WIRELESS TELEPHONES

And How They Work

BY

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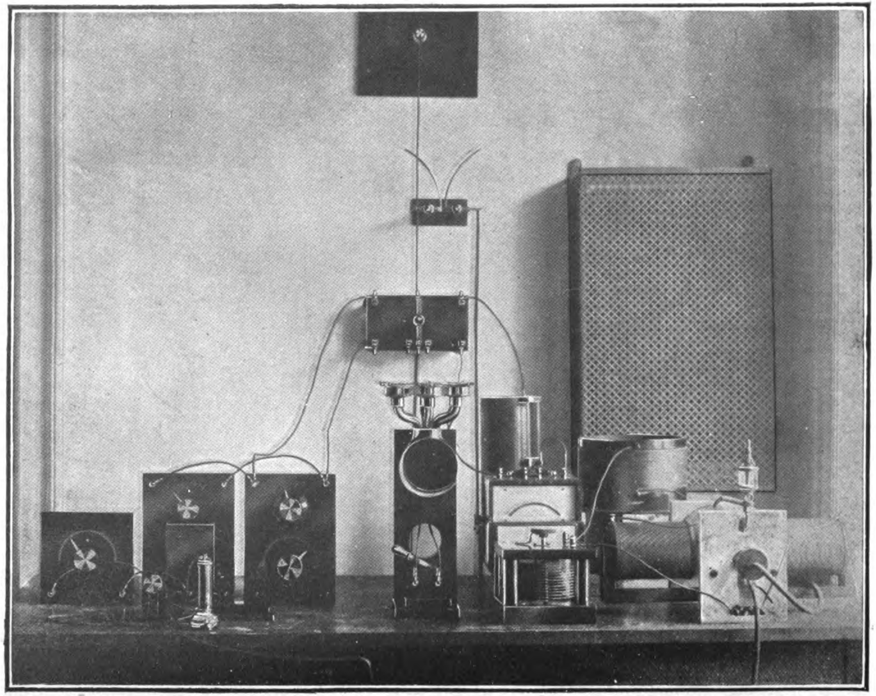

POULSEN WIRELESS TELEPHONE STATION. On the right is the transmitter; in the middle the microphones with aerial wire above; on the left the receiver. [From the *Electrician*, by kind permission of the publishers].

[*Frontispiece*.

PREFACE.

In the nine short chapters which follow I have attempted to give a well balanced sketch of a subject so complex that it has only been possible to show the leading principles in their proper values by excluding a mass of details of lesser importance.

Much time and thought have been expended in the attempt, but both will have been well spent if some of those to whom wireless telephony is as yet but a name are enabled to realise in some degree the dauntless perseverance of the inventors, the wonderful adjustment of means to ends, and the almost poetic beauty of the interlinking laws of Nature which together have gone to the establishment of this new means of intercourse.

I shall also be glad if what I have said in Chapter IX. rouses some of my countrymen to a realisation of the enormous value of cheap and rapid communications within the Empire.

Telegraphs and Telephones, of every sort, are the nerves of the body politic; they carry swift messages from the extremities to the brain centres, and transmit instantaneous orders for action from brain to hand. Their failure is paralysis. This Empire is peculiarly liable to such failure owing to the thousands of miles of sea which separate its parts. We must therefore welcome and encourage every new invention, such as wireless telephony, which tends to avert the most serious disease to which our national life is subject.

J. ERSKINE-MURRAY.

34, Norfolk Street,
London W.C.

December, 1909.

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WIRELESS TELEPHONES.

CHAPTER I.

HOW WE HEAR.

THERE are few more wonderful organs in Nature than the ear. From mere changes of air pressure on its drum it gives us a series of sensations, pleasant or unpleasant, musical or unmusical, and, most remarkable of all, it enables us to distinguish between many simultaneous sounds although these, when they arrive at it, are absolutely fused together as a mere motion of the particles of the air.

From whatever source a sound is produced, whether from the vibration of the vocal chords of a speaker, from the trembling parchment of a drum or the string of a violin, its mode of transmission to the ear is the same.

What passes out from the source is merely a rhythmical series of changes of pressure which spreads in ever widening spheres throughout the atmosphere. These compressions follow one another in an order which is different for every sound.

Thus it has been found that the sound "oo," as in boot, is the sensation produced by a uniform succession of equal changes of pressure following one another at equal intervals of time, and the sound "ah," by groups of pressure changes, each group containing a large pressure and several smaller ones. In more complex sounds the grouping of the pressures is more complex

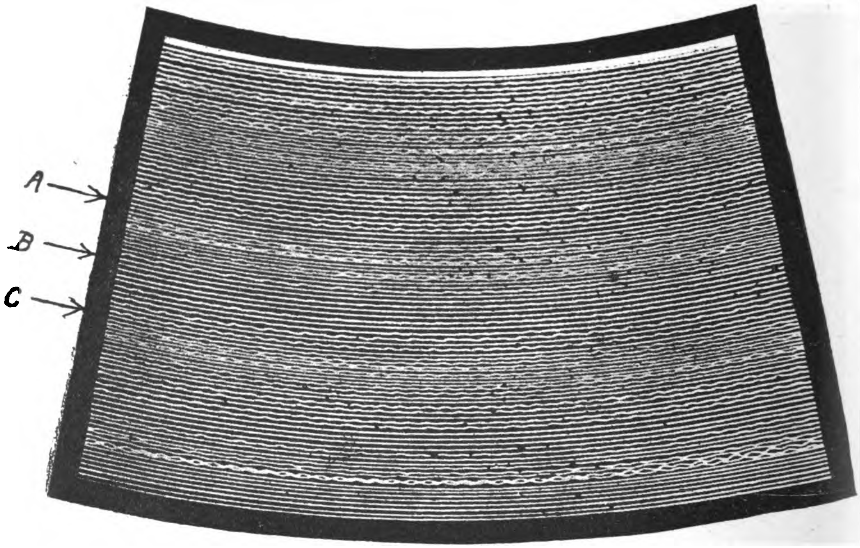

FIG. 1.—Portions of the Record of a powerful bass voice (Oreste Luppi, of Milan) singing *La Calumnia* from *Il Barbiere di Siviglia*. Examine with magnifying glass. Note the different types of wave corresponding to different sounds :— *e.g.*, at A, waves in groups of two; at B, waves which rise steeply and fall slowly; at C, a nearly uniform series of equal waves.
[From an article by Professor J. G. McKendrick, LL.D., F.R.S., in *Nature*, of 15th April, 1909.]

also, the changes sometimes following one another in an order so apparently confused that there is no way of analysing it but by the ear.

For instance, the sound of a band, as it reaches the ear, is compounded of all the various types and rates of compression waves given out by the different instruments, but it can be recorded in the form of one, apparently irregular, wavy line on the wax cylinder of a phonograph. The trained ear, however, can distinguish each instrument. It is this fact, and not the electrical questions, which renders telephony so mysterious a means of communication.

Once it is grasped that the physical cause of even the most confused sound—the din of an ironworks, the babel of a market place, or the music of a band—is merely a pulsation of the air, the rest is comparatively simple.

Sound is a picture, painted, not in space and colour, but in time and motion.

It is easy enough to understand that the varying pressure of the air acting on a flexible membrane may cause it to press together, alternately more or less firmly, two pieces of carbon, one of which is attached to the membrane, and that in so doing an electrical current, passing from carbon to carbon, must vary in strength in time with the changes of pressure.

In telephony this simple apparatus is called a microphone, or transmitter. At the other end of the wire the reconversion of the electrical variations into air-pressure variations is equally direct. As the electric current increases or decreases it attracts or releases a springy thin metal disc which, by its motion, compresses or rarifies the air next to it, causing changes of pressure, which are replicas in every characteristic of the original waves, to spread rapidly outwards, producing in the ear of the listener the sensation of the same sound as was spoken into the transmitter.

To understand how the sound of the voice is transmitted by a telephone one must, therefore, understand the physical nature of the sounds themselves. Now book-knowledge of nature is, alone, most unsatisfactory, so those who wish to know at first hand how things really are should make some trials for themselves.

To see the motion due to a wave of sound, for instance, hang from any convenient support a thin sheet of notepaper or cotton wool by two threads, each a foot or two long, attached to different points of the same edge of the sheet. When it has come to rest, hanging vertically, stand squarely facing it at a yard away, holding upright between your hands a board or cardboard not less than a foot square.

Get some one else to watch the hanging sheet closely and suddenly jerk the board towards you. The sheet jumps in the same direction as if tied to the board by a cord.

What you have observed is the progress of a wave of diminished pressure, or rarefaction, through the air, a sound wave in fact, but not of sufficient suddenness to give the sensation of sound, though it does move the drum of your ear slightly.

As you pulled the board towards you, you made a partial vacuum behind it, the adjacent air fell into the emptier space, and the falling in process travelled outwards till it moved the paper towards you, *i.e.*, when the wave reached the paper it reduced the air pressure on the side nearest you, so that the air beyond, which was at higher pressure, pushed the paper in.

If you take a spadeful out of the bottom of a heap of dry sand or gravel, you will see a very similar process occurring, the gap being nearly filled up again by sand falling in from further and further back in the heap. The grains of sand represent the molecules of the air, and their weight the elastic forces which move them. Owing to the mass of each sand grain being much greater than that of a molecule of air, while the force acting on it is less, the motion of the air wave is enormously more rapid than that of the sand.

The wave produced in the way described above is technically called a wave of rarefaction. A wave of compression may be produced by holding the board loosely in one hand and striking it sharply on the back with the closed fist of the other. Both kinds of wave travel at the same speed—about 1,100 feet per second, or taken roughly, 5 seconds to the mile—and an audible musical sound is produced provided the pulsations succeed one another uniformly at any rate between 30 and 30,000 per second.

The former is a very low note, and the latter a very high one. One cannot move the board to and fro with sufficient rapidity, while holding it in the hands, to produce a musical note, but if it be clamped to the back of a chair and struck sharply it will do so if of suitable size and thickness.

Air waves have actually been photographed by Mr. Vernon Boys. Fig. 4 shows a rifle bullet travelling at a speed of about 2,000 feet per second, and the dark lines slanting away on either side of the bullet, like the waves of a ship, are the air compression waves which on reaching the ear give the sensation we know as the

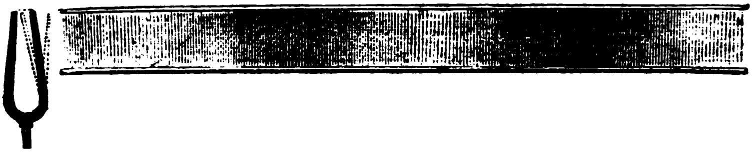

FIG. 2.

FIG. 3.

Two ways of representing Sound Waves. The denser portions where the pressure is high are represented by the crests in the lower diagram.

scream or whistle of the bullet. At the right hand side of the figure the sound waves are seen in advance of the flying particles of powder. This is because the latter are not travelling as fast as 1,100 feet per second, at which speed, or very near it, all compression waves travel in air whatever be their cause. The waves, therefore, run ahead of the particles.

On account of difficulties in drawing, it is usual to represent sound waves as wavy lines, like those representing waves on the surface of water; only the height of the wave represents the pressure, and not trans-

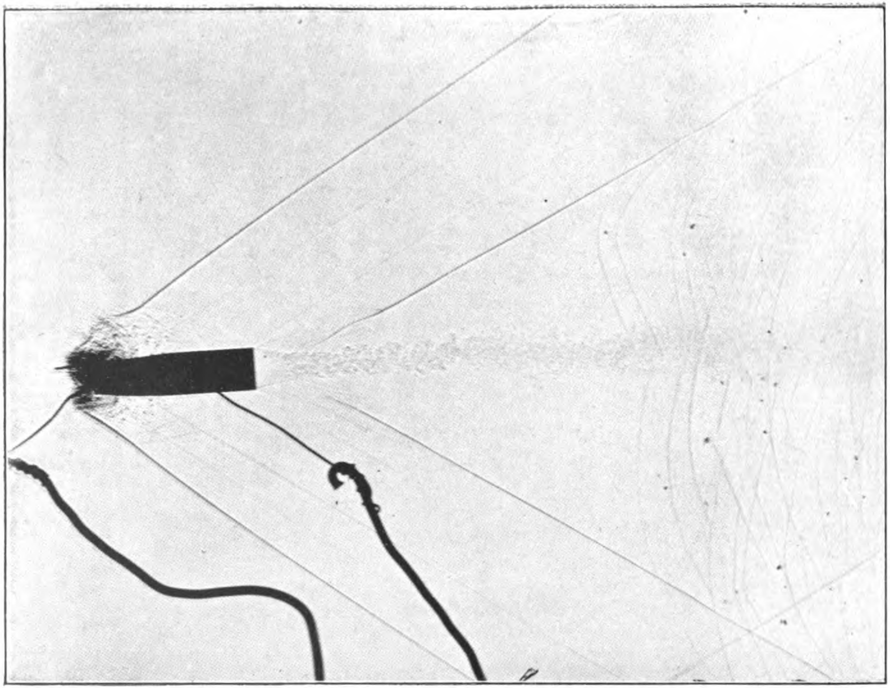

FIG. 4.—AIR PRESSURE WAVES IN PHOTOGRAPH OF FLYING BULLET. [C. V. Boys.] The lines extending on either side from near the front and rear of the bullet are Air Pressure Waves, which constitute the Sound of the whistle or scream of the bullet. The black crooked lines are wires which the bullet strikes, and so completes an electric circuit, causing an electric spark, which takes the photograph instantaneously. The powder at the head of the bullet is broken fragments of one of the wires.

[*To face page 6.*

verse motion. Another method would be to represent the increased pressure by a darker shading, but though this gives a better "picture" it does not make so useful a diagram, since it is easier to measure a simple distance than to judge the depth of a shade.

Figures 2 and 3 show the same waves represented by these different methods. It is obvious that fig. 3 is really more useful than fig. 2, although, apparently, less realistic, for the extra pressure at any point is shown as the distance of the curve from a horizontal straight line, and this, being simply a length, is easy of measurement.

In fig. 2 it is not possible to determine the change of pressure by any such simple method. The latter, however, gives a pictorial representation of the crowding together of the air molecules during the passage of a wave of pressure which renders the process more easily understood.

The loudness of a sound depends on the amount and suddenness of the change of pressure on the drum of the ear, and the note, or pitch, on the number of complete to and fro movements the drum is forced to make per second.

The quality of a sound, *i.e.*, the difference between two different vowels sung or spoken on the same note, or between the tones of a cornet and a violin, depends on the smoothness or jerkiness of the changes of pressure. It is here that the difficulties of telephony of every kind begin, for not only must the variations of the electric current be made to correspond roughly with the

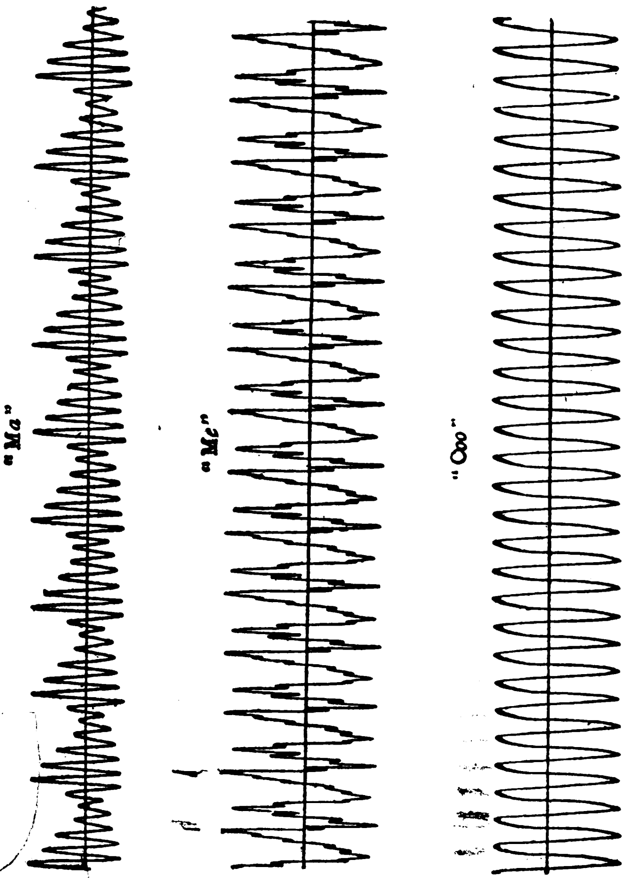

FIG. 5.—WAVES WHICH CAUSE VOWEL SOUNDS. From a paper by Mr. Duddell, in the Journal of the Institution of Electrical Engineers. [By kind permission of the Council.]

changes of air pressure, but they must actually resemble them in every small detail.

The changes of current must take place as rapidly as the changes of pressure, every slight check in the rate of increase of the one must be imitated by an exactly similar check in the rate of change of the other, and every increase or decrease by an equivalent increase or decrease. Without such exact similarity a sound of sorts may be transmitted, but it will be wanting in the quality which would distinguish one vowel or consonant from another; it will, in fact, be quite inarticulate.

The simplest way to get an understanding of how a pressure wave in air may have these characteristics is to hold out one hand, with the thumb uppermost, and move it to and fro. As it moves forward it presses against the air, causing a wave of compression to go forward, as the air waves from the bullet do in fig. 4. If you could move your hand to and fro at thirty or more times in a second it would produce a series of smooth pressure waves which the ear would appreciate as the sound "oo" sung on a note whose pitch would depend on the number of complete to and fro motions in a second.

If, however, instead of moving the hand in one smooth sweep from side to side you make it go by jerks, you will send out a pressure wave which will have in it a number of little extra waves in addition to the long one caused by the whole motion of the hand from right to left. A jerky motion like this, repeated sufficiently rapidly, would give to the ear the sensation of some more complex sound, such, for instance, as the vowels "ah" or "ee." Which of the vowels or consonants would actually be produced, depends solely on the number and type of the jerks in each whole movement.

It is thus that the movement of the diaphragm in the reproducer of a phonograph or gramophone is able to produce sounds of every quality.

The smoothness or jerkiness of the motion of the vibrating body, whether it be the vocal chords, or the thin metal plate of a telephone, is therefore the essential thing which gives the sound its distinctive character and enables the ear to distinguish one word from another.

Of the functions of the ear itself and how it translates changes of pressure into sensations of sound, or even analyses a complex motion, very little is known. Its anatomy is, of course, well understood, and to a certain extent the functions of its parts, but beyond these elements comes the region of psychology—a science of which even the foundations have as yet been but imperfectly laid.

Suffice it to say that the drum of the ear is a thin membrane so formed that it is capable of vibrating to sounds of almost any pitch or complexity, and that from the drum the vibrations are conveyed by the corresponding motions of a chain of small lever-like bones to an inner organ which appears to be capable of analysing the vibration before transmitting the impulses along the nerves to the brain.

CHAPTER II.

HISTORICAL.

THE history of the invention of a practical method by which words spoken in one place could be heard many miles away without the use of any artificial connection between the speaker and hearer is an interesting episode in the development of mechanical civilisation. It is also an instance of the curious way in which a line of investigation which has been laboriously followed for years with considerable promise of ultimate success, is suddenly shown to be but a side track by some discovery as unexpected as any chance can be.

Fully twenty years after the first demonstration of the power of the photophone to transmit the voice by means of the flickering of a beam of light controlled by the sound waves of the speaker's voice, the invention of electric wireless telegraphy, bringing with it the possibility of an electric wireless telephone, altered the situation completely.

The greater power and freedom from interference due to atmospheric conditions which the longer electric waves possess made their adaptation to telephonic purposes a desideratum which excited the inventive powers of many workers in electrical science, and very shortly after the construction of the first practical wireless telegraph by Mr. Marconi, quite a number of patents were taken out for a telephone based on the same principles.

It is true there had been attempts at electric wireless telephony previously, but the apparatus required was extremely large and inconvenient, and the distances bridged but small.

The early patents based on the Marconi telegraph were, however, unsuccessful, for the simple reason that it was impossible to transmit, say, three thousand sound waves per second, by means of about one hundred electric impulses per second, particularly as the impulses were separated by intervals of time much longer than the duration of any one of them. The original wireless spark gave such impulses, with comparatively long blanks between them, during which nothing was transmitted.

It was impossible, therefore, under these circumstances to reproduce speech in which as many as three or four thousand vibrations may occur in a second. Experimenters, therefore, turned their attention to the production of electric sparks at a very much higher rate. Professor Fessenden, for instance, employed a rotating disc with a large number of metal knobs upon it which made and broke the connection between the battery and the transformer as often as ten thousand times a second. The result was that ten thousand impulses were radiated in every second and telephonic transmission of speech became possible.

This method, though it gave some sort of transmission, was not satisfactory, as unavoidable irregularities in the sparking caused a harsh noise in the telephone, and the articulation at the receiving end was very in-

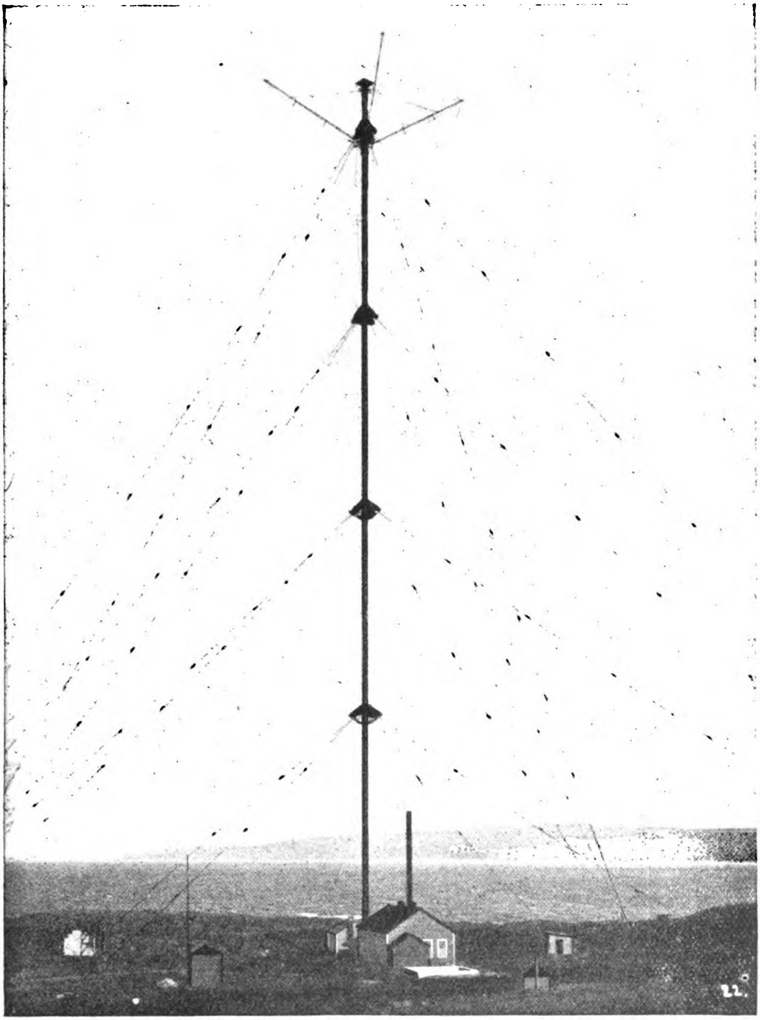

FIG. 6.—Steel Tower, 415 feet high, at Machrihanish, in Argyllshire, used by the National Electric Signalling Co. for wireless communication with a similar station at Brant Rock, near Boston. Professor Fessenden's Wireless Telephony experiments have been mainly carried on between the latter and others in America.

distinct. Professor Majorana tried other methods to obtain the desired result, but with no greater success.

By adopting Elihu Thomson's method of producing a very rapid series of electrical impulses, and improving it in many details, Fessenden was at last successful in obtaining an intelligible wireless transmission of speech. This was in 1902, and since then progress has been rapid.

Four years later the same experimenter had so far perfected his apparatus as to be able to give a satisfactory demonstration, to a number of telephone engineers, of wireless telephony over a distance of eleven miles. At the same time he showed that it was possible to connect up a wire telephone system with a wireless one, and thus to have a line of telephonic communication which was in part a line wire and in part wireless.

In fig. 6 is shown the great steel tower which was erected at Machrihanish, in Argyllshire, by Professor Fessenden's Company, as an aerial conductor for transatlantic wireless telegraphy; it is from an exactly similar tower at Brant Rock, Massachusetts, that most of his wireless telephone experiments have been carried out.

In his later experiments Mr. Fessenden has used an alternating current dynamo constructed to give from fifty to eighty thousand complete periods, or waves, per second. With this machine as a source of electrical energy, telephony is very clear and distinct, and has been carried on over a distance of several hundred miles.

The other workers who have had most success in getting practical results in telephony are Majorana, in Italy; Poulsen, in Denmark; the Telefunken Company and Ruhmer, in Germany; and De Forest, in America.

Professor Majorana has worked long and indefatigably, and has attained great success both as regards clear transmission of speech and in the distance over which conversations have been carried on. His microphone transmitter has proved to be very efficient, not only for wireless, but also for wire telephony.

Mr. Poulsen's successes in telephony without wires are a natural outcome of the type of wireless telegraph which he has done so much to develop. Basing his inventions on Mr. Duddell's discovery of the musical arc, he obtained alternating currents of sufficient frequency and energy to enable him to carry on radio-telephony over long distances.

Using somewhat similar apparatus, the Telefunken Company has made a large number of experiments in the past few years, and is understood to have obtained satisfactory results. Mr. Ruhmer's system differs from those already mentioned in the employment of a very high voltage current as a supply. This, though advantageous from the electrical point of view, renders the operation of the apparatus by unskilled persons rather risky, since the voltage is high enough to cause danger to life should the operator touch the wires accidentally.

In America Dr. De Forest has done much for the development of radio-telephony as a practical means of communication, his apparatus having been fitted on board the U.S. fleet which sailed round the world, and since then on other vessels and at inland stations.

These, so far, are the names of those who have done most in actual modern wireless telephony, though there are others who might be mentioned as having contributed to the general result. M. Blondel, of the government engineering service in France, for instance, patented a system some years ago, but as no experiments on more than a laboratory scale appear to have been carried out, its value has never been ascertained.

Although Mr. Marconi's original system of wireless telegraphy is quite inapplicable to telephony, his recently invented rotating disc generator of alternating current produces a current suitable for the purpose; Mr. von Lepel's wireless telegraphy system is also well suited to telephony. We may, therefore, expect that their respective companies will, before long, add telephonic apparatus to their existing telegraphic systems.

We shall now leave the historical development of the invention, and shall in the following chapters show how the waves of pressure in the air, which constitute the sound of a voice, can be converted into waves of electric current, and how these latter may be transmitted to great distances over land or sea and then be reconverted into air waves audible to the ear.

CHAPTER III.

THE CONVERSION OF SOUND INTO ELECTRIC WAVES.

SINCE the physical cause of every sound is simply a series of changes of pressure, electrical telephony resolves itself into the conversion of mechanical changes of pressure into changes in the strength of an electric current at the transmitting end, and the reconversion of these into mechanical motions in the receiver at the listener's ear.

The first instrument by means of which articulate speech was successfully transmitted electrically was the ordinary telephone, invented by Dr. Alexander Graham Bell about thirty-four years ago. Its début on this side of the Atlantic was at the British Association meeting at Glasgow in 1876.

The writer well remembers being taken as a boy to see the pair of wonderful little instruments by which the voice was transmitted some hundreds of feet from Lord Kelvin's (then Sir William Thomson) laboratory to the University Library across the quadrangle. To this day the receiver which one puts to one's ear is of the very same type; though at the transmitting end the microphone has taken the place of the original Bell telephone. That pair of telephones has multiplied enormously in the past thirty years, for there must now be several hundred thousands of them in daily use in this country alone, and over two millions in the world. Guinea pigs aren't in it.

The Bell telephone is exceedingly simple both in construction and in its action, which depends on the fact that change of magnetic force will induce a current in a wire placed near the magnet whose force is changed. In the figure the wire is shown wound round the magnet on a bobbin. The thin iron disc, which moves to or fro when the air pressure on it changes, causes at each movement a variation in the distribution of the magnetic force in its neighbourhood, and thus induces

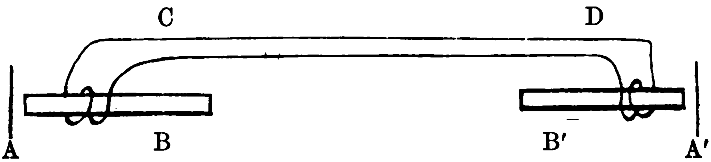

Fig. 7.—Bell's Telephone. A,A′, Thin Iron discs; B,B′, Magnets; C D, connecting wires. The motion of the disc A, when spoken to, causes a varying current in the wire, which in turn causes the disc A′ to move in the same manner as A and thus reproduce the air waves, *i.e.*, the Sound. The Ebonite covers are not shown.

in the wire currents which vary in time with the movements of the disc and are conducted along the wires to the other instrument.

As the current thus brought to the receiving instrument increases or decreases in strength, while flowing along the wire wound round the magnet, it adds or subtracts from the magnetic force of the latter, thus pulling in, or releasing, the thin iron disc near it. The disc, therefore, follows exactly all the changes of the current, and consequently reproduces the motions of the transmitting disc which are the cause of these variations. The receiving disc thus causes waves of pressure in the air next to it which travel to the ear and are recognised as the voice of the speaker at the other end of the line.

The first great improvement in telephony was the invention, by D. E. Hughes, of the Microphone, and its adoption as transmitter in connection with a Bell telephone as receiver. In the original telephone line, as described above, the energy transmitted by the wire

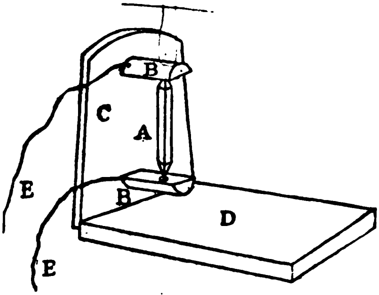

FIG. 8.—HUGHES' MICROPHONE. B B, Carbon blocks; A, Carbon rod; C D, supports; E E, Wires to battery and telephone.

as electric current cannot be greater, and is, indeed, much less than the energy of the speaker's voice. With a microphone as transmitter, however, the energy of the current may actually be much greater than that of the spoken sound, for the microphone acts as a valve, not transforming sound energy into electric energy, but merely controlling the current from a battery. The microphone is, in fact, like the steam valve, by turning which a child can control the movements of a great engine.

In its original form the microphone is a very simple instrument; merely two pieces of conducting material loosely touching one another and connected to a battery so that an electric current flows from one to the other through the point of contact. The most suitable material is carbon, one form of the apparatus being shown in fig. 8. Here the upper and lower blocks of carbon are slightly hollowed out and the double-pointed rod is loosely held between them.

Any change of pressure on the carbon rod causes it to press more or less firmly against the blocks, and thus increases or decreases the resistance of the contacts to the passage of the current. Since the electric pressure of the battery which drives the current through the resistance is a constant thing, a variation of the resistance causes a proportional variation in the current; hence, if the current be led by wires to a Bell telephone, the original sound, spoken to the microphone, will be reproduced.

The advantage of using a microphone instead of a Bell telephone as transmitter is that the variations of the current caused by speaking into the former are far greater than if the latter is used, their amount being only limited by the power of the carbon contact to carry current without becoming too hot. If the point of contact between the carbons does become very hot an arc is formed and the resistance is no longer varied by alteration of the pressure, thus though a large current may be passing it may not vary in accordance with the sound waves. This natural limitation to the power of a microphone is one of the greatest difficulties in wireless telephony, for large currents are here essential and the problem of their control has only been partially solved.

There is a very large number of types of microphone in existence at the present day, some having a single variable contact, some several, and others a very great many. The last named are small boxes containing, between conducting discs at front and back, a quantity of carbon granules loosely packed together. It is this type which is most commonly used for wireless telephony.

Prof. Majorana has devised a microphone on a totally different principle, and his achievement of wireless telephony between Rome and Sicily, a distance of 312 miles, is proof of its wonderful efficiency. A fine jet of conducting liquid falls just between two platinum plates, which are in the transmitting circuit, the nozzle being fixed to the diaphragm on which the voice acts. The vibrations cause the jet to vary in thickness, thus altering the conducting power of the film of liquid between the plates, and, therefore, the current which passes from one to the other.

In wire telephony there are many other subsidiary pieces of apparatus necessary to the production of the wonderfully loud and clear speech obtained in a modern telephone, but as these are not, in general, applicable to wireless transmission, it is unnecessary to go into detail.

CHAPTER IV.

WIRELESS TRANSMISSION.

In ordinary wire telephony the electric current is guided, or conducted, from place to place by the wire. The words "guided or conducted" are literally true, but notice that they do not exclude the idea that the electric action we call a current takes place without, as well as within, the wire; indeed, they rather indicate that it is mainly outside. This is in fact the case, and the insulator outside the wire is in reality as important as the wire itself.

If the wire is to conduct a current it must be insulated throughout its entire length by air, india-rubber, cotton, or some other non-conducting material; also, if the current is to go on flowing in one direction, the conductors must form a complete circuit, *i.e.*, a closed loop joining one pole of the battery to the other. If the loop is not closed momentary currents will flow into the loose ends from the battery or dynamo, but these will cease when the conductors become full up with electricity.

On the other hand the importance of the insulator in transmitting the current can be understood to some extent from the following experiment. Suppose that two bare copper wires are hung up across a pond, and made into a closed conducting loop by connecting one pair of ends through a microphone and the others through the wire wound round the magnet of a telephone. While they are insulated in the air speech can be transmitted from the microphone to the telephone, but if they be lowered into the water, which is a conductor, it will be found impossible to receive any sound at all. In order that electric current may be guided along a conductor it is therefore necessary that the conductor should everywhere be surrounded by a non-conductor.

An even more striking demonstration of the necessity for the insulator would be found by passing the two wires intended to form the circuit through two tightly fitting holes in a wall of copper a foot thick, forming one side of a completely closed copper room. In this case it would be quite impossible to transmit any current into the room by means of the wires, and experiment would show that where the wires entered the wall the current left them and passed across from one to the other, mainly in the surface of the copper which is in contact with the insulating air outside it.

Contrary to commonly accepted notions it is the fact that electric actions can be transmitted by an insulator without the presence of a conductor, although they cannot be transmitted by a conductor without the assistance of an insulator. Light, for instance, which is an electrical action, passes with ease through glass and other non-conductors, but cannot pass at all through copper.

The same is true of the longer electric waves discovered, mathematically by Clerk-Maxwell, and experimentally by Hertz; they are reflected from a sheet of metal without penetrating it appreciably, can pass directly across an insulating medium without the aid of a conductor, though if there is a conductor they will follow it; but they become restive at any bend,

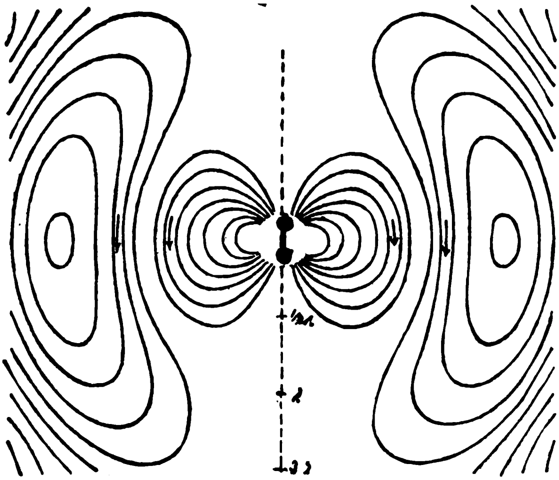

FIG. 9.—Electric waves radiating from a dumb-bell-shaped conductor with current surging to and fro in it. The lines show the direction of the electric force at the moment of the picture. The curves are enlarging and spreading outwards with the speed of light. [Hertz.]

preferring a straight path. Even ordinary alternating currents such as are often used for lighting, show a similar preference, and may be "choked" by bending the conductor into a coil of many turns.

In the figure 9 the closeness of the lines indicates the intensity of the force at the place; this is naturally greatest near the radiator during its periods of maximum radiation, and decreases outwards from it. It should be noticed that there is no radiation in a vertically up and down direction, and that the maximum is in the line at right angles to the middle of the radiating conductor, *i.e.*, horizontally, if the conductor be vertical, as in the figure.

Here, then, we have the possibility of entirely wireless communication, the possibility of sending an electric wave right across an empty space to some instrument which can detect its arrival at the other side. The first wireless telephone was, indeed, of this type, although light waves, and not Hertzian waves, were the means of transmission. With the photophone, invented by Dr. Graham Bell in 1878, speech was transmitted several hundred yards, while with a much improved, though similar, form of apparatus, Mr. Ruhmer has recently been able to converse over a distance of several miles.

Telephony by light, or by short Hertzian waves, has, however, two great disadvantages which renders either method quite unsuitable for general use. The first of these disadvantages is that the radiation, and, therefore, the transmission of speech, can only take place in a straight line over clear country, for it is deflected or absorbed by intervening hills, trees, or other solid objects. The second objection which applies to light, but not to the longer Hertzian waves, is that even a fog will entirely prevent communication.

The first difficulty is, however, so serious that telephony with short waves, as produced by Hertz, has not even been attempted, since the experience of wireless telegraphists has shown its impracticability.

Wireless transmission, whether for the purpose of telegraphy or telephony, is, therefore, carried out not by means of light, or even of free Hertzian waves, but depends on the use of electric currents conducted by the surface of the earth from the transmitter to the receiver.

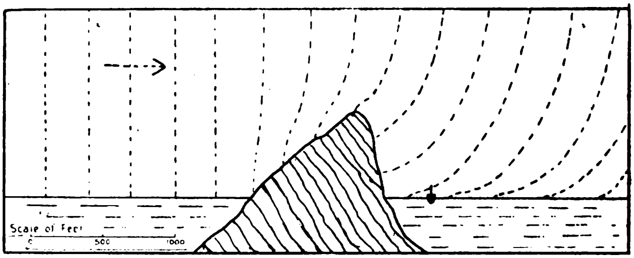

Fig. 10.—Electric Lines of Force (Waves) travelling over Sea and Land. Notice the bending behind the Island. [From *Wireless Telegraphy*, by J. Erskine-Murray.]

There are two methods by which this may be done, but only one of them is at all suitable for distances of over a very few miles. In the earlier form a long horizontal wire, supported on posts, is connected to the ground at both ends, one of the connections being through a microphone and battery. At the receiving station there is another long wire parallel to the first and connected to the ground through a telephone receiver. On speaking into the microphone the sound is heard in the telephone on the other line. The applications of this method are, however, very limited, for it is necessary that the length of each of the wires should be considerable, quite an appreciable fraction, in fact, of the distance between the stations.

The other method is that on which all modern wireless telegraphy and telephony depend. Only one earth connection is made at each station, the other end of the wire being elevated above the ground by a pole to a height which depends mainly on the distance between the stations. For distances up to twenty or thirty

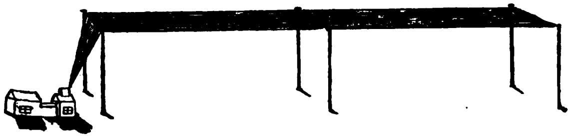

FIG. 11.—Aerial conductor of Mr. Marconi's Transatlantic Station at Clifden, Ireland. For short distances the fan-shaped portion would be sufficient. The horizontal wires are added to give greater power for long distances.

miles an elevation of about fifty feet is sufficient, while for greater distances greater heights are advantageous. There are, of course, limits to the height to which a mast can be raised, so that in practice it is common to add to the radiating power of a station by extending the wire horizontally at the top, or by using several wires, or, finally, by using more powerful instruments.

Here there is no closed conducting circuit as in wire telephony. Each wire ends at an insulator at the top of a pole, and the space between them contains only air, which at ordinary atmospheric pressures is one of the most perfect insulators known. There is only one conductor, therefore, between the stations, and this is the earth. Thus a steady current cannot be caused to flow from one to the other, all that is possible being a momentary current which dies out as the transmitting wire becomes full up with electricity. If, however, when this occurs the direction of the electric force in the transmitting wire is reversed, and the electricity forcibly driven out again, a further small quantity of energy is sent out along the earth's surface.

By repeatedly reversing the direction of the current in the transmitting wire we produce what is called an alternating current, and at each alternation a wave of current speeds out all round the station, ultimately dying away in the far distance. As this current sweeps in an ever widening circle past the receiving station it rushes up the wire, falling back again as the wave passes;—like a wave of the sea in a blow-hole on a rock-bound coast;—again surging up as the next wave passes. It is by means of this alternating current, radiating from the sending station and affecting the receiver as it passes outwards, that sound is transmitted in wireless telephony.

Now since at each alternation only a small quantity of energy is sent out, and of this small quantity only a minute fraction reaches the receiver, the rest going in other directions, it is clear that the alternations must be made to follow one another very rapidly in order that the quantity of energy arriving at the receiver in a given time may be appreciable.

The current in the transmitting wire must, therefore, alternate at a high frequency, *i.e.*, its direction must be reversed, and a wave sent out, not less than, say, a hundred thousand times in a second. A hundred thousand waves per second seems a great many, though as a matter of fact it is but a small number for wireless transmission, and incomparably smaller than the three-hundred-million-million waves of light which enter the eye in the same period of time.

CHAPTER V.

THE PRODUCTION OF ALTERNATING CURRENTS OF HIGH FREQUENCY.

THERE are several ways in which the electricity may be made to move to and fro at a very high rate. The simplest to understand, although not as yet the most usual in practice, is to use an alternating current dynamo so constructed that it gives a hundred thousand alternations per second, or thereabouts, instead of the usual number of fifty or a hundred employed in electric lighting circuits.

The difference is, of course, a very great one, necessitating the use of two or three hundred magnetic poles on the machine in place of, say, half a dozen, and the machine must have a very high speed of revolution. Professor Fessenden has used this type of high frequency current generator with success in America, obtaining a very clear transmission of speech over considerable distances by modifying the current in accordance with the sound waves by means of a microphone.

The dynamo is based on Faraday's discovery that if the end of a magnet be moved near a wire a current will be generated in the wire. An alternating current dynamo, therefore, may consist of one or more magnets mounted on a shaft, with their ends sticking out from it like the spokes of a wheel. Surrounding the magnets, but not touching them as the rim of a wheel would its spokes, is a fixed iron ring, like a magnified wedding ring in shape, on the inner surface of which is a large number of parallel saw cuts in which insulated wires are laid. Suppose now that a wire is laid in one slot, and then has its loose end bent back and laid in another slot, the two ends being connected to the apparatus to which it is desired to supply the current. The wire is now shaped like the letter U, each leg lying in a slot.

Now drive the shaft round by starting the steam engine or turbine attached to it. As the end of a magnet passes the part of the wire in the first slot it will create a current in it which will flow from right to left, and therefore, say, from one end of the wire, A, to the other, which we may call B. As the magnet passes away from the slot the current dies out. The magnet now, however, commences to influence the part of the wire in the second slot, producing, as before, a current from right to left. The result now in the circuit is therefore a current from B to A. Thus, as each magnetic pole passes the slots it causes a to and fro motion of electricity in the wire, and since the direction of this motion alternates between being from A to B, and being from B to A, the current is called an alternating current.

An ordinary alternating current dynamo is built on these principles, the only difference being that wires are put in all the slots on the inner side of the ring and are connected to one another so that each contributes to the production of current in the outer circuit where the work is done. The ring with the wires in it is called the armature.

The number of alternations of the current depends directly on the number of poles which pass a given wire of the armature winding per second. Thus the higher the speed of revolution and the greater the number of the poles the greater is the frequency (number per second) of the alternations of the current. The difficulties of this method are mainly mechanical or depend on mechanical conditions. Thus the speed of revolution is limited by the strength and weight of the moving parts—they would fly to pieces if driven too fast—the magnetic poles have, therefore, to be placed very close together, which is disadvantageous from an electrical point of view. The friction of the air at such high speeds as are necessary is also considerable.

These considerations, coupled with the expense of constructing machines of this type, have led many experimenters to adopt another method depending on an entirely different principle. In the alternator the movements of electricity are produced by the changing magnetic force on the wires due to the motion of the magnetic poles across them; in this other method a steady current is converted into an alternating one, or, rather, a part of it is so converted, in the same manner as a steady blast of air is changed into to and fro waves of pressure, *i.e.*, sound, by an organ pipe, or whistle.

Here the resistance to the passage of a draught of air through a certain opening in the pipe is variable owing to the bending of the lip under the pressure of the air blast against it. In the reed pipe the natural

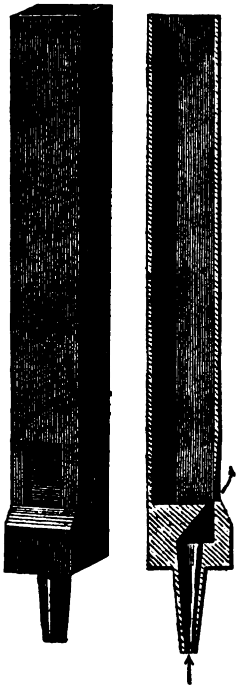

Fig. 12.—Organ Pipe, showing air blown against lip. Note the hollow part of the pipe (from the lip upwards), which controls the rate of vibration. The longer the pipe the slower the vibration.

rate of vibration of the reed itself controls the sound given out, but in the ordinary pipe, or whistle, the lip has no definite rate of vibration of its own, and the pitch of the sound produced is determined by the length of the column of air enclosed by the pipe.

In what is usually called the "arc" method of producing alternating currents the general principle is much the same as that of the ordinary whistle, except that an electric current is substituted for a blast of air; an electric resistance, which varies with the strength of the current through it, for the varying resistance of the lip, and a combination of conductors which has a natural rate of electric vibration for the column of air enclosed in the pipe.

The most suitable kind of variable resistance is a short gap filled with air or other gas between two solid conductors. When cold the resistance of such an air space is enormous, but when heated by the flow of a current across it, its resistance falls to a few ohms, and under proper conditions every little variation in the strength of the current causes a corresponding change in the resistance opposing it. Across the ends of this variable resistance is connected the system of conductors which determines the frequency or pitch of the electrical vibration, *i.e.*, the frequency of the alternating current produced. Expressed in ordinary language, 'frequency' means the number of times that the current goes to and fro in one second.

On sending the current from a direct current dynamo, or from a battery, through the air gap the electricity in the circuit attached to it commences to move to and fro at a rate which is controlled mainly by the electrical dimensions of the conductors, and continues to do so as long as the direct current is supplied. Here, then, we have a simple method of obtaining alternating currents whose frequency may be made as great as desired by changing the dimensions of the conductors of the circuit.

Like all other methods it has, of course, its weak points, but these have been overcome to a great extent by proper design of the apparatus.

In order that the variations of the resistance of the air gap may be large it is necessary that the air and the surfaces of the conductors from which the current passes across it, should be cooled as rapidly as possible. A very great deal of ingenuity has been expended on devising methods for doing this satisfactorily and without too many complications. As examples of these we have the copper electrode, cooled by air or water, used by Poulsen and others, the comparatively large metal plates separated by a layer of air only as thick as a sheet of paper which von Lepel uses, or the blast of air caused by the rapid motion of the plates in the Marconi apparatus.

Hydrogen gas, either in the form of a gas or alcohol flame, or in an enclosed arc lamp, has been used by Tesla and Poulsen to increase the efficiency of an arc as generator of the high frequency current; its function is not thoroughly understood, but it has undoubtedly the power of conducting heat away very rapidly, and it prevents the burning away of the electrodes which takes place in air, both of which properties are advantageous.

Many different forms of circuit have also been invented, though as yet the most successful telephony has been carried out with the earlier and more elementary forms. They all depend on the principle that under certain conditions as regards their relative dimensions, the electricity in a set of electrical conductors connected together will, when set in motion, oscillate to and fro before coming to rest.

There are many mechanical analogies by which this principle may be illustrated, two of the simplest being the violin and the watch. In the violin the steady forward motion of the bow produces the to and fro motion of the string; in the watch the forward motion of the mainspring produces the to and fro motion of the balance wheel. The two are typical of the two chief methods by which a direct electrical current may be converted into a high frequency alternating one suitable for wireless telephony.

The violin corresponds to the "arc" method, and the watch very nearly, if not quite, to the impulse method. In the violin the bow moves steadily on, while the string is caused by it to move to and fro; and in like manner the steady current in the arc produces an alternating current in the circuit connected to it. In the watch the intermittent, though always *forward*, motion of the wheelwork causes the balance wheel to vibrate backwards and forwards, just as the direct current impulses in such systems as the Lepel, cause the production of an alternating current.

In what follows the motion of electricity in the circuit is compared with the motion of the materials composing the springs and wheelwork of the watch.

The drum containing the mainspring slowly moves round as the spring unwinds itself, its motion being always in one direction—compare this to the supply current. This forward motion is transmitted by the train of wheelwork to the lever of the escapement which starts the balance wheel turning in one direction.

The wheel, however, does not turn far, as in turning it tightens the hair spring, and when the energy of the impulse given to it by the lever has all been used up in tightening the spring the force of the latter causes the wheel to reverse its motion. As it swings back it does not stop in its first position, but turns beyond it until the spring again checks it, and incidentally the escapement is released so that the lever is able to give another forward push. Here we have the direct forward motion of the driving mechanism converted continuously into the to and fro, or alternating, motion of the balance wheel. Moreover, the alternating motion is at a perfectly definite rate, each to and fro movement of the balance wheel taking in some watches a quarter of a second, in others a fifth.

This rate of oscillation is controlled by the dimensions and weight of the balance wheel and the stiffness of the hair spring, and does not depend on the force exerted by the mainspring. If it were not so the watch would race when it had just been wound up, and go very slow towards the end of the twenty-four hours.

A good timekeeper does not do this, so its rate must be controlled by the balance wheel and hair spring alone.

The inertia of the balance wheel in the watch is like inductance in an electric circuit, it tends to make the wheel go on moving in the direction in which it is moving, while inductance tends to make the electricity do the same. The spring is like an electrical capacity, it checks the motion of the balance wheel, and when it has become tight reverses that motion; the capacity in a similar way checks the motion of the electricity poured into it and then drives it back the way it came.

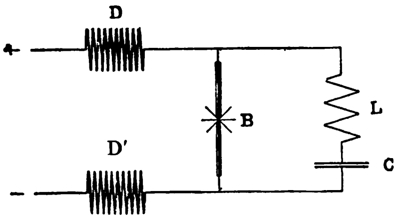

Fig. 13.—Electric Arc Circuit for Producing Alternating Currents of High Frequency.

Every conductor which is surrounded by an insulator has inductance and capacity. The inductance of a conductor can be increased by bending it into a coil, and the capacity by flattening it out at both ends, placing the plates so formed near to one another with insulating material between them. In practice the plates are naturally made from sheet metal or foil, and are connected to the wire which forms the rest of the circuit by soldering or screw connectors.

In fig. 13, L represents the inductance, C the capacity, and B the gap of variable resistance. The supply current comes in by the wire D and leaves by D′, which are connected to the dynamo, or battery. The battery corresponds to the mainspring of the watch, the leads to the wheelwork, the gap to the escapement, the inductance to the balance wheel, and the capacity to the hair spring.

The circuit L C B thus has in it an alternating current, the frequency of whose alternations is controlled by the dimensions of L and C. This circuit can, therefore, be used as a source of alternating current energy to be modified by the microphone, and finally radiated by the elevated conductor, or aerial wire of the station, from which the speaker is telephoning.

Many other forms of circuit are employed in recent generators of high frequency current, and the details of their electrical actions are different; in some methods energy is taken from the supply current during part of every wave, in others it is only taken intermittently at perhaps every third or fourth wave, in all cases, however, the object is to obtain a steady alternating current of high frequency from direct current or from low frequency alternating current.

CHAPTER VI.

HOW THE ELECTRIC WAVES ARE RADIATED AND RECEIVED.

In the last chapter it was explained how an alternating current of very high frequency can be generated; in this it will be shown how such a current can be modified in strength to correspond with the sound waves of speech, radiated from the transmitter, and received at a distant station.

The reasons why it is necessary to use a current of very high frequency;—*i.e.*, a current which reverses its direction a great many times in a second;—were partially explained in Chapters I. and III. Firstly, the frequency must be greater than 30,000 per second, for a lower rate would produce a loud note in the receiver which would interfere with the sound of the voice; secondly, it is much more easy to radiate a considerable amount of energy if the frequency be high.

What is required in wireless telephony is, therefore, a means of modulating the average strength of the alternating current affecting the receiver so that the current produced in the receiver shall be exactly proportional to the air pressure of the sound wave on the transmitter. Note that we are not now dealing with the actual current at any particular moment, but with the average rate at which the receiver is absorbing energy, or to put it more concretely, with the energy of each complete alternation, or wave, of the current. In wire telephony we dealt with the

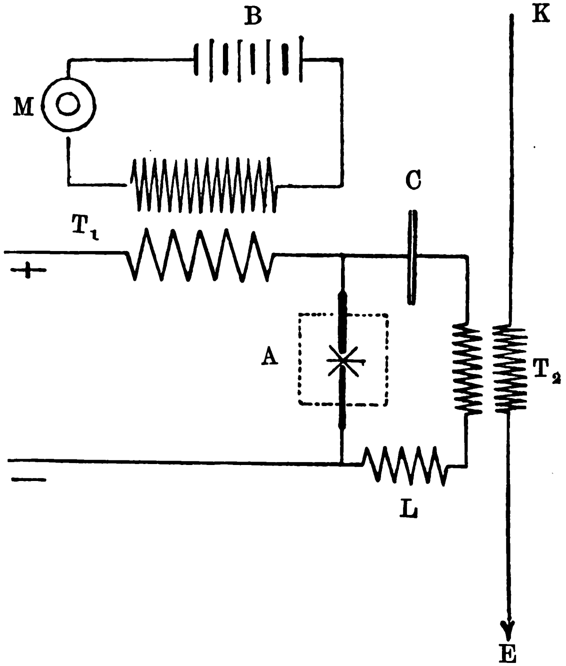

FIG. 14.—WIRELESS TELEPHONE TRANSMITTER. M., Microphone; B, Battery; T_1, Transformer, through which microphone current controls supply to arc A; A, Arc; C, Capacity; L, Coil of Wire giving inductance; T_2, Coupling of Generating Circuit A C L to Radiator or aerial K T_2 E.

actual value of the current, at any moment; here we deal with its average value taken over the very short time of one alternation.

In wireless telephony the energy absorbed by the receiver may be varied in two ways; either firstly, as in wire telephony, by varying the strength of the transmitted current by a microphone; or secondly, by varying its frequency by some other device.

There are two chief methods by which the amount of the radiated energy may be controlled so that it shall correspond exactly with the sound waves, for the microphone may be placed either in the direct current supply circuit or in the high frequency circuit itself. These are shown in figs. 14 and 15. In fig. 14 the microphone current acts by induction on the supply current, causing it to increase or decrease in sympathy with the sound waves impinging on the microphone.

The two coils of wire placed near together, but not conductively connected by means of which the action is transmitted from the one circuit to the other, are called a transformer. The principles of its action are simple experimental facts, viz., that every current has magnetic force all round it, the strength of which is proportional to the current; and secondly, that any variation of the magnetic force near a conductor produces a current in that conductor. The first applies to the action of the microphone current in producing a variable field of magnetic force, and the second to the effect which the variations of this force have on the coil in the supply circuit. There is a kind of wireless telephony between the two coils, but not one which is applicable to transmission over long distances, for in order that the one coil may act appreciably on the other the distance between them must be comparatively small.

In fig. 15, which is the way most generally adopted,

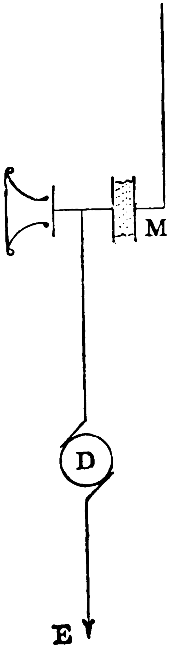

FIG. 15.—WIRELESS TELEPHONE TRANSMITTER (Fessenden) E, Earth connection; D, High Frequency Alternating Current Dynamo; M, Microphone in aerial wire, thus controlling the radiation, in accordance with the waves of sound spoken into it.

the microphone varies directly the strength of the high frequency current itself.

There are many forms of aerial conductor from which the current may be made to pass outwards along the earth's surface. Probably the best so far devised for wireless telephony is the fan-shaped aerial, or "antenna," as it is sometimes called, it has large capacity, low resistance, and small inductance—conditions which are favourable to the radiation of a large amount of energy with the kind of current used.

The lower end of the aerial wire is led into the instrument room and is there connected to one terminal of the current generating circuit, the other terminal of which is connected to a large metal plate, or network of wires, sunk in the ground. The electricity in the wire, from the earth to the top of the pole, may be likened to the string of a violin, the generator to the bow which causes it to vibrate, and the earth, to which the wire is attached, to a vast "sounding board." Only in making this comparison it must be remembered that it is the inaudible electric waves that are transmitted outward and that they can only be heard by being converted into sound by means of a proper receiver.

Since the current is actually conducted by the earth the electrical resistance of the ground has a great influence on the distance to which wireless transmission, either telephonic or telegraphic, is possible. Thus over sea, which has a very low resistance, the possible distance of transmission is much greater than over land, and similarly transmission is more easy over moist than dry soil. The differences are very considerable; a station which can transmit speech fifty miles over dry land being able to give equally good communication over about two hundred miles of sea. It is lucky that this is so, for in a world whose surface consists mainly of sea, the greater part of any long distance line of communication is usually over water.

There is another factor which affects the ease with which wireless communications can be carried on besides the resistance of the ground; it is called its specific inductive capacity or dielectric constant. This is greater for water than for any other substance, and adds, therefore, to its advantages as a conductor for wireless transmission. In order to show the relative ease of transmission over sea and land I have taken the following numbers from an interesting paper on the subject written by Dr. Zenneck; in each case the number given represents the distance in travelling over which the electric wave will be reduced to about one-thousandth of the value it had at one kilometer from the transmitting station, on the assumption that energy is not wasted in the atmosphere, but only in the ground or sea.

This assumption is only correct for short distances, but the results are, nevertheless, interesting as a first approximation. The numbers given then indicate the distance at which the wave is reduced, by resistance of the ground and by the fact that it forms a circle of ever increasing diameter, to a thousandth part of what it was at one kilometer from the sending station; they are: over sea, 5,000 kilometers; over wet ground, 100 kilometers; over dry ground or rock, 30 kilometers. In actual practice the first number would be considerably reduced by atmospheric absorption, probably to some-thing under 500 kilometers, the others remaining practically unaltered.

Atmospheric absorption also accounts for the curious difference between day and night, which Mr. Marconi discovered, and for the different amount of absorption which waves experience in passing over the same distance on different days.

At the receiving station there is an aerial conductor and earth connection exactly like those at the transmitting end, but they are connected to the receiving instruments instead of to the generator. In actual practice there is a receiver and transmitter at each station, either of which can be connected to the aerial and earth wires, so that speech can be transmitted from, or heard at, either station.

As each wave of electric force passes the receiving station it causes the electricity to move up and down again in the conductor between the ground and the top of the pole, and in so doing affects the receiving instruments; how these act will be explained in the next chapter.

CHAPTER VII.

THE RECEIVING INSTRUMENTS.

THE object of the receiving instruments is to convert the variations in strength of the electric current into sound waves. A diagram will make this clearer. In fig. 16 (A) represents some sound waves as spoken into the transmitter, (B) the electric waves corresponding to (A) radiated from the transmitter and picked up by the receiver, and (C) the sound waves similar to (A) produced by the receiver from the electric waves (B). In the receiver there are two steps in the conversion of the received current into sound waves; the first being from alternating current of high frequency into a direct current whose strength is always proportional to the average value of the alternating current, and secondly, the conversion of this varying direct current into air pressure waves by means of the Bell telephone. The first of these processes is the distinctively "wireless" one, the second being the ordinary telephonic reception which has been described in an earlier chapter.

Before coming to the actual transformation of energy we must go, in some detail, into the way in which the energy of the radiant current from the sending station is captured by the receiving aerial and transferred to

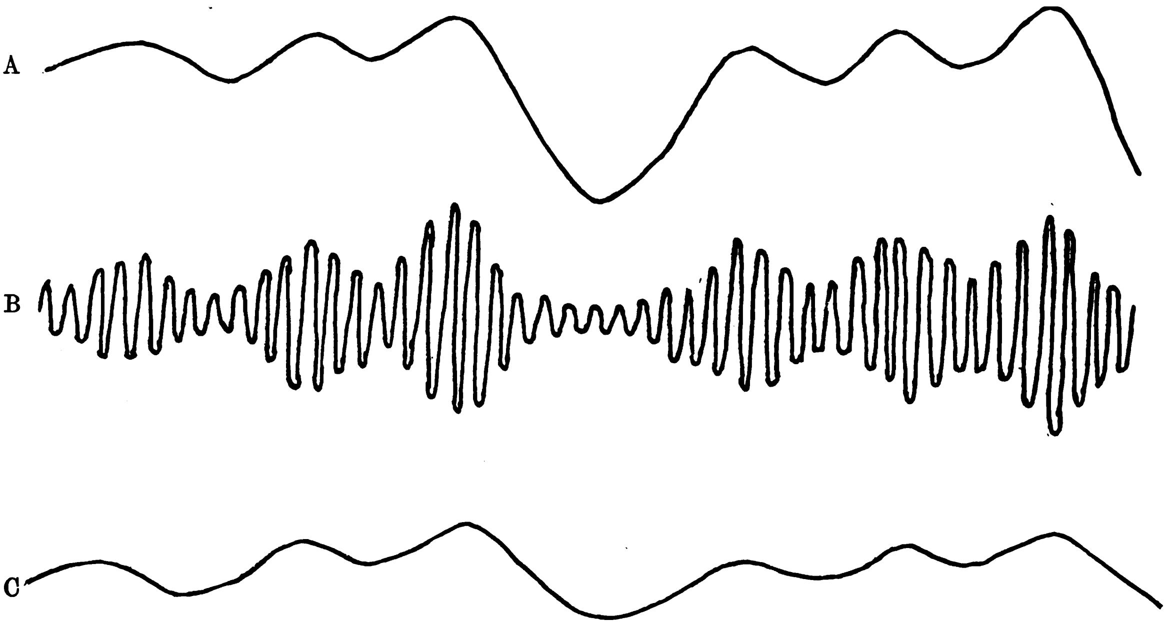

FIG. 16—A represents a sound as spoken into the Wireless Telephone. B represents the corresponding Current Radiated. C represents the waves A as reproduced by the receiver from the waves it absorbs from its aerial wire on which the waves B are striking.

the circuit in which the conversion into direct current takes place.

So far the action of the electric forces in inducing currents in the circuits of the receiver has been described as if the current at any moment was a purely "forced" one which was simply proportional to the external electric force acting on the circuit at that moment. It is possible to work under such conditions, but there is a much more efficient method which depends on the principle called by Lord Kelvin, "the superposition of small motions." This principle is of such universal importance in natural philosophy that it is worth taking some trouble to understand it thoroughly. The best way will be to consider some concrete examples.

We all know how one child swings another in an ordinary swing by giving a succession of little pushes just at the moments when the swing has reached the highest points of its backward motion, and we know that after twenty or thirty properly timed pushes have been given, the motion of the swing is so great that to attempt to stop it suddenly at the bottom of its course is to take the risk of being knocked over. The fact is that the energy of all the little pushes has been stored up in the moving swing, and to stop its motion suddenly requires a force which is equivalent to the sum of all the pushes given to it since it started. The small motions are superposed on one another, the result being a single, much larger motion.

If the pushes are not properly timed no such storage of energy will occur, and the motion of the swing will not grow larger and larger, but will be as much checked by the pushes which are out of time as it is assisted by those which synchronise with its natural time of swing, the result being a small and irregular motion, quite unlike the energetic oscillation produced by the properly timed impulses.

In the following case the rate of vibration is more rapid. Press down the loud pedal of a piano, *i.e.*, remove the dampers from the strings, and sing a note. When your voice has ceased you will hear the note sounding in the piano. Sing another note, it will also resound.

Here the oscillation is much more rapid, there being two hundred and fifty-six complete to and fro motions in a second if the note be middle C, instead one in four or five seconds, as is the case with the swing. The way in which the string gets up its vibration is, however, just the same. At each vibration of the vocal chords a wave of pressure goes out from the throat, and reaching the strings, gives every one of them a tiny push. A two hundred and fifty-sixth part of a second later the second pressure wave comes along, and after it, at equal intervals, follow many more. All the strings of the piano become slightly agitated, but only one gets into energetic vibration, namely, the one whose length, weight and tension are such that it vibrates freely 256 times a second if plucked and left to itself.

It is the only one to which the impulses of the voice come exactly rightly timed so that each adds its motion to the motion the string has already acquired, increasing it until it is sufficient to be audible. If a different note be sung it is, of course, another string which will respond.

In an exactly similar way it is true that an electric circuit will respond most readily to impulses which come timed to its own natural rate of vibration. It is the equalisation of the natural frequency of the receiving circuit to that of the transmitted impulses or waves that is called tuning in wireless telephony and telegraphy. The transmitter and receiver in all wireless telephones are tuned to one another, and if there are several circuits in either instrument, through which the alternating current has to flow, all of them are tuned to the same frequency.

By making use of the superposition of small motions we thus gain two notable advantages; firstly, from a series of small impulses a large motion can be built up, and secondly, no appreciable motion will be produced unless the impulses be properly timed to the natural rate of vibration of the second vibrator.

The principle applies to all vibrations however slow or however fast, whether mechanical or electrical, and even to the extremely rapid vibrations which constitute light. Both advantages have an important bearing on wireless transmission; the first making it possible to obtain signals or transmission of speech, at great distances, by mere repetition of small impulses without it being necessary to send any very energetic ones; the second providing a means of working several stations at once in the same neighbourhood without interfering with one another. This latter is accomplished by arranging the stations in pairs, each pair working with a current having a different rate of alternation from the other pairs. Each receiver will then receive only the messages from its corresponding station and not from any other. The arrangement can, of course, be changed in a few seconds so that any one station can communicate with any other.

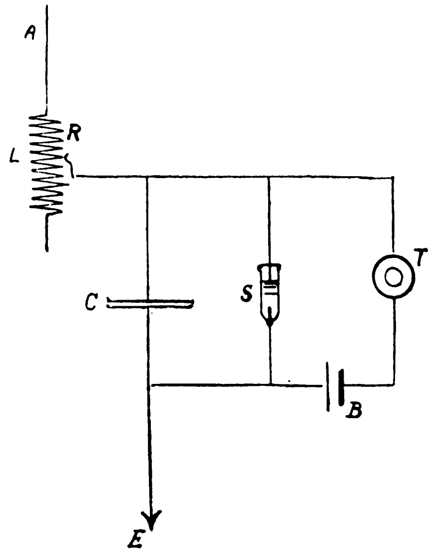

FIG. 17.—A SIMPLE WIRELESS TELEPHONE RECEIVER. T is the Bell Telephone; B, a Battery; S, the Detector, which turns the high frequency alternating current received into currents which can affect the Telephone; C, a Capacity; L, an Inductance, being a coil of wire with a sliding connection, R, for tuning the aerial earth circuit A R C E to the frequency of the transmitted current; A, the aerial conductor; E, the Earth connection.

As yet it is not possible to locate so large a number of stations in one district as would be required to replace the wire telephone system of a town or populous country, so there is no immediate likelihood of wireless telephony taking the place of the wire, but in a sparsely populated district, between islands, and across long stretches of forest or desert where the maintenance of a wire or cable is extremely costly and difficult, wireless certainly provides a more reliable and less expensive service.

The principle of resonance is applicable not only to transmission from the sender to the receiver, but also to the internal arrangements of both transmitting and receiving apparatus. Thus, in the receiving station there is usually more than one circuit, and each circuit has such dimensions that the natural rate of oscillation of electricity in it is the same as in the other circuits.

The current from the sending stations is thus, as it were, filtered out, in passing from one circuit to the next, from any interfering currents which may be going about. Of course it is possible to talk over a telephone and be understood in spite of a good deal of extraneous noise and "cross-talk," but it is naturally advantageous to reduce interfering sounds to a minimum.

CHAPTER VIII.

DETECTORS.

WE now come to the detector which converts the high frequency current into a direct current capable of causing audible sounds in a Bell telephone receiver. In the simplest type suitable for telephony a small sharp point of some material, often graphite (black lead), or some hard crystal, such as carborundum, presses against a surface of a metal or metallic sulphide. Wires are connected to the two materials, and the high frequency current, coming from the transmitting station *viâ* the earth and the aerial wires, passes from one to the other. In doing so it heats the fine point and thus causes the detector to become a generator of direct current, for it is a well known fact that if a junction of two different materials in a circuit be heated to a higher temperature than the rest of the circuit, a current, driven by the energy of the heat absorbed at the junction, is produced in the circuit.

This kind of current-production is called "thermo-electric." Many detectors have, in addition, the property of rectifying an alternating current, that is to say, of permitting current to pass more easily in one direction than in the other. By this means the high frequency current received becomes converted into direct, though pulsating, current which, if it varies in strength, will produce a sound in a telephone receiver.

A thermo-electric detector thus turns high frequency alternating current into direct current in two steps, firstly, the alternating current produces heat at the point of contact, and secondly, the heat produces a direct current because of the difference of the materials. In the case of the types which rectify the current the action is as yet not properly understood, though it appears to be one of those curious electrical phenomena which so often occur at points of contact between different materials owing to the existence of an almost infinitesimally thin film of some compound on the surface of one of them.

The electrolytic detector is also suitable for telephony. The most usual form consists of a very fine platinum wire a thousandth of an inch or less in diameter, one end of which just projects from one end of a glass tube which has been melted so as to fit closely round the wire. The point is placed in an acid solution and connections are made from the fine wire and solution to the receiving circuits.

In another form the electrolytic detector consists of an extremely fine tube filled with liquid connecting two larger vessels containing the same fluid, connections being made to the liquid in the latter. A battery of two or three dry cells is used to keep current flowing through the liquid, the cells being connected to an arrangement of wires termed a potentiometer, or potential divider, by means of which any desired fraction of the total electric pressure of the battery can be applied to the detector.

The potentiometer is adjusted until a faint hissing sound is heard in the telephone which is in circuit with the battery and detector. In this condition the detector is found to be very sensitive to high frequency currents, *i.e.*, a momentary current received from the aerial wire and transmitted by the receiving circuits through the detector, produces a sharp click in the telephone, while continued increases and decreases if rapid enough produce a continuous sound. The detector is, therefore, suitable for telephony.

There are many other detectors more or less suitable for telephonic reproduction of speech, such, for instance, as those in which the active portion of the circuit is gaseous instead of liquid or solid—a type which has been used for telephony by Dr. de Forest—and Mr. Marconi's magnetic detector, which, though it has not been much used for the purpose, appears to be eminently suited for installations where great sensibility is not required. Mr. Walter's tantalum detector, which consists of a fine tantalum wire dipping into mercury, is also used, and gives a very loud reproduction of the sound.

CHAPTER IX.

ACHIEVEMENTS AND EXPECTATIONS.

ALTHOUGH the transmission of speech by Dr. Graham Bell's photophone, in 1878, was wireless, the method even in its most recent form does not compare favourably with electric wireless transmission. All the difficulties of searchlight signalling are present, and atmospheric conditions play so important a part as to render vain all hopes of developing a really reliable system of telephony on this principle. It may form a useful adjunct where searchlights are used for other purposes, but cannot take the place of an electric telephone whether wire or wireless.

Mr. Ruhmer's experiments on the Havel, near Potsdam, no doubt showed that speech could be transmitted over several miles, both by night and day, and even in rainy weather, but the essential difficulty is, of course, that the country between the stations must be perfectly open so that the beams of light from the searchlights may strike direct on the receiving mirrors containing the selenium cells.

This difficulty would not arise over moderate distances at sea, but there, again, another exists, viz., the difficulty of directing the beam on to the receiver in spite of the rolling of the vessel on which the transmitter is placed. The photophone, even in its most modern form, cannot, therefore, compete with electric wireless telephony.

It was in the last year of last century that the first experiments in radiotelephony were carried out, but it was not until four or five years later that an apparatus was evolved which was capable of transmitting speech clearly and distinctly to a distance of ten miles or more. It was thus about three years ago that wireless telephony entered the arena of everyday life as a practicable means of communication, though even now but few people are aware that the voice can be transmitted without wires so as to be audible in a receiver several hundred miles away. Such a distance has, however, actually been covered by Fessenden in America, and by Poulsen and Majorana in Europe. These achievements are worth consideration in some detail, for though they do not mark, like the conquest of the air, an era in the world's history, they do indicate a very important step in that progressive annihilation of distance which nowadays renders social and business intercourse possible over thousands of miles of sea and land.

It is hardly realised by the majority of people what an immense change has taken place in the life of the world on account of the wonderful increase in the facility and rapidity of intercourse, whether by telegraph or by travel, which has been made in the last half century. In the case of our own Empire this development is of supreme importance, since the Empire consists of fragments, large and small, scattered over the whole surface of the globe. It is no longer banishment for life to go to one of the far distant dominions overseas, and every invention which tends to render intercommunications cheaper and more rapid is of far greater value to us than to any other country.

The Imperial Press Conference has done much to impress this fact upon the nation, but it cannot be too strongly insisted upon that the essence of national life is personal intercourse; intercourse between the members of a family scattered throughout the empire, as most families are, forms a series of links in the vast network of community of thought and interest which binds the whole together. Press messages are immensely useful in their way, but without personal communications—the letters, telegrams, and telephone messages of friends and relatives—they are as an egg without salt, substantial but uninviting, facts without living interest.

Many of us who have been absent some hundreds of miles from home during a time of trouble or anxiety, know the extraordinary satisfaction of hearing the actual voice of a loved one replying to one's anxious enquiries. It is the extension of this to thousands of miles instead of hundreds; indeed, possibly to all parts of the globe, whether sea or land, that is indicated by the actual present achievements of wireless telephony, and may be legitimately expected within the lifetime of most of us.

The story of Professor Fessenden's experimental development of a practical wireless telephone system is told in an interesting paper which he read before the American Institute of Electrical Engineers, in June, 1908. The writer describes the gradual evolution, commencing in 1900, of a wireless telephone from a wireless telegraph by the introduction of modifications rendered necessary by the physical laws which govern the transmission of articulate speech, and the satisfactory conclusion to which the experiments were brought in the demonstration of practical wireless telephony to the editor of the American Telephone Journal and other technical men, is proved by the reports which they have published.

The demonstration was between Brant Rock and Plymouth, in the State of Massachusetts, a distance of about eleven miles. It was shown that speech could be transmitted not only directly from one wireless station to the other, but also that a wireless section could form part of any line of telephonic communication. Thus the voice was transmitted over any ordinary telephone line to a wireless station, where it was automatically transformed into radiations which were received at the other wireless station and again converted into currents which reproduced the voice at the end of a second line wire. In July, 1907, the distance between the wireless stations was extended to nearly two hundred miles, viz., from Brant Rock, near Boston, to Long Island, near New York, and more recently to Washington.

Now, all this shows that the trunk connection between two local exchanges may be wireless, and, therefore, that a subscriber on the one exchange will be able to converse with any subscriber on the other, although there is no trunk wire between them. This statement implies more than appears on its surface, for it indicates the provision of telephonic connections between exchanges where no such connection is possible by wire.

Speech can be transmitted by wire over land to a distance of between one and two thousand miles, but across the sea, by submarine cable, the maximum is little greater than one hundred miles. Hence, over sea, as shown by Professor Majorana's results, quoted on page 21, wireless telephony has already outdistanced the cable, and speech has become possible at much greater distances than heretofore. Indeed, there is every reason to believe that where wireless telegraphy leads, wireless telephony will always be able to follow and that speech will be possible across the Atlantic and every similar stretch of sea. Then when we ask for "Trunks" we shall be able to say, "Give me 977 Toronto," or "459 Bombay," and in a few minutes will be told that we are "through."

The advantages of telephony over telegraphy are two in number:—Firstly, the rapidity with which an answer can be got to a question; and secondly, the very much greater number of words which can be dealt with in a given time by one operator. It is quite easy to get answers to ten or a dozen questions arising successively out of one another in the course of a three minutes' conversation on the telephone, at a cost of a very few pence. To have carried out the same conversation by telegraph would, under ordinary circumstances, have occupied from ten to twelve hours, and would cost over ten shillings.

The actual number of words which one person can transmit per minute is also much greater in telephony, it being quite easy to speak at two hundred words per minute, while in telegraphy the highest speed attainable, even by an expert operator, is less than fifty. The modern "high speed" systems of telegraphy, of which so much has been heard recently, do not appreciably increase the speed at which an operator can work, but merely add to the carrying power of the wire.

The cost of the transmitting operator's salary, per word, remains the same, the only economy effected being in the number of wires used, and to some extent in number of receiving operators, and this, in the case of ordinary short land-lines, can only affect a small fraction of the total expense. Telephony, in which the only expert operator required can deal with a considerable number of simultaneous conversations, is, therefore, far less costly.

Wireless telephony has the further advantage that it is possible for a number of people in different places far apart, to take part in a general conversation, just as they would do in a drawing-room, everyone hearing what any of the others may say. Both at sea and on land this opens up new possibilities.

In Europe wireless telephony has been successfully developed by Mr. Poulsen, the Telefunken Company, and others, during the last three or four years. The longest distance covered by the Poulsen system was about two hundred miles, mainly over land, between a station near Berlin and another in Denmark. The first demonstration in England was one given by the author during a popular lecture at University College, Nottingham, early in 1908, at the request of the Vice-Principal, Mr. W. H. Heaton. A small Poulsen arc was used in conjunction with condensers and other apparatus made to the author's requirements in the College laboratories under the able direction of Mr. A. H. Simpson. Speech was transmitted from a room at the back of the large College building to one at the front, through many walls, iron pipes, and other obstacles, without difficulty.

Later in the same year Dr. de Forest gave a demonstration to the Navy, at Portsmouth, in which telephony was successfully carried on up to a distance of over forty miles between H.M.S. "Vernon" and a cruiser detailed for the purpose. Twenty-eight ships of the American Navy had previously been fitted with similar apparatus which they carried with them on their voyage round the world.

Thus wireless telephony is an accomplished fact, and when we consider that in thirty years the number of telephone subscribers in the world has grown from nil to a vast total of over two millions, it is clear that this means of electric communication fulfils the needs of everyday business and social life far more perfectly than the telegraph; so much so, indeed, that the total number of words conveyed daily by telegraph is now only a very small fraction indeed of those transmitted by telephone.

With the advantages of telephony so amply proved by this enormous and ever increasing traffic, it is clear that radiotelephony ;—which renders telephony possible where it is impossible by wire, and obviates the difficulties of maintenance and cost of wayleaves unavoidable with a system of wires ;—will play, from now onwards, a part of immense importance in the intercourse of all civilised communities.

Glossary of Technical Words.

Alternator. A machine which, when driven by a steam engine or other source of power, produces an alternating electric current, *i.e.*, causes electricity to move to and fro in a conductor.

Arc. The very hot flame caused by the passage of a current of electricity through air or other gas.

Battery. An apparatus for producing steady, or direct, current always in one direction, from the chemical action of some liquid on two plates of different materials.

Capacity. (Electrical) Depends on the size and shape of the conductor, and on the nature of the insulator by which it is surrounded. Capacity measures the amount of electrical charge that can be forced on to the conductor when any given electric pressure (or voltage) is applied.

Conductor. A material which guides or conducts an electric current or wave. The commonest and best are the metals, among which copper is most generally used; carbon and also salt solutions and acids conduct, though not as well as the metals. Glass and non-metallic substances conduct extremely badly, and are usually called non-conductors

Current. A current can be recognised by the fact that magnetic force is produced all round it even when flowing through an otherwise quite non-magnetic material, such as copper, and by the fact that a wire which is conducting a current becomes warm. If the current is of very short duration, special apparatus is needed, such as a coherer or other detector.

Diaphragm. A thin flexible disc.

Dimensions. The electrical dimensions of a conductor are the measurements on which its electrical properties depend. These measurements cannot, as a rule, be made with an inch tape, but involve measurements of quantities of electricity.

Direct Current. An electric current always flowing in the same direction but not necessarily always of the same strength. It can be measured by instruments which depend on either the magnetic force or heat which it produces.

Dynamo. A machine which, when driven by an engine, causes electricity to move round a conducting circuit. There are dynamos which produce direct current, and others which produce alternating current (see p. 30).

Electrode. A conductor. Usually applied to a metal or carbon conductor which leads a current to a spot where the current has to pass through a gas or liquid.

Energy. The power of doing physical work.

Frequency. Number of complete to and fro movements, or vibrations, per second. For electric currents, 100 per second is a low frequency, 100,000 per second a high frequency.

Inductance. Work has to be done to start a current in a conductor because work has to be stored as energy in the magnetic force all round the conductor. When the current is being stopped this energy keeps on driving the current forward till the energy is used up. The amount of energy stored as magnetic force depends on the shape of the wire (*i.e.*, whether straight or coiled up). The inductance of the wire depends on the same things. Inductance in a circuit acts like a fly-wheel on an engine, making it harder to start and harder to stop the current.

Induction (Electrical). Electrical action through a non-conductor, *i.e.*, through air, glass, etc.

Inertia. Is the quality of matter in virtue of which it tends to remain at rest or to go on moving uniformly in a straight line; it is simply proportional to weight.

Insulated. A conductor is insulated when it is separated from all other conductors by non-conducting materials.

Magnetic Force. The force which tends to move a magnet.

Molecule. A quite invisibly small particle of matter, consisting of several atoms; the little bricks out of which ordinary materials are built.

Musical Arc. Mr. Duddell found that an electric arc could be made to sing by connecting a circuit having certain capacity and inductance to it. Change in the amount of the capacity or of the inductance changes the note. The musical arc produces electrical vibrations (alternating currents) as well as sound vibrations.

Ohm. The name of the unit of electrical resistance.

Oscillation. A to and fro movement.

Period. The time taken for a complete oscillation.

Photophone. Dr. Graham Bell's photophone transmits sound as the flickering of a beam of light reflected from a thin metal disc, which vibrates when spoken to, and thus causes the beam to flicker in time with the sound waves. At the receiver the beam strikes on a small piece of selenium, through which a current is made to flow by a battery. The selenium has the property that the brighter the light on it the more easily does the current flow; so the current is controlled by the flickering of the beam, and therefore reproduces the original sound in the telephone attached.

Pitch. Musical pitch is high when there are many vibrations per second (say 300 and upward), and low when few vibrations per second. The lowest audible note has about 30 per second, and the highest about 30,000 per second.

Resistance. Electrical resistance measures the value of a material as a conductor. Good conductors have low resistance and bad ones high resistance. More electrical pressure is required to drive a given current through a bad than through a good conductor of the same size.

Voltage. Electrical pressure, *i.e.*, that which drives a current.

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