination experiments can be arranged in either of two ways. For experiments in free space we use zinc, aluminium, or magnesium wires, or small amalgamated spheres of zinc provided with an iron rod. With these it can be easily shown that the illuminated surface of certain metals act in the same way as a flame-collector.

[1] A fact noticed by Bichat and Blondict.

[2] Calcium sulphide.

"For demonstration purposes the amalgams are run through a fine funnel, so that the freshly-formed surface of the drops may be illuminated. The dissipation of electricity which took place with an apparatus thus arranged showed that when *pure mercury* was charged *negatively* to 195 volts it fell to 175 in 36 seconds, while the amalgam of zinc fell from 195 volts to 116 in 15 seconds, the amalgam of sodium falling from 195 to 0 in 10 seconds; while the amalgam of potassium fell from 195 to 0 in 5 seconds, under the influence of light."

These same experimenters in the course of their researches came across a very peculiar fact, namely—that if sparks are just able to pass between a positively charged brass knob and a clean amalgamated zinc cathode, the illumination of the latter by ultra-violet light tends to check them. This is apparently in contradiction to the results which we have noticed at the beginning of this section, but, as Oliver Lodge well observes, the conditions are not exactly the same, for in Elster and Geitel's arrangement the discharging surfaces are kept at a steady high potential before the spark, whereas in the one shown at Figs. 12 and 13, the surfaces are at zero potential until the spark-rush occurred. It appears then, that whereas the action of light in discharging negative electricity from clean oxidisable metallic surfaces is definite enough, its influence on a spark discharge differs according to the conditions of that discharge—in cases of "steady strain" it tends to hinder the spark, in cases of "sudden rush" it tends to assist it.

§ 20. We have dilated somewhat on these experiments because we desire to accentuate, in the reader's mind, the great analogy, if not absolute identity, between electric waves and light waves. When one has clearly grasped this idea, the possibility of directing and controlling these electric waves so as to make them capable, not only of transmitting messages, but also power and light without the intervention of wires, or any other medium but that surrounding us, becomes plainly evident. As in the case of light, the apparent colour of which is determined by the number of billions of vibrations which occur in the medium per second, so in the case of the electric waves, properties are evinced that are clearly dependent upon the rapidity with which the vibrations succeed one another; and while the whole group of phenomena known as induction, X rays, Hertz waves, etc., are but manifestations of vibratory motions, yet the differences which exist between them are due rather to variations in the vibration rates than to any diversity of the motion itself. Hence we find that these electric waves, like light waves, are capable of being radiated, reflected, refracted, and polarized, and a knowledge of these properties will doubtless enable us to control their influence on specially prepared receivers and thus localize their effects, whether for heating, lighting, power distribution, or signalling, in an efficient and practical manner. Up to the present time beyond mere signalling very little has been done; the following being the chief practical applications of electrical wave power:—

§ 21. Professor Chunder Bose of Calcutta was the first to show the possibility of discharging a pistol, or firing a mine from a distance, without any intermediary but that of the atmospheric medium. For this purpose he arranged a form of coherer, which, although not absolutely new, was different from the Branly tube, partaking more of the nature of that used by Oliver Lodge in one of his lectures. This consisted of a smooth ebonite case, containing a number of spiral springs, having a metal plate as a cover touching these at many points, the springs on the one hand and the metal plate on the other completing the circuit when coherence takes place, under the influence of the electric waves. Having placed a coherer of this kind in circuit with a battery and an ordinary Abel's fuse, the resistance of the coherer having been previously adjusted by increasing or decreasing the pressure of the metal plate touching the springs, or by varying the battery power until the resistance of the coherer was such that it would just *not* allow sufficient current to pass to deflagrate the Abel's fuse, this latter was placed on the touchhole of a cannon, etc., and then in another room, or at any considerable distance (walls intervening), a spark was caused to pass between the balls of a suitable oscillator, such as that illustrated in our Fig. 7, *B*. On the reception of the waves thus set up, the coherer, having its resistance greatly lowered, allowed the battery current to pass, thus firing the fuse and discharging the cannon. It is quite evident, that in a similar manner a mine could be exploded from a distance of several miles. It would, however, for practical work, be advisable to use a *relay* in conjunction with the coherer, and to allow *this* to close the circuit of the main battery and the fuse. Our Fig. 14 illustrates the arrangement for this purpose.

§ 22. It will be evident, from a moment's consideration, that by means of an arrangement almost precisely similar to this, it would be possible to release the shutter of a snapshot camera placed at a distance from the operator (say in the car of a captive balloon, attached to a kite, or in any other not easily accessible spot), and thus obtain a

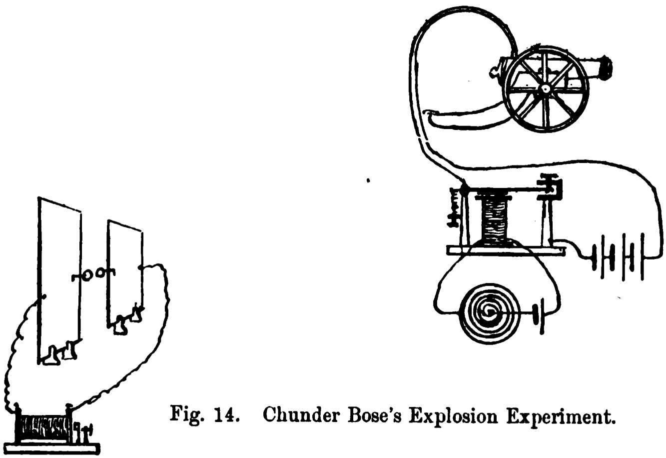

Fig. 14. Chunder Bose's Explosion Experiment.

picture at any desired instant, without having any wires or other tangible connection with the camera. This power may yet prove of great service in topography; and in time of war for obtaining exact information as to the location or the movements of the enemy, without danger to the operators.

§ 23. Another application of the Hertzian waves has been proposed by Nikola Tesla. This consists in the means of controlling and directing the motions of a boat (torpedo or other) from the shore or from another boat. We are not aware that hitherto such a boat has actually been built; but as there are many points in its construction which are extremely interesting, and which might be made of service in the performance of several operations in the work of a house which are at present executed more or less faithfully by domestics, we reproduce the main features of Mr. Tesla's invention. Of the annexed diagrams, Fig. 15 is a plan of Tesla's boat, presenting a general view of the apparatus employed; Fig. 16 is a

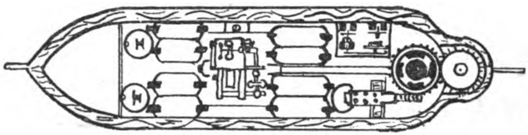

Fig. 15. Tesla's Boat: plan.

sectional view of the Tesla system; and Fig. 17 is a longitudinal section of the boat, showing the mechanism in side elevation. Tesla claims that, in a broad sense his invention differs from all other systems of controlling boats, in so far as he uses no intermediate wire, cables, or other form of electrical or mechanical connection with the object, save the natural media in space. The boat itself is provided with a propelling mechanism comprising a screw-propeller, secured to the shaft of an electric motor, driven by the storage battery. The vessel is steered by a rudder controlled by a steering motor. The apparatus by means of which the operation of both the propelling and steering is controlled involves the use of a receiving circuit, adjusted and rendered sensitive to the influence of the electrical waves or impulses emanating from a distant source, the adjustment being such that the oscillations of the circuit and of the source of disturbance shall occur in electro-magnetic synchronism. The receiving circuit consists of a terminal, a conductor, an electric controller similar to that used in wireless telegraphy, and means by which the current may be let

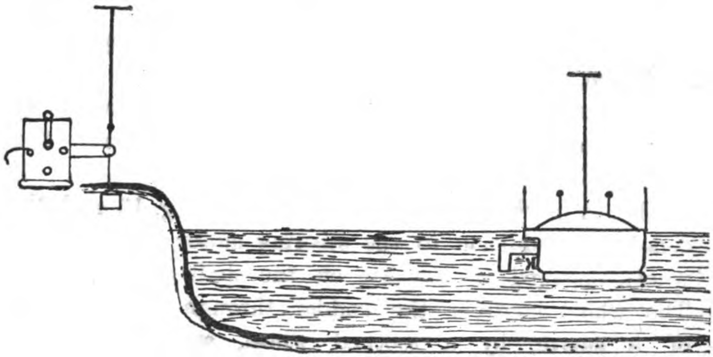

Fig. 16. Tesla's Transmitter and Boat: elevation.

to the ground through the medium of the vessel's keel. The circuit in question forms part of a local circuit in which are included a relay magnet, and a battery, the electromotive force of which is so determined that although the dielectric layers in the electric controller are subjected to great tension, yet normally they withstand the strain, and no appreciable current flows through the circuit. When, however, an electric impulse reaches the dielectric layers, they are broken down, thus suddenly diminishing the resistance, and permitting a current to pass through the relay magnet. The particular controller employed need not be described here, but is shown in side elevation over the motor, in Fig. 17. The relay magnet is used to control the operation of the propelling engine and of the steering apparatus. Placed in the circuit of the electric controller is a commutator, by means of which the direction of the current may be changed, in order to influence one of the two relay magnets placed in the circuit of the battery. While one relay, for example, is in operation, its armature closes a circuit passing through the motor, in order to cause the rudder to be swung to port. The other relay causes the motor to throw the rudder to starboard.

The steering apparatus, as shown in Fig. 15 and 17, consists, in addition to the steering motor, of a toothed wheel, engaged by a worm on the shaft of the motor. The wheel controls the rudder through the medium of a sleeve, by a toothed wheel, and a rod. A fixed vertical rod is mounted within the sleeve, and carries an insulating disc, to the under surface of which brushes are secured. The sleeve surrounding the rod, and turned by the motor, carries a disc, upon the upper face of which are secured two concentric circles of conducting contact plates interspersed with insulated plates. In certain positions of the disc, the brushes are in electric connection with the contact plates. Conductors connect the contact plates with the terminals of the propelling motor, and the poles of the battery are so connected with two of the brushes that when the

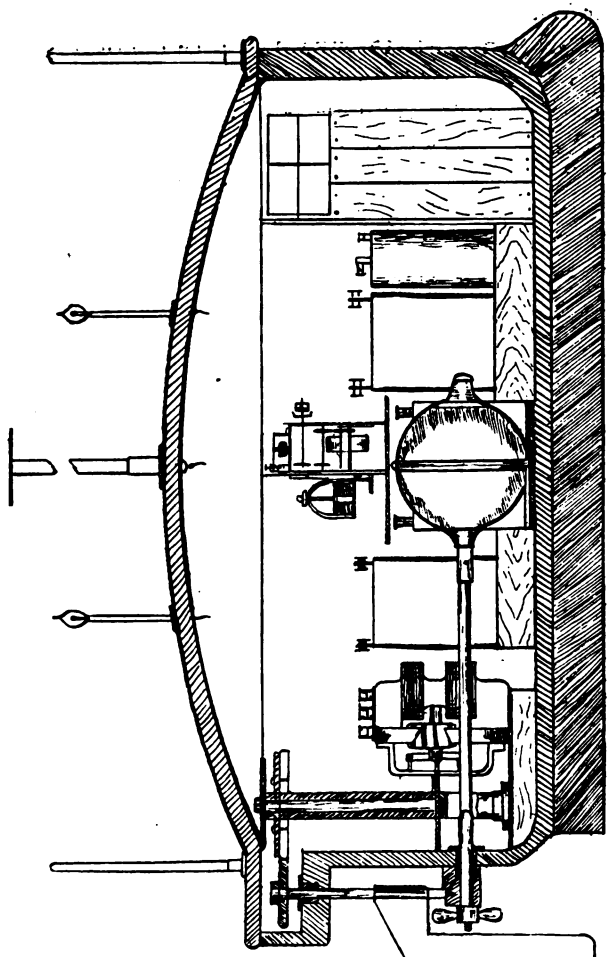

Fig. 17. Tesla's Boat: section.

rudder is in straight position, or turned to either side, the current is conveyed through these two brushes, and through the contact plates to the propelling motor. The steering motor is similarly driven by current taken from the battery, and conducted to two brushes of the plate. The motor, according to Mr. Tesla, may always be caused to rotate in one direction, whatever may be the position of the rudder; and may be used to rotate in either direction whenever the rudder is inclined less than 45° from the centre position. In addition to this mechanism the vessel carries a small auxiliary motor, Fig. 15, connected in series with the armature of the steering motor. By means of this auxiliary motor, lights on the ends of the standards may be flashed in order to indicate the course of the vessel to the operator at night. In Fig. 16, illustrating diagrammatically the operation of the system, the apparatus to the left indicates any source of electrical wave energy controlled by a switch located in a box. The handle of the switch is movable in one direction only, and stops on four points as shown, so that as the handle passes from stop to stop, oscillations are produced during a very short interval. Tesla places the handle of the switch, so that when arrested on the points at the top or at the bottom, the boat is deflected respectively to the left or to the right from its course. The normal position of the hands is horizontal. The impulses sent forth from the shore are, according to Tesla, received by the terminal, transmitted to the commutator, to influence one of the relays, and to cause the motor to act on the brushes to turn the rudder in whichever direction it may please the operator. The motion of the rudder causes the second set of brushes to act on the propelling motor to drive the vessel.

Whether, as Mr. Tesla claims, his apparatus, by reason of its certain and unlimited destructiveness, will tend to bring about and maintain permanent peace, is a question to be discussed.

Another Italian electrician, Emilio Guarini, a native of Puglia, is reported to have discovered the means of utilizing Marconi's wireless telegraphy over the greatest distances. This is accomplished by an invention called a repeater, which receives the electric waves and is capable of transmitting them to other repeaters for continuous repetition. There need only be a repeater at every five-hundredth mile, it is said, in order to establish communication with any given point of the surface of the earth. One of the many contemplated applications of Guarini's repeater is its use in future Polar expeditions, the commanders of which will, it is claimed, be able to maintain constant communication with home.

Emilio Guarini, the inventor of this repeater, is a youth little more than twenty years of age. In 1898 he was at college in Trani. One fine morning he quitted his studies, saying that he meant to go to Belgium to study electricity, for which he felt a great love. He devoted himself to the study with great ardour. Scarcely a year had passed before his invention was announced.

CHAPTER IV

CONSTRUCTIONAL DETAILS

§ 24. As most of those who have perused the foregoing pages will be desirous of performing the experiments themselves, either for the sake of making actual acquaintance with the known facts, or in the hope of improving, or even of making fresh discoveries and launching out into pastures new, we deem it advisable to give working directions which will enable any one gifted with a little neatness and patience to make up the whole series of apparatus necessary, with the ordinary tools usually found in a house. Where it would be impossible for the amateur to do without special appliances, such as a lathe, etc., for accurate round work, we shall specify this. When it is essential that the apparatus should be made of any particular size, the dimensions will be carefully given; where this is not done it is to be understood that the size may be varied to suit the convenience of the operator. The first piece of apparatus required is some machine or instrument for easily generating electricity. We will here describe two such appliances, either of which is well within the grasp of the enthusiastic amateur.

§ 25. **The Induction Coil.**—As for experimental work it will not be necessary to use a spark of greater length than $\frac{1}{2}''$, the following dimensions refer to a coil of this capacity. The material required for its construction are—a bundle of straight iron wires, No. 22 B.W.G., sufficient to make up a core $\frac{5}{8}''$ in diameter, and about $6''$ long; $\frac{1}{2}$ lb. No. 20 *d. c. c.* copper wire for the primary winding, and about $\frac{3}{4}$ lb. No. 36 silk-covered copper wire for the secondary winding; a piece of ebonite tube of about $\frac{7}{8}''$ internal and $1\frac{1}{8}''$ external diameter, $5\frac{1}{2}''$ long, to slip over the primary when wound on the core; two ebonite heads, $3''$ square and about $\frac{3}{8}''$ thick, to make the ends of the bobbin; one sheet of thin ebonite, about No. 24 gauge, $5''$ wide, $14''$ long, for covering the coil when finished; 1 lb. of paraffin wax for insulation; about 50 sheets of good demy paper, which after being paraffined will serve both for making the condenser and for separating the different layers of the secondary winding; $\frac{1}{4}$ lb. tinfoil wherewith to make up the condenser; one foot of $\frac{3}{8}''$ hard brass rod for contact pillars, etc.; $\frac{1}{2}''$ of No. 16 platinum wire for the contacts; 4 No. 2 post office terminals; a piece of brass tube about $1''$ long, $1''$ diameter, and $\frac{1}{8}''$ thick, in the shell; 1 piece of $\frac{3}{4}''$ tape for binding round core, etc.; sufficient thin mahogany (or any other hard wood), $\frac{1}{4}''$ thick, to make a shallow box $9''$ long by $5''$ wide and $1\frac{1}{4}''$ deep; also a piece planed deal to make a false bottom or cover to this box. It will be well to commence by making up this box first. For this purpose a piece of mahogany is cut $5'' \times 9''$, and 4 strips $\frac{3}{4}''$ wide are also prepared, two of them being $9''$ long and two $5''$ long; these are then mitred together along their edges, where they are glued and bradded, and then glued and screwed to the $9'' \times 5''$ piece first cut, so as to form a shallow tray 9″ long, 5″ wide × 1″ outside, and ¾″ deep inside. At each corner inside should be glued a well-fitting triangular block, standing about ½″ high and ½″ wide on its two narrower sides (see Fig. 18). When this is done, this box (which is to form the base of the coil) had better be clamped together and set aside to dry. While this is going on the operator can plane up and take the dimensions of the thin false bottom, which should be about 4½″ wide × 8½″ long. When the box is quite dry and the glue

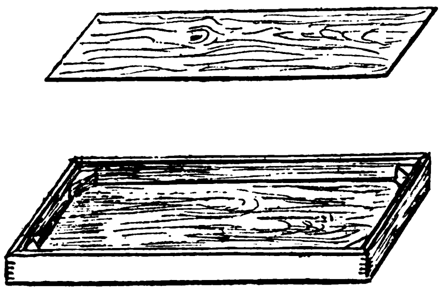

Fig. 18. Coil base; inverted.

hard, the box may be sandpapered down preparatory to varnishing or polishing at the operator's option. We mentioned that screws should be used with which to fasten the upper band to the sides of the frame; if such be employed they should be small brass ones, flat-headed, and counter-sunk flush with the level of the wood: some may prefer to use dowels. The base being thus prepared, attention can be given to paraffining the paper which will have to be used in the construction of the condenser, etc. About fifty sheets, 4″ × 5″, should be cut perfectly square from the demy paper; and a little tin tray, or, in fact, an ordinary tin baking-dish, which must be *perfectly clean*, and somewhat larger than the papers, must be chosen, and placed on the hob or other warm place with about ¼ lb. of paraffin wax in it. The heat must be sufficient to melt the paraffin wax to a clear oil, without causing it to boil. The sheets of paper are then immersed and withdrawn one by one, allowed to drain on the edge of the dish, and then hung up on a line by a pin in one corner until the paraffin is set. When all the sheets have been paraffined, they must be placed one by one between folds of white blotting-paper, and ironed over with a moderately hot iron, so as to remove any excess or any irregularity of the paraffin. In precisely similar manner are the sheets prepared which are to serve to wrap round the several layers of the secondary coil; the only difference being the size of the sheets, which must be not less than 4¾″ wide by about 14″ long. Any superfluity can be trimmed off just previous to laying on. It must be borne in mind, that the first layers of secondary will only be about 3½″ in circumference; but as more layers of wire are wound on, the circumference will increase until the last layers will be nearly 10″; so that the 14″ strips will admit, at the beginning of cooling, of being cut into three, and then into two, shorter lengths. To make up the condenser it will be well to procure two pieces of ordinary window-glass (not thick) 4″ × 5″, and having cut fifty strips of tinfoil 5″ long × 3″ wide, the operator will place one glass sheet on a flat table, and on the glass sheet will put squarely and smoothly two sheets of paraffined paper. Taking a sheet of tinfoil in his hand he will lay it on the paraffined paper, so as to leave a margin all round of ½″ except on his *right*-hand side, when the tinfoil will extend *beyond* the paper for ½″. Over this tinfoil he will place a single sheet of paraffined paper, and then again a sheet of tinfoil, but this time the overlapping piece must be placed on the *left*-hand side. Again is placed a sheet of paraffined paper, followed by a tinfoil to the right, and so on—paper, tinfoil, paper and tinfoil alternately, until all the tinfoil sheets have been thus interleaved—Nos. 1, 3, 5, 7, etc., overlapping on the *right*-hand, and 2, 4, 6, 8, etc., on the *left*-hand. The disposition of these several sheets of

Fig 19. Section of Condenser.

tinfoil and of paper is shown in our Fig. 19, in which the thick lines represent the tinfoil and the thin lines the paper. It will be understood that for the sake of clearness the different sheets are shown as if at some distance apart, whereas, in fact, they are lying one upon the other. The last tinfoil is then to be covered with two or three sheets of paraffined paper, when the second glass sheet is placed over this, cautiously pressed down tightly, and bound together by winding some tape, slightly on the cross, round the narrower width of the condenser, leaving, of course, the two extremities at which the tinfoils project free. The end of the tape can then be stitched to the layer below. Finally, each of the projecting ends of the tinfoils are rolled up tightly for after connection to the contact-breaker pillars of the completed coil. Fig. 20 illustrates the completed condenser.

The core or iron bundle should now be prepared for winding. A piece of brass tube or a brass ring, the inside diameter of which is precisely $\frac{5}{8}''$, is now selected to serve as a gauge for the size of the completed bundle, and a sufficiency of iron wire straightened out and cut to exactly 6″ in length to fill the ring or tube. Beginning at one end, and pushing the ring or tube downwards as he proceeds, the operator will bind the bundle tightly round

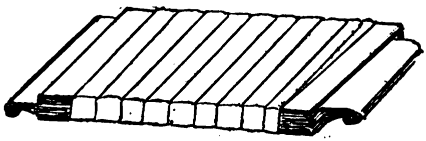

Fig. 20. Finished Condenser.

somewhat spirally with a wide tape so as to form a firm round cylinder of iron wire. He will fasten off the tape at both ends by stitching down. It is essential that this bundle should be firm and hard. After being thus wrapped with tape, the iron core should be immersed in hot melted paraffin wax until bubbles cease to appear. The core is then removed and stood on end to drain, and when cold will be ready for binding.

To wind the core, about 6″ of the No. 20 copper wire should be left free for future attachment, and then beginning at about $\frac{1}{2}''$ from one extremity of the iron bundle, it should be tied firmly to it by means of a piece of strong silk twist, and the core wound as evenly, closely, and tightly as possible, to within ½″ of the opposite extremity. Here it would be well, in order to prevent the wire slipping, that an assistant should tie the last coil down tightly to the core; when a second layer in one continuous length with the first layer must be wound on in the *same direction* of winding until the starting extremity is reached, when the wire can be again fastened down by tying with silk twist and cut off, leaving as before a projecting end 6″ in length. In order to ensure *perfect* insulation, which is so essential to success in making coils, it will be well to give these two layers of wire a good coat of shellac varnish, allowing the varnish to soak in well so as to penetrate the subjacent layer. The wound core should now be suspended in a warm place to enable the varnish to dry hard and glossy, and the operation repeated until this end is attained.

A piece of ebonite tube 5½″ long, of sufficient bore to slide *not too loosely* over the wound core, is now chosen. It should be about ⅛″ in thickness. To make a good job of the bobbin this should be fitted to the heads, which we have previously mentioned as being 3″ square and about ⅜″ thick, by having a screw-thread cut for about ⅜″ at either extremity, fitting into holes of similar diameter, and threaded with a female screw in the centre of each head; but unless the operator has a lathe and chasing tools he will not be able to do this himself; in which case he had better content himself with boring central holes in the ebonite heads with a centre-bit to fit as tightly as he can over the extremities of the tube to which they can be fastened squarely and firmly, either with hot Prout's elastic or with thick shellac varnish; either of which will hold the heads firmly to the tube.

This being satisfactorily fitted, it should be mounted between two standards by driving a cork or bung tightly at each end of the tube and pushing a stout iron or other wire through the centre of each bung, the wire resting in slots at the top of the standards; one end of this wire or rod being bent twice at right angles to serve as a handle by means of which the bobbin can be rotated when between the standards. Below the bobbin on the same standards, holes should be made, through which another stout wire can be passed that serves to support the spool of No. 36 silk-covered copper wire with which the secondary is to be wound. We give an illustration of the bobbin mounted between the standards with a spool of wire below, at Fig. 21. A small pin should be driven in the centre of the top edge of the left-hand bobbin-head, and about 6″ of the No. 36 wire coiled tightly round this future attachment; then by rotating the handle which passes through the bobbin the wire from the spool below will be found to wind itself evenly and smoothly on the ebonite tube. The greatest care must be taken in winding, first, that there should be no breaks; secondly, that there should be no kinks; thirdly, that each succeeding turn should lie close to and yet not overlap its neighbour; fourthly, that the wire should not be allowed to uncoil or slip back. To prevent this, in case the operator should have to stop before one layer has been completed, it is well to have a pin on the standard or on the bobbin round which the wire can be twisted during the interruption. The coiling should not commence quite against the head, but a bare space of tube of about ¼″ wide should be left, and the same margin should be allowed at the finishing end. When therefore the operator has reached to within ¼″ of the opposite head, he will fasten the wire to a pin or otherwise to prevent slipping, and then will baste the completed

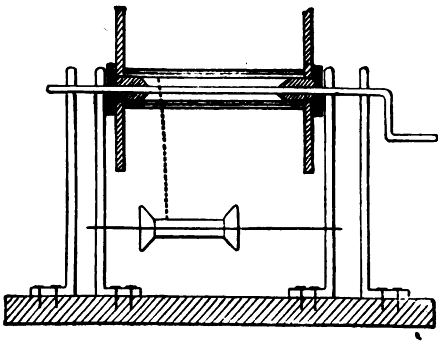

Fig. 21. Bobbin-Winder.

layer with hot melted paraffin wax, after which he will immediately wrap one layer of paraffin paper neatly and tightly round it, taking care to draw the end of the wire of the last turn through the lapping edge of the paper just laid on, so that it comes out at ¼″ from the ebonite head and ready for continuing winding (the pin having previously been withdrawn), care being taken to rotate always in the same direction, with all the precautions above mentioned, coiling on the wire towards the first head, until within about $\frac{5}{16}''$ of it.

The second layer is basted with paraffin wax and covered with a layer of paraffined paper as was the first, the wire being brought out as before, and a third layer wound on, and so on until the whole half-pound has been laid on, each layer diminishing in length by about $\frac{1}{8}''$. The winding of the last layer should be so managed, that the end of the wire terminates at the head *opposite* the one at which the starting wire is attached to the pin. When this has been effected, about 6″ of the termination is wound into a helix for future attachment to its terminals. These can now be put on the coiled bobbin. To this end, the bobbin is to be removed from between the standards, the corks and central rod taken out, the last layer of wire wrapped very smoothly and evenly with several layers of paraffined paper, the edges of which can be fastened down by warming with a moderately hot iron, which will melt the paraffin wax. The bobbin being set on a table with the wire ends uppermost, two terminals are selected, with shanks of such size as to admit of being screwed into holes which will be drilled, one in the centre of the top edge of each bobbin-head. A thread is put in these holes by gently screwing the terminals in, the merest suspicion of oil being used to lubricate if they go in too stiffly, for fear of splitting the edge of the ebonite. The terminals having been thus fitted, they are slightly unscrewed, and then, the ends of each extremity of the secondary wire, having been bared of their silken covering and cleaned with fine emery paper, are coiled loosely round the skank of their respective terminals, which can then be screwed home. The wound bobbin can now be wrapped neatly with one layer of the thin ebonite sheet, which should be cut to fit exactly between the two cheeks of the bobbin. It should be made to overlap a little below, *id est*, at the opposite diameter to where the terminals have been fixed in the heads. To fasten this ebonite cover in its place, it will be necessary to make a few holes with a hot wire along the lapping edges, which can then be threaded with silk twist and laced together like a shoe. The wound core can now be placed in the tube of the bobbin, leaving about $\frac{1}{2}''$ of the iron wires projecting at each end, and taking care that the spare ends of the primary copper wire also project, as these will be required for after connection to the contact-breaker, etc. In order to insure perfect insulation and to prevent the core from shifting in the tube, the bobbin should be supported on end (with the free ends of the copper wire projecting below), and any interstices between the wound core and the bobbin tube filled in by pouring in melted paraffin wax at the upper end.

The contact-breaker is the next portion that will demand our attention. To make this, in order to get the correct height, the coil-bobbin is placed on its base, and the exact height from the base to the centre of the coil-core is measured and noted. A piece of round brass rod, a little longer than the measured height, and about $\frac{3}{8}''$ diameter, is fitted with a little flange at one end and pierced centrally up the stem at this end; the whole being then tapped to take a small cheese-headed screw of $\frac{1}{2}''$

in length. The other extremity of this brass rod has a hole drilled transversely through it at a point exactly opposite the centre of the coil-core, when this rod is standing without its screw on the base. This hole must now be tapped and fitted with a milled-headed screw, having a shank about ¾″ in length; and a nut of nearly the same diameter as the milled head must be fitted to the other end of the screw. A fine hole of about $\frac{1}{16}$″ diameter is now to be drilled in the centre of the tip of this screw to the depth of about $\frac{3}{16}$ of an inch. A tiny globule of solder is put in this hole, and a short piece of No. 16 platinum wire is pushed in the hole over the solder. The whole is now held over the flame of a spirit-lamp so as to melt the solder and ensure adherence between the brass and the platinum; when cold, the platinum is cut off, so as to leave about ⅛″ projecting beyond the brass. The greatest care must be taken not to use any excess of solder, because if any solder were to get on the platinum it would cause it to oxidize, and ruin it for this purpose. This completes the *platinum screw contact-pillar*.

To make the vibrating hammer portion, a piece of springy steel, such as a thin clock-spring, of about the same height as the contact-pillar just finished, and about ¼″ wide, is procured. This must be softened at its two extremities, and also at its centre, by being held over the flame of a spirit-lamp, after which three holes are drilled along its central line, one near the bottom edge, one in the middle, and one at the top, exactly facing the centre of the core. A piece of round soft iron, ½″ in diameter and ½″ long, is now cut off, smoothed on both its faces and cleaned round its circumference. In the centre of one of its faces is drilled a small hole of the same size as that put in the top of the spring. This hole is then tapped with a screw-thread, the spring laid over it, and screwed down to it by means of a suitable small cheese-headed screw. At the central hole in the spring is fitted, by a rivet, a second but much weaker spring, bent so as to incline slightly outwards away from the iron hammer-head; and to the second spring, at a point exactly opposite the platinum tip of the contact-pillar, is riveted a little platinum button, made by pushing a short length of No. 16 platinum wire through a hole in the top of this second spring, and hammering it on an anvil until sufficiently spread out. A piece of ⅛″ brass, about ⅜″ wide, is now bent twice at right angles, one side being about ¼″ in height, and the other about ½″. A hole is now drilled and tapped at the central portion of this rectangle, to which is adapted a cheese-headed screw similar to the one at the bottom of the contact-pillar. A milled head, having a screw projecting on either side of the head (which should be about ½″ in diameter), is selected, and a hole drilled and tapped through the upper end of the ½″ projection to take this milled screw. Finally, the spring itself is screwed against the ¼″ projection, with its iron bob on the same side as the ½″ projection, so that the milled-headed screw can be made to press against the mainspring, and thus regulate its stiffness. This completes the contact-breaker, of which we give an illustration at our Fig. 22.

The coil parts being thus completed, the whole can be put together as follows:—

Two terminals are put through the top of the frame, which serves as a base-board, near the opposite corners of the narrow end. These should be placed sufficiently far from the edges to clear the little triangular blocks which serve to strengthen the frame; and the shanks of these terminals should be fitted with neat little nuts which can be run on from the *inside* of the frame or tray. These

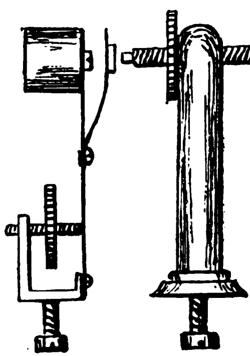

Fig. 22. Contact-Breaker.

serve to facilitate the attachment of the wires. The frame is stood with its false bottom downwards, and the coiled bobbin placed upon it, the contact-screw and the vibrating hammer being held *pro tem.* in their correct place along the centre of the frame which constitutes the base-board, care being taken that the coil is so placed with reference to the terminals just put in, that the head at which the free ends of the primary wire project should face these terminals. The iron bob of the contact-breaker should clear the iron core of the coil by about $\frac{3}{16}''$, and the platinum tip of the screw contact-pillar should just touch the platinum stud on the *weak* spring. The position of these parts being thus taken and marked on the base-board, the operator will drill holes through the base-board, first, to admit the screws passing through to the contact-pillar and vibrating hammer respectively; secondly, two holes through which screws will be put, reaching into two holes drilled for this purpose in the centre of the lower edges of the ebonite heads. Exactly opposite where the wires of the primary come out of the coil-head two fine holes will be drilled in the base-board to admit of the passage of these wires into the interior of the base-board, the wires being previously straightened out so as to lie flatly and neatly against the coil-head. The condenser must now be put in its place, which is effected by turning the coil upside down, so as to expose the bottom of the box, in which the condenser is placed lengthwise, as near as possible to the end farthest from the terminals: it is fastened in this position by two little buttons screwed in the sides of the box. To connect up, one of the primary wires (previously bared and cleaned) is coiled once round and under the shoulder of the screw which holds the vibrating hammer in place, the screw being then tightened up to ensure perfect contact. This same wire is then stitched through the roll of tinfoil projecting from the condenser at the end nearest to it. Care should be taken in stitching the copper wire through the roll that no leaves should be torn, but that good contact should be made. The other wire from the primary goes direct to one of the terminals, without touching the condenser at all. From the other terminal a wire is taken to the platinum screw contact-pillar, as before, by passing the wire under the shoulder of its holding screw, and thence taken right along one side of the box to the opposite rolled ends of the condenser's tinfoil to which it is stitched as was the first wire. As it is essential that the current from the battery should

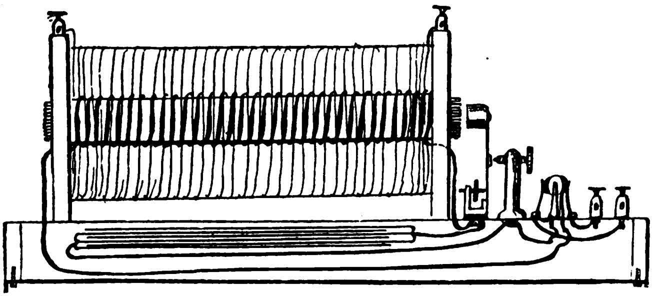

Fig. 23. Completed Coil: section.

pass through these wires without short circuiting, it would be advisable to separate them, wherever they cross, by strips of paraffin paper. We give an illustration at Fig. 23 of this mode of connecting up; and for the sake of clearness have shown one of the primary wires as proceeding from the *back* of the coil, whereas it will really be in front like the other. We have also shown a *commutator* in position, in case the student should care to make it part and parcel of the coil. This is, however, optional.

§ 26. To make the Wheatstone commutator, the operator procures a piece of cylindrical wood, about 1½″

long by 1″ in diameter. This may be of boxwood, mahogany, or any other hard and well-seasoned wood. At a pinch it may be constructed out of a piece cut from a circular broom-handle. Having been cut to the requisite length and trued up (if possible on a lathe) so as to be perfectly cylindrical, it should be boiled in melted paraffin wax until no more bubbles are given off. When this is the case it must be removed, allowed to drain in a warm place, and, finally, polished up by rubbing with a piece of flannel. A piece of stout brass tube, of such an inside diameter as to fit tightly over this wooden core, is now procured, cut to the same length as the wooden core, and forced on it. Two small holes are now drilled on each side of these tubes, at the points diametrically opposite each other. These holes are to be countersunk, as they are to receive four small screws, which will serve to retain the tube fixed to the core. The screws for this purpose must be fine flat-headed brass ones, not exceeding $\frac{1}{4}$″ in length, so that they may leave a clear space through the centre of the core of $\frac{1}{2}$″ in diameter. These screws, having been inserted into their four respective holes, are driven in until the heads are quite flush with the surface of the tube. Any projection must be carefully filed away with a fine file. When this operation has been satisfactorily performed, a line is scribed at two points along the length of the cylinder, diametrically opposite each other, and equidistant from the two lines of screws. Now, with a fine hack-saw, the operator proceeds to cut the brass tube longitudinally, with four cuts, one on each side of the lines just drawn, at a distance of about $\frac{3}{16}$″ on either of them. He cuts right to the wood, but no farther, and then removes the strips he has just parted from the tube. This operation leaves a wooden core, with two separate brass cheeks equidistant from each other. The next step is to make or procure two small copper washers, about $\frac{1}{2}''$ in diameter, with a $\frac{3}{16}''$ hole in the centre of each. Two ordinary brass screws (with thread for wood) are then selected that will just pass freely into the holes in these washers. They should be about 1″ long. A washer having been placed on one of the ends of the wooden core quite centrally, a small hole is bored with a gimlet to admit the screw, which must not penetrate more than $\frac{3}{8}''$ into the core. When this screw has been inserted by means of a screw-driver to this depth, a little drop of solder is run round the shank of the screw and the washer to connect them electrically together. The head of the screw is then cut off with a fine hack-saw, leaving nearly $\frac{5}{8}''$ of the shanks projecting. When this has been accomplished, the other washer is fastened in precisely similar manner to the opposite end of the core, the greatest care being taken to secure centricity in the screws, the shanks of which will afterwards serve as trunnions on which the "commutator" turns. By means of a short piece of copper wire not thicker than the washer, and a drop of solder, the operator now connects *one* washer with *one* brass cheek of the commutator, and the *other* washer with the opposite brass cheek, as shown in Fig. 24. A small base-board of polished mahogany, about 5″ × 4″ × $\frac{3}{4}''$, is now procured, and two L-shaped pieces of sheet brass $\frac{1}{16}''$ thick prepared, standing about 2″ high, and having a hole nearly at the top of each, of sufficient diameter to just allow the screw-shanks on the "commutator" to pass through. Two holes are also drilled in the foot of each L, one to admit an ordinary brass screw, the other to take a terminal. These two uprights are slipped on to the projecting screw-shanks of the brass-cheeked cylinder, and being held closely against the washers, with their bent extremities *outwards*, are screwed down in a central line on the base-board in its longest direction. The two terminals are

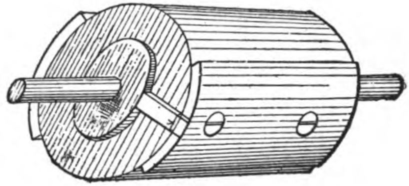

Fig. 24. Roller of Commutator.

then screwed into the outer two holes, so as to make good metallic contact with the brasses. Two similar pieces of brass, about 2½″ high, filed and hammered thin so as to be springy, are now fastened by means of screws to the base-board, one on each side of the cylinder, and so bent as to press pretty firmly against it. Two terminals are connected to these springs also; and for the sake of avoiding confusion, it is well that they should be of different pattern to those attached to the L-shaped standards. All that now remains to be done is to affix a little wooden handle to one of the screw-shanks, so as to be able to turn the cylinder to the right or left, at will. This handle should be so placed that it stands *vertically* when neither brass cheek touches the spring; that is to say, when the cheeks point perpendicularly, upwards and downwards. This is shown in Fig. 25. It will be evident that if the two poles of a battery are connected to the terminals in connection with the trunnions, while the outer circuit is

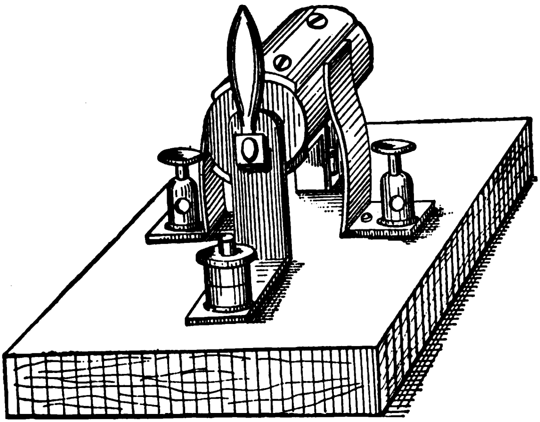

Fig. 25. Wheatstone's Commutator.

coupled up to the binding screws attached to the lateral springs, *no* current will pass so long as the cylinder stands as shown in the cut. If, however, the handle be turned to the *right*, so as to bring the upper brass cheek in contact with the right-hand spring (the lower, of course, simultaneously touching the left spring), the current will flow to the outer circuit in one direction; but if the handle is turned to the *left*, so that the upper cheek touches the left-hand spring, the current will flow in the *opposite* direction in the outer circuit. This form of current reverser serves at once, therefore, as a two-way switch, and as an interrupter, or *rheotome.* This instrument, when used in connection with wireless telegraphy, can either be placed on the base of the coil, as shown in our Fig. 23, or else be quite independent of the coil, being placed in circuit between the coil and the battery; in this latter case it will be advisable to place a thin piece of ebonite between the hammer-head of the clapper and the core of the coil, and then to screw up pretty tightly, so as to insure the coil working or stopping immediately the commutator is turned "on or off."

§ 27. A tapping-key is also very convenient for the purpose of signalling, and if the Morse system is employed, more handy than the commutator. To make this instrument for our purpose, the following simple plan may be adopted. A piece of mahogany about 6″ long, 3″ wide, ½″ thick, is selected, and after having been squared and smoothed up, is fitted with a drawing-pin at the centre of the narrower edge. This drawing-pin is put into connection with a terminal by means of a brass strap, about ½″ wide and $\frac{1}{32}$″ thick. At the other extremity of the board a hole is drilled for a second terminal, under the shoulder of which passes a rather stiff spring (a piece of crinoline steel about ½″ wide will do very well), of such a length as to reach and cover, when pressed down, the head of the drawing-pin. A hole must be drilled at this extremity of the spring exactly over the centre of the head of the drawing-pin, and in this hole must be fitted a stout piece of brass rod, which can be sweated or screwed into the hole in the spring, and furnished above with a neat little knob of ebonite, or box-wood. This arrangement is shown at our Fig. 26. The best position for this tapping-key is in series between one pole of the battery and one terminal of the coil. In this case, as in the last described in our section on the commutator, better results are obtained when the vibrating hammer of the coil is screwed up tight. If, however, it is desired to signal by the dot and dash system, the coil

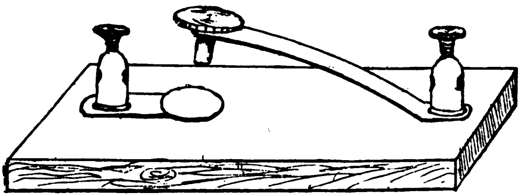

Fig. 26. Tapping-Key.

hammer must be left free, in order that the rapidly recurring vibrations may simulate the effect given by the continuous current needed to produce a dash.

§ 28. For experimental work, and especially for bell signalling, for explosion experiments, etc., the Wimshurst is far more convenient than the coil and battery. To make a Wimshurst suitable for this purpose, a pair of ebonite plates, 12″ in diameter, $\frac{1}{16}$″ thick, will be needed. A hole $\frac{1}{2}$″ in diameter should be drilled in the centre of each. The plates should then be mounted on central bosses, made of any hard wood, turned up to cylinders $1\frac{1}{2}$″ in diameter, $2\frac{1}{4}$″ in length. Each boss or cylinder should be bushed centrally with a piece of brass tube ½″ internal diameter.

The plates are to be fastened to the bosses by means of three flat-headed screws placed equidistantly round the central hole. The screws must be countersunk flush with the ebonite; and to ensure the non-splitting of the ebonite it is well to make the holes in the ebonite through which these screws have to pass, by pushing a nearly red-hot wire through the ebonite at the desired points. At the extremities of these two bosses or rollers, farthest from the plates, a ¼″ groove must be cut, in which the driving-band will lie. This groove should encircle the rollers at about a ¼″ from their extremities.

For the driving pulleys, a piece of mahogany should be selected, about 4¾″ in length, and a sufficient thickness to turn up to 1¼″ in diameter. A hole should be drilled centrally and longitudinally through this of sufficient size to admit of ½″ steel spindle being driven tightly through it. (The spindle can be cemented to this wooden cylinder by giving it a coat of glue before driving it in.) The spindle should project 1″ at one end and 2″ at the other. When the cylinder has thus been fitted to the spindle, it should be put between the centres of a lathe and turned up to about 1¼″ in diameter. A couple of flat pulleys 5″ in diameter, ¾″ thick, with a ¼″ groove cut in their edges, should now be turned up out of mahogany, with central holes to fit tightly on the roller last mentioned. The exact positions of these must be ascertained by placing the roller parallel to the bosses when the plates face each other, and seeing that the grooves on the bosses are in perfect alignment with the grooves on the large pulleys. These latter can be glued in *that* position on the roller. A frame and standards must now be prepared. For this purpose a well-seasoned board of mahogany or oak should be cut and planed 1″ thick, 15″ long, and 8″ wide. At the centre of each wider edge, at 1″ in from the extreme edge, a mortice-hole is cut 2″ long, ½″ wide, right through the plank, and two uprights or standards are made to fit these holes. These standards should be about 12″ long, and should taper from 2¼″ wide at the bottom to 1½″ at the top, where they are rounded. The thickness of these standards should be about 1″. A tenon piece should be cut at the lower extremity of each standard to fit exactly the mortices already cut in the base. These standards should now be temporarily put in place, and the position of the holes which will have to be made in the standards, first, to admit of the spindle which carries the larger driving pulleys, and secondly, those which will bear the upper spindle supporting the plates themselves, ascertained. Approximately, the first pair of holes will be at 2¾″ from the base-board, and the upper ones at ¾″ from the rounded tops of the standards. A piece of round mild steel-rod fitting accurately into the brass tube bushing of the rollers supporting the plates is now selected, and while the plates are being held in position between the standards, this rod is slid through the holes in the upper part of the standards and through the bosses of the plates, and then cut off of such a length as to be exactly flush with the outsides of the standards.

A couple of glass jars, about 1½″ in diameter and

6″ in height, should be procured, and coated with tinfoil inside and out, to the height of about 2″ from the bottom, *not more.* Two short wooden cylinders should now be turned up to fit *loosely* inside these jars, reaching to the same height as the tinfoils, and from the centre of each wooden cylinder should rise a brass tube surmounted by a brass ball $\frac{3}{4}$″ in diameter. Before cutting the brass tube off to correct length, the jars should be placed on the base-board, one at each extremity, in a line with the edges of the plate, and at such a distance from them that the brass balls should clear the edges of the plate by about $\frac{1}{2}$″. The position of the bottoms of the jars should now be marked on the base-board, and by means of a 1$\frac{1}{2}$″ centre-bit a hole should be countersunk at these two points to admit of the jars entering into the apertures thus made to a depth of about $\frac{1}{2}$″. The jars having been placed in these holes, the exact height at which the brass tube may be cut off, to allow the brass balls to stand at diametrically opposite points of the circumference of the plates, ascertained, and the tubes cut off and screwed into the balls. The wooden cylinders may now be cemented into the jars by pouring in melted paraffin wax to just over the height of the tinfoils. Care must be taken to make the jars pretty warm first, and not to have the paraffin too hot, otherwise the glass jars will surely crack. The Leyden jars thus prepared can now be fitted with the "collectors," which consist in two **U**-shaped pieces of No. 14 brass wire of about 5″ in length, sharpened at the points and bent so as to embrace the edges of both plates, clearing them by about $\frac{3}{8}$″ on each side. A chamfer is cut across the face of each ball with a rat-tailed file, and into this depression the bend of the U is soldered. If this has been properly done, when the jars are placed in their holes, with the U-shaped collectors embracing the plates on each side, these latter will be in a line with each other across the horizontal diameter of the plates, the points reaching about 1½″ in from the edges of plates, not touching the plates at any point, but clearing them, as we have already said, by about ⅜″. We can now proceed to fix the jars in their position. As for our purposes we shall make use principally of the discharge obtainable from the outer coating of the jars, it will be necessary to lay a little strap of very thin brass (about $\frac{1}{64}$″ wide will be sufficient), and reaching from the bottom of the holes into which the jars fit, to two small binding screws, which will be screwed in the base-board on the side farthest from the driving handle. Of course it will be necessary, if it be intended to polish the base and standards, etc., to do this before fitting finally the jars and brass work in their places. The straps above-mentioned being inserted in the holes, a little thick shellac varnish should be painted round the bottom of the jars, and also round the sides of the holes (but not on the brass strips), and the jars pushed in their places, care being taken, of course, that the U-pieces of the collector are in their correct places, as above-mentioned. The next operation is to make the neutralizing brushes. For this purpose two lengths of hard-drawn brass rod $\frac{3}{16}$″ in diameter and about 15″ in length, are bent into the form of a bow, reaching from one semi-diameter of each plate respectively, round the top of the standard to the other semi-diameter, at a distance of about 1″ in from the extreme edges of the plates. The extremities of these two bows must not come into actual contact with the plates, but must clear them when rotating by about $\frac{5}{8}$″, and a small hole should be drilled down the ends of these rods to a depth of about $\frac{1}{2}$″ for future insertion of the "brushes." Two small brass discs, $\frac{1}{16}$″ thick, are now cut out, $1\frac{1}{2}$″ in diameter, and the bows soldered to these across their centre, the discs lying inside the concavity of the bow. Two small holes are now drilled in these discs to admit of two small screws, which will hereafter serve to attach the neutralizing rods to the upper extremities of the standards. But before doing this, the brushes must be fitted into the extremities of the rods. The best material for the brushes is certainly "tinsel-cord," which can be obtained from most trimming shops. A small piece of this, about 2″ long, is bent once upon itself, and the folded portion pushed into the hole made in the extremities in each rod, and fastened in place by driving in a little wooden wedge, made by pointing an ordinary match. This latter must be cut off flush, leaving only the fibres of tinsel-cord projecting. The brushes having thus been put in the ends of the two rods, these latter can be screwed up in their place at the top of the standards. The exact place of the brushes is of great moment, for the Wimshurst will not excite itself unless they hold a certain position with reference to the direction of rotation. In a machine such as we are describing, each neutralizing rod, as seen from the front of the plate swept by its brushes, should point like the hands of a clock when marking "5 minutes to 5." It will be seen, therefore, that the centres of the discs carrying the neutralizing rods and brushes will come centrally over the ends of the spindle which carries the plates. The machine requires some form of spark-gap arrangement, so as to regulate the length of the spark given. For this purpose the most convenient form is that of a piece of stout hard-drawn brass wire about $\frac{3}{16}''$ in diameter and furnished with a brass ball at each end; the length of this "discharger" should be about 18″ long, the size of the balls 1″ in diameter. When thus fitted with its balls, the rod should be bowed, and then the extremities bearing the balls bent sharply inwards towards the convexity of the bow, in such a manner that when the centre of the bow is resting on the top of the standard farthest from the driving-handle of the machine, these two balls touch the centres of the large balls on the tops of the Leyden jar. With a rat-tailed file, a little channel, rather larger than the diameter of the wire of the discharger, is now made along the top of the standard previously mentioned *parallel with the plates*, this channel being lined with a little piece of washleather, glued in; the discharging-rod is laid in the channel at its centre, and held down firmly in place by a little brass strap, also lined with leather, being placed over the top of the standard, and screwed down at each extremity. This will allow the bowed discharging-rod to be approached or receded from the balls on the Leyden jars, and the packing should be sufficiently stiff to retain the rod in any desired position, after adjustment. The plates must now be *sectored;* for this purpose the operator will cut out 60 pieces of tinfoil, wedge-shaped with rounded ends, each sector being 1½″ long, ¼″ in width, at the widest end, diminishing to a little over ⅛″ at the narrower end. He will paint over one side of each sector with a light coat of "white hard varnish," and lifting up each sector with the brush with which he applied the varnish, he will stick the sectors down on the plates, so that each plate will have a circlet of thirty sectors on it, the smaller extremities pointing towards the centre of the plate, and the larger extremities towards the edge, at a distance of about ¾″ from the extreme edge. The sectors should be equidistant from one another, and great care should be taken that the line of their top edges forms a perfect circle. As it is well that the varnish should be somewhat tacky before the sectors are stuck down on the plate, it is advisable to apply the varnish to six or eight sectors before commencing to stick them down, and then to begin with the sector first varnished, which by this time will have acquired a milky appearance. The sectors can be smoothed and pressed down with the assistance of small pieces of clean blotting-paper. The 2″ end of the spindle passing through the driving pulleys should be squared or furnished with a screw-thread, to enable it to take a handle not more than 3″ long. The machine can now be put together, the standards glued in, and when dry will be ready for immediate work. Fig. 27 represents the completed machine, from the side on which is the discharging-rod. Leather bands must be arranged to convey the motion from the driving-pulleys to the driven bosses of the plates;

that on the handle side being an open belt or band, while the one on the other side must be crossed, as the plates must rotate in contrary directions.

§ 29. **The Transmitter.**—Two forms have received atten-

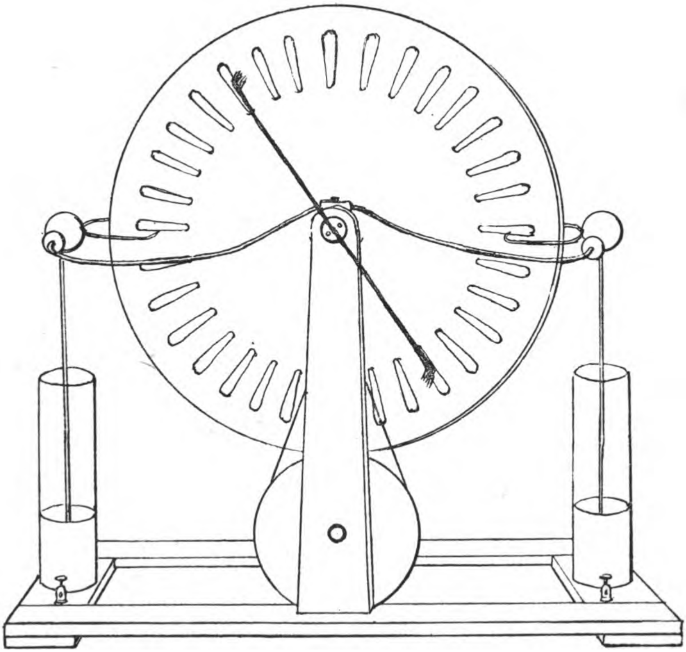

Fig. 27. Wimshurst Machine.

tion; the first is one in which two or more brass balls are enclosed in a glass tube with vaseline between the surface of the balls, and with metallic extensions outside the tube to put them in connection with the coil or Wimshurst.

We do not recommend this form, as practically little is gained by the presence of the vaseline, and it is much more difficult to construct. The form we shall describe, and which is shown at Fig. 28, is one due to Prof. Oliver Lodge, slightly modified to suit our special requirements. A piece of mahogany is cut and planed up 9″ long, 3″ wide, $\frac{5}{8}$″ thick. In the centre of this is drilled a $\frac{3}{8}$″ hole, and at the opposite extremities, at about 1″ in, two other holes of the same diameter are also drilled. A brass ball $2\frac{1}{2}$″ in diameter is screwed on a $\frac{3}{8}$″ ebonite rod about $1\frac{5}{8}$″ in length, and this is fitted in the centre hole, so that the bottom of the ball clears the base-board by about an inch. Two smaller brass balls, about 1″ in diameter, are now procured and fitted by screwing with two brass stems about 5″ long and $\frac{3}{16}$″ in diameter. Two $\frac{3}{8}$″ cylindrical ebonite rods now have holes drilled transversely across their upper extremities, at about $\frac{1}{2}$″ from their tops, of such a size as to allow the brass rods to slide in them rather stiffly. In the centre of each of these ebonite rods, at the top end, is drilled and tapped a hole to admit the stems of a pair of "telephone" binding screws. These must screw down on the transverse brass stems. These binding-screws serve two purposes—1st, to connect the transmitter up to the source of electricity; 2nd, to clench the transverse rods in place, when the smaller balls have been adjusted at the desired distance from the central ball. Before firmly fastening the balls with their ebonite stems in their position on the base-board into which they are cemented with a little hot Prout's elastic glue, the base-board should be polished or varnished. The brass balls also (as, in fact, all the brass work of the Wimshurst machine) must be polished with the greatest care, and kept polished, since much of the success depends on the production of clean, sharp, snapping discharges; and it is impossible to obtain such unless the sparking balls are kept at mirror-like brightness. In using this instrument the terminals of the coil, or those from the bottoms of the Leyden jars or the Wimshurst, are connected by means of heavily insulated wires (not touching anything on their way) to the

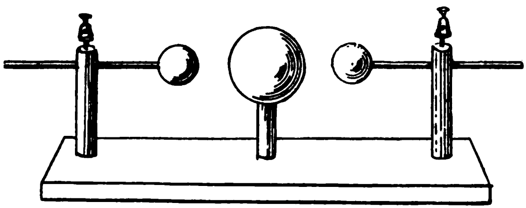

Fig. 28. Lodge's Transmitter.

terminals of the transmitter. The lateral balls are then adjusted to suitable distances from the central ball, which may vary from $\frac{1}{16}''$ to $2''$ or more, according to the space which has to be traversed by the wave.

§ 30. **The Receiver** consists of four essential parts, namely, the *Relay*, the *Coherer*, the *Bell* with its decoherer, and the *Batteries*. To make the relay the operator will cut a sufficient number of lengths of No. 22 soft iron wire, to make up into two bundles $1\frac{1}{2}''$ long and $\frac{3}{8}''$ in diameter. He will either turn up out of boxwood two small bobbins $1\frac{1}{4}''$ long, $\frac{3}{4}''$ in diameter at the heads and as thin as possible in the body, to fit over these bundles or cores; or, if he has not a lathe, he can make the tubes of the bobbins by rolling and gluing strips of brown paper to the same dimensions and fitting them with circular ebonite heads, which can be glued on the extremities of the tubes. He will then procure and square up a piece of soft iron 1″ wide, 1½″ long, ⅛″ thick, through which he will drill two holes barely ⅜″ in diameter, at such a distance apart that if the bobbins previously described have their projecting iron cores pushed into these holes, the flanges or heads will just touch each other. In order to keep the bundle of wires cylindrical while the bobbins are being made and wound with wire, they should be tightly bound round with a strip of gummed paper. The iron cores, having been inserted into the holes made in the iron, should be fastened in place permanently by soldering from the back, any excess of solder being afterwards carefully filed away. A little strip of thin sheet brass about $\frac{1}{32}$″ thick, 1½″ long, and about ½″ wide, is soldered along one of the edges of the iron, for future attachment to the base. The bobbins should now be wound very carefully and evenly (each layer being separated by one turn of tissue-paper) with about 1 oz. of No. 36 silk-covered copper wire so as to form an electro-magnet. Care must be taken that the wire in passing from one bobbin to the other does so in the form of a letter S. About 3″ of the extremities of the wires must be left free, for after connection. Care must be taken also that the faces of the iron wire bundles which project slightly through the bobbin-heads should be filed perfectly smooth and level, and into the centre of that bundle or core which is to the left of the operator when the electro-magnet is lying flat with the brass strip downwards and farthest from him, he will force in a piece of No. 20 platinum wire, cutting it off so that it projects about $\frac{1}{32}''$ only above the level of the face of the iron bundle. A small iron armature must now be made, $\frac{3}{8}''$ wide, $1\frac{1}{4}''$ long, and $\frac{1}{8}''$ thick. This must be squared up very accurately and at the top extremity, at about $\frac{1}{16}''$ in, two small holes must be drilled in the edges to the depth of about $\frac{1}{16}''$. These holes must be exactly opposite one another, so that if this armature were suspended by a pin inserted in each hole, it would swing freely and hang perpendicularly. The diameter of the holes should not exceed $\frac{1}{16}''$. In order to support this armature before the poles of the electro-magnet, a little brass bracket must be made, by bending a piece of brass $\frac{3}{30}''$ thick and about $\frac{1}{4}''$ wide into the shape shown at our Fig. 29, and of such a size as to allow the armature to swing freely between the jaws without touching. A sharp pin is inserted and soldered point upwards in the lower part of this bracket, and a fine metal screw, also terminating in a sharp point, is fitted in the upper portion, as shown in our Fig. 29. The armature can now be placed between these two points, and the upper screw tightened until the armature can swing perfectly freely without too much play. A piece of vulcanized fibre, about 4″ in diameter, $\frac{1}{4}''$ thick, is taken for a base, and the electro-magnet, previously described, screwed down to this by means of two holes made in the projecting brass strip. Under the head of one of these screws, a loop of No. 24 copper wire should be passed, to serve for connection to a small telephone-terminal placed above and rather to the left of the electro-magnet. The two fine wires (No. 36) forming the ends of the electro-magnet winding, are brought out to the nearer semi-diameter of the base, and attached in good metallic contact with two small terminals inserted in the base, at equidistant points along its lower edge. The swinging armature is now temporarily put in position on the base; it must be

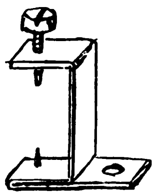

Fig. 29. Bracket for Armature.

adjusted so that the swinging iron plays in front off and exactly opposite the iron cores, reaching just below the lower core and hanging parallel with them, when it swings so far forward as to touch them. This position having been found, the place where the foot of the brass bracket stands should be marked. Two small holes, one behind the other, to take two small screws, must now be drilled through the brass. The bracket can now be screwed in its place, and under the head of one of the screws is clenched a loop of No. 24 copper wire, which is taken under the shank of a second binding-screw inserted at the right-hand side of the fibre base, to the right of the electro-magnet. We have now four connections on the base, namely, two above, by means of which a circuit can be closed between the *iron* of the electro-magnet and that of the armature and screw; and two below, by means of which current can be sent round the *coils* of the said electro-magnet. There only remains to put a platinum contact on the portion of the armature exactly facing the platinum point projecting from the lower electro-magnet core. To this end the screw in the bracket is loosened, the armature removed, and a strip of thin platinum-foil, about $\frac{1}{4}''$ wide, and reaching from edge to edge of the iron armature, is soldered across the armature, by its edges only, in such a position that the platinum-point in the centre of the lower core of the electro-magnet shall surely strike the centre of this strip of platinum-foil, when the armature swings forward and touches the end of the electro-magnet. The greatest care must be taken that no solder gets on the surface of the platinum, and to this end no excess of solder should be used, for platinum sucks up melted solder like loaf-sugar does water. The swinging armature can now be replaced, and the holding screw slightly tightened. To obtain the best results, sufficient play must be left to allow the armature to oscillate freely, but at the same time there should be no lateral or up and down wobbling. A little brass pillar carrying a transverse screw inserted in the base just behind the armature, and in a line with the lower pole of the electro-magnet, will be found advantageous, as by screwing this up any excessive swinging or chattering of the armature can be prevented. This relay must always be used in a vertical position, with the armature hanging downwards. (See Fig. 30.)

§ 31. A very good *coherer* may be constructed on the following plan, which is, with the exception of the material used for the filings, the same as that adopted by Mr. Leslie Miller. A piece of thin brass tubing (known as

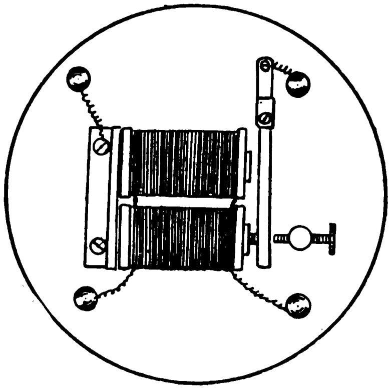

Fig. 30. Completed Relay.

triblet) about $\frac{3}{16}''$ in diameter, $\frac{1}{8}''$ bore, and $\frac{5}{8}''$ in length, is cut and cleaned up carefully inside and out. Two little ebonite caps or stoppers are fitted to this tube, one at each extremity. They should be made to fit tightly so as to exclude air as far as possible, and should not extend into the tube more than $\frac{1}{16}''$, and should have a little flange so as to project a trifle over the ends of the tube. Two pieces of No. 18 platinoid wire, about 4″ long, are now selected, cleaned, and straightened out. The extremity of one of these pieces is to be bent into the shape of a ring, of such a size as to encircle tightly the aforesaid brass tube. The caps are then *pro tem.* removed from the tube, the ring of wire, with its projecting end, slipped over the tube until it reaches midway. The ring is then to be soldered neatly in this position to the tube, and any excess of solder carefully cleaned away, by scraping and filing with a fine triangular file. Through the centre of one of the ebonite caps a very fine hole is now drilled, only just sufficient in size to allow the platinoid wire to be pushed in with difficulty. The wire should be pushed so far through the cover as to project $\frac{1}{8}''$ above the level of the inside, and then the longer portion remaining on the outside of the cover should be bent twice at right angles, the first bend being as close as possible to the cover, and the second bend at about $\frac{3}{8}''$ from it, and parallel to the piece projecting from the inside. A piece of ebonite, about $\frac{3}{32}''$ thick, is now cut into the shape of a lozenge, $\frac{3}{4}''$ long at its greatest length, and about $\frac{1}{2}''$ wide at its narrower portion. Through the centre of this lozenge is made a hole of sufficient size to allow the tube to fit tightly in. Near the longer extremities of this lozenge, equidistant from the central hole, two small holes are drilled into which the platinoid wires can fit tightly. One of these wires, as we have already mentioned, should be bent twice at right angles; now the cap bearing this wire should be fitted in the tube, with its bent wire on the side of the tube opposite to the straight wire projecting from the tube itself. This latter wire is now bent up parallel to the wire to the lid, the amount of bend given to each wire being such that the free extremities of the wires will enter with a little coaxing into the holes made in the two corners of the ebonite lozenge. The platinoid wires can be bent conveniently with the assistance of a small pair of flat-nosed pliers. The lozenge should now be slid down the wires until it arrives to the tube, and then pushed over the tube until it reaches the centre, where the ring of platinoid wire is soldered to it. At this point the wires are once again bent at right angles over the lozenge so as to project straight out from the tube to a distance of about 3″ on either side of the tube. It will be understood that the lozenge is only fitted to the tube to impart a certain amount of rigidity to the connecting wires. We have therefore now a metallic tube in direct electrical connection with one wire, but insulated from the other wire, which passes some little way up its centre, by the ebonite cap. This latter cap will form the bottom of the coherer. At this stage the operator will clean, most scrupulously, the inside of the tube and the projecting end of the platinoid wire, by rubbing round the inside with a little stick such as a match, covered with a bit of washleather. He will then put sufficient coarsely-powdered metallic antimony into the tube to reach a little over half way, but not touching the upper cover when this latter is inserted, which it should be at once. The antimony for this purpose is the ordinary commercial metal, but clean and freshly fractured pieces should alone be used, and the hands of the operator should be clean, and *above all things perfectly free from grease* or perspiration, as these are fatal to the efficiency of the coherer, if the antimony imbibes any. The size of the antimony powder (or other filings) is of some importance. If very coarse, it conducts too freely, and does not decohere so readily; if too fine, it presents a great resistance, and requires both more stimulation from the electric wave and more battery power to enable it to work satisfactorily. Two little sieves should be made for the purpose of obtaining the correct size of antimony or other filings; one made of copper-gauze having 64 meshes to the linear inch, the other having only 32 meshes to the linear inch. The clean antimony, having been put in a clean iron mortar, is reduced to a coarse powder with a clean iron pestle, and then thrown on the finer sieve. What passes through *that* must be rejected as being too fine for our purpose. The remainder is placed in the second sieve, and the grains which can come through these coarser meshes will be of suitable size. It is neither necessary nor advisable to powder a large quantity of the antimony at a time, since it works much better when it has not been long exposed to the atmosphere, notwithstanding the fact that antimony is not readily oxidizable. The coherer is now complete, and ready for connection to the relay, etc. We present our readers with an illustration of this form of coherer, at Fig. 31, where the tube is shown in section in order that the position of the filings may be clearly seen. Another form of coherer is that devised by the author, for use where very great delicacy and a great range of sensitiveness is required. This consists of a number of brass tubes similar to the one previously described. Each tube is closed at the bottom by a brass cap soldered on, from the centre of which projects a short piece of No. 18 platinoid wire, the upper extremity of each tube being closed as before with a tightly-fitting ebonite cap, through the centre of which passes a piece of similar platinoid wire, reaching to within about $\frac{1}{8}''$ of the bottom of the little brass cell, the other extremity projecting outwardly from the centre of the ebonite cap. Each tube is about half

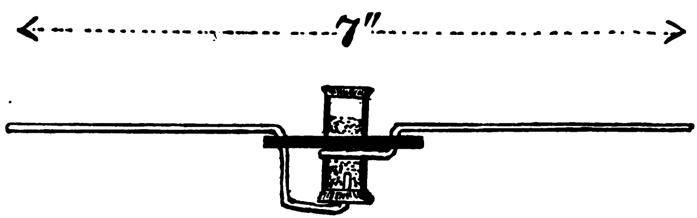

Fig. 31. Simple Coherer.

filled with the antimony powder, as in the case previously described, with, however, this difference, namely, that each tube has a powder of a different degree of fineness in it, beginning with that of an almost impalpable dust, and increasing in coarseness till it reaches that which will pass through the 32-mesh sieve already mentioned. A convenient number of these tubes is seven. A triangular frame of brass is now prepared, one portion of which is made by cutting a piece of hard sheet brass about $\frac{3}{16}''$ thick into the shape shown in our Fig. 32, *A*; the other, *B*, of precisely the same shape, but double instead of being a single piece; in other words, three pieces of brass are required; ten small holes are now drilled through the two pieces forming the lower half, *B*, of the frame, those along the lower edge being equidistant. These holes are to be fitted with very fine screws and nuts to bolt the two pieces which form the lower half of the frame together.

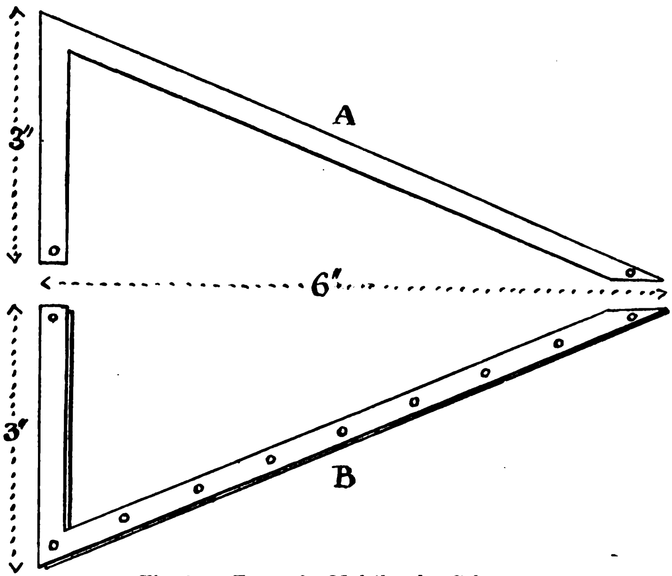

Fig. 32. Frame for Multilocular Coherer.

In the upper half of the frame, *A*, only two holes are required, and these must also be fitted with screws and nuts. The quickest way to make these latter is to run a short length, say three or four inches, of No. 16 hard-drawn brass wire through a suitably sized hole in a screw-plate, and then cut off portions of the screws thus produced of suitable length (about $\frac{1}{4}''$ to $\frac{3}{8}''$), and then, in a No. 16 gauge brass strip, drill and tap 24 holes about $\frac{3}{8}''$ apart. When these holes have been tapped with a screw-thread, so as to fit the screws just made, the strip can be cut up into little squares or hexagons to form the nuts. A piece of ebonite of the same thickness as the brass *A* is now fitted between the portions *C* and *D* (see Fig. 33) by four of these nuts and screws. The ebonite strips should separate the upper and lower portions of the frame by about $\frac{1}{2}''$ at the points *C* and *D*. They serve, at one and the same time, to connect them together mechanically, and to insulate them electrically. The frame being thus joined together, the operator proceeds to lay the seven coherers in position across the frame, as shown in our Fig. 33, at equal distances apart, with their tubes in a line with *C* and *D*, the ebonite caps looking upwards towards *A*, the soldered wires reaching downwards to *B*. The equidistant position being marked on the frame, the wires proceeding from the ebonite caps of the coherers, and resting on *A*, are soldered in the positions marked, any wire projecting being cut off, and all excess of solder being carefully and neatly filed away. One precaution is here necessary. In order to get the best results, those tubes containing the finer filings should be at the narrower end of the frame; those with the coarser should be placed at the wider extremity. The screws and nuts on the lower base of the frame are then loosened, the wires from the lower ends of the tubes slipped in their places, cut off flush with the edges of the bar, and then the screws and nuts replaced and tightened up. All that

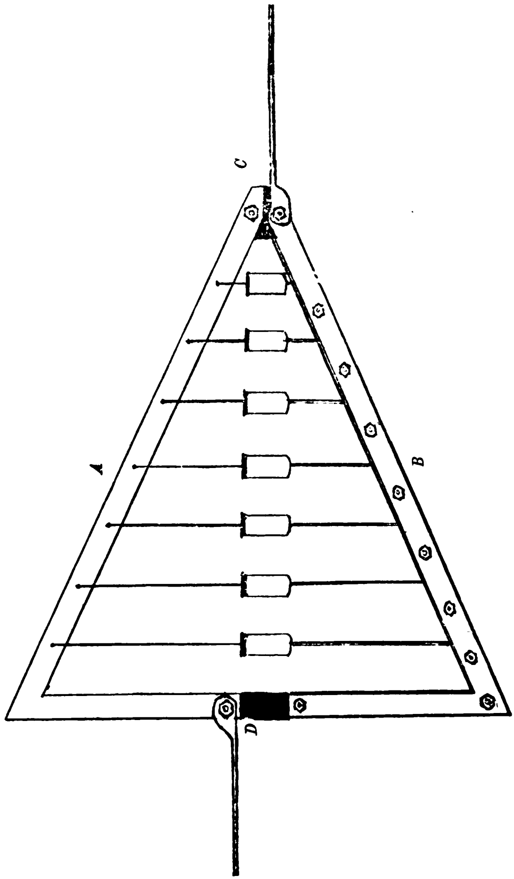

Fig. 33. Completed Multilocular Polytonic Coherer.

remains to be done is to put two brass tabs with wire extensions at the upper and lower corners, *C* and *D*, under these nuts. These are to serve as connections to relay, cell, etc.

§ 32. It is hardly advisable for the amateur to construct his own bell, since electric bells can be bought so good and so cheaply as to render it practically impossible for any one to make a bell that shall compete in efficiency with one costing three or four shillings only. Two or three precautions, however, should be observed in choosing the bell.

1st. The size should be that known as 2½″ gong.

2nd. The contacts *must* be platinum.

3rd. The winding should be No. 26 silk-covered copper wire.

The purchaser should notice that the bell rings freely if held vertically against a wall, with the gong uppermost and the hammer downwards, when actuated by a small dry cell, about 4″ by 1½″, or by a one pint Leclanchè cell. Having selected a bell answering these requirements, the operator, holding the bell in the position last described, namely, against a wall, or other flat vertical surface, with gong looking upwards and the hammer downwards, will make a scratch or other mark on the surface of the ball which serves as the hammer at a point opposite the ground-line: that is, perpendicularly downwards. If the ball of the bell can unscrew, he will then unscrew it, and drill and tap a hole at the spot marked, of sufficient size to take a piece of No. 16 hard brass or platinoid wire on which a screw-thread has been previously cut. If the ball will not unscrew, a little block of wood may be placed between the ball and the gong, and the hole drilled and tapped while the ball is in position on its stem. The piece of wire having been inserted into this hole and screwed tightly home, any excess over 1″ should be cut off with a pair of sharp-cutting pliers. It is needless to remark, that if the ball has been removed, for facilitating drilling, etc., it should be replaced and screwed up again previous to inserting the 1″ length of wire. This projecting 1″ of

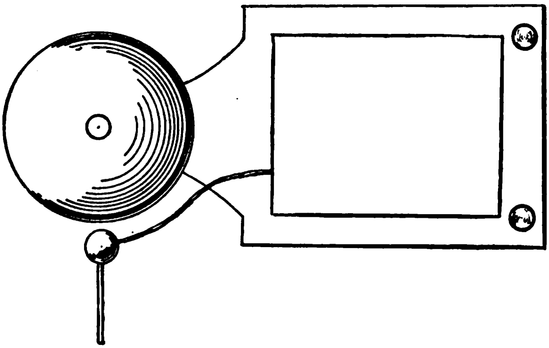

Fig. 34. Bell with Decoherer.

wire forms the *decoherer*. We give an illustration of the bell fitted with its decoherer at Fig. 34.

§ 33. The batteries required in these experiments will vary somewhat with the nature of the experiments themselves. Between the coherer and relay one, or at most two, ordinary dry cells, standing about 6″ by 2″, will be found ample, or a single pint Leclanchè may be substituted. The battery between the relay and the bell may also be a Leclanchè, or dry cell; but if, instead of ringing a bell, it be desired to light a lamp, or fire a fuse, the battery power needed will be greater. For firing fuses, or any explosive experiment in which a low-tension fuse is employed, a one-pint chromic acid cell will be found generally useful.

If, however, it is intended to use the apparatus to light a lamp, or to drive a motor on the reception of the wave, it will be necessary to employ batteries of sufficient power to do the work. For instance, if it were desired to light a lamp of 16 volts 5 c.p., eight small accumulators must be put in circuit with the relay and lamp (the bell of course being cut out of circuit). If it were intended to use the receiver to start a ¼ horse-power motor into action, the motor taking, say, 10 ampères, at 20 volts pressure, then 10 accumulator cells arranged in series and capable of giving 20 ampères for the required number of hours' work, will be needed.

§ 34. For the benefit of those who have not had any experience in fitting together the different pieces of apparatus, we subjoin a few instructions as to the best method of so doing. Two pieces of mahogany, 12″ long, ¾″ thick, and 6″ wide, must be planed up and polished, and one piece attached lengthwise across the middle of the other, by two screws passing through the centre of the lower board, into the centre of the edge of the upper board. The result will be similar to a letter ⊥ upside down. For facility of description we will call the horizontal board the *base*, and the vertical board the *plank*. We begin by inserting two cylindrical mahogany pegs, protruding about 1½″ from the surface, into the plank, at about ¾″ from the base, and 1½″ in from the opposite edges of the plank. These pegs should be about ¾″ in diameter, and should be constructed of mahogany, having a channel or groove near the end farthest from the plank. These serve as supports for the rods which are used as "wings" or syntonizers. A pair of similar pegs, $\frac{3}{4}''$ in diameter and protruding $\frac{3}{4}''$ from the level, are now inserted in the plank, the height of the centres of these being $1\frac{1}{4}''$ from the base, and the distance from the edges of the plank being 3″, so that there is a space of 6″ clear between the centres of these two latter pegs. Into the middle of these two last-mentioned pegs are drilled holes of sufficient size to admit of small "telephone" terminals being screwed, one in each. In the peg to the right, the hole should be continued until it reaches to the other side of the plank. The terminals are now screwed in these pegs, taking care to insert a piece of No. 24 silk-covered wire into the right-hand hole (from the back of the plank), reaching to the front of the peg, where it makes one turn round the shank of the terminal, which is then screwed up tightly so as to make good electrical contact with the wire. The student will understand that the end of this wire, that has been pushed through the hole, must have previously been bared of its covering, to ensure this. About 10″ of the No. 24 silk-covered wire should be allowed to project from the back of the plank for future connection.

Under the shank of the terminal on the left-hand peg is clenched a loop of No. 24 silk-covered wire, also bared when it passes under the terminal, and projecting for 3″ or 4″ to the left of the peg.

The coherer can now be placed in its position. For this purpose the holes in the terminals must be screwed round by means of a pin temporarily inserted in them, until they are in a line with each other. The milled heads of the terminals are then unscrewed, and the two wires which project, one on either side of the coherer, inserted in the terminal holes, when the milled heads are tightened up, so that the coherer's wires lie parallel to the base with the brass tube thereof standing vertically in the centre, the bent wire pointing downwards. We now proceed to place the bell with its decoherer in position. If the bell be fitted with hanging lugs at the back, these should be unscrewed and removed. The bell should be laid on the plank, with the gong in the centre, and the electro-magnet to the right, the tip of the decoherer (the piece of wire projecting from the ball of the bell) just resting lightly on the ebonite cap of the coherer, or, better still, clearing it by about $\frac{1}{32}''$. The position the bell now occupies should be lightly marked on the plank. The bell is now temporarily removed, and two holes drilled from the *back* of the plank, to the front, of a size sufficient to admit of two flat-headed wood screws, about 1″ in length, passing through the plank, and entering the wood frame of the bell. These holes should be countersunk at the back of the plank, so that the screws when finally adjusted may lie flush with it. The bell is then held in the position previously marked, and the screws driven home, so as to retain it in place. The relay can now be placed on the plank to the left of the gong of the bell, at about an inch from the left-hand edge of the plank, and in a line with the centre of the bell. As the relay must be capable of adjustment, it is not to be screwed down to the plank, but simply supported in the position above described, by three cheese-headed screws placed at equal distances round the periphery of the vulcanized fibre disc, two being placed below and one above. The screws are so set, that the disc rests on their shanks, while the heads project inwardly, so as to clench slightly the edges of the disc. The screws are then tightened to such a point, that the disc is held firmly against the plank, but yet not so tightly as to prevent it being turned clockwise or counter clockwise without difficulty. To facilitate this motion it is well to put a little brass handle (a piece of stout brass wire) in the edge of the disc at the extreme left hand. The relay, when in its normal position, should stand on the plank so that the swinging armature hangs with its free end downwards, and with the yoke of the electro-magnet paralleled to it. When in action the swinging armature at the platinum contact end should clear the lower pole of the electro-magnet by about $\frac{1}{16}''$.

Four terminals should now be inserted in the upper edge of the plank, two on the right-hand side and two on the left, the distance between each terminal of these pairs being about $1\frac{1}{2}''$. Between these two pairs of terminals, also on the upper edge of the plank, a neat leather strap, $\frac{3}{4}''$ wide, about 7″ long, and bowed up so as to form a handle, should be fastened with a screw at each end. We can now proceed to connect up. The wire from the left-hand coherer terminal is connected to the right-hand lower relay terminal. Another wire is passed under the shank of the terminal to the extreme left of the edge of the plank, and brought down and connected to the left-hand lower relay terminal. Another wire is taken from the right-hand upper terminal of the relay, round to below the frame of the bell, on to the lower terminal of the bell itself.

Another wire connects the upper terminal of the bell to the extreme right-hand terminal on the edge of the plank. From the second terminal to the right, on the edge of the plank, proceeds a wire leading to the upper left-hand terminal of the relay. All these wires should be coiled into rather loose helices, to allow for a little play necessitated by the movement of the relay. No. 24 silk-covered wire is convenient for this purpose; it being understood that all portions that enter into, or pass under, the shanks of the terminals, must be bared of their covering and cleaned to ensure of their making good contact. The last contact to be made is that between the right-hand coherer terminal and the inner left-hand terminal on the edge of the plank. To effect this we turn our receiver round so that the back of the plank faces us, and having straightened out the wire which we had passed through the back of the plank, we draw it transversely till it reaches the only free terminal left, which, while the plank is in this position, is the second terminal from the right-hand corner. Having slightly loosened this terminal, and bared the wire at this point, we loop it under the shank of the terminal, which is then driven home, and cut off any excess of wire. This last wire should not be coiled into a helix, but lie flat on the back of the plank. Lastly, we place a couple of dry cells of any good make, standing about 6″ high and 2½″ in diameter, on the ledge on the back of the plank, one opposite each pair of terminals, and fasten them there in position by means of leather straps passing around them, which straps are secured to the back of the plank by means of a screw at each extremity. This arrangement will be found very neat and portable. To put the receiver in readiness for action, it will only be necessary to connect the wires from each cell to the terminals close to it. The complete receiver is illustrated at Fig. 35.

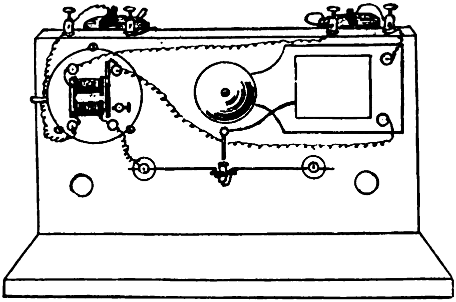

Fig. 35. Completed Receiver.

§ 35. To use the apparatus described in the preceding sections, the coil with its tapping-key, or the Wimshurst, is connected to the transmitter, and arranged to give clear snapping discharges, the negative ball of the transmitter being earthed, and the positive ball, being connected to any metal rod pointing skyward, this latter rod being otherwise insulated. The receiver is now placed perfectly level, at any spot facing the transmitter balls. By means of the little brass handle, the entire relay is slightly rotated on its axis, until the swinging armature *just clears* the poles of its electro-magnet. The batteries are then coupled up to their respective terminals, and notice is taken that the end of the decoherer wire is perpendicularly over the centre of the ebonite cover of the coherer, not touching it, but clearing it by about $\frac{1}{32}''$, so that if the hammer-shank of the bell be sprung and allowed to fly back, the decoherer will strike the coherer.

This adjustment is essential, as, if the decoherer is too far from the coherer, this latter will not decohere, and the bell will go on ringing, instead of giving a clear stroke, for each signal; on the other hand, if the decoherer be too close to the coherer, the play of the bell-hammer will be interfered with, and the bell will give a thud, instead of a clear ring. The next step is to put the receiver in tune with the transmitter. Beginning at a distance of about 10 feet between the two instruments, a spark should be produced between the transmitter balls ($\frac{1}{8}''$ spark should be sufficient at this distance). If the bell does not ring, two pieces of $\frac{1}{8}''$ copper or brass-rod should be placed on the receiver, resting, on the wooden pegs, with their inner extremities bearing against the under portion of the coherer terminals. One of these rods may be earthed. These rods are called syntonizers, or wings, and, for short distances, a couple of stair-rods will do very well. The bell will now ring sharply, when a spark is passed between the transmitter balls, facing the receiver. Should it not do so, the spark-gaps on the transmitter should be increased or diminished until the desired result is obtained. It must be noted that for every change in the capacity of the receiver, effected by lengthening or shortening the wings, a corresponding change will be necessary in the character of the spark, which sets up the wave, at the transmitter; and it by no means follows, that because a long spark will not set the receiving apparatus into action, that a very much shorter spark may not do so.

The distance between the transmitter and receiver may now be increased *ad libitum*, but it must be borne in mind, that in proportion as the distance increases, so also must the spark-gaps of the transmitter be increased. Likewise the length of one of the "wings" on the receiver and on the transmitter, respectively, must increase with the distance, at the rate of about 10 feet per mile: it being understood that the other "wings" are taken to earth. In order to avoid running down the batteries, or risking to polarize the relay, it is advisable never to leave the batteries connected, when not signalling.

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