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THE MODERN APPLICATIONS OF ELECTRICITY

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OF

ELECTRICITY

BY

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TELEPHONE: VARIOUS APPLICATIONS: ELECTRICAL TRANSMISSION OF ENERGY

WITH NUMEROUS ILLUSTRATIONS

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THE MODERN APPLICATIONS OF ELECTRICITY.

PART I.

TELEPHONES AND MICROPHONES.

A TELEPHONE is an instrument by means of which a sound, a melody, a noise, a song, or any utterance of the human voice can be transmitted to a distance.

Preece has divided these apparatus into two large classes, according to the results obtained—

1. Musical telephones (tone telephones) are instruments for the transmission of melodious sounds.

2. Articulating telephones are those employed for the transmission of the human voice.

Microphones, as will be seen later on, naturally come under the same category as telephones, and require no special classification.

Tone telephones coming first in historical order, and being the simplest, we begin with them.

In a special chapter, we shall describe some telephonic apparatus, in which the transmitter, the receiver, and sometimes the line, are under such singular conditions that no definite place can be found for these instruments in a methodical classification.

CHAPTER I.

TONE TELEPHONES.

THE first mention of the principle of these telephones dates back as far as 1837, when an American, named Page, discovered that rapid changes of magnetization of iron bars produced what he called galvanic music. The sounds emitted by the bar depended on the number of changes produced in a second. Sixteen at least were required to produce a distinct sound.

These effects were carefully studied by a great number of physicists. De la Rive, of Geneva, in 1843, increased the effects of Page's vibrations—as these phenomena are sometimes called—by using wires of great length arranged in coils.

Later on, Sullivan discovered that the vibration of a wire composed of two metals produced an electric current which lasted as long as the vibration itself, but this discovery received no practical application, and would have fallen into oblivion without Bell's researches on the past history of the telephone. In 1855, Léon Scott, of Martinville, invented an apparatus to which he gave the name of phonantograph, consisting of a stretched piece of skin vibrating under the influence of the voice, of singing, or any other sound. This instrument was designed for a graphic representation of vibrations. This is the origin of the vibrating plate of the telephone.

Reiss' Tone Telephone.—In 1860, Reiss constructed an apparatus by means of which a melody produced in a certain place could be transmitted to a great distance.

This apparatus is a successful combination of Page's vibrations and of Scott's phonantograph; it is represented in Figs. 1 and 2. The former shows the apparatus for transmission, the latter that for reception. At the station where the tune is played, a large tube T, leading into the box K, receives the vibrations of the air produced by the musical instrument. The box collects and strengthens the sound. In the upper part, a membrane *m* is stretched, which vibrates in unison with the vibrations which it receives. The movements of the membrane are easily transformed into measured emissions and interruptions of an electric current.

Let us suppose a battery, one of whose poles is at earth, connected by the other electrode with the screw marked 2 in the figure; from thence a metallic conductor, formed of a thin copper plate *i*, and connected with a platinum disc *o*, conveys the current to a point opposite the lever *a b c*. Each time that the membrane *m* is raised, the point will touch the disc, and a current will be established; it is, on the contrary, interrupted when the membrane comes back into rest.

The upper part of the box K in our figure is cut off to show the details of the membrane and of the electrical connection which repeats the vibrations.

To transmit the electric current to a distance of 100, 200, or 500 kilometres, a line is required starting from the screw 1 (Fig. 1) and connected with the screw 3 (Fig. 2) of the reception apparatus. This latter consists of an iron rod *d d*, surrounded by a spiral of insulated copper wire; one of the extremities of the wire is connected with the screw 3, and the other with the ground by means of the screw 4, in order to complete the circuit of the battery.

Rod *d d* is about the size of a knitting-needle; coil *g*, consisting of the copper spiral and the rod, stands on a hollow box B, made of very thin wood; a cover D fits over the coil. The whole of this arrangement is intended to

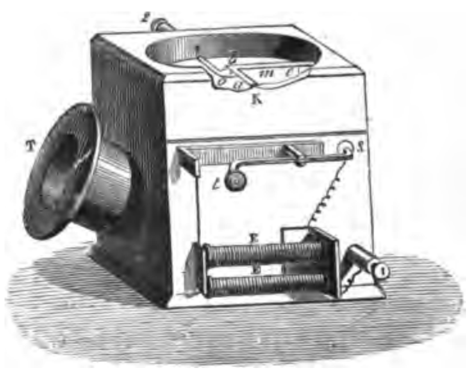


Fig. 1.—Transmission apparatus of Reiss' telephone. K, box for collecting the vibrations; *m*, indiarubber membrane closing the box (the upper part of the box has been cut off); *o*, platinum disc fastened to the membrane; *a b c*, movable lever touching the membrane; *t s*, key for manipulation; E E, electro-magnet receiver for correspondence; 2, 1, binding screws for connecting the wires with the battery and the line; T, mouthpiece.

strengthen the vibrations which produce the successive interruptions of the current across the rod *d d*. The principle is the same as in a piano, where the intensity of the notes is increased by the resonance of the case.

It is a remarkable fact that the vibrations of the rod *d d* are exactly synchronical with those of the membrane *m*, and consequently with those of the instrument playing the tune. Not only time is kept, but also tune; the two factors which constitute melody, pitch and interval, are automatically reproduced, without any possible error.

To complete the description, we have to add that there is, in Fig. 1, a lever *t s*, and an electro-magnet E E, manipulator and receiver, as in an ordinary Morse, for establishing communication between the two correspondents.

In Fig. 2, too, the manipulating lever is to be seen there is also a receiver, which is not represented in the diagram.

The form to be given to the box K is an important factor in the construction of this telephone; it has been found most advantageous to make the sides of curved

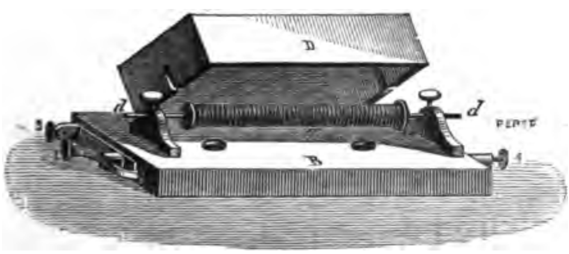


Fig. 2.—Receiving apparatus of Reiss' telephone. B, resonance box D, cover of this box; *d d*, wire vibrating by the passage of the current; *g*, coil through which the current passes; 1, 3, 4, binding screws for connecting the wires with the battery and the line.

boards, to increase the effect on the membrane by successive reflections of sound. The power of the receiver has also been increased by introducing several iron rods into the coil; the sound, which was in the first instance muffling, has acquired a more pleasing timbre.

It cannot be doubted that Reiss' instrument can reproduce articulate speech: it may not have done so before the invention of the Bell telephone, although there is evidence that the Reiss instrument did reproduce articulate speech in 1862; but it cannot be denied that Reiss was the first inventor of an instrument for producing undulatory currents in a closed circuit, that he was the first to use undulatory currents to reproduce sounds with the assistance of the galvanic battery, and that he was the first to invent an instrument which reproduced articulate speech.

As in the case of Pacinotti's machine, so also here, it is one thing to make a great discovery and quite another thing to utilize it and make it commercially successful. Reiss, the poor artisan, without having himself realized the greatness of his invention, died poor as he had lived, in 1874; and a few years after, Professor Bell had the good fortune to announce to the world his speaking telephone, in which the principles of the Reiss receiver are found in an instrument in which the bar armature of the Reiss is changed into a circular armature.

Elisha Gray's Telephone.—The apparatus constructed by Elisha Gray, of Chicago, in 1874, is nothing but a musical telephone, of the same kind as Reiss'; it was, however, more especially intended for multiple telegraphic transmissions, and the experiments made with it by Bell, Gray, Edison, and Varley, have led to the marvellous discovery of the articulating telephone. In Gray's telephone, the receiver has been provided with Helmholtz's resonance box.

The principle of the resonance box is that a volume of air contained in an open vessel emits a certain note when it is made to vibrate. The pitch of the note depends on the dimensions of the vessel and that of the opening.

On bringing a resonance box close to the ear, when musical sounds are produced in the surrounding air, it will be found that the one sound which is in unison with the fundamental note of the instrument is strengthened and distinctly heard from amongst all the others.

With a series of globes, graduated in such a manner that each corresponds to a special note, compound sounds have been analyzed and resolved into their elements. At

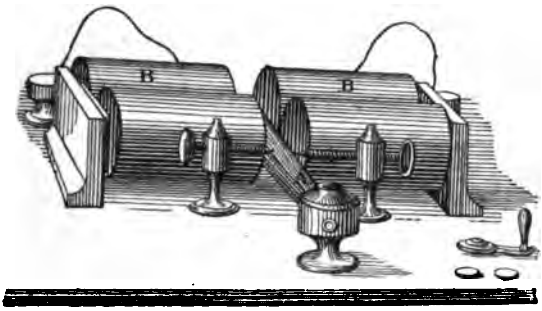


Fig. 3.—Vibrating transmission apparatus of Gray's musical telephone.

the outset, the musician plays the tune by pressing the touches of a piano of sixteen notes; these touches are each connected with a distinct vibrating metallic strip, giving the note which corresponds to the touch.

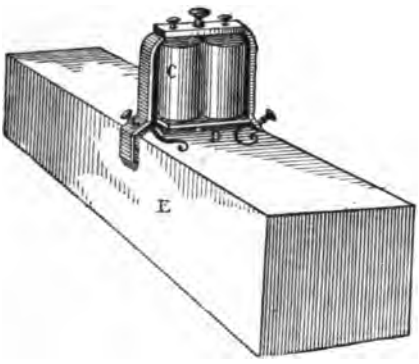


Fig. 4.—Resonance box of Gray's musical telephone (receiver).

Fig. 3 represents one of these metallic strips A vibrating between the coils B B. When it is on the right, for instance, the current no longer passes into the electro-magnet on the right, but passes into the one on the left, which attracts the strip; at the moment when the strip has arrived on the left, the current passes again into the electro-magnet on the right, and so on. The strip thus performs rapid oscillations, the number of which only depends on the length of the strip. Sixteen pieces, similar to those of Fig. 3, are placed above the piano; the length of the strips of each of them is calculated so as to give all the notes of the two octaves. Each time that a note is struck, the electric currents cause the corresponding metallic strip to vibrate.

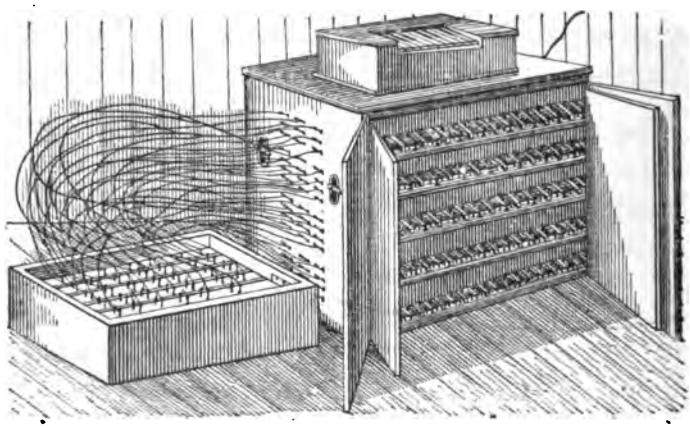


Fig. 5.—Gray's telephone-piano, played at Philadelphia.

The tune is thus produced by the local electric current. As the strips vibrate at the outset, they open and close a line current, but all these interrupted currents reach the receiver, placed at a distance, by one single wire.

They must, therefore, on their arrival be separated by a new contrivance, the principle of which is based upon Helmholtz's resonance box. The receiver is composed of a series of resonance boxes E (Fig. 4), with electro-magnets C, whose armature is formed in each case of a steel ribbon

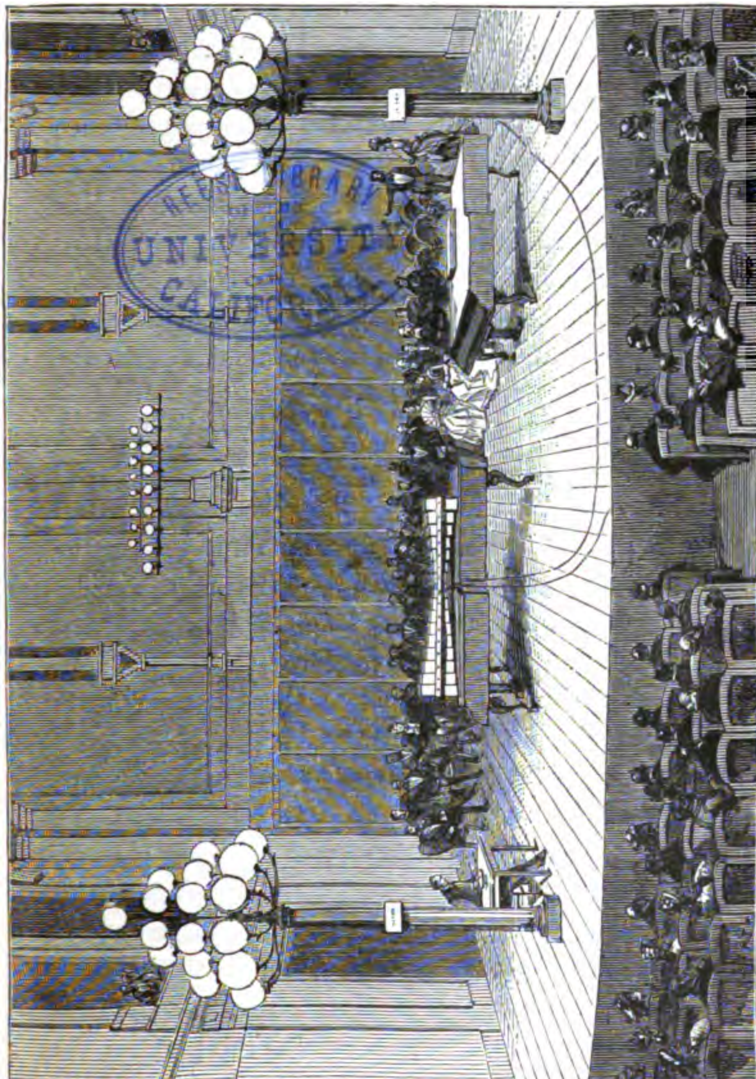


Fig. 6.—Experiment with Gray's musical telephone. A New York audience listening to the sounds produced at Philadelphia.

D, arranged so as to vibrate on the top of the resonance box E.

There are sixteen of these resonance boxes all connected with the line wire. Each of these partial receivers has, from its very arrangement, a sort of selective power; each appropriates and retains the vibration in unison with its resonance box, and is not influenced by the others. The electric waves produced at Philadelphia by the vibrations of the metallic strip answering to the note C, for instance, will traverse all the receivers at New York, but they will only cause a vibration in the apparatus in unison with the note C.

Fig. 5 represents the piano of the musical telephone played at Philadelphia.

All these apparatus, in spite of the great interest which they must naturally present, were soon surpassed by the articulating telephone; but before we pass on to its description, we must first mention an apparatus with a very original receiver, and which, from the results it produces, must be classed among the musical telephones. We are speaking of the singing condenser.

Singing Condenser.—The principle of this apparatus was discovered by Varley, as early as 1870, but Pollard and Garnier have given it its practical form.

The receiver consists of a condenser, formed of thirty sheets of paper, nine centimetres by thirteen, separated from one another by twenty-eight sheets of tinfoil, nine centimetres by twelve, joined in such a manner as to form the two armatures of the condenser. For this purpose, the even sheets are joined together at one end of the paper pile, and the odd sheets at the other end.

This pile is spread on a piece of stiff cardboard, after being carefully tied with a strip of paper; the pieces of tinfoil, united at the two ends of the condenser, are pressed between two copper bands carrying binding screws for the wires of the circuit, and thus a veritable singing apparatus is obtained. If the sheets are pressed by a heavy weight placed on the condenser, its action is not arrested, only the sounds are weakened, and become more harmonious. The theory of an attracting motion of the sheets, which had been originally started to explain these effects, is rendered rather doubtful by this latter experiment.

The transmission apparatus consists of a sort of telephone without handle, with a very thin vibrating tin plate, in the centre of which a cylindrical piece of carbon is soldered; and against this carbon presses another cylinder of the same material, which is fixed to a jointed wooden cross-bar, fastened on one side to the lower edge of the telephone box, and on the other to the opposite edge of the box by means of a regulating screw. A curved spring (a piece of clock-spring) placed across this piece gives it a certain elasticity which is necessary for the working of the apparatus. The tin plate is connected with one of the poles of a battery, and the lower carbon is connected with the primary helix of an induction coil, which has been connected with the second pole of the battery. Finally, the two ends of the secondary helix of the induction coil are directly connected with the two armatures of the condenser.

The secondary helix is formed of twenty layers of wire, No. 32, or better still, No. 42, covered with silk; and the primary helix is formed of four layers of wire, No. 16. The circumference of the coil must not exceed seven centimetres, and the diameter of the core of fine iron wire must be about one centimetre.

To obtain a song on the condenser, the two carbons of the transmitter must not touch under normal conditions, but must be sufficiently near one another to effect contact by the vibrations of the plate produced by the singing. This adjustment is easily obtained by repeated trials, and by sounding the same note until the condenser resounds. If three successive notes are clearly reproduced, the apparatus may be considered satisfactorily adjusted, and is set in action by simply singing into the mouthpiece. To make sure of a good result, the plate of the apparatus must be heard to vibrate like a reed-flute. Instead of the carbons, platinum contacts may be used.

Janssens has constructed a singing condenser, in which the speaker has the form of a Bell's telephone; the coil is placed in the handle, which renders the apparatus very portative and convenient. All musical telephones are nowadays only considered as objects of curiosity, or apparatus for physical experiments; they are, however, worthy of mention as having in some way prepared the way for the invention of articulating telephones.

CHAPTER II.

ARTICULATING TELEPHONES, OR SPEAKING TELEPHONES.

It is the admirable apparatus of Professor Graham Bell which finally solved, by a method of marvellous simplicity, the problem of electric transmission of the spoken word to a distance. Bell's telephone, patented by its inventor on the 14th of February, 1876, made its first appearance at the Philadelphia Exhibition, and Sir William Thomson, at a time when this invention met with almost universal incredulity, designated it by the name of "marvel of marvels." Before analyzing the researches which led Bell to his discovery, we must cast a rapid glance at the previous researches on this subject, and the state of the question when it was taken up by the successful inventor.

String Telephone.—Leaving aside acoustic tubes, which, so to speak, only constitute a canalization of the human voice through a tube, the first telephone deserving of this name was the string telephone, the invention of which dates back more than two centuries; in fact, there is no doubt that amongst the natives of India this device was of still greater antiquity.

As will be seen in the sequel, the problem of telephony resolves itself into this: To produce a synchronical vibration of two objects placed at a certain distance from one another.

The simplest method is to take two cylindrical tubes of metal or cardboard, to close one of the extremities of each tube with a membrane of paper, parchment, or thin cardboard, and to connect the two vibrating sheets thus formed by a string fixed in the centre by a knot.

When the string which joins the two parts is well stretched, and not too long, and one of the tubes is held to the ear whilst another person is speaking very close to the mouthpiece of the other tube, all the words are transmitted by the string to the membrane of the receiver, and a conversation can be carried on with a very low voice.

Here we have a mechanical transmission of vibrations and a synchronical movement of the two membranes.

Speech can thus be transmitted as far as 200 metres. By using diaphragms of very thin iron, and insulating the wire on glass supports, Huntley, who made the experiment, was heard at a distance of 2450 feet, in spite of the zigzags of the line. String telephones have for a long time remained in oblivion, and have only lately been taken up again.

It was Charles Bourseul who, in 1854, first gave vent to the idea of transmitting sound to a distance by electricity, and Count du Moncel declares, in his work (*The Telephone, the Microphone, and the Phonograph*, 2nd edit., 1882. London: Kegan Paul, Trench, and Co.), that this idea was regarded as a fantastic dream. All the researches, excepting those of Reiss and Gray, made from that time till 1876, when Bell's telephone came out at the Philadelphia Exhibition, had for their object the construction of musical telephones. Helmholtz's researches on the synthesis of sounds opened the way for articulating telephones.

Nobody could have been more fitted than Graham Bell to undertake these investigations and lead them to a successful issue, for the invention of the telephone is the result of a long series of researches which Graham Bell had made in conjunction with his father, Alexander Melville Bell, of Edinburgh. He commenced with the study of the sound of vowels, made experiments analogous to those of Helmholtz on the artificial reproduction of vowels by means of electrical tuning-forks, constructed an electrical harmonium, a Morse sounder, and devoted himself entirely to the study of electrical reproduction of speech. The whole of Graham Bell's investigations on the telephone are contained in a paper which the author read before the Society of Telegraphic Engineers, in London, on the 31st of October, 1877.

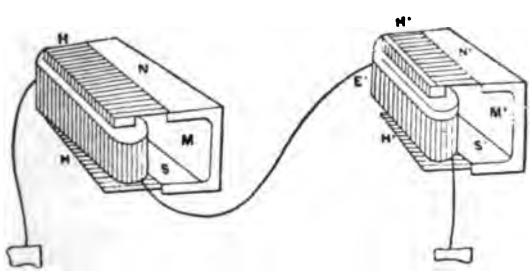


Fig. 7.—First form of Bell's articulating telephone.

After having, with remarkable impartiality, given an account of the whole of the anterior researches made in the same direction by his predecessors, and after some general remarks on undulatory currents, which would be out of place here, the inventor thus describes the first form of telephone which he had constructed—

"The apparatus represented in Fig. 7 was my first form of articulating telephone. In this figure, a harp with steel chords is attached to the poles of a permanent magnet N S. As soon as any one of these chords is set in vibration, an undulating current is produced in the coils of the electro-magnet; the corresponding electro-magnet E′, attracts the chords of the harp H′, with a variable force, and sets in vibration the one chord which is in unison with the chord vibrating at the other end of the circuit. This is not all; the amplitude of vibration in one of the chords determines the amplitude of vibration in the other, for the intensity of the induced current is determined by the amplitude of the inducing vibration, and the amplitude of vibration at the end of reception depends on the intensity of the attracting

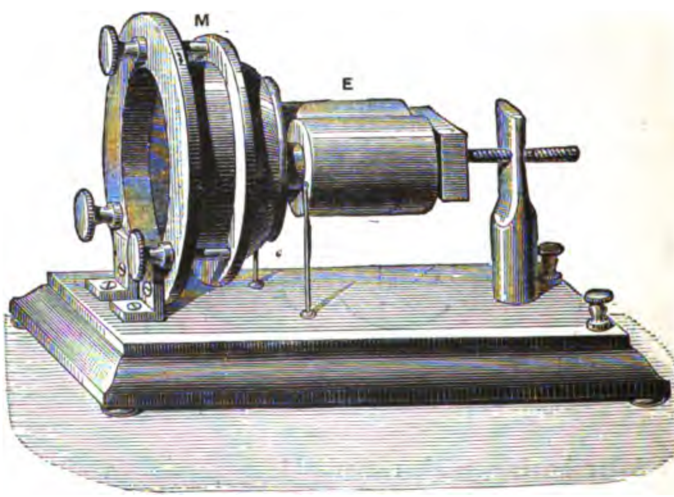


Fig. 8.—Bell's speaking telephone at the Philadelphia Exhibition (speaker).

impulses. When we sing into a piano, certain chords of the instrument are thrown into sympathetic vibrations by the action of the voice, and, for different degrees of amplitude, an approximate sound of the vowel pronounced issues from the piano. Theory shows that if the piano had a much more considerable number of octave chords, the sounds of vowels would be reproduced to perfection. My idea of the action of the apparatus which is indicated in Fig. 7 was the following:—To emit a sound in the neighbourhood of the harp H, and certain chords would be set in vibration with different amplitudes. At the other extremity of the circuit, the corresponding chords of the harp H′ would vibrate with their proper relations of force, and the timbre of the sound would be reproduced. The expense of construction of a similar apparatus prevented me from entering upon this line of research."

After having reviewed the first apparatus which he constructed for reproducing speech at a distance, Bell describes the apparatus exhibited at Philadelphia, in 1876.

In this apparatus, the transmitter (Fig. 8) was formed by an electro-magnet E and a vibrating membrane M, on which Bell places, as a sort of armature, watch-springs of the size of a thumb-nail.

The receiver (Fig. 9) was formed of a tubular Nicklès' electro-magnet E, on which was fixed with a screw a slight armature of sheet iron, of the thickness of a strong piece of paper, which acted as a vibrator; a small bridge placed on the socket acted as a sounding-box.

It must, however, be remarked that the apparatus thus constituted was not an electro-magnetic telephone, for a battery of several elements was placed in the connecting circuit of the two apparatus. The sound was only transmitted by a sort of induction produced by the armature on the current of the battery traversing the electro-magnet E of the speaker. This apparatus enabled Bell and his friend Watson to obtain telephonic transmissions, which put them on the right way.

"I remember," said Mr. Bell, in his lecture, "an experiment made at that time with the telephone, which gave me great pleasure. One of the two apparatus was placed in one of the lecture-rooms of Boston University, the other in the basement of a neighbouring house. One of my pupils was observing this latter apparatus whilst I held the former. After pronouncing the words, 'Do you understand what I am saying?' what was my joy when I heard myself this answer through the instrument, 'Yes, I understand you perfectly.' The articulation of the words was certainly not perfect yet, and it required the greatest attention on my part to distinguish the words of this answer; yet the articulation of the words was a fact, and I was led

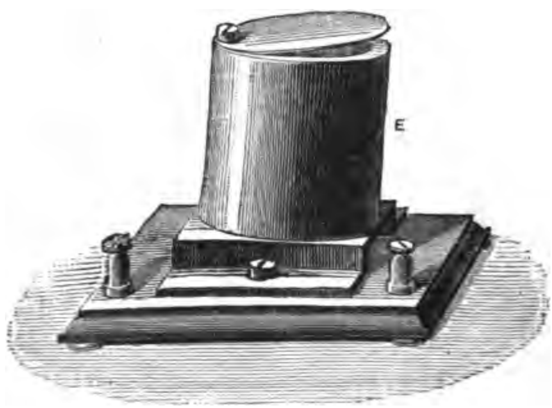


Fig. 9.—Receiver of Bell's telephone at the Philadelphia Exhibition.

to believe that their want of clearness was simply attributable to the imperfection of the instrument."

The great defect of the receiver was that it could not serve as transmitting apparatus; two apparatus were, therefore, required at each station. After a long series of experiments, Bell suppressed the battery, and used a permanent magnet as magnetic core.

This is the first magnetic telephone, represented in Fig. 10 in its original form, as brought before the Essex

Institute, at Salem, Massachusetts, on the 12th of February, 1877. On that occasion he reproduced, before an audience of 600 persons, a speech delivered at Boston into a perfectly identical apparatus.

Fig. 11 (p. 20) shows the lecture-room at Salem at the time when Graham Bell delivered his lecture; the telephone wires ended at Boston, twenty-two kilometres (fourteen miles) distant, where one of the assistants distinctly heard the words pronounced by Mr. Bell (Fig. 12, p. 21), and a few minutes after, the enthusiastic applause of the Salem audience was distinctly heard at Boston. During this memorable experiment, Bell communicated with Boston

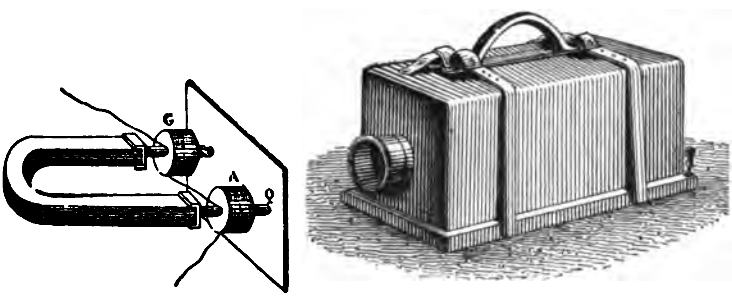


Fig. 10.—Bell's telephone (model with identical transmitter and receiver tested at Salem, on the 12th of February, 1877).

through an ordinary Morse telegraph, worked on the platform where Bell was standing; this telegraph fixed the moment of the beginning of the experiment.

There is only one more step to Bell's telephone such as we know it in its practical and portative form.

Preece was the first to show the possibility of using magnets of very small dimensions, and also to determine the most convenient form which was to be given to the mouthpiece.

Before describing the different telephones from the point

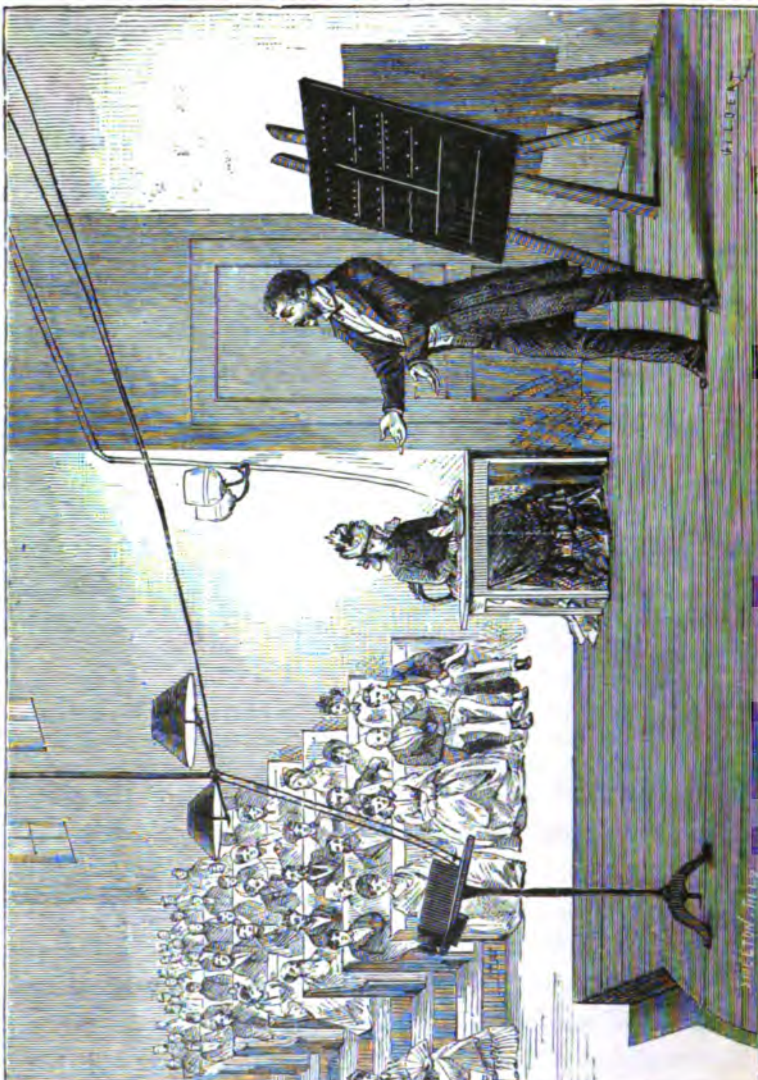


Fig. 11.—Lecture on the telephone, given at Salem (U.S.A.), on the 12th of February, 1877, by A. Graham Bell.

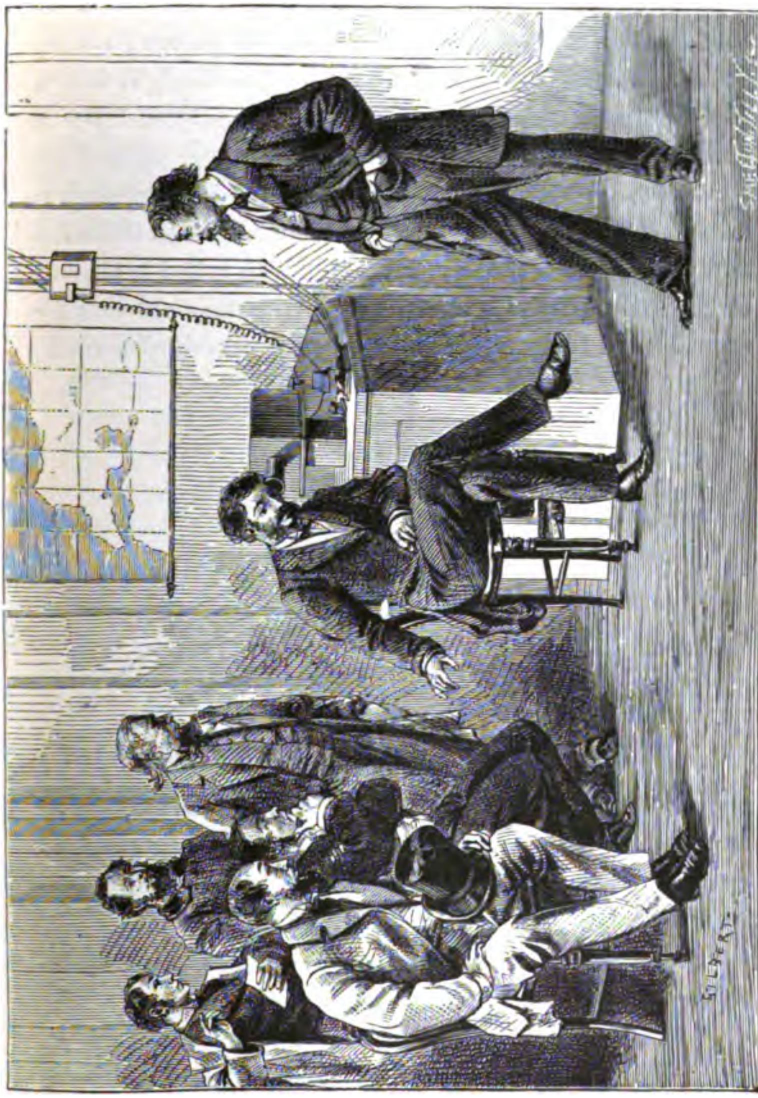


Fig. 12.—An audience at Boston (twenty-two kilometres from Salem) hearing the words pronounced by Graham Bell.

of view of their principle and their construction, we must say a few words on the part which Elisha Gray took in the invention of the telephone; and for this we can have no better authority than Du Moncel, who has closely followed the numerous researches made on this subject. By a remarkable coincidence, of which we have already had an instance with regard to the principle of dynamo-electric machines, Bell's and Gray's patents were lodged on the same day, the 14th of February, 1876, and both called attention to the importance and necessity of undulating currents for the electrical transmission of speech or of combined sounds.

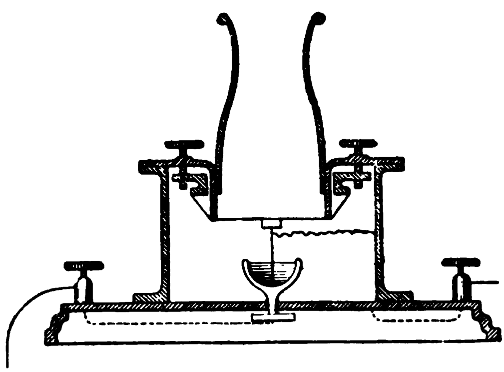


Fig. 13.—First model of Bell's transmitter (with a liquid).

In the apparatus patented by Gray, the undulating currents required for telephonic transmission were obtained by varying the electrical resistance of the circuit, and consequently the intensity of the current in this circuit.

Bell's and Gray's speakers are identical as regards principle, and similar as regards construction.

We reproduce (Fig. 13) the diagram of Bell's transmitter, in which a platinum wire attached to a stretched membrane completed the voltaic circuit by being immersed in water. The vibrations of the membrane modified the resistance of the transmitter, and consequently the intensity of the current. This is the principle of the battery telephone, and Edison's carbon telephone and the microphone are nothing but improvements upon this latter apparatus.

In reality, the problem had been followed up and solved by both the inventors, but by very different methods; whilst Gray has persisted in constructing telephones with a battery and a liquid transmitter, Bell has first constructed a magnetic telephone without battery. Finally, it has to be recorded that Yeates, of Dublin, as early as 1865, in attempting to improve Reiss' telephone, constructed a transmitter similar to Gray's, by introducing a drop of water between the platinum contacts of Reiss' apparatus. The musical telephone might have become an articulating telephone under these conditions, but this result was not obtained on account of the imperfection of the instrument.

Classification of Telephones.—The number of telephones of different systems increases every day, but, notwithstanding the infinite variety of these apparatus, they can be divided into two quite distinct classes—

1. Telephones without battery, or magnetic telephones.
2. Telephones with batteries.

This latter class comprises carbon telephones and microphones.

Magnetic telephones being the simplest and least numerous, we will commence our review of the principal telephonic apparatus with them.

Magnetic Telephones.

Every telephone, whatever may be its construction, consists of two quite distinct parts—

1. The transmitter, which transforms the spoken

words into undulatory currents, which are sent along the line.

2. The receiver, which, as the name implies, receives the undulatory currents, and transforms them again into sonorous vibrations.

The first characteristic property of magnetic telephones is the absolute identity of transmitter and receiver, both of which can easily act either part. A complete magnetic system, therefore, consists of two apparatus only, while battery telephones employ four—two for each station.

The first and simplest of all magnetic telephones is Bell's, whose successive modifications have already been described, in the inventor's own words, at the beginning of this chapter.

Bell's Telephone.—The latest form given to this instrument by its inventor consists of a small wooden or ebonite box, provided with a handle F F′ (Fig. 14), which contains the magnet A placed opposite the vibrating plate M, and serves at the same time for holding the instrument in the hand. By means of a screw placed at the extremity of the handle, the magnet A is brought near the vibrating plate or removed from it, and this constitutes the adjustment of the instrument. At the extremity of the magnetic bar is a bobbin B, whose thickness of wires and number of spirals must be proportionate to the length of the line, in order to obtain the best effects. The vibrating plate, which has only a diameter of five centimetres in its free part and a thickness of $\frac{1}{30}$ to $\frac{2}{30}$ of a millimetre, is of sheet iron, and coated with varnish or tinfoil to prevent its oxidation. The mouthpiece E screws on to the box either by independent screws, as in Fig. 14, or by a screw-channel, and the vibrating plate is squeezed between it and the box and thus kept in position.

The working of the apparatus is well known; we recall it in a few words. On speaking before the mouthpiece of a telephone, the plate vibrates; by its movements it modifies the division of magnetism in the magnetic bar, and gives rise to induced currents in the bobbin placed at its extremity. The telephone is, therefore, a real generator of electricity—a generator of marvellous sensibility, which modulates the intensity of the currents it produces and makes them follow all the varying and complicated undulations which characterize articulate sounds.

These undulatory currents, thus developed in one telephone by the vibrations of the plate, are conveyed by

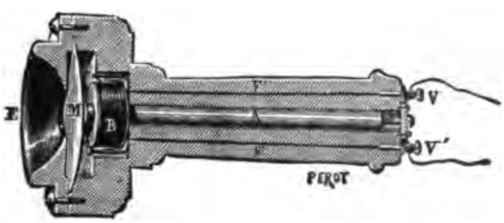


Fig. 14.—Bell's telephone (ordinary hand model).

two conducting wires to a second telephone, which transforms them again into sonorous vibrations. For a first explanation—inaccurate inasmuch as it is incomplete—it may be assumed that the undulatory currents of alternately inverse sense reach the receiving telephone, increase the magnetism of the bar if they traverse the bobbins in a sense favourable for magnetization, and diminish it if they are of inverse sense; the plate obeys these changes of magnetization, approaches the coil when the magnetic force increases, withdraws from it by its own elasticity when the force diminishes, and by this undulatory action, like the exciting currents, vibrates in unison with the plate of the transmitting telephone, although with imperceptibly smaller displacements.

The sounds emitted by the receiving telephone are not perceptibly weakened by the interpolation of several telephones in the circuit. As many as ten or twelve telephones have been placed in the same circuit, and the words pronounced at the other extremity of the line have been distinctly heard by ten or twelve persons at the same time.

We only quote this experiment to show the extreme sensitiveness of the marvellous instrument invented by Professor Bell. We shall have many opportunities of referring to it again in the subsequent treatment of our subject.

The successive transformations which take place in the inappreciable interval between the moment when the sound issues from the mouth of the transmitter, and the moment when it strikes the ear of the listener, are most interesting. They are seven in number—

1. The vibration of the air sets the plate of the transmitter in motion.

2. This motion changes the magnetic division of the magnetic bar.

3. The change in the magnetic division develops induced currents in the bobbin of the speaker.

4. These induced currents traverse the line and the bobbin of the receiver.

5. These currents produce changes in the magnetic bar of the receiver.

6. These changes of magnetism act on the plate and cause it to vibrate.

7. The vibrations of the plate are communicated to the air, and strike the tympanum of the listener's ear.

This is one of the most beautiful illustrations of the equilibrium and the unity of natural forces—an equilibrium which is so well established, that no change, however slight, can ensue in one of them without immediately producing corresponding changes in all the others. The effort developed by the emission of a sonorous vibration is very slight, and yet the telephone reproduces its echo at a distance of 300 or 400 kilometres (200 to 250 miles)!

Many have been the imitations of Bell's telephone, and most of them are modifications without much practical value and without much importance. We cannot examine all these apparatus, whose number is legion; we must confine ourselves to the description of those modifications which have given in practice superior results to the inventor's apparatus, and have enabled the listener to hear the words more distinctly on placing himself, in some cases, at a certain distance from the receiver. We must, however, not lose sight of the fact that the magnetic telephones we are going to describe in no way constitute a new discovery or invention, but simply an improvement of more or less practical value.

Gower's Telephone.—This is an important improvement of Bell's telephone, for it renders the words pronounced by the receiver audible in every part of a room. It must, however, be remembered that Bell had partly obtained this result in his memorable experiment at Salem. In Gower's apparatus (Fig. 15), the magnet N O S is very powerful, notwithstanding its small dimensions. The two poles support a small oblong piece of iron, on which the bobbin is fixed. The whole is enclosed in a flat brass case, whose cover carries the vibrating plate M. The thickness of this membrane is slightly greater than that of the preceding apparatus; it is fastened to the cover by a ring and some screws placed in the circumference of the ring.

Gower employs, instead of the ordinary telephonic mouthpiece, flexible acoustic tubes like those of a speaking-trumpet.

To sound the warning, Gower employs a special arrangement, represented separately in half natural size. It con-

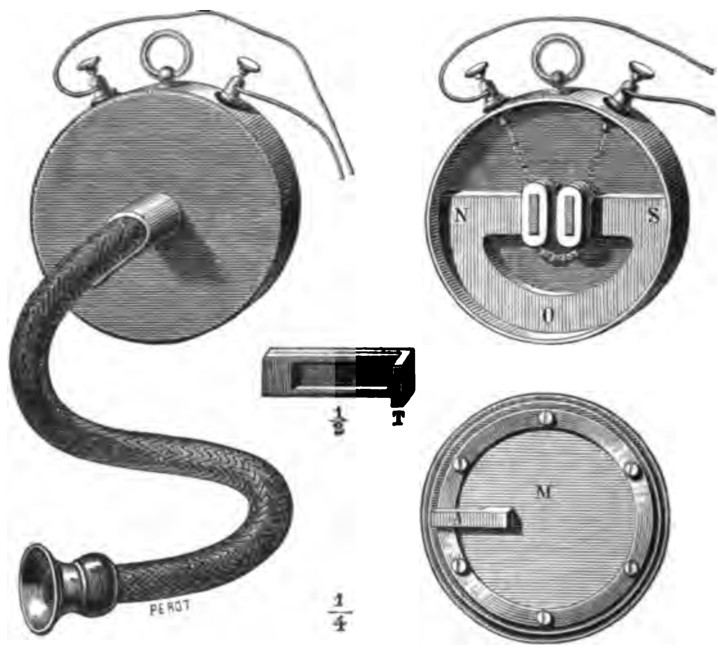


Fig. 15.—Gower's telephone.

sists of a tube bent at right angles, with one end T opening on to the vibrating plate, and the other end into the case; it contains a vibrating reed L. By blowing into the acoustic tube, the reed vibrates and communicates its vibration to the plate of the telephone much more effectually than could be done by shouting into the mouthpiece.

These intense vibrations produce powerful induced currents, which give rise in the receiver to corresponding vibrations, and thus create a considerable noise.

The peculiar timbre of the sound renders it easily perceptible in the midst of a certain dull noise.

By adding a large resonant ear-trumpet to the apparatus, the sound can be heard at a distance.

The addition on the membrane of the tube A in no way disturbs the clearness of transmission.

Ader's Telephone.—We find again in this instrument the circular magnet and the double bobbin of Gower's telephone, but it differs from the latter by having a circular armature of soft iron placed in the body of the mouthpiece in front of the diaphragm. The armature produces an overcharge in the magnet; this overcharge might be obtained by increasing the mass of the diaphragm, but the result would then be obtained at the expense of its vibrating capacity. Ader's armature fulfils the same purpose while not interfering with the lightness of the membrane; Gower's telephone, however, shows that the mass of the vibrating plate has no injurious effect.

Although Ader's telephone is more especially constructed to act as receiver with battery transmitters (of which more hereafter), it must nevertheless be counted amongst the magnetic telephones, because two similar conjugate apparatus can transmit speech like two Bell's telephones.

Most of the magnetic telephones which will be described in the following pages act also as receivers of battery telephones; by examining them in their proper place we shall only have to quote them on studying each system of transmitter.

Crown Telephone.—In this instrument, which serves more especially as receiver for Edison's carbon telephones, the straight bar of Bell's telephone is replaced by six ring-shaped magnets, arranged in such a way that their north poles, for instance, are connected with the core, and the other poles touch the front border of the diaphragm (Fig. 16). By this means, the magnetic field is considerably strengthened, and the instrument is very powerful. It is the invention of an American, Phelps, and owes its name to its crown-like form.

Fig. 16.—Phelps' crown telephone.

Pony-Crown Telephone.—This model, too, is due to Phelps, and is nothing but a Bell's telephone, whose magnet is bent in the form of a circle (Fig. 17). We find in it, again, the ebonite mouthpiece E, the plate P, a small cylinder of soft iron G fixed on the magnet, and forming the core of the bobbin B.

The apparatus presents nothing special, except its very convenient shape, which allows of its being applied to the ear, or easily suspended when it is not used. It is generally employed for telephonic communications by Edison's system.

Goloubitzky's Telephone.—Starting from the fact that several telephones placed at the receiving station can simultaneously reproduce speech without any sensible loss of sound in each of them, Goloubitzky thought that, by condensing these several telephones into a single one, an

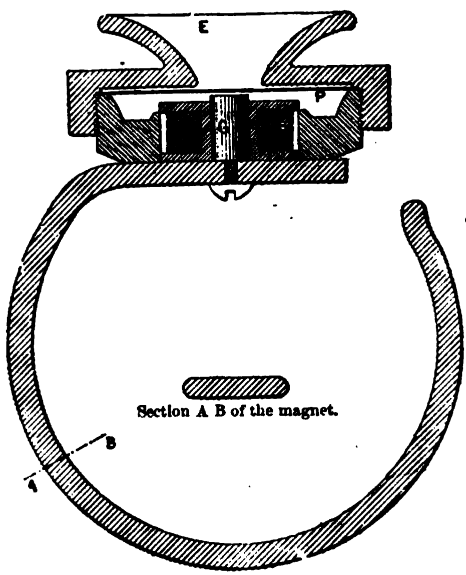


Fig. 17.—Pony-crown telephone.

apparatus might be obtained which would produce more energetic sounds. A further step in the same direction led him to the conclusion that several magnets, acting at the same time on the same diaphragm, would fulfil the same purpose, provided that the vibrations produced were concordant. These considerations resulted in the construction of the apparatus shown in Fig. 18. The poles of two horse-shoe magnets crossing each other at right angles are placed in front of the diaphragm, in the annular region corresponding to the centres of vibration; the four poles of the two magnets form the four angles of a perfect square,

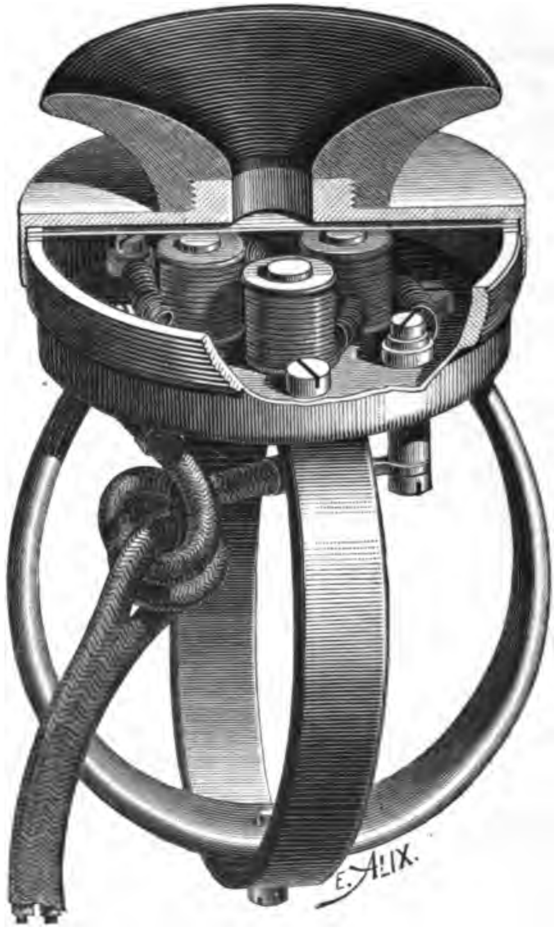


Fig. 18.—Goloubitzky's telephone.
(*From La Lumière Électrique.*)

two poles of the same name being placed alongside each other. For the purpose of magnetization they need only be held for five minutes against the poles of the magnetizing electro-magnet. The diaphragm is separated from the cylindrical box of the telephone by a small copper ring surrounding the border. It is stretched and held in convenient distance from the four magnetic poles by the cover carrying the telephonic mouthpiece. If a hollow sound is produced by tapping on the diaphragm through the opening of the mouthpiece, the adjustment is complete. The bobbins of the electro-magnets are first of all connected so as to correspond to the two different poles of the same

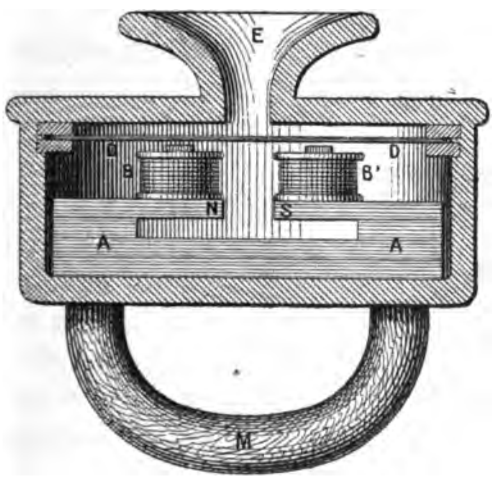


Fig. 19.—Kotyra's telephone (receiver).
(*From La Lumière Électrique.*)

magnet, and the two pairs of bobbins are subsequently joined for tension.

Goloubitzky asserts that the power of his apparatus is superior to that of the best telephones in the proportion of 3 to 12.

Kotyra's Telephone.—In this apparatus the electro-magnet is formed of a large number of small thin plates of tempered steel, cut out of the same bar and joined together so as to present the form of a horse-shoe M (Fig. 19).

This arrangement renders the construction at once less expensive and less difficult; for, supposing that two bundles of plates A A longer than the others and placed above them, constitute the mass of the electro-magnet, the arms and the polar extremities of this latter are simply formed by placing above the two ends of A A two short steel or iron plates, and, on top of these, two longer plates N S, which carry the two iron cores forming the enlargements of the poles. Two bobbins B B′ surrounding the cores complete the electro-magnetic system, in which no piece has to be forged, and which, every plate being magnetized individually, produces a much more energetic and much more durable effect than the system with a massive electro-magnet made of one single piece. The remainder of the apparatus, in which D is the diaphragm and E the mouthpiece, resembles an ordinary Bell telephone.

Fig. 20.—Kotyra's telephone.
(*From La Lumière Électrique.*)

Kotyra has also simplified the mounting of the posts, by enclosing in the box of the telephonic transmitter itself the commutator intended for placing the line in communication with the call-bell or the telephone. This system can, of course, act with or without a battery, but Kotyra prefers using as a transmitter a telephone of his own system, to which he gives somewhat larger dimensions, and which he arranges in such a way as to receive the voice under a certain angle, like the common desk transmitters, which are so extensively used now. The apparatus thus presents itself under the form shown in Fig. 20, and the telephonic receivers are suspended from hooks which protrude into the circular box of the telephonic receiver, and act on the commutator in a similar manner to other systems. The handles which are seen on the back of the telephones are of wood, and have nothing in common with the handles of the Ader telephone which constitute the magnets of the apparatus.

The Kotyra telephones have been successfully tried on the Northern line in France; they certainly have the advantage of cheapness over most of the other systems in use.

Siemens' Electro-Dynamic Telephone.—In this telephone the coil is movable, it is fastened to a membrane, and moves in the magnetic field formed by a powerful electro-magnet energized by an external source. The induction currents are produced by the displacements of the coil in the magnetic field; the action is due to electro-dynamic induction, and not to a change of magnetism of a magnetized bar. The receiver is identical with the transmitter.

D'Arsonval's Magnetic Telephone with Concentric Poles.—In telephones with two poles and two bobbins (Gower's, Siemens', Ader's, etc., systems) the only really useful part is the wire placed between the two poles; the part of the wire which is outside is almost completely lost for induction and simply creates a useless resistance, all the lines of force of the magnet being concentrated in the interpolar space.

To subject the whole of the wire to induction, D'Arsonval has constructed an annular magnetic field, as in Nicklès' electro-magnets, by taking as centre one of the poles of the magnet, whilst the other pole surrounds it in the form of a circle. The induction coil being fixed to the central pole, all the parts of the wire are perpendicular to the direction of the lines of force, and consequently subjected to maximum induction.

In order to concentrate the lines of force at the poles, D'Arsonval adopted the circular form for the magnet which had been utilized by Ader in his telephone. The magnet

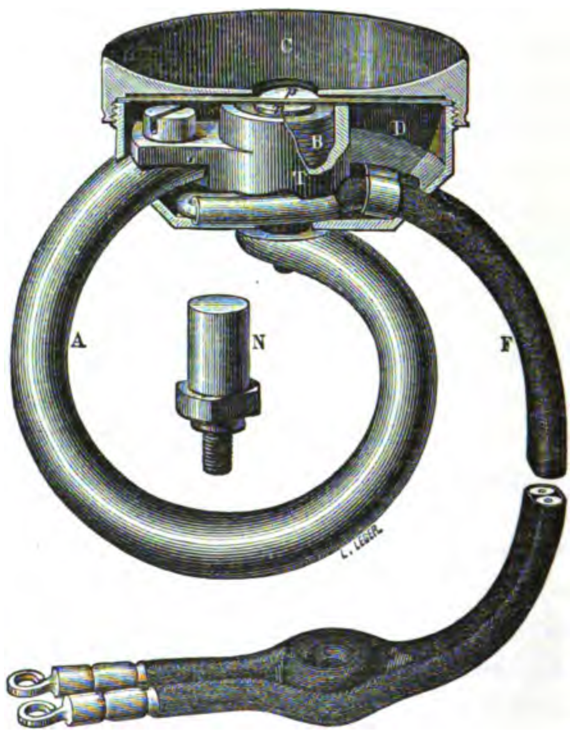


Fig. 21.—D'Arsonval's magnetic telephone.
(*From La Lumière Électrique.*)

has received a spiroïdal and not a cylindrical form, to enable it to surround the central pole without touching it. The magnet, therefore, consists of a spiral part A (Fig. 21), one extremity of which carries the central pole N, on which is placed the bobbin B, the other extremity carries an iron cylinder T, surrounding on all sides this bobbin, which is thus, as it were, buried in a circular magnetic field of great intensity. Finally, with this arrangement the box D which carries the iron diaphragm is fixed in the most simple and most solid fashion without requiring any screws. The box is simply squeezed between the magnet and its core, represented partly at N. The terminals have likewise been suppressed by a very simple system of fastening the double conducting cable F.

In this form the complete instrument only weighs 350 grammes, and gives really surprising effects considering its feeble weight. Speech is reproduced without any alteration of tone, and as regards force it can rival the best Gower; provided with a speaking-trumpet, it is heard in every part of a room. Another recommendation is its low price; owing to the simplicity of its construction it is even cheaper than a Bell telephone.

The transmitter ought properly to find its place amongst the microphones, but is inserted here in order to give a complete account of the system. It consists of a Hughes microphone with four pencils, and differs from the original instrument in the two following points:—

1. The mode of regulation of the contacts.

2. The mode of suspension intended to stifle all sounds extraneous to the voice.

As will be seen from Fig. 22, the microphone is composed of four parallel light carbons placed on a vertical board of thin wood. These carbons are joined, two for quantity and two for tension. To avoid the peculiar spitting noise inherent in Hughes' apparatus, each carbon pencil is surrounded in the middle by a thin sheet of tin; behind the four carbons is a small horse-shoe magnet, indicated in the figure by

Fig. 22.—D'Arsonval's telephone (transmitter).
(*From La Lumière Électrique.*)

dotted lines, which can be brought more or less near the carbons by a simple screw. This method for regulating the pressure of the carbons gives even better results than regulation by pressure. It presents over this latter the double advantage of permitting the microphone to act in any position, and of receiving, with the same carbons, a sensitiveness varying with the special use for which the instrument is intended. In practice, the employment of any kind of spring for effecting this contact had to be rejected, because springs can only transmit pressure through the intermediary of a rigid body, which invariably results either in a sliding movement or in actual vibrations, the fatal consequences of which manifest themselves in extraneous noises. Weight and magnetic attraction do away with this inconvenience.

D'Arsonval has found, by numerous experiments, that one of the necessary conditions of good transmission is to place on the vibrating plate itself the two parts of the microphone, partly fixed and partly movable, in order always to avoid any movement in a lateral direction and simply to produce changes of pressure.

In ordinary cases the magnetic regulation is in itself sufficient, but when the instrument has to be used in a factory or any other place which is exposed to shocks, a very simple system of suspension has been employed which gives perfect results.

The microphonic board is glued on a small box carrying the regulating magnet, and the side of the box opposite the microphone is covered with a piece of flannel, which acts as a damper. It has been remarked that this piece of flannel considerably improves the voice. The microphonic box is suspended from the wall by means of two elastic bands tightly stretched. This mode of suspension, in spite of its great simplicity, is so perfect that nails can be hammered into the wall without in the least interfering with the action of the instrument. Finally, a box, likewise fastened to the wall, carries a single receiver with two acoustic tubes, which are suspended from two lateral hooks, of which the one on

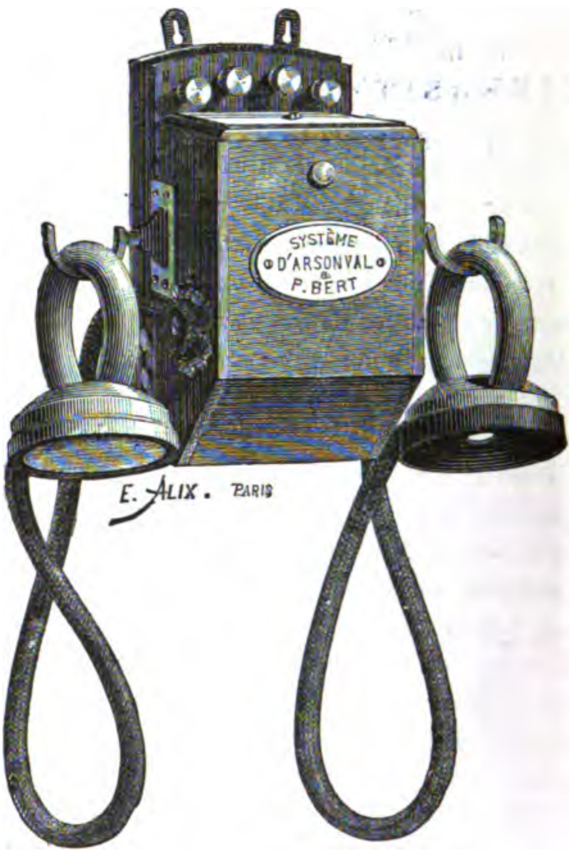


Fig. 23.—D'Arsonval's telephone (transmitter).
(*From La Lumière Électrique.*)

the right serves as an automatic commutator. This box also contains the induction coil, which was first used for telephonic transmissions by Elisha Gray, and subsequently by Edison.

Instead of employing a single receiver, two movable ones can be used; this, however, increases, without any marked advantage, the price and the resistance of the apparatus.

Fig. 24.—D'Arsonval's telephone (transmitter).
(*From La Lumière Électrique.*)

A transmitter of a more portable form is represented in Fig. 23. The microphone is held in the hand, and consists in its essential parts of a magnet with two circular poles, and of four carbons provided as above with tin cylinders, which are held opposite the poles by a vibrating plate of wood, six centimetres in diameter. The apparatus then looks exactly like a telephone and weighs less than 300 grammes. This small model, completed by a receiver and a box containing the automatic commutator, the induction coil, and, if required, the call-bell, gives, as regards clearness of transmission, as favourable results as the large instrument, and acts in any position. Moreover, as the microphone is movable, it can be placed on a small stand and moved from one place to another without the necessity of displacing the numerous conductors of a telephonic post, such as bell-wires, line and earth wires, and batteries for working the call-bell, the telephone, etc.

A third model is represented in Fig. 24. The suspension is effected by two springs tightly stretched inside the pillars of the apparatus, which can be placed on a table. The frame containing the microphone is movable round two trunnions fastened to the middle of the springs, and can thus assume any position required. The receivers are movable and suspended from two hooks, one of which acts as an automatic commutator. It is clear that, given the principle of regulation by magnetic attraction, which allows the apparatus to act in any position, the arrangement of the microphone varies according to the use for which it is intended and the place in which it is to be used.

Different Models of Bell's Telephone.—We can only briefly mention here a number of modifications of Bell's telephone—modifications which were effected with the view of increasing the intensity of the sounds emitted by the receiver, although the results have not always been in accordance with the hopes of the inventors.

As early as October, 1877, Wilmot proposed to increase the number of vibrating membranes and of magnets, to increase the intensity of the currents developed under the influence of the human voice. About the same time, Trouvé also constructed a telephone with multiple membranes; but these apparatus did not give satisfactory results. Phelps and Elisha Gray in America, and Cox Walker in this country, constructed apparatus with several membranes. These apparatus gave better results than Wilmot's and Trouvé's, and their description is to be found in Count du Moncel's work on the telephone; but in practice these complicated apparatus, which require a special adjustment for each membrane, have been abandoned, and telephones with a single membrane are exclusively employed.

The snuff-box telephone is nothing but a Bell's telephone in which the magnet is rolled into a spiral, making almost a complete turn; this renders the instrument less voluminous, and gives it the appearance of a small round box.

By fixing a wooden handle of a few centimetres to the side of this box, the apparatus is transformed into a telephone-mirror.

BATTERY TELEPHONES.

In magnetic telephones, the transmitter acts like a real generator of electricity; the mechanical work of the voice is partly transformed into induction currents, and these currents, on passing into the receiver, make it vibrate synchronically with the membrane of the transmitter. The currents sent along the line must, therefore, have a limited intensity, and in no case will the receiver be able to emit more powerful sounds than those emitted before the transmitter.

The case is different with battery telephones. In these apparatus, the vibrations of the transmitter are no longer utilized to produce currents, but conveniently to distribute those emanating from a constant source; their intensity is, therefore, only limited by that of the source employed. Under these conditions, the power of the receiver can be very great, and even repeat with more intensity the sounds emitted before the transmitter. The microphone will offer a number of these examples.

All transmitters of battery telephones are founded on the same principle—to utilize the vibrations of a plate, or some such piece, in order to produce a variation of the electrical resistance of a circuit, and consequently to modify to a certain extent the intensity of the electric current traversing that circuit.

This general principle requires the transmitter to be composed of a special substance, with variable resistance, more or less ingeniously arranged in the circuit, and modifying its resistance under the influence of the vibrations it receives. From this results a very simple classification of the battery transmitters, depending on the nature of the substance which is instrumental in producing the variable resistance.

We distinguish three classes of battery transmitters—

1. Liquid transmitters, in which a liquid is employed to produce variable resistance.

2. Transmitters with voltaic arc, in which a thin layer of air and high tension currents fulfil this function.

3. Carbon transmitters, the only important and practical ones, comprising microphones.

We shall only say a few words on the two first classes, which have not given satisfactory results in practice, reserving a larger space for carbon transmitters, which are now exclusively used.

1. *Liquid Transmitters.*

These are, from an historical point of view, the oldest articulating telephones. It has been mentioned that, as early as 1876, Bell and Gray invented an apparatus reproducing speech by varying the resistance of a liquid placed between two platinum points. The same was attempted in a rough sort of way, but without success, by Yeates, of Dublin, in 1865, with the view of improving Reiss' musical telephone.

In 1877, Richmond patented in the United States a liquid telephone similar to Bell's (p. 24), to which he gave the name of electro-hydro telephone.

On the 18th of February, 1878, Salet brought before the Académie des Sciences a telephone with liquid transmitter, in which a small aluminium lever in communication with the battery was fixed to the vibrating plate, and carried at its extremity a small platinum plate; very close to this latter was a second one connected with the line. A layer of liquid separated the two plates.

"The vibrations of the membrane, trebled or quadrupled in their amplitude, are not altered in their form, owing to the smallness and the lightness of the lever. The variations produced in the liquid mass by the passage of an intense current engender analogous variations in the attractive force of the receiver. The sound transmitted is very clear, and the timbre faithfully preserved. The consonants, however, are not as distinct as those transmitted by Bell's instrument. This inconvenience, however, which makes itself specially felt when the lever is somewhat heavy, might easily be avoided. The electrolysis, moreover, produces a continuous rustling, but without very much interfering with the clearness of the sound."

J. Luvini and Carlo Resio, of Genoa, have also constructed telephones similar in principle.

Luvini's instrument can, by a special arrangement of the transmitter, send differential and alternating currents. The current ceases when the plate is in equilibrium, and the intensity of the currents varies with the extent of displacement of the system above or below this equilibrium. All these apparatus have merely a scientific interest, and are not employed in practice.

2. *Transmitters with Voltaic Arc.*

These telephones have been constructed with the view of obtaining larger variations of resistance than with liquids for the same amplitude of vibration of the diaphragm, but the employment of large resistances such as those of gaseous conductors also necessitates the employment of high-tension currents. Trouvé, who first constructed a telephone of this kind, suggests the use of his elements with discs moistened with copper sulphate and zinc sulphate. He arranges 400 or 500 of them in series to obtain a sufficient tension.

These apparatus, like the liquid transmitters, have found no practical application.

3. *Carbon Transmitters and Microphones.*

The invention of the first carbon transmitter is due to Edison, who constructed it in 1876, immediately after Graham Bell's discovery. The first microphone is of more recent date, and is due to Hughes, the inventor of the printing telegraph, who exhibited it for the first time in January, 1878, before the officials of the Submarine Telegraph Company.

But the principle which Edison and Hughes have first applied to electrical transmission of sonorous vibrations—we purposely choose this vague and general term—was discovered, in 1856, by Count du Moncel.

It had been believed for a long time that the contact between two metals was sufficient to render them capable of transmitting an electric current, without introducing any resistance in its passage.

After numerous researches on electrical interrupters, Du Moncel was the first to state that pressure exercised at the point of contact between two conductors touching one another, had a considerable influence on the intensity of the resulting electricity.

Du Moncel first of all attributed this effect to a physical cause which had not been properly appreciated; but he was afterwards led to the conclusion that it arose from a larger or smaller amount of pressure of two bodies at their point of contact. The variation of resistance at the point of contact is the greater the more resistance is offered by the conductors; it also depends upon their degree of hardness, and upon the more or less clean state of their surface.

The principle discovered by Du Moncel was applied, in 1865, by Clérac, a French telegraph officer, to a carbon rheostat formed of a tube filled with graphite, in which a movable disc forming the electrode caused, by pressing more or less strongly on the graphite, a considerable variation of resistance in this substance.

Edison's Carbon Telephones.—The original form of this instrument has undergone a great many changes since its

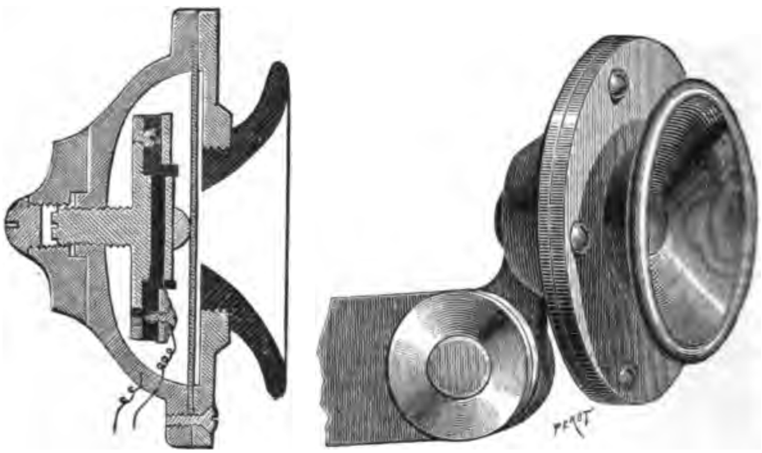


Fig. 25.—Edison's carbon transmitter (model of 1879), in section and perspective.

first appearance in 1876. The model represented in Fig. 25, in section and perspective, is the one employed in France at the present moment for telephonic communications.

The transmitter consists of an ebonite mouthpiece, a vibrating plate, and a disc of prepared carbon of the size of a shilling piece, placed on a support, which can be removed from the vibrating plate or brought near it by means of a screw at the back part of the speaker. A small platinum plate with a rounded ivory button is fixed to the upper surface of the carbon plate. The vibrations of the membrane are communicated to the carbon by the small platinum plate; the variations of pressure produced by these vibrations cause a variation of electrical resistance in the carbon, interpolated between the circuit of a battery and a receiver (Bell's, Phelps', Ader's, etc., magnetic telephones), and cause it to vibrate synchronically. In practice, however, the current of the battery, transformed by the speaker into an undulatory current, is not sent directly into the receiver, but is localized, traverses the inducing wire of a small induction coil, and leaves through the induced wire, which is connected with the receiver of the opposite station. Before going any further, we have to explain the reasons for this special arrangement.

Use of Induced Currents in Battery Telephones.—The function of the transmitter in battery telephones is restricted, as we have seen, to the production of variation of electrical resistance in the circuit; this variation immediately occasions a proportionate variation, in an inverse sense, in the intensity of the passing current.

For a given vibration, the change in the resistance of the circuit will have a given value, which we will assume, for argument's sake, to be one ohm. If the entire circuit has a feeble resistance—ten ohms, for instance—the variation of one ohm produced in the transmitter will vary the intensity by one-tenth of its total value, and consequently the receiver, which acts under the influence of these variations of intensity, will vibrate with great energy, and speak with a certain force.

If, on the contrary, the total resistance of the circuit is large—1000 ohms, for instance—the variations of intensity will not be more than $\frac{1}{1000}$ of the total intensity, the lengthening of the line itself having weakened it to a considerable degree.

To obtain, therefore, an equally powerful effect, it would be necessary to increase the number of the elements of the battery to a very large extent, and to increase the variations of resistance—a result which is in a certain measure obtained by multiplying the carbon discs as in Navez's telephone, or the microphonic contacts as in Crossley's microphone and in Maiche's electrophone. The employment of a powerful battery is neither practical nor economical, and the number of discs cannot be increased indefinitely, for they introduce their own resistances into the circuit, and the advantage resulting from multiple contacts would thereby be counterbalanced. At a given moment, equilibrium is produced, and, by increasing their number, the effect is more injurious than useful.

Edison cleverly got over this difficulty by employing an arrangement applied already, in 1874, by Elisha Gray to his musical telephone. Instead of causing the current of the transmitter directly to traverse the line, Edison makes it pass into the coarse wire of an induction coil. One of the extremities of the fine, or induced, wire is connected with the earth; the other end is attached to the line, traverses the telephone of the receiving station, and goes to earth. Two immense advantages are gained by this arrangement. The transmitter now only acts upon a feeble resistance, represented by the battery, the transmitter, and the inducing wire. The variations of resistance of the transmitter have now a considerable relative value. These variations manifest themselves in the inducing wire by variations of corresponding intensity, and in the induced wire by induction currents of proportional amplitude.

But, on the other hand, with reference to the functions of the induction coils, the currents developed in the induced wire acquire in the coil a high tension, which enables them to overcome large resistances, and this property allows of telephonic messages being sent to a considerable distance with the current of three Leclanché's elements.

Edison's telephone, for instance, acts in the following manner:—The currents of variable intensity, modulated by the transmitter, traverse the inducing wire, and, allowing for the feeble total resistance of the circuit, produce variation of intensity between rather wide limits; the undulatory currents then act upon the receiver as in Bell's telephone.

The carbon plate, which is the very essence of the transmitter, deserves special mention. It is made of lampblack obtained by burning petroleum lamps with long wicks in a nearly closed space. The lampblack is afterwards condensed by compressing it lightly under a coining press. It is thus formed into a rather friable plate, but sufficiently compact when kept in position between two platinum plates, and of extreme sensitiveness as regards the variation of its electrical resistance in proportion to the pressure.

Various Modifications of the Carbon Telephone.—It has already been mentioned that Navez, a colonel in the Belgian artillery, had employed several discs instead of one, and we have indicated how far this alteration might be of advantage.

In Pollard and Garnier's telephone, the transmitter consists of two graphite points, placed on metallic carbon-holders, pressing with a certain regulated force against the vibrating plate. As in Edison's telephone, it is the induced current arising from a small coil which is conveyed to the receiver. Hellesen has constructed a reaction telephone, in which the transmitter is formed by a carbon pencil pressing against the plate, and by a real hollow electro-magnet, whose coarse wire is traversed by the current after this latter has passed through the carbon pencil and the plate. The reactionary effects are due to the strengthening and weakening of the magnetism of the electro-magnet placed opposite the vibrating plate, and are, according to Hellesen, favourable for the action of the apparatus. The circuit of the receiver consists of a long coil of fine wire surrounding the coarse wire of the electro-magnet, and the induced currents developed in this second coil act on the magnetic telephone receiver.

Houston and Thomson also constructed, shortly after Hellesen, two similar telephones, whose peculiarity is that they can act either as transmitter or receiver. A complete description of these two apparatus, which practice has not sanctioned, is to be found in Du Moncel's work on *The Telephone, the Microphone, and the Phonograph.*

Righi's transmitter consists of a plate carrying a flat disc, which exercises a variable pressure on a mixture of powdered graphite and silver, placed in a small trough above the disc. This transmitter can only act horizontally, which is a decided drawback. The receiver is a Bell's telephone of large dimensions, whose vibrating plate consists of a sheet of parchment, in the centre of which a small disc of soft iron is fixed. Two Bunsen elements are sufficient to work the apparatus, which repeats the sound of a trumpet or a flute in every part of a room. Words can be heard at a distance of three metres (ten feet) from the receiver. For short distances, the receiver is in the same circuit as the battery and the transmitter, but for somewhat longer distances, Righi employs induction coils, like Gray and Edison.

Ader's Electrophone.—This apparatus differs from other battery telephones by some novel and interesting modifications. The transmitter consists of a sort of movable wooden carbon-holder, ending in a saucer-shaped mouthpiece. The extremity of the carbon-holder terminates in a small carbon cylinder, rounded at its extremity, and which presses against a second fixed piece of carbon of larger dimensions. The current traverses the fixed carbon, the small movable carbon, and leaves by a very fine and very elastic wire to rejoin the line. By keeping the apparatus in a vertical position, the circuit is opened; by shaking it, shocks are produced, which manifest themselves in the receiver by an intense noise, which can be heard at a considerable distance; by holding the apparatus in a slightly inclined position, a feeble contact between the two carbons ensues, and direct telephonic transmission, without induction coil, is effected with great clearness and force.

The receiver is a drum of fifteen to eighteen centimetres in diameter, closed by a sheet of parchment, on which six small, very thin and very narrow armatures of sheet iron are arranged on a circle of six centimetres in diameter.

Opposite these armatures, six small microscopical electro-magnets are placed, each of which can be separately regulated by means of a screw. These small electro-magnets were first used by Marcel Deprez in his recorders, to overcome the magnetic inertia of larger electro-magnets—an inertia which causes a delay in the magnetization, and consequently in the registering of the phenomena. The six small electro-magnets are all arranged for tension, and act simultaneously on their armatures, in the same sense and with great rapidity.

With this receiver, words can be heard at a distance of about eighteen feet, by using the transmitter we have described; but its adjustment is very difficult, because the membrane is too sensitive to heat and moisture. We remember a lecture at which the apparatus, although it had been accurately adjusted a few hours previously, absolutely refused to give forth a single sound before a most attentive and well-disposed audience—conduct of which no well-behaved instrument ought to be guilty in public.

Ader now generally employs his telephone with magnetic overcharge as receiver; the results are nearly as powerful as with the electrophone, and infinitely more certain.

Boudet's Telephone.—This system is characterized by the arrangement of the transmitter. In order not to describe the apparatus twice, we refer the reader to the medical applications of the microphone by Boudet, of Paris (p. 173). The arrangement of the apparatus as a telephone is slightly different; the disc is fixed on the plate of the transmitter, and follows its movements.

Boudet's telephone is very powerful. On using a Bell's telephone with a rather thick plate as receiver, the words can be heard in every part of a room, provided an ear-trumpet is added to the apparatus, as for the phonograph; but this transmitter is, like Ader's receiver, rather capricious, and requires frequent adjustment.

We only mention in passing Bourseul's and Locht Labye's telephones—modifications of the carbon telephones without any importance. They constitute intermediate systems between carbon transmitters, properly speaking, and microphones.

Blake's Transmitter.—This system, which is now very much used in England with induced currents and Bell's telephone as receiver, has a transmitter of considerable power. The contact which produces the variable resistance is formed by two movable organs independent of the diaphragm, and always in slight contact with one another. The rigidity of one of the parts is replaced by its inertia by fixing the carbon to a heavy mass; the second part of the contact is formed by a small bead of platinum pressed slightly against the carbon by means of a small spring. The contact of the two pieces never being broken, no crackling sounds result from the opening or sudden closing of the circuit. In Fitch's telephone, one of the carbons is placed on felt, which gives a certain elasticity and also prevents the crackling sound. Our space does not allow us to describe a large number of other modifications, which differ from the leading types that have been examined only by some unimportant details. We must, however, say a few words of a new telephone constructed by Hopkins, which is especially remarkable for the facility of its adjustment.

Hopkins' Telephone.—The transmitter consists of a plate of mica A (Fig. 26), on which a small copper vessel B is fixed, enclosing a small carbon cylinder. A vertical carbon pencil F presses against the small carbon cylinder fixed on the plate, and is maintained in this position by the upward pressure of a bath of mercury into which it plunges; the mercury is placed in a glass vessel D, which can be raised or lowered by means of the support E, regulated by a screw. The pressure exercised by the mercury is transmitted to the contact in B, and can thus be very easily regulated. The use of mercury in the apparatus naturally renders it more or less stationary. Figs. 26 and 27 will sufficiently explain the construction of the apparatus, which employs induced currents, like most other carbon telephones.

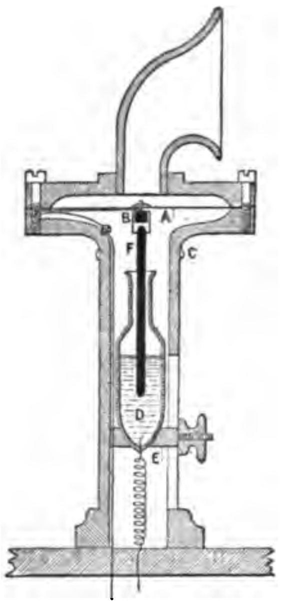


Fig. 26.—Transmitter of Hopkins' telephone (one-half natural size).

The bell-shaped mouthpiece at the upper end concentrates the vibrations on the plate. The receiver of the station is an ordinary Bell's telephone, whose mouthpiece rests on a second ear-trumpet. By taking up a position very close to the apparatus, and shouting "Oh!" into the mouthpiece, the receiver at the other station can be clearly heard in every part of a comparatively

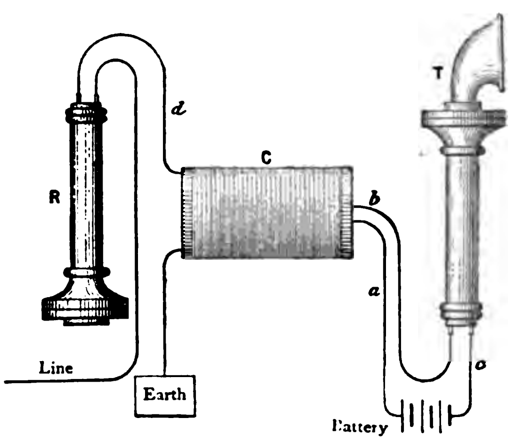


Fig. 27.—Diagram of the mounting of a Hopkins' telephone station.

quiet room. This enables the listener to dispense with any sort of commutator, and prevents errors, which are of rather frequent occurrence with other apparatus.

As shown by the diagram (Fig. 27), the two receivers are mounted in the same circuit, as well as the induced wires of the two coils. At each station the battery is

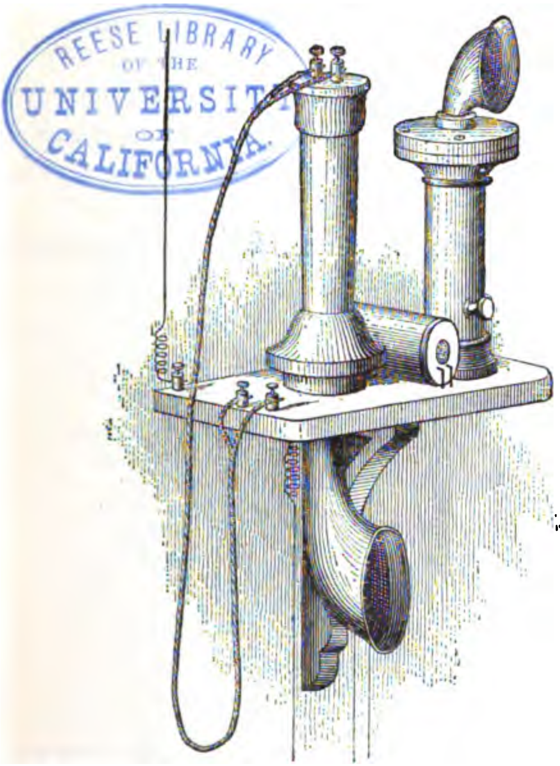


Fig. 28.—Hopkins' telephone (complete station).

closed on the telephone T and the inducing wire *a b* of coil C.

Fig. 28 represents the complete arrangement of a station in perspective.

Here we must conclude our list of carbon transmitters, which increase in number every day; and pass on to the examination of transmitters of a special kind and of infinitely greater delicacy.

MICROPHONES AND MICROPHONE SPEAKERS.

The microphone is nothing but a telephone transmitter of special form, but it owes its name, which was given it by its inventor, Hughes, to the results it enables us to obtain.

The microphone is in reality an amplifying apparatus of

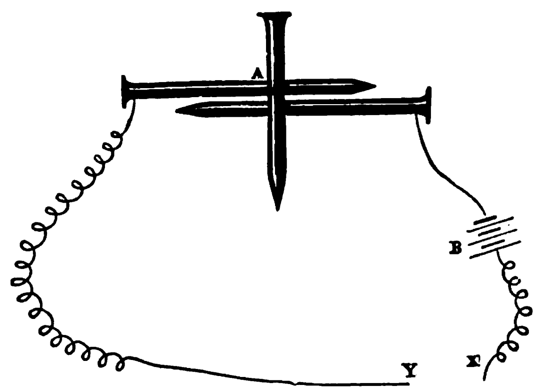


Fig. 29.—Elementary microphone.

mechanical vibrations of feeble intensity, which it transforms into undulating currents. These undulating currents, sent into a receiving telephone, very often produce sonorous vibrations of much greater intensity than the original source. It performs, therefore, in acoustics, with regard to feeble sounds, the same part as the microscope does in optics as regards small objects.

It will be easier, after having described Hughes' simple apparatus, to explain how these startling and unforeseen results have been obtained.

The simplest apparatus employed by Hughes in his numerous researches is represented in Fig. 29. Two nails A are fixed on a small horizontal board, at a distance of about one millimetre from one another. The wires X and Y fixed to these nails are connected with a battery B and a telephone, so that the space between the nails forms the only interruption in the circuit. On placing a third nail across the two first, the current passes through the points

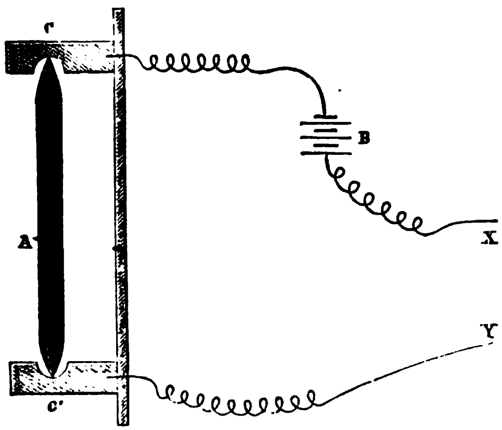


Fig. 30.—Hughes' microphone.

of contact of the two nails, which form an imperfect contact, to which the apparatus owes all its sensitiveness; and this apparatus constitutes a perfect telephone transmitter. Words spoken, airs sung to this little nail, which can dance on the two others to the sounds or the notes emitted, are instantaneously transmitted to the receiver at the other extremity of the line, with marvellous clearness and power. The effect produced is better still with carbon pencils.

But the most sensitive apparatus which Professor Hughes has constructed, and which has remained, excluding a few unimportant modifications, the microphone *par excellence*, is represented in Fig. 30.

It consists of a small pencil of gas carbon A, terminating in a point at each end; the two ends rest lightly between two small circular holes of two pieces of carbon C C′, and

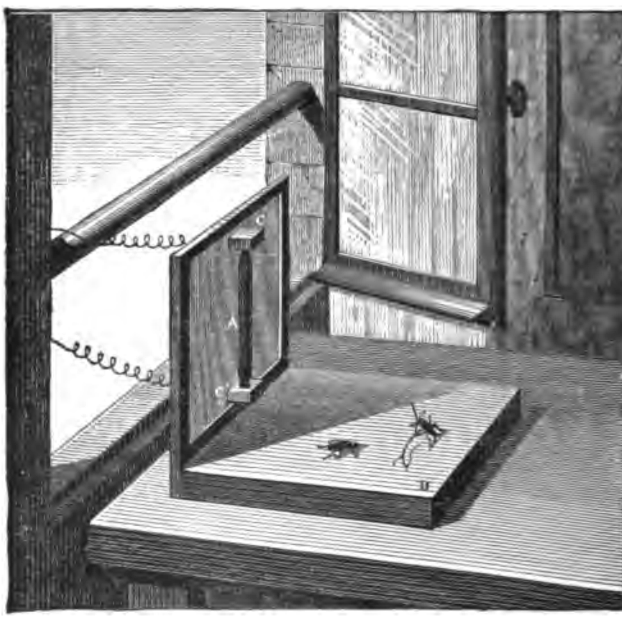


Fig. 31.—Hughes' microphone. The sound produced by the walking of insects heard at a distance.

the carbon pencil has a vertical position; C and C′ are fixed to a thin sounding-board, which is placed on a solid block D (Fig. 31). The pieces C and C′ are connected by the wires X and Y with the battery and the line wire leading to the telephone. This instrument, rough as it looks, is of a surprising and marvellous delicacy.

It converts into sonorous vibrations not only musical notes and words, but the slightest oscillations, and even an imperceptible rustling. The slightest touch, the least friction against the block, is sufficient to produce a grinding noise in the telephone. The point of a small brush rubbing against the block, the fall of a small cotton ball, produce a perfect uproar in the receiver; a fly or any other insect walking on the block D is distinctly heard by a person at a distance of over a mile from the transmitter.

Effects produced in the Microphone.—Now we can appreciate the very slight differences between Edison's carbon transmitter, and the microphone in its simple form as constructed by Hughes.

In both apparatus, the telephonic or microphonic action is produced by variations of electrical resistance, resulting from vibrations communicated to the transmitter.

In Edison's carbon telephone, these vibrations act on a plate which exercises a variable pressure on a disc; in Hughes' microphone, the vibrations effect a change in the points and the surface of contact. The former is intended for transmission of words alone, while the latter is more especially intended for transmission of indistinct sounds. It was, therefore, quite natural at first, that Edison's and Hughes' inventions should be considered as two distinct inventions, as much from the effects realized as for the methods employed.

A number of apparatus have appeared since to fill up the gap which existed between the two apparatus at the time of Hughes' discovery, so that the line of demarcation has quite disappeared, as will easily be seen by referring to Blake's, Boudet's, and Ader's transmitters. We can designate by the generic term of carbon transmitters all microphones and microphone speakers, which had originally formed a separate class.

Edison himself, in one of his latest models of a carbon speaker, employs an arrangement which is nothing but a microphone speaker of Blake's kind.

Edison's claims concerning Hughes' invention were as little founded as they were courteous, and the whole credit of the invention belongs to Hughes.

It will easily be understood how Hughes' microphone can transmit the faintest sounds by amplifying them, on considering what takes place in a microphonic contact. Let us take, for instance, the insect walking on the block of the microphone (Fig. 31).

Each step taken by the insect produces a slight mechanical movement, not intense enough to produce an impression on the ear, but acting on the microphonic contact; the points of contact are thereby displaced and changed, and variations of intensity produced in the current. These slight mechanical displacements are effected the more easily the less stable the equilibrium of the carbon pencil; and, in fact, the apparatus loses part of its sensitiveness on placing it horizontally. From a philosophical point of view, Hughes' marvellous instrument is very imperfect in the sense that it does not act in proportion to the vibrations which it receives.

Very feeble vibrations are very much amplified, those of greater intensity are reproduced with their real intensity, and powerful sounds are, on the contrary, reproduced with a very much reduced intensity. The apparatus, therefore, acts like a microscope would that enlarged small objects and lessened the big ones. For want of apparatus which allow of a direct measurement of the intensity of sounds—

their pitch alone can be measured at present, and their intensity and timbre approximately estimated—it is impossible to determine how this accommodation of microphonic sounds is effected. It suffices to have mentioned the fact; its accuracy can easily be tested.

Hughes' Microphone (Type Ducretet).—This small instrument enables us to reproduce most of the experiments with the greatest ease (Fig. 32). A small pencil C of gas carbon or graphite, pointed at its extremities, is maintained in a

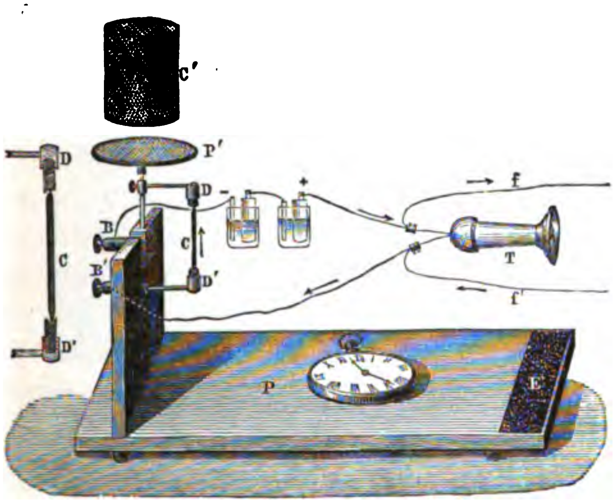


Fig. 32.—Hughes' microphone (type Ducretet).

vertical position between two gas carbons D D′. The support of the upper trough D is arranged in such a way that the equilibrium and the play of the carbon between the troughs, and consequently the sensitiveness of the microphone, can easily be regulated at any moment. The two troughs are in direct communication with the two terminals B B′. The whole is fixed on a small board and a wooden block P. Two indiarubber tubes form the legs of the block, and insulate it from extraneous vibrations, The slight frictions produced on the rough surface E of a band of emery paper are transmitted by the apparatus.

A battery of two or three Daniells or Leclanchés, and a telephone placed at a distance, form a complete circuit, comprising the carbon pencil C with imperfect contacts.

Trouvé has constructed a very portative model of a microphone by enclosing the carbon pencil in a small cylindrical box of ebonite.

Crossley and Maiche have constructed microphones with

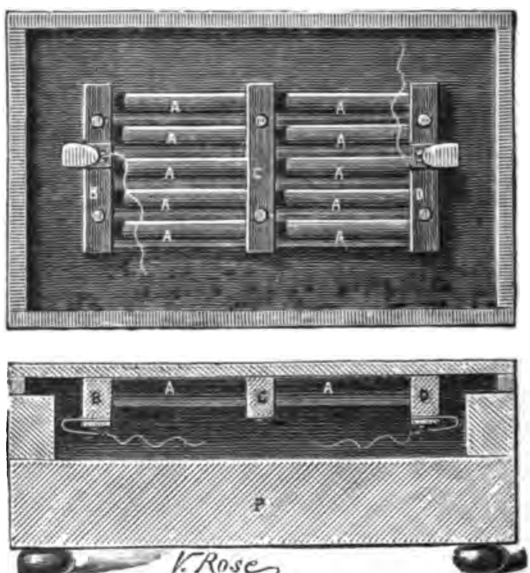


Fig. 33.—View from below and longitudinal section of Ader's transmitter placed on a leaden socket for repetition of theatrical performances.

multiple contacts, as Navez had constructed a carbon transmitter with several discs; but these imperfect contacts, when extensively used, offer the same drawbacks which we have pointed out in Navez's telephone.

Ader's Transmitter.—This microphone, which is now the most extensively used in France, is represented in Fig. 33. It consists of ten small carbon pencils A A arranged in two rows of five, and resting their extremities on three cross-bars of carbon B, C, D, fixed to a small deal board, which receives the vibrations and serves at the same time as cover to the apparatus. It is fastened to a leaden socket P, supported by four indiarubber legs, in order to prevent the concussions of the stage floor from reaching the transmitter.

This precaution is essential, especially at the opera, where the floor is violently shaken by the dancing, and a disagreeable crackling noise would be the consequence. In Ader's apparatus, thanks to the indiarubber legs and the inertia of the block of lead, these concussions do not reach the transmitter, which is only influenced by the sonorous air waves.

Paul Bert and D'Arsonval's Microphonic Transmitter.—In this transmitter all the contacts are mounted for quantity. Each contact is made separately, and is very slight, which ensures sensitiveness; the current is divided between all the contacts, which form as many separate microphones, and diminish the resistance in proportion to their number.

The inventors have constructed several models of these microphones; in some the adjustment is effected by the pressure of mercury, as in Hopkins' telephone (p. 55); in others springs are used, or magnetic attractions which constitute a weightless spring; in others, finally, a weight acts as regulator. Fig. 34 represents this latter system. It consists of a resonance box similar to that of stringed instruments, or a simple ebonite or deal board which carries the series of contacts.

These contacts consist of a number of small cylinders of

German silver, which are strung like beads on a common metallic axis, and are suspended in a vertical direction on one side of the box. Their motion is independent, and each of them rests on a transverse bar of carbon, which acts as a collector, and receives the vibrations of the resonance box or of the board. The pressure of these carbons on the

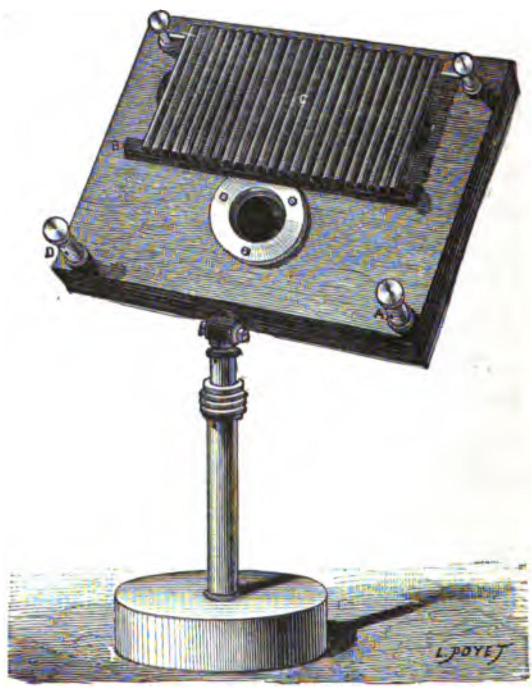


Fig. 34.—Paul Bert and D'Arsonval's microphone. C, carbons enclosed in German silver tubes; the vibrations of speech are transmitted to the centre by a speaking-trumpet. B, carbon on which the tubes C rest; D and A, binding screws.

collector is more or less strong, according to the inclination of the box, which can either be mounted as shown in Fig. 34 or suspended in the room by the two conducting wires. The current arrives through the upper axis, is divided between the carbon pencils, and leaves by the collector. The number of contacts can be increased at will, as well as the dimensions of the box.

Dr. Herz's Telephonic System.—Dr. Herz was the first to apply inverted currents to his system, and also to employ condensers as receivers. His earliest experiments showed him the efficiency of microphonic contacts obtained by the superposition of carbon discs or similar substances of moderate conductivity. He used four systems, A, A′, B, B′, of horizontal contacts, arranged at the four corners of an

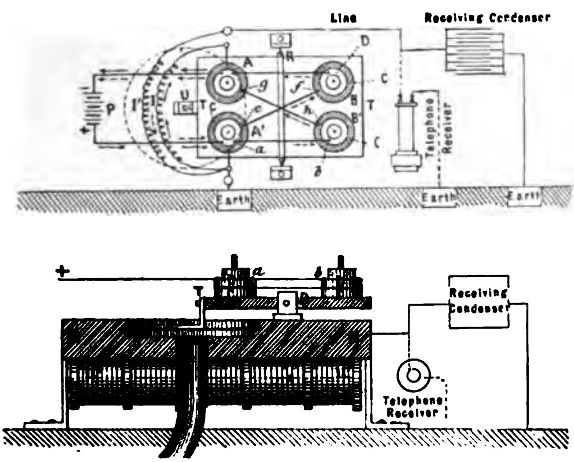


Fig. 35.—Herz's telephonic system.
(*From La Lumière Électrique.*)

ebonite plate C C (Fig. 35). They are connected together, as indicated on the figures—that is to say, the upper discs *e, g, f, h,* by wires parallel with the sides of the plate, and the lower discs A, A′, B, B′, by diagonal wires. The plate oscillates round an axis R, the discs are traversed by pins fixed in the plate, and small leaden discs press on the upper discs. One end of the plate is connected by a rod T to a telephonic diaphragm. It is clear that the vibrations produced by the diaphragm will cause an oscillation of the plate C C, and two successive effects will take place on the part of the discs. The first will be, for the ascending vibrations, an increase of pressure between the discs on the left, in consequence of their force of inertia, which is augmented by that of the leaden discs; the second will be, for the discs

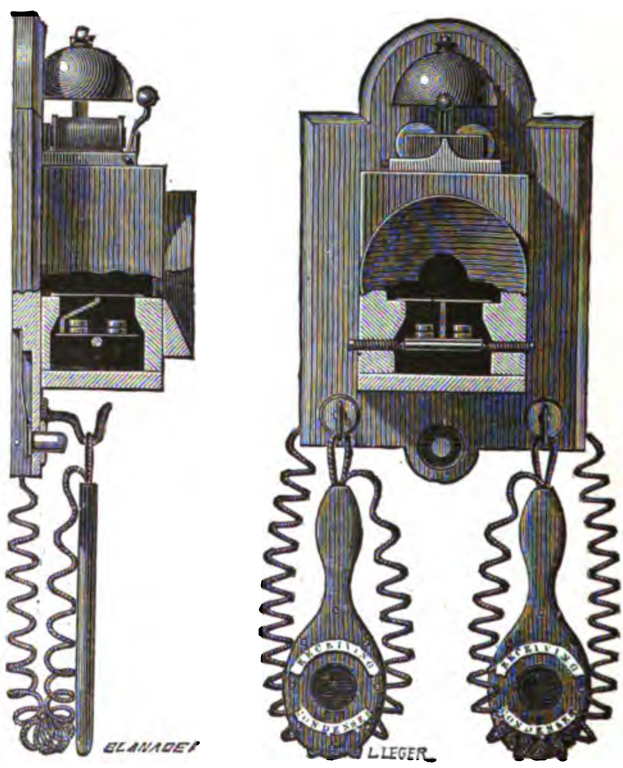


Fig. 36.—Herz's telephone.
(*From La Lumière Électrique.*)

on the right and from the same reason, a weakening of pressure, which will take place at the moment of the change of direction of the vibratory movements.

If the current of a battery traverses all these discs through the connections which we have indicated, and passes through the primary helix (by the wire I) of an induction coil H H′ placed beneath the apparatus, and if the secondary current of this coil, by the wire I′, is in correspondence with the telephonic line, on which a telephone or speaking condenser is placed, the result will be that, at the moment of the ascending vibrations, an induced current of inverse sense will be produced, which will be immediately followed by a direct induced current; this latter, being reversed by the diagonal connections of the discs, will continue the action of the former or prolong its duration, and consequently its motive force, through the telephonic receiver.

This system has been successfully applied to lines of great length and also to lines which are exposed to the hurtful influences of induction, where an ordinary telephone would be useless.

Fig. 36 represents the practical form of an apparatus intended for this latter purpose. It constitutes a complete post, and comprises in a compact and graceful form all the necessary mechanism for a call and for the communications. The diaphragm is horizontal, but a mouthpiece placed in front of the box collects the sounds, so that the voice of the speaker is transmitted in all its intensity from a distance of fifty centimetres from the apparatus. Four pairs of microphonic contacts are placed on an oscillating plate situated beneath the diaphragm and connected with it by a rigid rod, which communicates to it all the vibrations. These contacts, of special construction, communicate with one another, with the battery, and with the line, as has been mentioned above. No induction coil is used with this apparatus, and the number of elements of the line battery must be proportionate to the distance of the two posts; for instance, between Paris and Orleans (a distance of eighty miles) thirty Daniell elements were required for each post, to obtain the maximum intensity. Moreover, the condensers have to be previously charged to reproduce speech, and another battery has to be placed on the line for this purpose. It might

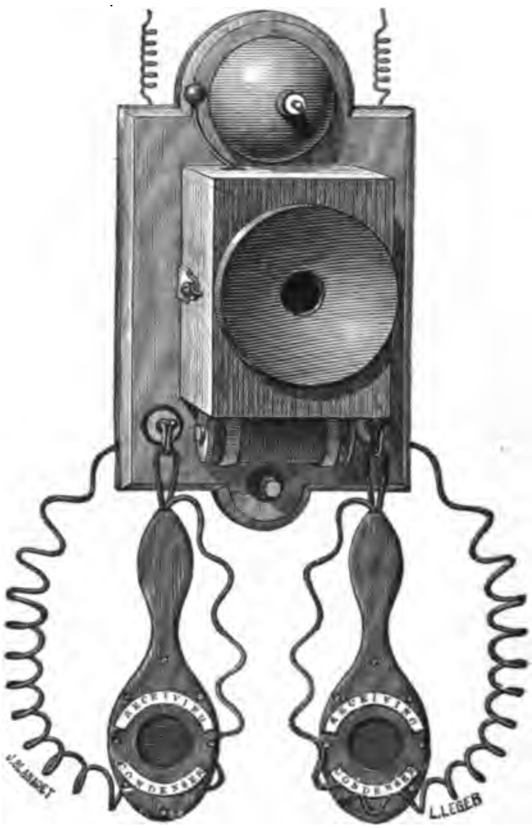


Fig. 37.—Herz's receiving condenser (perspective).
(*From La Lumière Électrique.*)

therefore appear, at first sight, that the necessary number of elements ought to tell against a practical use of the apparatus; but it must not be forgotten that, on the one hand, the battery intended for charging the condensers is nearly

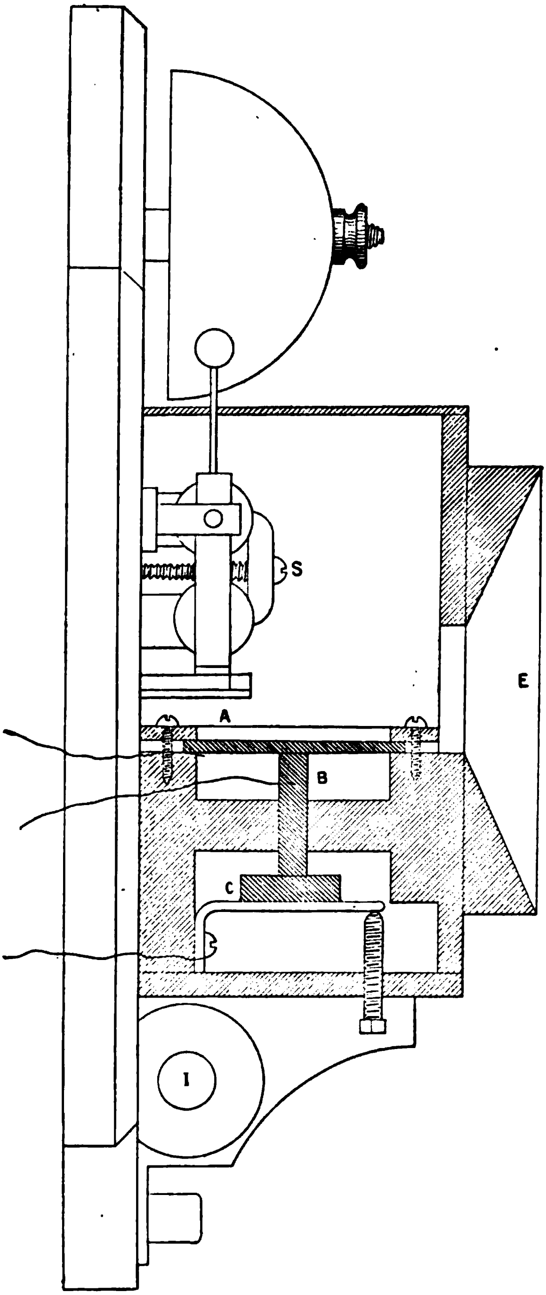


Fig. 88.—Herz's receiving condenser (section).
(From La Lumière Électrique.)

always open and expends very little, and, on the other hand, that the instrument is employed on lines which could not be worked with any other receiver.

Figs. 37 and 38 represent an apparatus in which the inversion of the current is effected by an entirely different method from the preceding one, and in which the induction

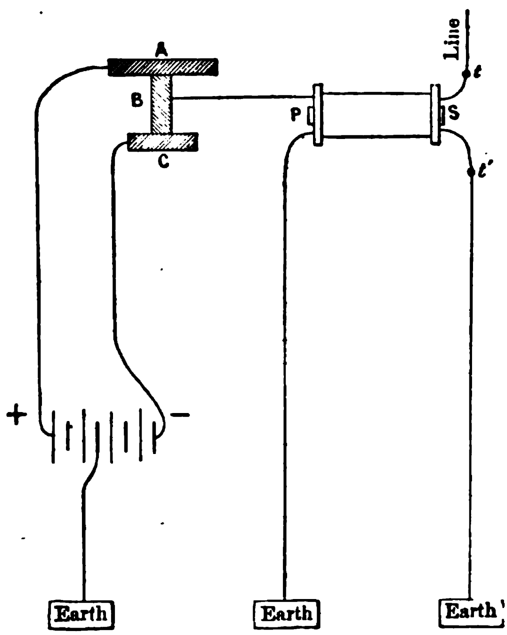


Fig. 39.—Herz's telephone (diagram).
(*From La Lumière Électrique.*)

coil is employed to diminish the number of necessary elements on a long line.

The vibrating plate A is made of a conducting material; below it and in slight contact with it is a cylinder B, whose base presses against a disc C, both being made of the same material as the plate. The disc C is placed on a spring, by means of which contact is established between the three pieces A, B, C. The plate A and the disc C communicate each with one of the poles of a battery of four elements which has an earth connection. Finally, the cylinder B is in connection with one of the extremities of the primary wire of an induction coil whose other end is at earth. The secondary wire of the induction coil communicates on one side with the line and on the other with the earth.

Fig. 39 shows the working of the apparatus. On speaking before the plate A, the vibrations bring about alternate augmentations and diminutions of pressure on the cylinder B. During the first period, the conductibility increases suddenly at A, whilst the inertia of the cylinder B prevents any increase at C, and the current follows the path +, A, B, P, earth. On the contrary, during the second period, the conductibility diminishes at A, but increases at B, and the current follows the path —, C, B, P, earth. It will be seen that, during these two periods, currents of contrary sense pass into the primary circuit of the induction coil, and that in the secondary circuit four currents are produced, two and two being of contrary sense, and pass into the line. In this arrangement the telephones are placed on shunts between the line and earth. This instrument has always given good results on long lines, where static charges are often considerable.

Another principle which has been utilized by Herz for increasing the power of his telephones is that of earth-shunts.

Fig. 40 represents one of the apparatus constructed on the principle of shunts. Beneath the vibrating plate are four pairs of contacts arranged as in Fig. 36, but with different electrical communications; the four lower contacts are connected together and the four upper ones also, so that all the pairs act together without producing any inversion.

Fig. 41 shows the arrangement of two corresponding stations. When the two receivers *t t'* are hooked on, either of the stations can make a call by pressing the button *c*. When the receiving station has replied, the telephones are

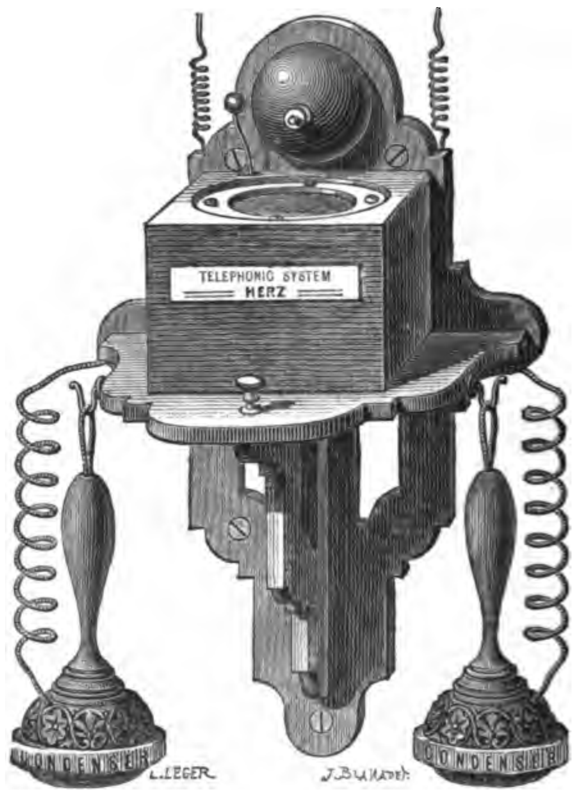


Fig. 40.—Herz's telephonic condenser (horizontal form).
(From La Lumière Électrique.)

taken off the hook, the communications are thereby changed, and the conversation begins before the two apparatus. Let us suppose, first of all, that the right-hand station has spoken; the current of the battery passes through the contact *t'*, which is re-established as soon as the receiver is

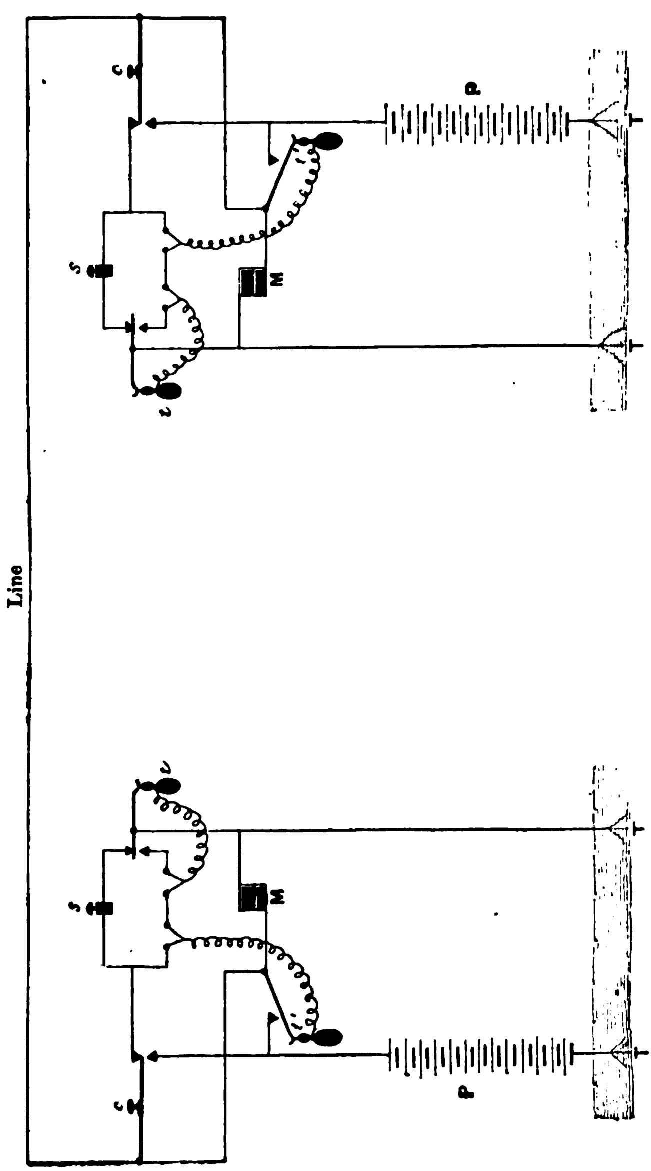


Fig. 41.—Herz's telephonic system (diagram of two stations).
(*From La Lumière Électrique.*)

taken off the hook, then bifurcates, on one side to the line and on the other to the microphone M and thence to earth. The variations of conductibility produced by the microphone in the shunt M T will cause a variation in the same sense in the line current whose resistance is constant.

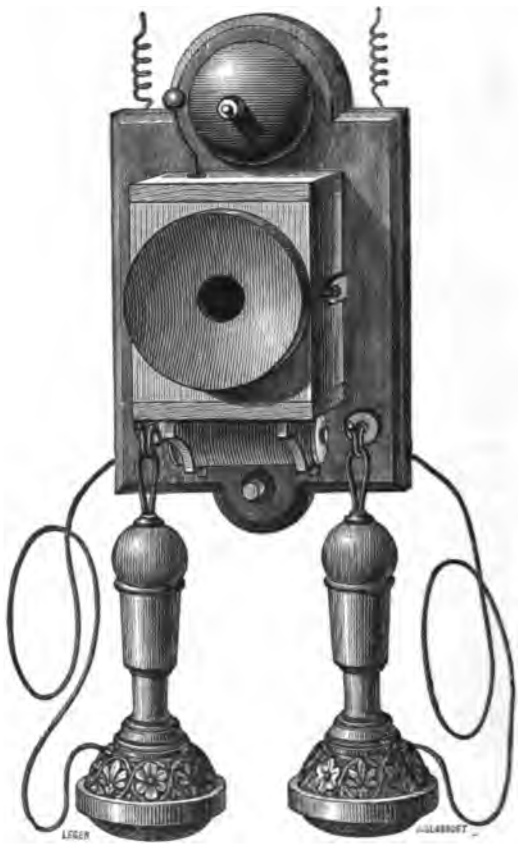


Fig. 42.—Herz's telephonic condenser (vertical form).
(*From La Lumière Électrique.*)

At the receiving station, on the other hand, the current arriving through the line passes on to *c*, then to the telephones, and finally to earth, the oscillation at *t′* having established the lower contact.

The apparatus which we have described is placed horizontally, and the speaker stands right in front of the diaphragm, but it has also received a vertical form, as shown in Fig. 42. This, however, is only an exterior arrangement, and in no way affects the interior position of the horizontal plate and of the contacts. The apparatus described utilize three special principles for facilitating communications under different conditions; these principles are the employment of condensers as receivers, the inversion of the current in the line, and the system of earth-shunts. They do not form an entirely new method of telephonic communications, but each of them ought to be employed in cases where its application is more specially indicated, and they certainly constitute important auxiliaries for telephony.

Herz's Telephonic Trumpet.—With an ordinary Gower telephone Herz has constructed a trumpet capable of reproducing with great clearness and strength an air which had been softly sounded on a trumpet.

To understand the possibility of amplification of sonorous sounds by electric means, it must be borne in mind that, according to Guillemin's researches, the quantity of electricity obtained from a battery in a given time is so large compared with that obtained from a friction machine, that a condenser of very large surface can be instantaneously charged by a battery, whilst a certain time would be required to charge to saturation the same condenser with a friction machine. It is true that the tension of the charge would be much greater in the latter case, but the quantity of condensed electricity will be much less, and, for producing effects of the kind mentioned, quantity and not tension is the essential condition. It will, therefore, be easily understood that, by placing large condensers in a telephonic circuit, rapid effects of charge and discharge can be obtained, which will result in the circulation of relatively large quantities of electricity, and act most energetically on the telephonic receivers. To apply this principle in practice, the transmitter must for each double vibration of the diaphragm cause both a charge and discharge of the condenser. This result can be obtained by placing on either side of the dia-

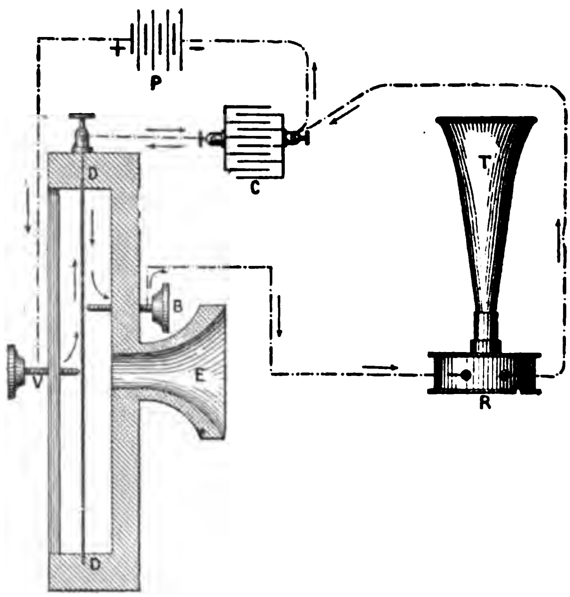


Fig. 43.—Herz's telephonic trumpet.
(*From La Lumière Electrique.*)

phragm two contacts—the one in communication with the battery, the other connected to one of the armatures of the condenser, the diaphragm itself being connected to the second armature of this condenser.

In Fig. 43 the receiver is represented at R, the transmitter at E, P is the battery, and C the condenser. The receiver is an ordinary Gower telephone with an acoustic trumpet T. The receiver is a simple telephonic mouthpiece, whose diaphragm D D is placed between two contact screws V and B connected to the battery and to the condenser and receiver, as indicated in the diagram.

Under normal conditions, neither of the two screws V and B touches the diaphragm, but immediately on the production of a tone before the mouthpiece, the vibrations on the left place the battery in communication with the two armatures of the condenser, by causing a current to circulate in the direction of the arrows; and the left armature of the condenser receives a positive charge through its connection with the positive pole of the battery (through the intermediary of the diaphragm and the screw V), whilst the right armature is charged negatively by its direct and permanent communication with the negative pole. On the contrary, the vibrations on the right of the diaphragm D D, by suppressing the contacts with the screw V and re-establishing them with the screw B, establish communication between the two armatures through the circuit on which the telephonic receiver is placed. The result is a series of discharges through the receiver corresponding to the interruptions of the circuit, which are caused by the vibrations of the diaphragm, and which reproduce the sounds, the cause of these vibrations.

The condenser employed by Herz is an ordinary submarine cable condenser of an electro-static capacity of about seven microfarads, and the battery is a Leclanché of five elements.

Ader's Microphonic Trumpets.—The apparatus shown in perspective in Fig. 44 amplifies sound to such an extent that a hunting-song which is being merely hummed before a singing condenser produces the effect of a hunting-horn.

Four of these apparatus were placed side by side at the Paris Electrical Exhibition, and performed a quartette of hunting-songs. Fig. 45 shows the interior arrangement of one of the microphonic systems which composed the apparatus.

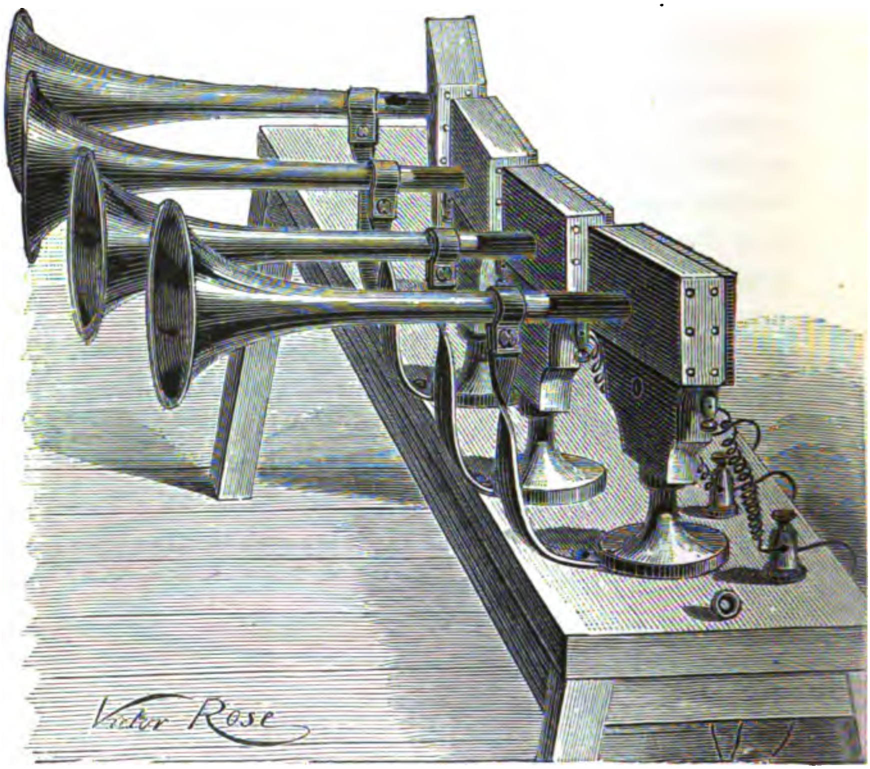


Fig. 44.—Ader's microphonic trumpets (perspective).
(*From La Lumière Électrique.*)

A B is a horse-shoe electro-magnet, having at each polar extremity a flat soft-iron plate; the two plates are arranged in such a manner that there is only a distance of about two millimetres between them, and they carry two flat bobbins E E′, which do not quite reach as far as their extremities. In front of them is a small and very light armature, three millimetres wide by eight millimetres long, and one millimetre thick, supported by a small wooden block, which is glued to a small and very thin pine board L forming the diaphragm. In front of this board is placed the small resonance box to which the cornet *c*, used as the trumpet, is fitted. The distance of the armature from the magnetic poles is regulated in such a manner that, at the moment of the passage of the current, a shock is produced between these two parts of the magnetic system. These repeated shocks reproduce the sounds on the horn of which we have spoken, and which are not always very harmonious.

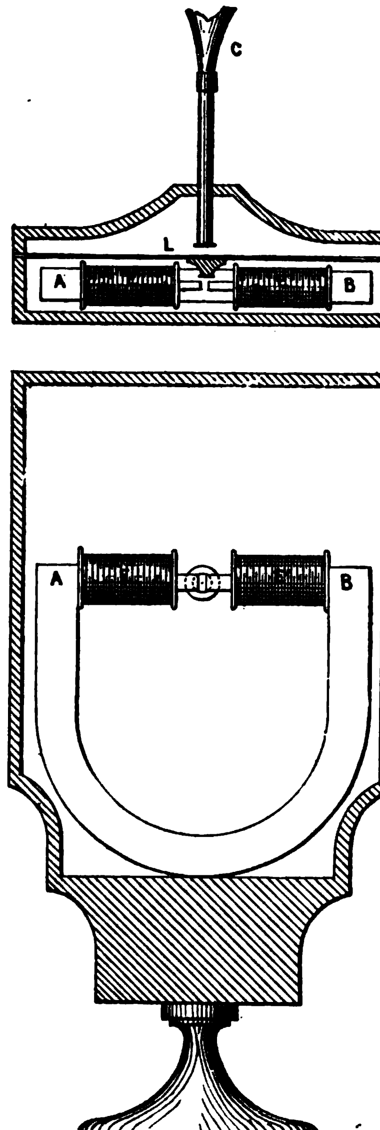


Fig. 45.—Ader's microphonic trumpets (interior arrangement of receiver). (*From La Lumière Électrique.*)

The transmitters were Reiss transmitters with platinum contacts; they were arranged as for the singing condenser, only their construction was more solid and much more finished. Three Leclanchés were used for each microphone.

Maiche's Telephonic System.—In this system a condenser is used instead of an ordinary telephonic transmitter; a mouthpiece is placed in the centre of the condenser, and behind this mouthpiece is a plate of mica to protect the apparatus from the effects of the exhaled moisture. The condenser is composed of about thirty pieces of tinfoil separated by sheets of note paper, care being taken that the alternate sheets are not pressed too closely together. With this arrangement speech has been transmitted in a telephone as clearly as with an ordinary telephonic transmitter. Speech has even been transmitted with a singing condenser employed as receiver, but the sounds were very feeble, unless the latter had been previously polarized by a second battery. The presence of an induced coil is therefore no longer necessary, as had been thought in the first instance.

Maiche's Microphonic Transmitter.—The apparatus consists of a system of multiple diaphragms, four or six in number, arranged in a circle, and each provided with a small mouthpiece. These small mouthpieces are all covered by a large one, which concentrates the sonorous waves and distributes them over the small ones. The diaphragms have the diameter of a two-shilling piece, and consist of sheets of card paper; they are coated with varnish to protect them from moisture. In the centre of each of these diaphragms, and on their backs is fixed a carbon lozenge, against which abuts the carbon contact intended to produce the microphonic effects. This contact consists of a small spherical piece of carbon suspended, like the bob of a clock, by a copper rod to an articulated piece; it is therefore, as in Ader's, Herz's, and other apparatus, the weight which supplies the necessary pressure. It has been found that this system is the most favourable for the clearness of sound. All these contacts, to the number of four or six, are united for tension, so that the transmitted current traverses them all, one after the other, before arriving at the primary helix of the induction coil.

This coil has, in Maiche's new apparatus, quite a particular construction, so much so that it is the coil which constitutes the telephonic receiver. Its arrangement is as follows:—

Instead of a bundle of iron wires placed inside the primary helix, a magnetized bar is used. The wire of the primary helix is put in communication with the microphonic transmitter, and the secondary wire is connected to the line; but the two polar extremities of the magnetic core, provided with iron diaphragms arranged as armatures, are connected to two acoustic tubes which now constitute the telephonic receivers; so that the bobbin itself reproduces the sounds when the transmitter does not act, and it is the bobbin which sets the telephones of the receiving station in action when the transmitter is at work. In this way the circuit is freed from the resistance of the telephonic bobbins, and the effects are more intense.

Dolbear's Telephones.—Here again we find the use of a condenser instead of the ordinary telephonic receiver. The condenser has two armatures formed of very thin metallic discs D D′, and the insulation is effected by a layer of air of about half a millimetre in thickness, which separates the two discs, the whole being mounted in an ebonite ring, as will be seen from Fig. 46, where the two discs are drawn apart to show the supporting frame; and on this ring are screwed on one side the receiver, which is applied to the ear, and on the other the handle, which is nothing but a big button

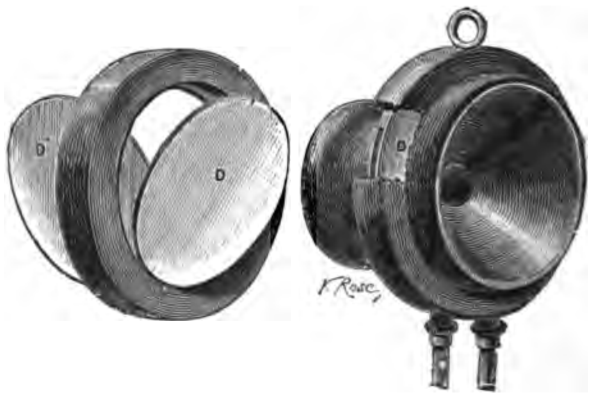


Fig. 46.—Dolbear's condenser-receiver.
(*From La Lumière Électrique.*)

traversed by an adjustment screw A (Fig. 47), by means of which the distance separating the two discs can be regulated. Fig. 47 represents a section of this apparatus, in which only one of the discs can vibrate, the other D abutting in its centre against the adjustment screw B. The transmitter which corresponds to this telephonic system is an ordinary microphone (Fig. 48), consisting of a piece of carbon C suspended to an articulated lever, which presses against a carbon lozenge glued on the vibrating disc D.

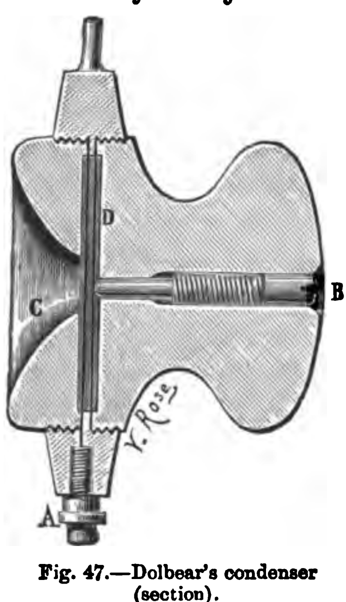


Fig. 47.—Dolbear's condenser (section).
(*From La Lumière Électrique.*)

The current of a local battery of one or two Leclanché elements traverses these carbons and the primary helix of a long induction coil whose secondary helix has a resistance of 4000 ohms, and, by placing the two wires of this latter helix in communication with the two armatures of the condenser, a very distinct and sufficiently strong reproduction of speech is obtained without the necessity of a previous polarization of the plates of the condenser by a second

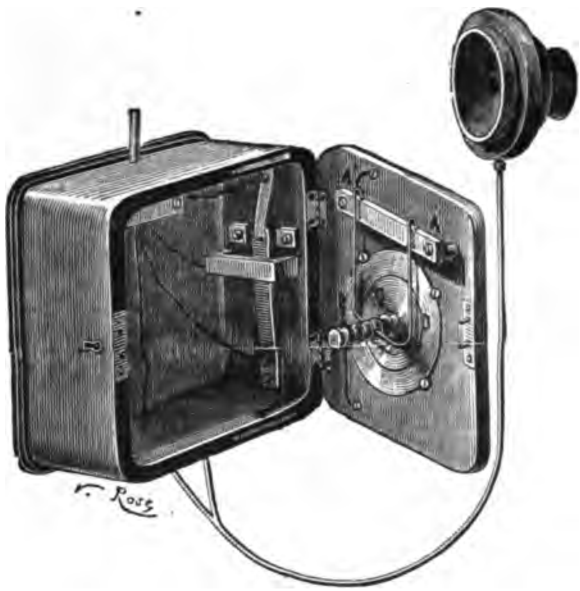


Fig. 48.—Dolbear's microphone transmitter.
(*From La Lumière Électrique.*)

battery, or even the battery of the sending station, as in Herz's system. However, according to Dolbear's statement, this polarization increases the intensity of the sounds.

It is clear, from this experimental evidence, that condensers which employ air as an insulating material do not behave like condensers with solid insulators, and the cause might be attributed to the fact that in the former case the vibrations of the air are effected directly and more easily than in the latter. And in fact, according to the theory of the conservation of electrical energy, the sonorous vibrations produced in a condenser may be attributed to alternate contractions and dilatations of the layer of air interposed between the armatures consequent upon variations of charge in the condenser, and these vibrations, being communicated to the armatures themselves, could the more easily produce the corresponding sounds, as they could be effected without being stifled: this would account for the fact that the vibrations can be more easily obtained with an air condenser than with a solid one. Whether this is the correct explanation or not, Dolbear has transmitted speech between London and Norwich, a distance of 126 miles.

Boudet's Microphone.—In this system the contacts are mounted for tension, instead of being placed on a shunt as in the preceding apparatus. The transmitter, represented in Fig. 49, consists of a mouthpiece E attached to the extremity I of a glass tube T of one centimetre diameter, which is itself fixed to a jointed support, so that the whole of the apparatus can be bent at any angle.

The mouthpiece carries an ebonite plate D of one millimetre thickness, to which is fastened a copper rod M^1, which slightly penetrates into the glass tube. In this tube are placed six balls of gas carbon, of slightly smaller diameter than the tube, so as to allow the balls to move freely inside the tube.

The microphone is completed by a second copper piece M^2 pressing against the bottom R of a hollow breach K by the aid of a small spiral spring which is not represented in the diagram. The screw V fixed on the stirrup Q regulates the pressure of the piece M^2 against the balls. B and B′ are binding screws for battery and line wires. The variations of resistance in the microphone equally affect all the contacts of the balls, because when speaking before the mouthpiece the vibrations are almost instantly transmitted, as in the well-known experiment with the billiard balls.

Before reviewing the different applications which the tele-

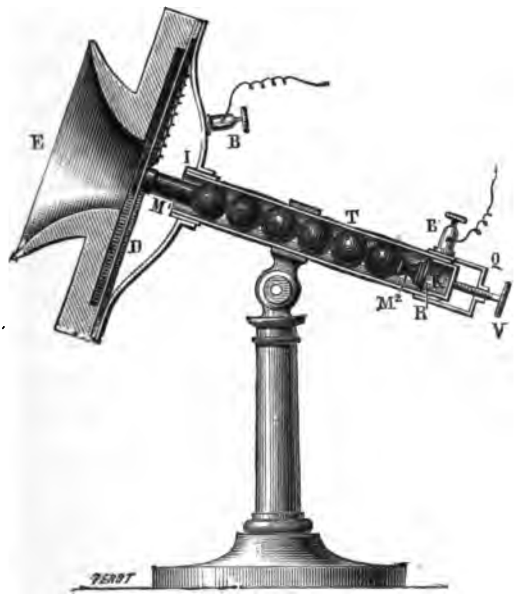


Fig. 49.—Dr. Boudet's microphone.

phone in its various forms has already received, we must examine, under the title of "special telephones," a number of apparatus in which the telephonic movements—meaning the phenomena which connect the transmitter and receiver —are produced by actions of a very different order from those which have been previously mentioned.

This examination will enable us to establish a more complete theory of the multiple actions which come into play in telephonic transmissions, and accurately to determine the part of each of the organs which constitute these marvellous instruments.

CHAPTER III.

SPECIAL TELEPHONES.

In all the telephones described in the preceding pages, we invariably find a magnetic transmitter, either carbon or microphonic transmitter, sending an undulatory current along the line, and this undulatory current acting on a receiving telephone, in which we always find as essential parts: 1, a vibrating plate; 2, a magnetic core, and sometimes an electro-magnet; 3, a coil.

Not one of these parts can be said to be indispensable for the reception of articulate sounds in the telephone. Certain receiving apparatus do not even employ a single one of them; in some telephonic transmissions the words have been heard without a receiver; in others, as in Bell's photophone, transmission is effected without wire, by the help of a luminous ray; in other telephones the receivers assume irregular forms,—the principles on which they are constructed are not based on magnetic action; in some we have physiological actions, as in Gray's receiver; in others, chemical action, as in Edison's electro-motograph, etc. We are going to examine the most important and most original of these apparatus.

Telephones without Vibrating Plate.—The first simplification to be applied to Bell's telephone consists in the suppression of the vibrating plate. In that case words are no longer distinctly transmitted if the transmitter is a magnetic telephone, but the receiver articulates on using a carbon transmitter and induced currents, as in Edison's telephone. The words, however, are very faint; but Du Moncel, who has made a great many experiments on this subject, has found that the effect is the more intense the more strongly the core is magnetized and the smaller its size.

By employing a thoroughly magnetized watch-spring with a coil of fine wire at the end, Du Moncel has been able to hear spoken words with Bell's magnetic telephone. This fact and a number of others, the results of various experiments, will be considered hereafter.

By the side of these telephones without diaphragm, Brégueť's experiments may conveniently be mentioned, in which the thickness of the membrane has been increased up to fifteen centimetres without depriving the telephone of its power or its faculty of articulation. In the former there is no plate at all, in the latter there is too much of it, and the telephone articulates in either case.

Telephones without Membrane and Magnet. Ader's Experiments.—The presence of a magnetized core in the receiver is not indispensable, and we have seen that Ader's electrophone employs small microscopical electro-magnets of soft iron. Whilst making experiments with these apparatus, Ader was led to construct a receiver composed of one simple iron rod of one millimetre diameter, surrounded by a coil of fine wire, and has been able, under these conditions, to transmit words with great clearness. The small iron wire was stuck into a board, and he found that, by applying a heavy mass to the free end of the wire, the intensity of the sounds was more than doubled.

He then constructed the simple receiver represented in Fig. 50, formed, of a handle B, a soft-iron rod C C′ of one millimetre diameter stuck into a pine block P P five centimetres wide, and a small bobbin A rolled round a goose quill. The transmitter employed by Ader was that of his electrophone (p. 53), but the telephone thus constructed will speak with any carbon transmitter. A very amusing spiritualistic trick can be performed with this little instrument by fastening the iron wire C C′ to the reverse of a

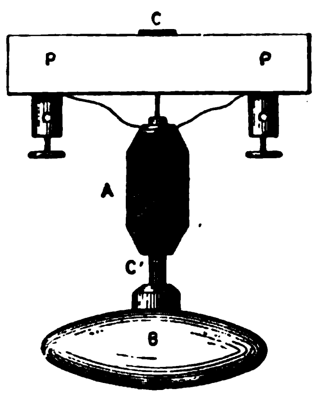


Fig. 50.—Ader's telephone without membrane and magnet.

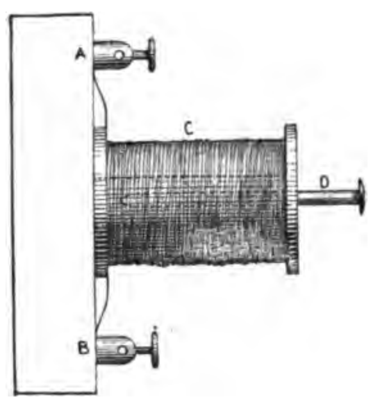


Fig. 51.—Ader's telephone without magnetic core.

table-board, carefully concealing the conducting wires, and having a confederate speaking into the transmitter in a distant room. If the trick is performed in silence, at an advanced hour of the night, the whole table speaks—it can be heard by all those standing round, and the experiment produces the most singular effect on credulous people.

Continuing his experiments, Ader constructed a second, still simpler, telephone (Fig. 51). It consists of a small board A B, and a coil C fastened to the board, round which a fine wire is loosely wound. This apparatus speaks under the influence of a carbon transmitter and three Leclanché elements. If the spirals of the coil are too close or too thickly coated with gum, the telephone no longer speaks, but on introducing into the coil a nail D, a small iron wire, or a magnetized needle pressing against the board, the words are immediately heard with perfect clearness. On taking the nail out, the telephone again becomes mute.

Telephone without Membrane, Magnet, and Coil.—The following telephone is simpler still:—It consists of a soft-iron rod A (Fig. 52) and a small wooden bar B. By applying the bar B to the ear, and a heavy metallic mass to the other end of wire A, Ader has reproduced words by employing a carbon transmitter. De la Rive, in 1846, had found that sounds could be produced under similar conditions by intermittent currents, but Ader was the first who produced articulate sounds by such simple means.

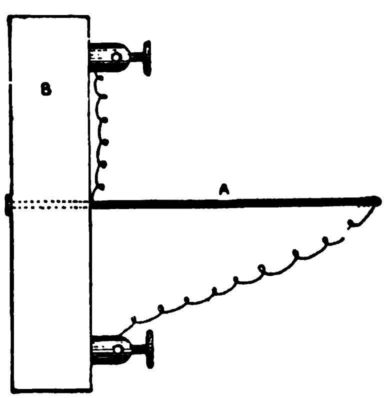


Fig. 52.—Ader's telephone with iron wire.

Since Ader's experiments, Boudet of Paris has constructed a receiving telephone similar to the one represented in Fig. 51, in which the wooden board is replaced by a steel diaphragm. This apparatus reproduces words with the microphone speaker of the same inventor, by employing a single Leclanché. Percival Jenns has also constructed a receiving telephone without membrane or magnet, formed of a coil with iron wire. The apparatus reproduces words by employing Edison's carbon transmitter as speaker.

All these phenomena, as will be seen presently, are explained by Page's effects, which Reiss first applied to his musical telephone.

Willoughby Smith's Inductophone.—This apparatus, which illustrates rather a novel principle, consists of a flat coil of fine insulated wire placed between two pieces of cardboard C (Fig. 53) and traversed by an intermittent current, which is produced by the vibrations of an electric diapason D, and imparts to the disc undulatory variations analogous to those which characterize the telephonic currents.

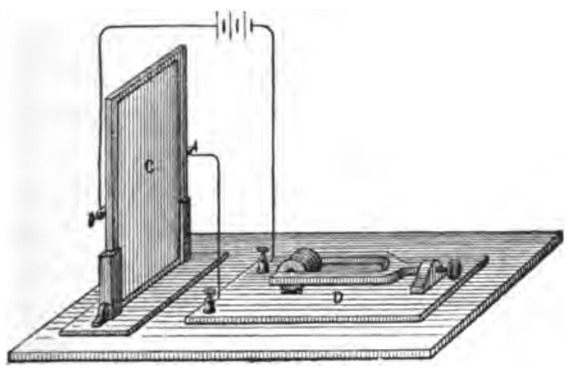


Fig. 53.—Willoughby Smith's inductophone.
(*From La Lumière Électrique.*)

The membrane of a telephone, with or without magnet, on being brought near the board C, begins to vibrate synchronically with the diapason. The sounds emitted are the more intense the nearer the observer is to the board. The distance beyond which the influence of the disc ceases to be felt has not been determined.

This interesting experiment clearly shows that telephones can be actuated by a circuit to which they are not connected by any material conductor.

Preece's Thermo-Telephone. — Wiesendanger, in 1878, ascribed the reproduction of words in certain telephones to the vibratory motions resulting from molecular expansion and contraction consequent upon variations of temperature, which were caused by currents of variable intensity traversing the telephonic circuit.

The objection raised against this explanation rests on the slowness of calorific effects, which would not be prompt enough to produce vibrations.

Preece, the chief engineer of the London Post Office, has taken up this particular line of study, and, after a number of attempts, has succeeded in constructing a veritable thermo-telephone, consisting of a platinum wire, $\frac{7}{100}$ to $\frac{8}{100}$ millimetre thick and fifteen centimetres long, fixed to a support at one end, and to a disc of cardboard or a vibrating plate at the other end.

This simple apparatus is worked with Edison's carbon speaker; the effects are due to the rapidity with which these fine wires gain and lose their temperature, and to the great expansive power of fine wires of large electrical resistance.

Microphone Transmitters used as Receivers.—Preece attributes to similar causes the phenomena observed for the first time by Hughes, shortly after the discovery of the microphone. Hughes showed that the microphone was reversible, like the magnetic telephone, capable of transmitting as well as receiving vibrations. There was no further need of a plate, or coil, or magnet, or magnetic wire; nothing but two pieces of carbon at each station, connected by two conducting wires with a battery interpolated in the circuit.

The experiment is rather delicate, and all microphones do not in the same degree reproduce the phenomena we have mentioned. Boudet's microphone gives the best results, but the two identical apparatus, speaker and receiver, must be adjusted to perfection for the purpose. A single Leclanché is then sufficient to produce these effects.

Pollard and Garnier, too, have obtained words from their carbon transmitters, and Carlo Resio, of Genoa, has used his liquid transmitter as receiver. It is impossible, in the present state of science, exactly to explain what happens in these telephonic transmissions.

Blyth's Speaking Microphone.—Into a flat box of thirty centimetres by twenty centimetres, Blyth places some gas cinders and two plates of sheet iron at the extremities of the box; this constitutes the microphone. According to Blyth, by placing two of his microphones in the circuit of a battery of two Grove's elements, words pronounced before one of the microphones can be heard in the other, which acts as receiver. Du Moncel has modified Blyth's apparatus by employing large fragments of coke and two electrodes, one of zinc, the other of copper. By putting water into the box and connecting the two electrodes of the apparatus with the two terminals of a Bell's telephone, a telephonic system is formed, in which the battery serves as transmitter, and the transmitter serves as battery. The variations of interior resistance due to the slight movements of the carbon in this peculiar battery microphone, produce undulatory currents, which are transformed into articulate sounds in Bell's telephone.

Edison's Electro-Chemical Telephone.—In this instrument, the receiver alone requires description, for the transmitter is nothing but Edison's carbon transmitter.

Let us first examine the principle of the apparatus, which has enabled Edison to construct his electro-chemical telephone—a principle which was first applied by the inventor to a telegraphic relay, under the name of electro-motograph. Let us soak a sheet of blotting-paper in a saturated solution of caustic potash, and place it on a metallic plate connected with the positive pole of a battery composed of two or three Leclanchés. On passing a platinum-foil, about one centimetre wide, over the surface of the paper, and exercising a certain pressure on this foil, a resistance to the sliding motion was felt, owing to the friction of the foil against the paper, which possesses a certain roughness of surface. If the platinum-foil, while sliding over the paper, is connected with the negative pole of the battery, the resistance to the sliding will be diminished to a very great extent; the electric current has, therefore, the effect of smoothing, lubricating or, as it were, of lathering the rough surface of the paper—in other words, it diminishes the coefficient of friction between the platinum-foil and the surface of the paper. This effect of the electric current is proportionate to the intensity of the current, it commences and ceases with it, and is so sensitive that the feeblest currents, those for instance which do not act on an electro-magnet, are rendered quite perceptible.

It is very difficult clearly to explain this phenomenon; for our purposes it suffices to note the effect, and to remember that an electric current of variable intensity can produce a variable sliding motion, proportionate to the intensity of the current. This fact being well established, it will be easy to understand the working of Edison's receiver, of which Figs. 54 and 55 represent the interior view and diagram. A thin plate of mica, eight to nine centimetres in diameter, carries in its centre a platinum plate C, which presses against the cylinder A with a constant pressure, due to the spring S, and regulated by the screw E.

The cylinder A is made of a paste consisting of lime, caustic potash, and a small quantity of mercuric acetate. This paste acts the part of the paper soaked in potash in the preceding experiment.

The cylinder turns with a regular motion by means of

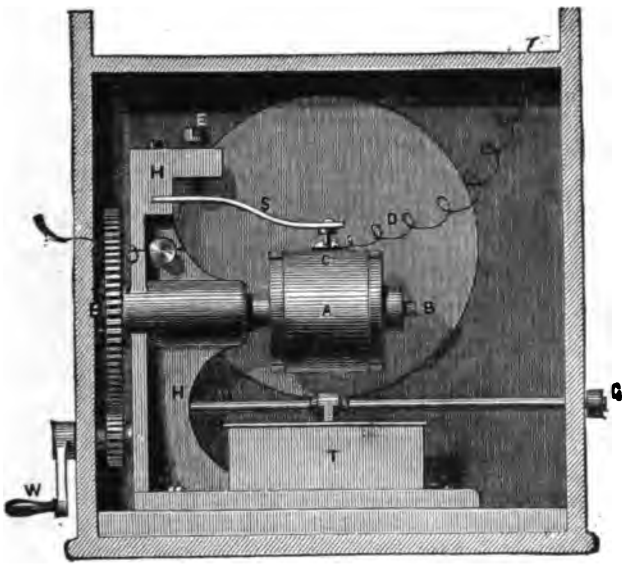


Fig. 54.—Interior view of Edison's electro-motograph. A, cylinder of ime and caustic potash ; B, axle of the cylinder set in motion by the winch-handle W ; C, platinum plate fixed to the mica membrane ; D, line wire ; E, regulating screw of the spring S ; H, support ; S, spring for regulating the pressure on plate C ; T, reservoir containing a solution of potash ; G, lever for working the moistening roller.

a system of multiplying wheels, and of the handle W. This system is replaced by a clockwork movement in more recent apparatus.

The electric current coming from the transmitter arrives by the support H, traverses the cylinder A coated with the paste, and the platinum plate, and leaves by the wire D to go to earth. By turning the cylinder A (Fig. 54) in the direction of the watch-hands, the friction between the plate C and the surface of the cylinder A produces a traction on the plate C. The mica disc, on account of its elasticity, will take up a certain position of equilibrium, which will depend on the traction of the plate C, and consequently on the friction between A and C; each variation in the current which traverses A and C will thus produce a variation in the traction of plate C; this will cause a certain displacement of the mica disc, which will thus vibrate synchronically with the undulating current, and consequently synchronically with the membrane of the transmitter.

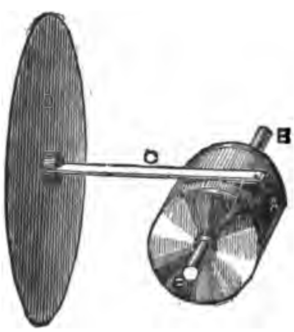


Fig. 55.—Diagram of Edison's electro-chemical receiver.

The vibratory motion of the mica disc is, therefore, not directly obtained by the electric current, but is produced mechanically by the rotation of the cylinder A. The current only produces a certain stoppage, resulting in a variation of the sliding motion, which explains the great power of the apparatus.

On the other hand, the mica disc, possessing little inertia and a considerable elasticity, effectually transmits the impulses received by the plate C. It need scarcely be mentioned that when the handle is not turned the telephone does not act.

Rotation may be effected in either sense. The platinum plate C acts according to the circumstances, either by pulling or by pushing the mica disc. The substance with which the cylinder A is coated must always remain moist, and this result is obtained by raising from time to time a small roller immersed in a solution of caustic potash, which is contained in the reservoir T (Fig. 54).

In more perfect models, the cylinder is formed of a composition which can remain dry, and this simplifies the working of the electro-chemical telephone to a considerable extent.

Dolbear's Friction Telephone.—In this apparatus, which

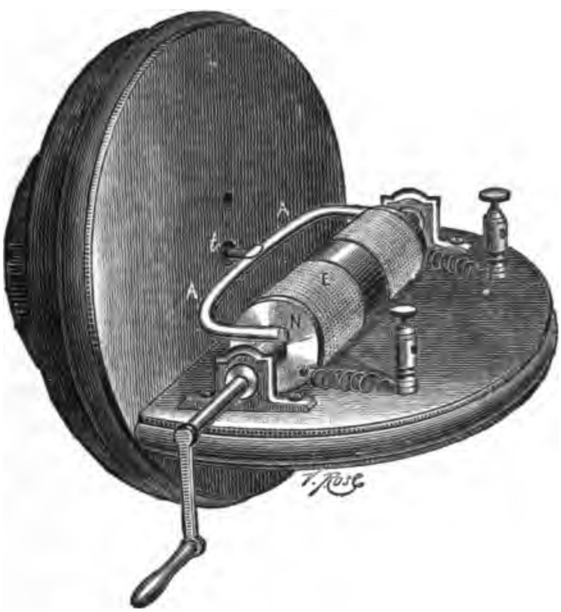


Fig. 56.—Dolbear's friction telephone.
(*From La Lumière Électrique.*)

is represented in Fig. 56, the vibrations result from the differences in the sliding movement of a soft-iron armature in contact with movable magnetic poles, these differences being proportionate to the more or less energetic magnetization of the magnetic core by the traversing undulatory currents.

A straight electro-magnet N E, with movable core and pivoted on its axis, can be rotated by means of a handle adapted to one of its extremities; a bent iron piece A A, forming a sort of armature, presses against the poles of the electro-magnet, and is held by a spring *t*, which is fixed to a disc of mica or metal. This disc is mounted like the diaphragm of an ordinary apparatus, and, as it can be carried on by the electro-magnet in its rotary movement, or repelled in an inverse sense by the diaphragm which acts like an antagonistic spring, according as the current does or does not pass through the electro-magnet, vibrations of the diaphragm will be produced in proportion to the interruptions of the transmitted current, and musical or articulate sounds will be reproduced, according as the currents are intermittent or undulatory. As in Edison's electro-motograph, the electro-magnet must be turned while listening, which, after all, is not very practical.

The apparatus can also be constructed in several other ways. A number of small soft-iron discs can be adapted to the magnetic core, and a circular electro-magnet thus obtained; then the armature can be straight, and simply press against the circumference of the discs; or else, a strip of paper can be placed between the armature and the poles of an ordinary relay, and, by slowly unrolling that sheet, the vibrations transmitted to the relay by an undulatory current can be heard. The strip of paper need, to this effect, only be applied to the ear.

The Hand as Receiving Organ of a Telephonic System.—The apparatus capable of transforming the vibratory current emitted by a battery transmitter can assume, as we have already stated, the most singular and most unexpected shapes.

On pursuing his experiments on the transmission of musical sounds, Gray was accidentally led to construct a telephone in which the hand of the operator acted as receiver.

The phenomenon was first observed by Gray on the zinc lining of a bath, and the following is the author's description of the experiment and the apparatus to which it led:—

"My nephew was playing with a small induction coil, and, according to his expression, was giving shocks to amuse the little children. He had connected one of the extremities of the induced circuit with the zinc lining of an empty bath. Holding with his left hand the other extremity of the coil, he touched the zinc with his right hand. As he was thus establishing contact, his hand was for a short time sliding along the edge of the bath. At that moment I heard a sound issuing from beneath his hand at the point of contact. This sound seemed to me of the same pitch and the same quality as that of the interrupter or vibrating electrotone of the apparatus, which I heard likewise.

"Immediately I took the electrode into my hand, and on repeating the operation, I found, to my great surprise, that, by rubbing hard and fast, I produced a clearer sound than that of the interrupter.

"Following up the idea suggested by the experiment of the bath, I constructed several apparatus with metallic plates for the reception of a sound by means of manual friction. An easy method for obtaining this result is the following:—

"The instrument is composed of a metallic support of sufficient weight to maintain it fixed during the operation. A horizontal axis resting on pads is mounted on the support. One of the extremities of the axis carries a winch, with a handle made of an insulating substance; to the other extremity a cylindrical sounding-box of thin wood is fixed, the surface of which has a metal coating of convex form, in order to render it more solid. This box has an opening in the centre, in order to increase its sonorous qualities. The box is in electrical communication with the metallic support by means of a wire. If the operator connects the metallic coating with the earth by the intermedium of the support, and, seizing with one hand the extremity of the line, presses his fingers against the box, which he turns with the other hand by means of the winch-handle, the sound emitted at the extremity of the line is distinctly heard in every part, even of a large room. These conditions being carefully observed, the more rapid the motion imparted to the plate the clearer are the musical sounds, the slower the motion the softer are the sounds. When the motion ceases, the sound also ceases completely."

Antoine Bréguet's Mercury Telephone.—Bréguet's apparatus utilizes electro-capillary forces and the electric currents produced by them. The phenomenon which led to the construction of this instrument is absolutely reversible; the transmitter and the receiver are, therefore, two identical apparatus.

The mercury telephone differs from Lippmann's electrometer only by its being of simpler construction and of smaller size.

The point of a capillary tube T (Fig. 57) containing mercury M, plunges into a vessel V. The vessel is partly filled with mercury M′, and partly with acidulated water A; the capillary point does not reach the mercury, and only dips into the dilute acid.

Two platinum wires P and Q communicate respectively with the mercury M and the mercury M′.

If the two wires are connected with one another, the level of the mercury in the capillary tube will be established at an invariable height. But if an electrical source is interpolated in the circuit of the platinum wires, the level will assume another position of equilibrium, depending on the potential of this source.

In short, a definite level of the mercury will correspond to each difference of potential. Above the mercury M is

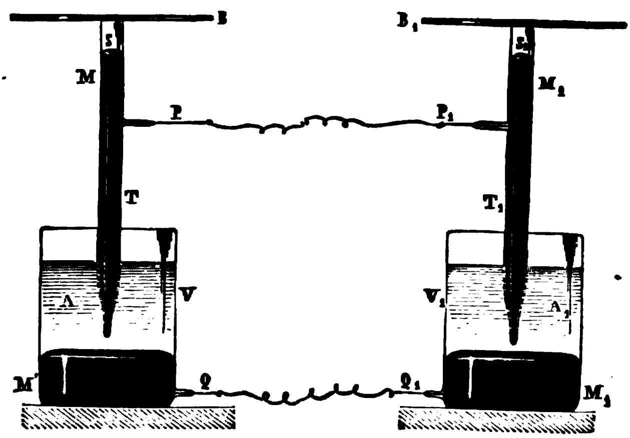


Fig. 57.—Brégnet's mercury telephone.

a layer of air S, whose pressure evidently varies every time the level of mercury itself varies.

The apparatus is reversible, that is to say, if by some modification of the pressure S the level of the mercury suffers displacement, a difference of the potential or, in other words, an electro-motive force will be established in the two conductors P and Q.

Let us now couple together two similar apparatus by connecting the wires P and P_1, Q and Q_1, as shown in

Fig. 57. If pressure is exercised at S, an electro-motive force corresponding to that pressure will be produced in the circuit, and this electro-motive force will produce a change in the level of the mercury M_1 of the second apparatus, and consequently a change in the pressure at S_1.

On speaking above the membrane B stretched across tube T, the air contained in this tube enters into vibration. These vibrations are communicated to the mercury, which changes them into variations of electro-motive force, and these variations engender in the receiving apparatus exactly corresponding vibrations of the mass of air S_1, so that, if the ear be placed above the membrane B_1, stretched across tube T_1, all the words pronounced into the tube T will be heard.

Instead of making use of displacement of mercury, displacement of the glass tubes containing it may be utilized, these latter being less voluminous. It is clear, in fact, that the relation of the two attracting and attracted volumes must be as different as possible in order to be able to consider one of the two masses as immovable and, consequently, the other mass as influenced by a maximum displacement.

Telephone without Receiver.—Some very curious experiments made by a French officer of the Engineers at Lunéville, have shown that the words emitted by the transmitter can be heard at the receiving station without any telephone whatever. M. Crépaux gave the following account of these experiments at a meeting of the Société d'Encouragement on the 13th of June, 1879:—

"There exists at Lunéville a telephonic system established under rather primitive conditions. The line wire is of galvanized iron, three millimetres thick, and tightly stretched. It is fixed to a post at the top of a hay-loft, and runs in an obtuse angle along the chimney-stack of a neighbouring house at a distance of about ten metres. The chimney-stack naturally corresponds with the fireplace of a room in the first floor of the building. On speaking into the telephone from one station to the other, not only the receiver speaks and can be heard on holding it close to the ear, but, and this is most inexplicable, the chimney along which the wire runs speaks, the fireplace speaks, and a person lying in bed in the room hears from his bed all the words transmitted to the wire more distinctly than those who at the end of the line use the receiving apparatus. It is impossible to deny this fact, of which I have been a frequent witness. The wire of the chimney-stack has been insulated by glass plates, and yet the words have been heard as before; at the most remote station, at a distance of about 200 to 250 metres, a similar fact has been observed.

"The earth wire follows in its path a zinc drainage pipe; this pipe has ramifications leading to a flag-stone: the flag-stone speaks.

"I have been told that at each connecting point the line wire speaks; by bending it several times round a nail fixed in the wall, the knot thus produced speaks.

"It is probable that the fact, which I warrant to be correct, is only produced in the neighbourhood of the point of connection and of contact."

These experiments, in which the active agents have an extremely feeble power, show what a marvellously sensitive and delicate organ our ear is.

We have also to mention Watson's and Ader's telephonic transmissions with open circuit, in which the effects seem to be due to phenomena of charge and condensation as yet imperfectly known.

Graham Bell and Sumner Tainter's Photophone or Optical Telephone.—Experiments dating back as far as 1872 have shown that selenium is a body extremely sensitive to the influence of light, and that this influence manifests itself by modifying the electrical resistance of selenium. Bell and Tainter, after numerous experiments, succeeded in intensifying this sensitiveness, and have constructed an apparatus to which they gave the name of photophone, which enables them to transmit words to a distance by aid of a luminous ray.

For this purpose, the rays of a powerful and constant luminous source—the sun, for instance—have been thrown on a thin and highly polished mirror. On speaking behind this mirror, its curve is modified in such a manner that the reflected rays are dispersed according to the vibrations of this plate, and vary in intensity in a given direction.

At the receiving station, the luminous rays of variable intensity strike a parabolical mirror, which concentrates them in its focus; a cylinder of selenium, specially prepared for the purpose, is placed in the focus of the mirror. This selenium modifies its electrical resistance according to the luminous intensities which strike it, and as it is placed in the circuit of a battery and of a Bell's telephone, it acts like a genuine microphone in changing the intensity of the current in the circuit, and produces articulate sounds in the telephone.

This result is simply marvellous, and is another proof—where none, however, was needed—of the ingenuity of the inventors.

Graham Bell's Account of the Photophone.—After a few introductory sentences, Graham Bell goes on to say, "We (Graham Bell and Sumner Tainter) have found this property

—sensitiveness to light—in selenium, gold, silver, platinum, iron, etc., and the only substances from which we have not obtained results are carbon and thin microscopical glass. We find that when a vibratory beam of light falls upon these substances they emit sounds—the pitch of which depends upon the frequency of the vibratory change in the light. We find, further, that when we control the form or character of the light-vibration on selenium, and probably on the other substances, we control the quality of the sound, and obtain all varieties of articulate speech. We can thus, without a conducting wire as in electric telephony, speak from station to station, wherever we can project a beam of light. We have not had opportunity of testing the limit to which this photophonic influence can be extended, but we have spoken to and from points forty-three metres apart; and there seems no reason to doubt that the result will be obtained at whatever distance a beam of light can be flashed from one observatory to another."

Graham Bell now gives the history of the discovery of selenium and tellurium, where we need not follow him. He then goes on to describe the properties of the two metals, and how the sensitiveness of selenium to light was determined by a large number of experiments made by Willoughby Smith, Professor Adam, Siemens, and others. "All observations by these various authors had been made by means of galvanometers (measuring the electrical resistance of selenium, which is greatly diminished by the influence of light); but it occurred to me that the telephone, from its extreme sensitiveness to electrical influences, might be substituted with advantage. Upon consideration of the subject, however, I saw that the experiments could not be conducted in the ordinary way, for the following reason:—

The law of audibility of the telephone is precisely analogous to the law of electric induction. No effect is produced during the passage of a continuous and steady current. It is only at the moment of change from a stronger to a weaker state, or *vice versâ*, that any audible effect is produced, and the amount of effect is exactly proportional to the amount of variation in the current. It was, therefore, evident that the telephone could only respond to the effect produced in selenium at the moment of change from light to darkness, or *vice versâ*, and that it would be advisable to intermit the light with great rapidity, so as to produce a succession of changes in the conductivity of the selenium corresponding in frequency to musical vibrations within the limits of the sense of hearing. For I had often noticed that currents of electricity, so feeble as to produce scarcely any audible effects from a telephone when the circuit was simply opened or closed, caused very perceptible musical sounds when the circuit was rapidly interrupted, and that the higher the pitch of sound the more audible was the effect. I was much struck by the idea of producing sound by the action of light in this way. Upon further consideration, it appeared to me that all the audible effects obtained from varieties of electricity could also be produced by variations of light acting upon selenium. I saw that the effect could be produced at the extreme distance at which selenium would respond to the action of a luminous body, but that this distance could be indefinitely increased by the use of a parallel beam of light, so that we could telephone from one place to another without the necessity of a conducting wire between the transmitter and receiver. It was evidently necessary, in order to reduce this idea to practice, to devise an apparatus to be operated by the voice of a speaker, by which variations could be produced in a parallel beam of light, corresponding to the variations in the air produced by the voice."

The inventor then describes some unsuccessful attempts, and after that the preparation of the selenium cells used in the instrument. These cells are small cylinders of brass coated with selenium. "The mode of applying the selenium is as follows:—The cell is heated, and when hot enough, a stick of selenium is rubbed over the surface. In order to acquire conductivity and sensitiveness, the selenium must next undergo a process of annealing.

"We simply heat the selenium over a gas stove and obscure its appearance. When the selenium attains a certain temperature, the beautiful reflecting surface becomes dimmed. A cloudiness gradually extends over it, somewhat like the film of moisture produced by breathing upon a mirror. This appearance gradually increases, and the whole surface is soon seen to be in the metallic, granular, or crystalline condition. The cell may then be taken off the stove and cooled in any suitable way. When the heating process is carried too far, the crystalline selenium is seen to melt. Our best results have been obtained by heating the selenium until it crystallizes, and continuing the heating until signs of melting appear, when the gas is immediately put out. The portions that had melted instantly recrystallize, and the selenium is found upon cooling to be a conductor, and to be sensitive to light. The whole operation only occupies a few minutes."

After saying that they constructed about fifty forms of apparatus for varying a beam of light in the manner required, and giving a short account of several of these forms, Graham Bell continues—

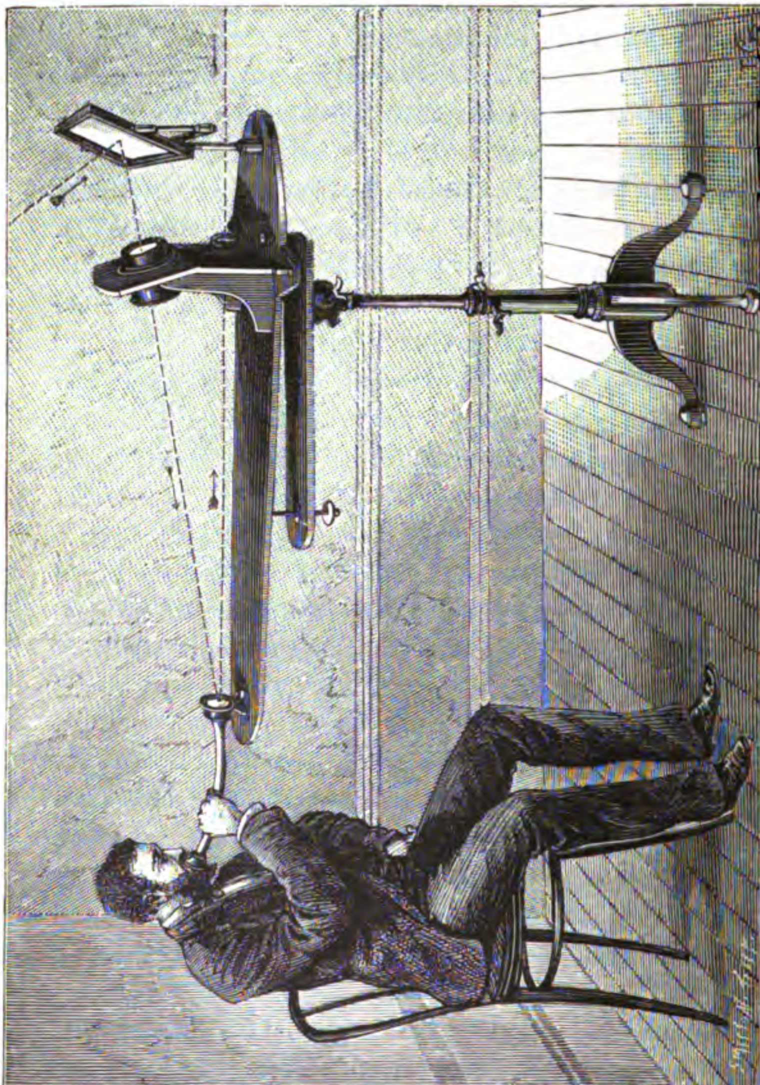


Fig. 58.—Graham Bell and Sumner Tainter's articulating photophone. After reflection on the vibrating mirror of the speaker, the luminous ray, indicated by a dotted line, is directed towards the distant receiver.

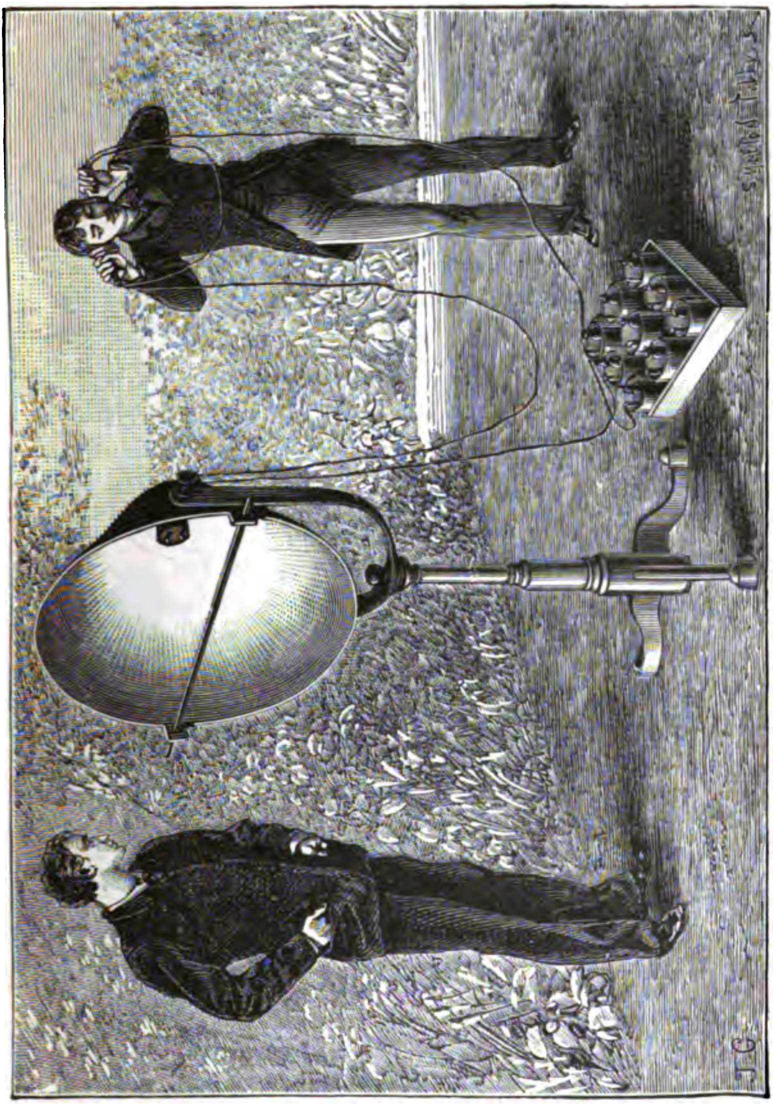


Fig. 59.—The receiver of the articulating photophone. The words transmitted by the luminous rays are heard in the telephones connected to the apparatus.

"The best and simplest form of apparatus for producing the effect consists of a plane mirror of flexible material, such as silvered mica or microscopic glass. Against the back of this mirror the speaker's voice is directed. The light reflected from this mirror is thus thrown into vibrations corresponding to those of the diaphragm itself.

"In arranging the apparatus for the purpose of reproducing sound at a distance, any powerful source of light may be used; but we have experimented chiefly with sunlight. For this purpose a large beam is concentrated by

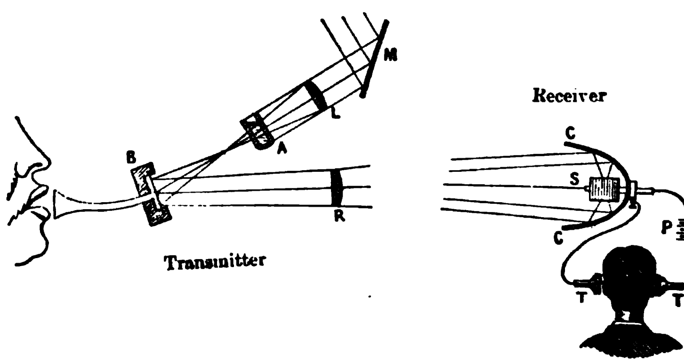


Fig. 60.—Diagram of the articulating photophone (after a sketch by Graham Bell). *Transmitter:* M, mirror for the projection of solar light; L, achromatic lens; A, transparent vessel containing alum; B, support of the vibrating mirror; R, lens for rendering reflected rays parallel. *Receiver:* C C, parabolical mirror of silvered copper; S, prepared selenium cell; P, battery; T T, telephones.

means of a lens upon the diaphragm mirror (Fig. 58), and, after reflection, is again rendered parallel by another lens. The beam is received at a distant station upon a parabolic reflector (Fig. 59), in the focus of which is placed a sensitive selenium cell, connected in a local circuit with a battery and telephone. A large number of trials of this apparatus have been made, with the transmitting and receiving instruments so far apart that sounds could not be heard directly through the air."

After describing one of these experiments, he continues—

"By such experiments we have found that articulate speech can be reproduced by the oxy-hydrogen light, and even by that of a kerosene lamp. The loudest effects obtained from light are produced by rapidly interrupting the beam by the perforated disc. The great advantage of this form of apparatus for experimental work is the noiselessness of its rotation, admitting the close approach of the receiver without interfering with the audibility of the effect heard from the latter; for it will be understood that musical tones are emitted from the receiver when no sound is made at the transmitter. A silent motion thus produces a sound. In this way, musical tones have been heard even from the light of a candle. When distant effects are sought, another apparatus is used. By placing an opaque screen near the rotating disc, the beam can be entirely cut off by a slight motion of the hand, and musical signals, like the dots and dashes of the Morse telegraph code, can thus be produced at the distant receiving station."

Tellurium and Lampblack Radiophone.—Professor Adams showed that tellurium, like selenium, changes its resistance under the influence of light, and Bell and Tainter tried to replace the selenium by tellurium in their photophonic receiver. The receiver thus constructed, although it gave no indication of its sensitiveness with a reflecting galvanometer, gave sounds in a telephone. Bell made an alloy of selenium and tellurium, which, on account of the extreme electrical properties of the two bodies, ought to have had mean properties. Considering the extensive molecular motions produced by the action of an intermittent ray on lampblack, Tainter thought that an analogous variation would be produced in the passing current, and that it might be possible to replace the selenium by lamp-black in the electric receiver.

Experience has confirmed this idea, and the discovery is of vast importance, taking into account the very high price of selenium and tellurium. Fig. 61 represents the lamp-black element which has given the best results. A mirror is coated with a layer of silver, and the coating is removed so as to form a zigzag line with two perfectly distinct parts,

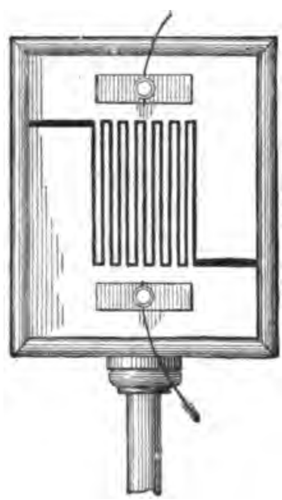


Fig. 61.—Lampblack element producing a sound under the influence of an intermittent ray or an intermittent current.

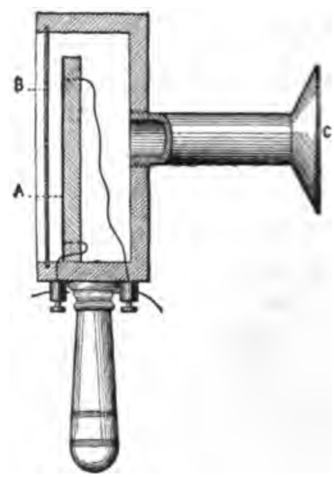


Fig. 62.—Arrangement of the apparatus for the simultaneous action of an intermittent electric current and an intermittent ray.

which have the appearance of two combs the teeth of which fit into each other. Each comb is attached to a screw, which enables the element to be interpolated in an electric circuit.

The surface is then blackened, so as to fill the whole interval between the teeth of the two combs with lamp-black. On connecting the lampblack element with a telephone and a battery, and exposing it to the influence of an intermittent ray, an intense musical sound is produced in the telephone. This result seems rather due to the physical conditions of the conducting substance than to its nature, and any metal in a spongy state produces similar effects. By employing an induction coil the effects are intensified, and the sensitive elements can be employed as well for the reproduction of articulate speech as for musical sounds.

The lampblack element itself reproduces sounds when traversed by an intermittent electric current, and can even be employed as telephonic receiver for the reproduction of articulate sounds.

Fig. 62 shows the arrangement for a very interesting experiment based upon these two properties. When an intermittent current traverses the lampblack element A, or when an intermittent ray is thrown on the element through the mirror B, a powerful sound can he heard on applying the ear to tube C. By the simultaneous action of an intermittent current and an intermittent ray, two distinct musical sounds are obtained, which produce a throbbing noise when their pitch is about the same.

Mercadier's Selenium Photophone.—Two strips of very thin brass (about 0·1 millimetre) *a a′* and *b b′* (Fig. 63), one of which is represented in the figure by full and the other by dotted lines, are separated by two strips of parchment paper, of about 0·15 millimetre thickness and of the same width, which serve as insulators, and may be considered as indicated in the figure by the blank spaces which are left between the lines. These four strips are coiled as close as possible into a spiral. The block thus formed is placed between two brass plates *c* and *d*, one millimetre thick, which communicate with the two extremities *b′* and *a′* of the metallic strips, and the whole is squeezed as tightly as possible between two pieces of hard wood or of brass, connected together by two long screws or two insulated rods M N with screw nuts. Two studs A and B communicate with the plates *d* and *c*, and, consequently, with the extremities of the metallic strips which form, the one the even and the other the odd spirals. The apparatus is represented in perspective in Fig. 64, where V and V′ are the screw rods, and B and B′ the terminals.

The block thus squeezed is first roughly filed on its two faces, gradually the surface is filed as smoothly as possible,

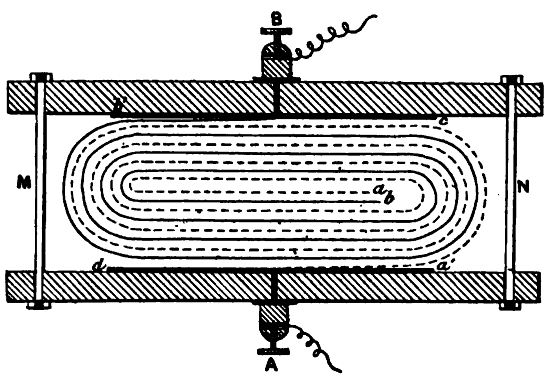


Fig. 63.—Mercadier's selenium photophone (section).
(*From La Lumière Electrique.*)

and finally polished with emery paper, care being taken not to leave any copper filings which would establish metallic communication between the spirals. There always is, in fact, a feeble communication between the spirals, for the parchment paper is not a perfect insulator, but it is so feeble that it does not interfere with the action of the apparatus.

After having thus polished the block and ascertained, with a sensitive galvanometer, the absence of metallic communications, one of the surfaces or both are coated with selenium in the following manner:—The apparatus is heated in a sand-bath, or by placing it flat on a thick copper plate heated with a Bunsen burner to the precise moment when a selenium pencil pressed against the block begins to fuse; the pencil is then passed along the surface, so as to cover it with a very thin coating. If the temperature is not allowed to rise above this point, it assumes the slaty tint which is characteristic of the state in which it is most sensitive to light. The apparatus is allowed to cool down slowly, and is ready for action. To preserve the selenized surfaces, they can subsequently be covered with a thin sheet of mica or with a coating of varnish laid on when hot.

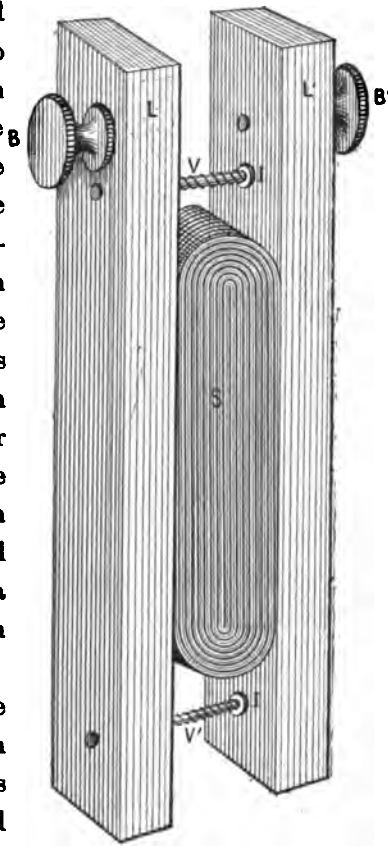


Fig 64.—Mercadier's selenium photophone (perspective).
(*From La Lumière Electrique.*)

Excellent apparatus are thus obtained, varying in width from five millimetres to twenty millimetres, and they can be made of very variable resistance — for instance, by selenizing only part of the surface, or coating it first altogether and taking off the selenium by degrees. The resistance of these apparatus can thus vary between 1200 and 200,000 ohms, and they all produce very distinct sounds. With apparatus of such high resistance, without sensibly diminishing the intensity of the battery current or the effects produced, several telephones can be placed in series or in quantity, and a certain number of persons can hear the sounds produced at the same time. Further, in the same apparatus and between two pieces of wood, several narrow receivers can be joined in such a manner as to constitute a sort of radiophonic battery with selenium cells as elements, and these elements can be arranged in series or in quantity; the resistance of the battery-receiver can thus be varied, and it can be adapted to the best advantage to the given conditions of external circuit, of telephone and of battery. If an apparatus of this kind gets out of order, it need only be filed carefully and the surface freshly selenized. Other metals besides brass can be used as supports for the coating of selenium—for instance, iron, copper, platinum, silver, and aluminium.

The arrangements for the transmission of speech with this apparatus are very simple. A series of selenium cells of variable resistance are placed at the sending station in circuit with a battery of a few elements and with the line which terminates at the sending station by an equal number of receiving telephones. Intermittent luminous radiations, interrupted like the Morse alphabet, are directed on the transmitters. The height of these radiations is fixed, but different for each transmitter. The corresponding telephonic receivers are arranged so as simply to strengthen the corresponding tone. Every telephone will, therefore, produce a series of longer or shorter musical notes, which will be interpreted at the receiving station, like ordinary Morse signals. Great simplicity, continuity of current which charges once for all the conductor, and very feeble variations necessary for the production of sounds, are claimed for this system.

It has been found that not only selenium and lampblack, but substances of all kinds, solid, liquid, and gaseous, can produce sound under the direct influence of radiations; but as electricity does not play any part in these phenomena, they do not come within the scope of this book.

With this we must conclude our review of special telephones, whose forms are innumerable, like the active agencies which they employ; our intention was simply to describe the latest and most interesting.

After this examination, it will be easier to establish a theory, if not complete, yet at least more accurate, of the telephone—a theory which, since Graham Bell's marvellous discovery, has made rapid strides, and has given a new impetus to acoustic research by placing a powerful instrument of observation in the hands of the observer.

Theory of the Telephone.—The theory of the transmitter presents no difficulty, and has been explained several times in the preceding pages; we need not refer to it again. The discussions which arose on the theory of the telephone especially referred to the receiving apparatus. How does a receiver—Bell's telephone, for instance—transform an undulatory current into an articulate sound? What are the physical phenomena which bring about this transformation?

We have admitted as a provisional theory, convenient for the explanation of the apparatus, that the undulatory current produced in the receiver a successive strengthening and weakening of the magnetic force of the magnet, which manifested itself by greater or lesser attractions of the plate, which then vibrated synchronically with the undulations of the current and the magnetic power of the magnetized bar.

This plausible explanation is sometimes verified in battery telephones with carbon transmitters, but it is inadmissible with Bell's telephone. Count du Moncel, who from the outset rejected this explanation, has seen his ideas partly confirmed by the numerous experiments which have followed Bell's invention; nowadays his theory is almost universally adopted, and we are going to put it before our readers in a few words.

Numerous experiments and measurements made by Warren de la Rue, Brough, Galileo Ferrari, and others, have proved that the intensity of the currents developed by Bell's telephone does not exceed that of a Daniell's element after having traversed 10,000,000 kilometres of telegraph wire—that is to say, 100,000,000 ohms—which represents a telegraphic circuit of a length equal to 250 times the circumference of the earth.

This makes it very difficult to believe that the difference of magnetism produced in the magnetized bar by currents of such feeble intensity could manifest themselves by variations in the attraction of the vibrating plate placed at a distance.

Bréguet's experiments, made with plates of fifteen centimetres thickness, and Ader's, who employed no plate at all, put an explanation based on magnetic attractions alone out of the question.

Page's experiments have shown that an iron rod placed in a bobbin vibrates under the influence of interrupted currents. Reiss' musical telephone is, as we have seen, a practical application of this phenomenon. These vibrations are occasioned in the very core itself by successive changes of magnetization of the core. In Bell's telephone the core vibrates longitudinally under the influence of the undulatory current traversing the bobbin.

This second phenomenon, however, is not sufficient to explain Ader's telephone without magnetic core; a third influence must be admitted, due to the action of the spirals of the helix upon each other. In other cases the helix and the magnetized bar act upon one another, and this contributes to the production of sounds.

Sometimes a fifth influence of purely mechanical origin is at work, manifesting itself in the same way as the transmission of sound through solid bodies. Crépaux's experiments (p. 104) are the most curious and most remarkable instance of this.

In a given telephone, the five agencies which have been mentioned are not all at work with the same energy; sometimes one of them is predominant, others disappear completely; in certain cases all five act, but not with the same degree of energy. In certain telephones the vibration of the plate itself plays a rather important part in giving to the transmitted sounds a very peculiar timbre, but this is chiefly the fault of the transmitter, which sends a deformed undulatory current along the line by the very action of its vibrating plate.

And yet it would be a mistake to conclude from all this that telephonic currents coming from a magnetic transmitter cannot produce vibrations in a diaphragm by purely magnetic attraction. Ader's alarum, for instance, acts with currents developed by Gower's magnetic telephone. Here we have a direct magnetic action producing a veritable attraction.

These various considerations will sufficiently show that the theory of the telephone is very complicated, and that it is very difficult exactly to define the part played by each of the agencies at work. The numerous discussions on this subject arise from the fact that the influence of each of these agencies has been exaggerated individually, and at the expense of the others. The truth is that they are simultaneous, and manifest themselves with a different degree of intensity for each particular case. In any case, it is quite certain that molecular action, which is as yet so imperfectly known, plays an important part in acoustic phenomena, and that the telephone, like the phonograph, will give a new impetus to research in this direction, by opening up for that branch of physical science a new horizon as vast as it is unknown.

Before passing on to the applications of the telephone, we must give a brief account of an apparatus which created considerable sensation at the time of its invention by Edison in 1877, and which has been mentioned in the preceding lines, namely—

The Phonograph.[1]—This apparatus consists chiefly of a steel point attached to the disc of a telephone and pressing lightly on a strip of paper passed beneath the point at a uniform rate. The vibrations of the disc are thus recorded, and can be translated.

The apparatus (Fig. 65) consists of a mouthpiece E, across the inner orifice of which is a metal diaphragm, and to the centre of this diaphragm is attached a point, also of metal. A brass cylinder R, is supported on a shaft A A, to which is also attached a crank M and a fly-wheel V. The shaft is screw-threaded, and turns in a nut T, for a bearing, so that when the cylinder is caused to revolve, it has a horizontal travel in front of the mouthpiece. It will be clear that the point on the metal diaphragm must, therefore, describe a spiral trace over the surface of the cylinder. On the latter

[1] From *Nature*, January 3, 1878.

is cut a spiral groove of like pitch to that on the shaft, and around the cylinder is attached a strip of tinfoil P. When sounds are uttered before the mouthpiece, the diaphragm is caused to vibrate, and the point thereon is caused to make contacts with the tinfoil at the portion where the latter crosses the spiral groove. Hence the foil, not being there backed by the solid metal of the cylinder, becomes indented, and these indentations are necessarily an exact record of the sounds which produce them.

It might be said that at this point the machine has

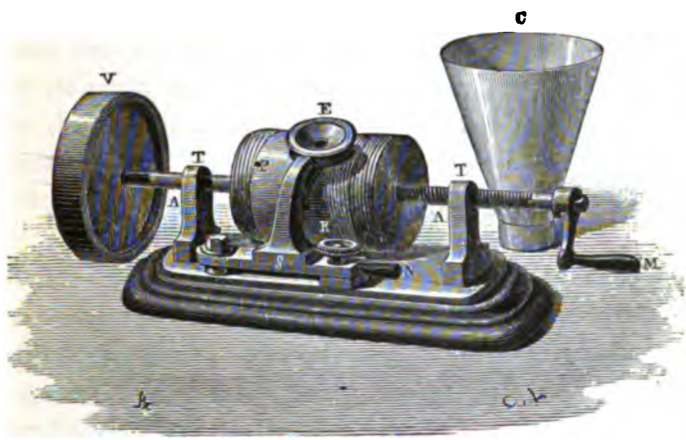


Fig. 65.—Edison's phonograph.

already become a complete phonograph, but it yet remains to translate the remarks made. The reading mechanism is nothing but another diaphragm held in a tube on the opposite side of the machine (to which is attached the funnel C to reinforce the sounds), and a point of metal which is held against the tinfoil on the cylinder by a delicate spring. N S is a lever, working on a pivot, for bringing the mouthpiece E near to, or away from, the cylinder R.

It makes no difference as to the vibrations produced, whether a nail moves over a file or a file moves over a nail, and in the present instance it is the file or indented foil strip which moves, and the metal point is caused to vibrate as it is affected by the passage of the indentations. The vibrations, however, of this point must be precisely the same as those of the other point which made the indentations, and these vibrations, transmitted to a second membrane, must cause the latter to vibrate similarly to the first membrane, and the result is a synthesis of the sounds which, in the beginning, we saw as it were analyzed.

It is to be regretted that some sounds are very indistinctly rendered by the instrument; for instance, the two words *bite* and *bout* could not be distinguished, and some words like *see* disappear altogether. The mechanical obstacle of the tinfoil, which has to be indented and offers too much resistance, seems to be the cause of this.

The invention is highly interesting, the effects produced are sometimes startling (as in cries, coughs, laughter, music), the philosophy of the process (taking a permanent impression of a very complex compound vibration, and taking it as a mould for reproducing that vibration) is exceedingly attractive, but at present the instrument has not risen beyond a lecture illustration or a philosophical toy.

CHAPTER IV.

THE APPLICATIONS OF THE TELEPHONE.

ALTHOUGH Bell's discovery of the telephone only dates back to the year 1876, it would require several volumes to describe all the applications which it has already received in so short a space of time.

We shall select, amongst the applications of the telephone, some of the most important or most interesting, and feel justified in assigning the front rank to telephonic communications.

TELEPHONIC COMMUNICATIONS.

This application of the telephone, as it is the most natural, so it is also the most advanced; but, despite the great future which must be in store for it, we must guard against the exaggerations which have found their way into print since the invention of the instrument.

A complete revolution of the whole telegraph system had been anticipated, but this anticipation was not fulfilled for two very good reasons. First of all, the telephone does not preserve a trace of the messages sent; and secondly, its rapidity in sending messages cannot be compared with that of improved telegraphs, which can produce as many as 8000 words per hour with a single wire.

The telephone, however, presents the immense advantage that it can be used without any previous special training; it is used in public buildings, in mines, submarine works, the navy, the army, etc.

The telephone does not represent, any more than any other apparatus, the universal panacea destined to cure all evils. It ought to be used in all cases where it can render good service, and not applied where it can but incompletely fulfil its functions.

Telephonic Communications in Towns.—The system of telephonic communications which has been introduced or is on the point of being introduced in all large towns of the Old and New World, requires a central office in correspondence with all the subscribers.

The central office has to reply to the calls made by the subscribers, and to place them into correspondence with any one of the other subscribers. The advantages of this combination are clear: each new subscriber constitutes for all the others a new correspondent, which daily increases the importance and usefulness of the system. Without entering into general considerations, which will suggest themselves to the reader, we will select a few examples of telephonic communications, by describing the systems employed in America and in Paris for establishing a regular service of communications.

To give our readers an idea of the practical working of the telephone, we will take him to the Merchants' Telephone Exchange, 198, Broadway, New York. In the large hall of this central office (Fig. 66) we see a number of switchmen busy establishing communication between the subscribers. Here (Fig. 67) is a switchman corresponding with one of the subscribers who has called. In Fig. 68 we see another *employé* replacing the warning signal.

Fig. 66.—Interior of a central telephone office.

In town, at the subscriber's office, we see the office telephone (Fig. 69), in the form generally used in houses. This form is very convenient for business, for it enables the correspondent to speak into the mouthpiece on the left, to listen with the telephone which he takes from the hook to apply to his ear, and at the same time take notes on the desk with his right hand, which remains free.

Fig. 67.—Switchman corresponding with a subscriber.

Before following the series of operations which constitute a complete call, let us cast a rapid glance over the system of telephones employed at the central office.

This system belongs to the class of battery telephones which are employed because the battery can be used at the same time for the ordinary electrical signal bell, as shown on the desk of Fig. 69.

Transmitter.—The transmitter is Edison's carbon telephone, described on p. 48. The circuit is formed by the battery—two Leclanchés; the transmitter is a small Ruhmkorff coil without a hammer. The circuit forms the primary

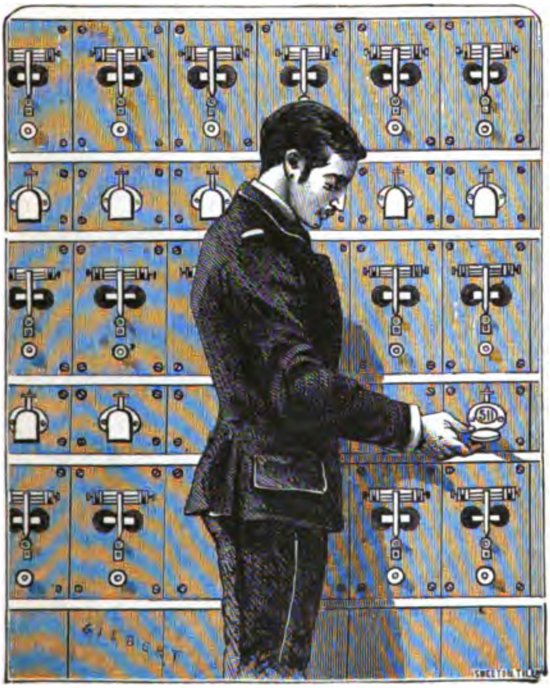


Fig. 68.—Switchman replacing the warning signal.

circuit of the coil. The line and the receiver of the distant station are connected with the secondary wire of the coil, the other extremity of this wire is connected to the receiver of the station and to earth.

Receiver.—The receiver is Phelps' telephone, similar to Bell's, but with a ring-shaped magnet, which makes it very convenient for handling (Fig. 69). In the position of rest, the telephone is suspended on the hook, and thereby throws a piece forming a commutator into a swinging motion, which withdraws the telephone from the circuit, only interpolating the electric bell. On taking the telephone into the hand, the piece begins to swing again, and automatically replaces the telephone into the circuit.

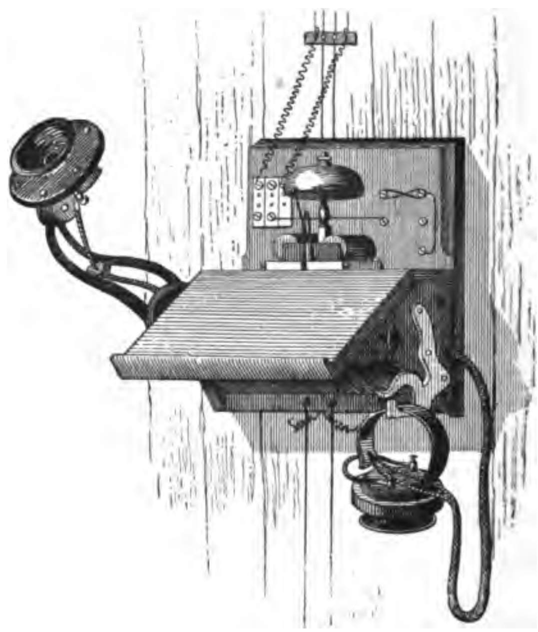


Fig. 69.—Telephone at subscriber's office.

The telephones of the central station, transmitter and receiver, are similar to those of the subscribers; but in order to facilitate the handling of these apparatus, the transmitter and receiver are mounted on the same steel rod slightly curved, which serves as a handle, as represented in Fig. 67, and forms at the same time the magnet of the receiver. And now we can follow the whole series of operations.

Let us suppose that subscriber 731, whom we will call Brown, wishes to communicate with subscriber 511, whom we will call Robinson. Brown begins by pressing on a small stud at the right of the desk (Fig. 69). The telephone being suspended, the current of Brown's battery traverses the line and a small electro-magnet placed at the central station; the electro-magnet becomes active, and detaches a small wicket, which on falling makes sufficient noise to attract the attention of the switchman, and exhibits number 731. The switchman thereupon enters in communication with Brown, by placing the wire connected with his telephone on a longitudinal copper bar which is likewise connected with Brown's line. The conversation now commences with the shout, "Halloa! halloa!"

Brown asks the switchman to put him in communication with No. 511. If No. 511 is disengaged at that moment, the switchman presses on a stud after having connected the wire of No. 511 with it. Robinson's electric bell begins to ring, and when he is ready for correspondence, he presses the stud of his electric bell, which causes the wicket corresponding to his number to fall. A direct connecting wire is then placed between the two horizontal bars connected with Brown's and Robinson's wires, and the communication between the two is established. If at this moment the switchman withdraws his telephone from the circuit, the conversation becomes private. If during the time of Brown and Robinson's conversation, No. 42, whom we will call Jones, wishes to correspond with Robinson, for instance, the switchman can interrupt the conversation, as a servant would in announcing a visitor.

The switchman calls Robinson, who can reply immediately or send word to Jones how soon he will be disengaged. If

Brown and Robinson do not object to Jones taking part in their conversation, the switchman is ordered to establish communication between these three persons. This is equivalent to saying "Come in," on hearing a knock at the door.

Telephonic communications thus conceived and utilized can render the greatest services, for they establish a sort of real presence, independent of any distance, between the correspondents, who can hear each other as if they were together in the same room, although often separated by considerable distances. A few other very ingenious details must be mentioned.

When the conversation between Brown and Robinson is finished, they both put back their telephones on the hooks, and press their studs, whereupon the number of each of them is exhibited again at the central office. The switchman now knows that the conversation of the two is finished; he shuts the wicket, suppresses the direct communication between Brown and Robinson, and everything is ready for a new call.

At stations with a large number, say 500 or 600 subscribers, the numbers are arranged in order in frames of fifty to 100 wickets in each row. Special arrangements must then be made to connect the rows with each other.

The central office at New York exchanges at least 1000 communications daily, and all the arrangements are carried out to the greatest satisfaction of the subscribers. The telephone has become for them as indispensable as the omnibuses for the Londoners.

In Paris, two separate companies have been carrying on the telephonic communications, much to the detriment of the subscribers and the development of the system. A fusion of the two companies has been effected lately, and matters have considerably improved since. One of the companies employed Edison's system, under almost identical conditions with those we have described. The second originally employed Gower's magnetic telephone and Ader's alarum.

As regards the lines, they are either air or underground lines. Each of these systems has its advantages and its drawbacks. Air lines have the advantage of diminishing the injurious effects of reciprocal induction of the wires upon each other, but they involve an enormous loss of power, and are sure to become, if their number increases too much, a permanent source of danger. Of the underground wires, which are more easily worked, a large number must be joined into a comparatively thin cable, in order not to interfere with drainage pipes. The effects of induction are then very intense, and sometimes render communication difficult.

The employment of a return wire—that is to say, of an entirely metallic circuit—diminishes these inconveniences, but increases the original outlay.

At the outset, as stated above, Gower's magnetic telephones were adopted in Paris, and Ader invented a most ingenious apparatus for the release of a signal at the central station, under the action of the electro-magnetic currents of Gower's telephone. Lately, electro-magnetic systems have been abandoned, because battery transmitters give incomparably better results.

Haskin's Telephone System for Stations of Secondary Importance.—In this system, of which a diagram is shown in Fig. 70, the telephonic lines *a*, *a*, *a*, etc., are connected to vertical metallic bars, by means of which they are placed in communication with the different commutators, as will be seen at A. At the lower end of these bars are movable pegs *b*, *b*, *b*, which establish communication with the annunciator *c*, *c*, *c*, through an intermediate commutator B. The wires then pass on from this annunciator *c*, *c*, *c* to a second series of pegs *b'*, *b'*, *b'*, which establish earth connection, and thus the call circuit of each subscriber is completed.

Metallic bars placed crosswise above those mentioned, and which belong to the commutator A, allow the stations to be connected two and two, as a reference to the figure will show, at *d'*, *d''*, *e'*, *e''*. The first of these wires communicates with the upper contact of an automatic interrupter *f*, whose functions will be described later on, and thence to a commutator with a handle and two contacts, which is in connection with a magneto-electric generator placed in an adjoining room. The second wire *d''* leads to the contact on the right of the preceding commutator, and can, therefore, be put in direct connection with the first wire by a circular displacement of the handle. The same is the case with the wires *e'*, *e''*.

On the switch-board C are placed a number of small trial plates *h'*, *h'*, *h'*, intended for verifications; they are the continuations of the wires *d''* and *e''*, and constitute what is called the third branch of a circuit, or in other words, the commencement of a shunt which can be completed during the action of the apparatus. On the same frame C, called the conjunction table, is placed an indicator J J, to which corresponds each of the first wires of the circuit, such as *d' e*. The clerk in charge has, besides, under his control a complete telephonic system with a special circuit, by means of which he can make the necessary trials; an explorator *k*, and an interrupter *n* actuated by a pedal *p* complete this trial system.

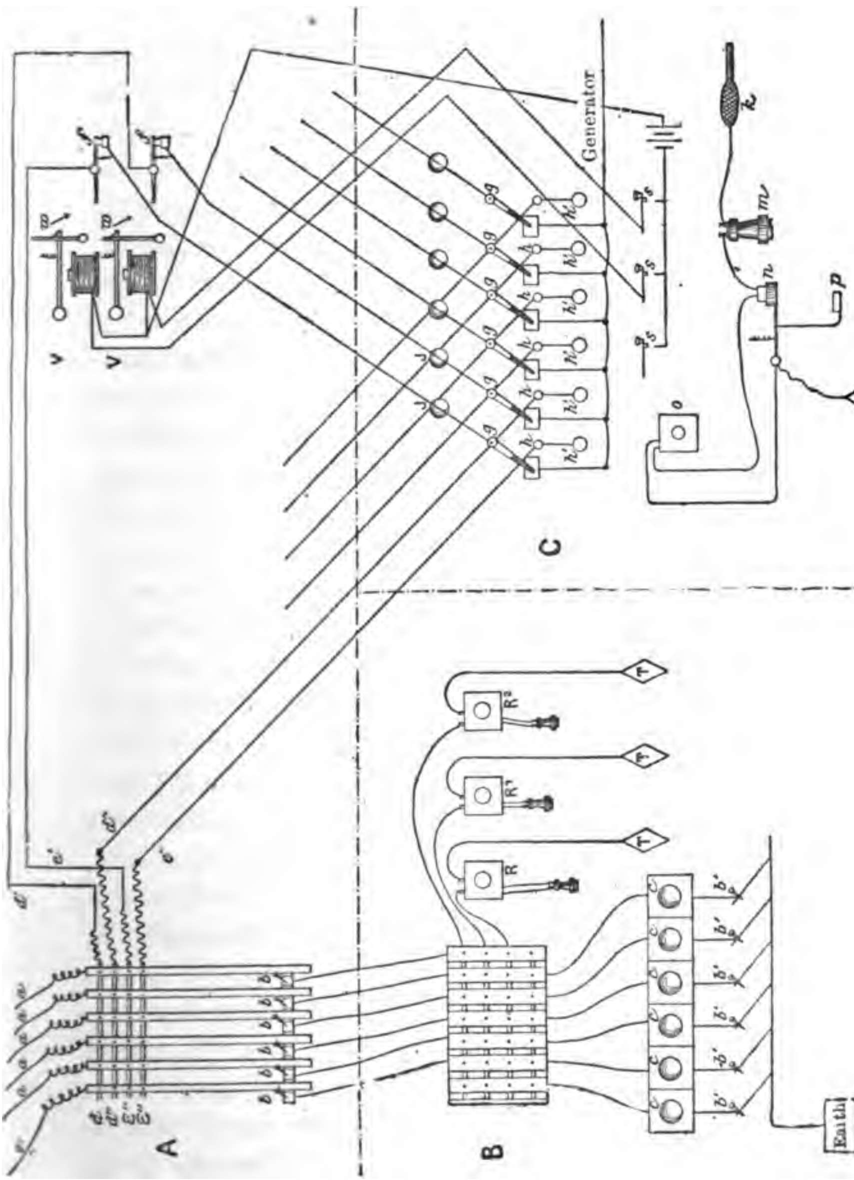


Fig. 70.—Haskin's telephone system (diagram).
(From La Lumière Électrique.)

If, whilst the contact *n* is closed, the explorator is applied to one of the plates *h′*, always provided the corresponding line be completed, the subscribers can be heard through the telephone *m*, but the same result can be obtained whilst communication is established, and even when the circuit is opened; for in this latter case the current passes through the contact *n* and thence to the transmitter *o*, which is then out of circuit,—to place it in circuit, the connection is cut off at *n* by means of the pedal *p*, and the clerk can now speak to the different subscribers. The system works in the following way:—Let us suppose a subscriber is making a call; the current, before going to earth, takes the following path: It enters at *a*, goes thence to *b*, then to *c*, and to earth at *b′*. By its action the plate of the indicator *c* falls, and the clerk who attends to fifty subscribers takes off the peg *b* to cut off the earth connection; then he places the connecting peg on the commutator B, to connect his telephone placed at R and to ask the subscriber what he wants. No. 32—who has called, for instance—asks for No. 520; the clerk takes off the peg connecting his telephone to line, goes to commutator A, takes off the two pegs *b* and *b* corresponding to the numbers 32 and 520 and joins their lines on the two transverse bars of commutator *d′*, *d″*. As it is No. 32 who has called, he is supposed to keep close to his apparatus; there is no necessity of a bell-call, and he is put in communication with the wire *d″*, but No. 520, who is not warned, is placed in line at *d′*. Now, following under these conditions the path of the circuit, it will be seen that No. 520, in consequence of this arrangement, is called through the influence of the magneto-electric generator; further, that the clerk of the switch-board C is immediately warned by the appearance of the number on his board; and that, by turning the handle of the corresponding commutator, he establishes connection between *g* and *h* without knowing what is going on.

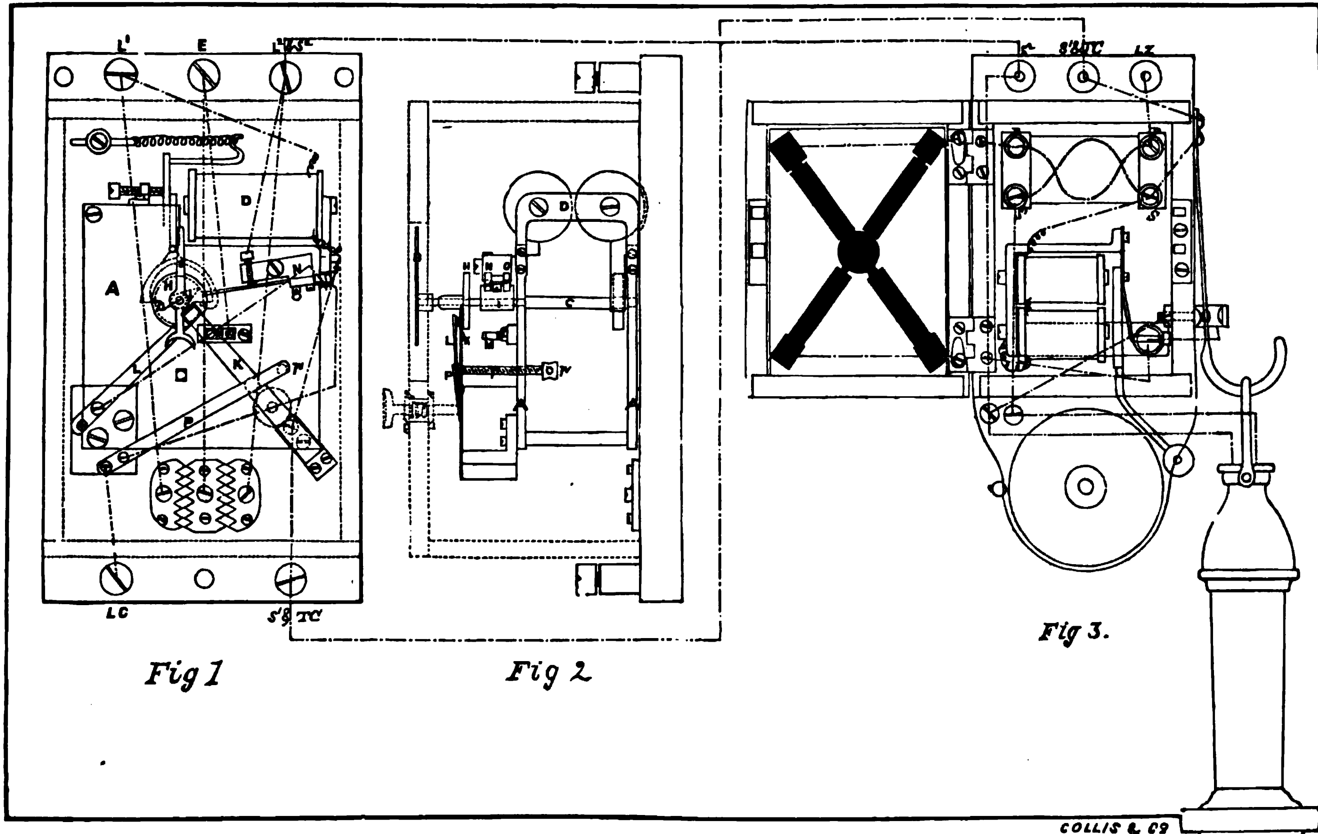
On the other hand, the clerk responsible for the answer, who is placed at the switch-board B, has only to establish communication between the respective couples of wires after having ascertained what is wanted of him, and, as soon as this is done, he replaces the peg at *b'*.

When Nos. 32 and 520 have finished their conversation, they give a signal or they call; the former is indicated on the board J, and the clerk of switch-board C closes the interrupter of the local circuit, and brings up an indication on the switch-board. Each of the boards C contains all the necessary arrangements for twenty-five communications, and at each extremity of the commutator A is an indicator for cutting off the connections, which is shown at V V, and whose wicket *w*, by falling, interrupts the circuit of the generator and causes it to pass through the interrupter *f*. Now, when the wicket corresponding to wire *f'* falls, the clerk of switch-board C is warned, and he replaces the pegs for communication at *h h*, and also the wicket in its former position. This proceeding must be accurately followed, for, if the circuit is not opened at *f* when the commutator is replaced at *g*, the subscriber 520 would be called to no purpose a second time.

It is clear that, with this system, no conversation amongst the clerks is necessary, and the operations can be carried on without any sensible noise and with the greatest rapidity. Haskin's system gives the most satisfactory results for stations of secondary importance. At Milwaukee (Wisconsin, U.S.A.) there are four offices with 600 subscribers each, all connected with the central station. It is thought that the system would act equally well with 1000 subscribers.

Brown and Saunders' Telephone System.—At an exhibition at the Bristol Hotel, London, by the United Telephone Company, it was shown that a number of people could receive the same sounds on different instruments; and at the houses of Colonel Gourand and Major Flood Page, it has been shown that conversation can be carried on over the line, whilst at the same time the musical sounds of an organ or orchestra are being carried. This points to the fact that the telephone will take up a number of sounds at one and the same time. Under ordinary business conditions, however, this sensitiveness is troublesome, and hitherto each user of a telephone has been compelled to have a distinct wire for his work. The introduction of exchanges minimized the length of wire used; but with Brown and Saunders' apparatus one line can be used by a number of instruments, and this, too, without danger of any one but the right person overhearing the conversation; in other words, secrecy is maintained. The instruments used are designed for twelve to be placed on the one line. It is suggested that the apparatus would be very useful in suburban districts, or wherever the work of the line was light, as well as in large factories, but in all probability its utility will extend further than this, and it will doubtless be found that no evil effects will arise from putting three or four instruments on most of the wires belonging to the larger exchanges. If this surmise is correct, then we have at once the means of diminishing considerably the dangers arising from the multiplication of so many wires. The apparatus is compact, and consists of a transmitter and receiver, with a bell and local battery. At the terminal stations, the line batteries are placed to work in opposition, so that, except in the act of signalling, no work is required of them; hence they remain active for a long time. The signal instrument consists of a clockwork movement A (Figs. 71 and 72), controlled by an electro-magnet D, and actuating a main arbor or axle C. This axle carries a hand B to indicate the numbers of the respective subscribers; also a slotted disc H and a cam I. Metallically attached to the main framework is a ringing spring K, which extends over the slotted disc H, and, under normal conditions, makes contact with the spring L, which is attached to the main framework by a piece of ebonite. Affixed also to the main framework by the same piece of ebonite is another spring P, but insulated therefrom by an ivory stud. This spring P, when spring K is pressed, falls upon and makes contact with a screw stud *p*, screwed through the top of the main framework, but otherwise held out of contact therewith by spring K. When the hand B comes round to the number or signal belonging to the station in which that particular instrument is placed, the cam I comes into contact with and slightly lifts the ends of two springs N and O, attached by a piece of ebonite to the main framework, as shown, and in so doing breaks the contact of N with a screw stud with which it normally makes contact when not so lifted by the cam.

The connections are then as follows:—A wire leads from the line (marked L′) or upper left-hand terminal of the signal (looking at it from the front) to the electro-magnet D, the other side of this coil being attached to the main framework. The current then goes by the terminal marked S^1 & T C, being the lower right-hand terminal, and the similarly lettered or centre terminal on the switch-bell transmitter (Fig. 73), to one side of the secondary coil of



Figs. 71, 72, 73.—Brown and Saunders' telephone system (signal instrument and transmitter).

the induction coil, calling on its way at the top—or centre of motion—of the switch-hook, as shown. From thence the current goes on through the secondary coil, and telephone or telephones (if more than one be used they should be joined in quantity or multiple arc, so as to diminish instead of increase their combined resistance) to the under stud of the switch-hook, or to that stud with which the hook makes contact when the telephone is hanging thereon, thence on to the terminal S^2, being the left-hand terminal of the switch-bell transmitter, and finally on by the short external bridge wire between the two instruments to line.

There is thus always a complete circuit through the instrument for the current by the parts above named. The part of this circuit consisting of the telephone and secondary, however, is normally kept short-circuited by two distinct methods as follows:—One of these shunt circuits starts from the clock-frame by the spring K, which is normally in contact with spring L, and thence goes on to spring N, which is normally in contact with its screw stud; from which a wire leads to the terminal marked line 2 or L^2, being the upper right-hand terminal of the signal, which is also the terminal to which the wire from the other end of the secondary and telephone is joined. The other short circuit is through the switch-hook, as will be seen (when the telephone is hanging thereon), but this short circuit is, of course, broken when the telephone is taken off the hook.

This completes the set of connections for the line circuit.

For the local circuit, a wire is then run from the copper pole of the local cell or cells to the terminal L C, being the lower left-hand terminal of the signal. From hence a wire leads on to the lower cross spring P, and also to the lower spring O of the pair of springs N O. It will be seen that at both of these points the local battery is capable of being put into contact with the main framework, either by hand (by pressing spring K, and so dropping spring P on to its contact stud *p* in the frame) or automatically (by bringing cam I into contact with spring O).

In either case the local current, having been put on to the main framework, will traverse the following circuit:—

First it passes out of the signal instrument by the terminal S^1 & T C and the outside connecting wire to the similarly lettered terminal on the switch-bell transmitter along with line current, with which, however, it makes no contact, in consequence of there being no connection whatever with the other pole of the local battery, except by its own wire. From the top or centre of motion of the switch-hook then, to which this terminal is connected, the local current goes on through the bell coils to the upper stud of the switch-hook (or that stud with which the hook is in contact when the telephone is removed therefrom), so that, when this is the case, the bell is short-circuited. From this point the current goes by the transmitter and primary coil of the induction coil to the terminal L Z, being the right-hand terminal of the switch-bell transmitter, from which a lead is run back to the zinc pole of the local bell or bells, thus completing the local circuit.

The action of the whole is as follows:—

The hands standing at zero (indicating that the line is disengaged), any subscriber can call by pressing his ringing plunger. The spring K will then be pressed through the slot in the disc on to a stud M, which is in electrical connection with the earth terminal E, or upper central terminal of the signal, the slot in the disc H being then, and then only, in position to allow of this taking place.

This puts an intermediate earth on the line, and so brings the opposed line batteries into effective action; the one battery working all the instruments on the one side of the caller, including his own instrument, and the other battery working all the instruments on the other side of the caller, the effect of the current being to draw up the armatures of all the electro-magnets D, and so cause the clocks to advance one half-step. By then letting his plunger come back, and so breaking the contact of spring K with the earth stud M, the armatures will be again released, and the clocks will advance another half-step. By thus alternately pressing and releasing the plunger the subscriber can bring the hands round to the number he wants, and then stop. The cam I in the instrument belonging to that number will then be in contact with spring O, thus ringing his bell, and will also, by breaking the contact of spring N with its contact stud, break the short circuit through the signal of the telephone and secondary coil, thus placing him in effective speaking condition. It is then his duty to answer, by taking off his telephone and calling "Yes" through the transmitter, the act of taking off his telephone automatically removing the remaining short circuit thereof, and at the same time short-circuiting the bell, thereby stopping its sounding and concentrating the local current on to the transmitter.

The same effect is also produced by the calling subscriber taking off his telephone previous to listening for receiver to reply by so calling "Yes." It will be seen that the short circuit through the signal of caller's speaking instruments (or telephone and secondary coil) was automatically broken by him in calling by the breaking of the contact of springs K and L, in consequence of the former

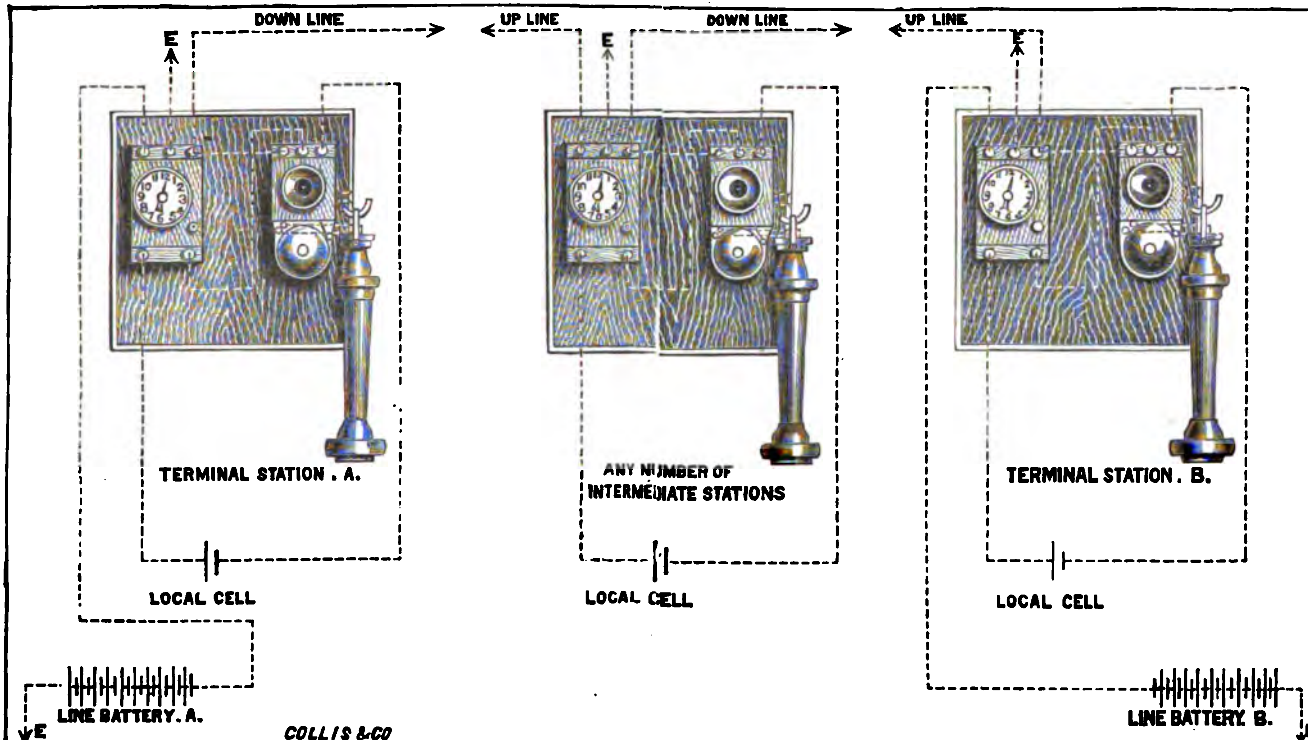


Fig. 74.—Brown and Saunders' telephone system (receivers).

passing under the insulating disc H at the first stroke of the plunger, from which position it cannot emerge until the disc again comes round to its zero position, that is, when the caller clears the line.

He also automatically puts the local current on to his bell and transmitter by the dropping of spring P on to its contact stud *p* in the clock-frame. The current is, however, as before, concentrated on to the transmitter while they are speaking, in consequence of the bell being short-circuited by the switch-hook; but this short circuit is again broken when the telephone is hung up, and the bell, therefore, then commences to ring, and thereby gives him an unmistakable signal to clear the line, in case he should neglect to do so. This he does by again pressing his plunger in and out until the hand comes round to zero, when spring K comes up through the slot in the disc H, makes contact with spring L, and, at the same time, lifts spring P out of contact with its stud *p*, thus breaking his local circuit and stopping his bell, and rendering the line available for any other subscriber who may wish to use it.

It will be seen, however, that while the line is so engaged by one subscriber, the slots in the discs of all the other instruments are out of position for allowing the springs K to pass through, so that these subscribers cannot ring until the line is cleared by the caller; neither can they break the short circuit through the signal of their speaking instruments, in consequence of spring L following up and remaining in contact with spring K right up to the surface of the disc H, through which K cannot pass; and the cam I is then out of position to break the short circuit by lifting spring N, except at the instrument at which the caller stops—that is, the one he wants to call.

The vibrating bells are retarded a little by letting out their adjusting screws, so that the hammers require to make three or four vibrations before striking the bells, in order that the latter may not be sounded, or at most not sounded more than a very few strokes, by the momentary completion of the local circuit as the cams in the instruments down the line successively pass their contact springs, but only be sounded continuously in that instrument at whose number or signal the caller allows the hands to stop or remain—that is, the one he wants to call.

The connections necessary for the installation of this instrument are very simple. With an intermediate station, the copper pole of the local cell is connected to the terminal L C, and the zinc pole to L Z. The earth terminal is connected to the binding screw E. The line wires are connected to L^1 and to L^2 S^2 respectively. The line connections at the terminal stations are a little different, one at each station being connected to the zinc pole of the line battery, whilst the copper pole is put to earth.

Connolly and MacTighe's Automatic Telephone System.—This system, too, establishes direct communication between a limited number of subscribers. Fig. 75 shows the general arrangement of the system. The subscribers' apparatus, indicated in the figure by the numbers 1 to 18, are all connected—on the one hand to a local battery and to earth, and on the other hand to a single line leading to the central apparatus or central automatic station. Each of these lines, in the first instance, goes to earth at the central station as long as the current acts on the mechanism intended to establish the desired communication with another line, but the earth connection at this point is suppressed as soon as the two lines are placed in communication.

The mechanism of the central station, which is intended thus to establish the communications, is set in motion by the emission of successive currents supplied by the local batteries of the subscribers. Each private apparatus for this purpose comprises an arrangement similar to that of the transmitter of Bréguet's dial telegraph, which acts by successively establishing and interrupting the line current. We need not describe the action of this well-known instrument, but pass on to the apparatus on which these currents act, and whose joint action constitutes the central station.

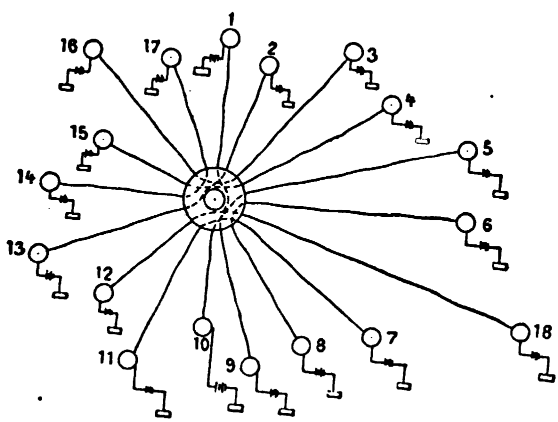


Fig. 75.—Automatic telephone (general arrangement).
(*From La Lumière Électrique.*)

Fig. 81 represents these joined apparatus, which are of four distinct kinds, and each of which is repeated as many times as there are subscribers in the district. They are: Relays E E on which act, in the first instance, the line currents; electro-magnets F F energized by a central battery and controlled by the relays E E; wheels R R mounted on the same vertical axle, and which can rotate independently of each other under the influence of the armatures of the electro-magnets F F; finally, vertical rods, called contact rods.

To each line, therefore, corresponds a relay, an electro-magnet, a wheel, and a contact rod. The relays are arranged in a circle on the socket of the apparatus; the electro-magnets are fixed at different heights on the frame of the apparatus, so that each of them is at the same level as the corresponding wheel; finally the vertical rods form, as it were, the bars of a cylindrical cage surrounding the wheels.

On an insulating ring placed at the foot of the apparatus are a number of metallic contact-pieces in pairs, one pair for each line, and the longest of the contact-pieces is permanently connected to the line. These and other parts which will be described later on, constitute for each line a commutator, intended to connect the line, either with its relay or with its contact rod.

Under normal conditions the circuit of each of the electro-magnets F F is open; it is closed whenever the armature of the corresponding relay is attracted, and every time it is closed, the armature of the electro-magnet F is attracted, and, by means of the rod T (Fig. 76), causes the advance of a ratchet-wheel placed above the corresponding wheel R. Since the passage of the current through the relays, and consequently through the electro-magnets, corresponds to the movements of the manipulator at the subscriber's house, it will be seen that a given point of wheel R—the one, for instance, which carries a small arm H—will follow exactly the angular movement of a corresponding point of the toothed wheel of this manipulator. Hence the possibility for the subscriber of bringing this arm H into any position he likes, by a synchronical movement similar to that of a Bréguet telegraph. Each wheel consists of two superposed discs, which are separated by an insulating material. The lower one is in permanent contact with the axis, and thereby with earth; the upper one is insu-

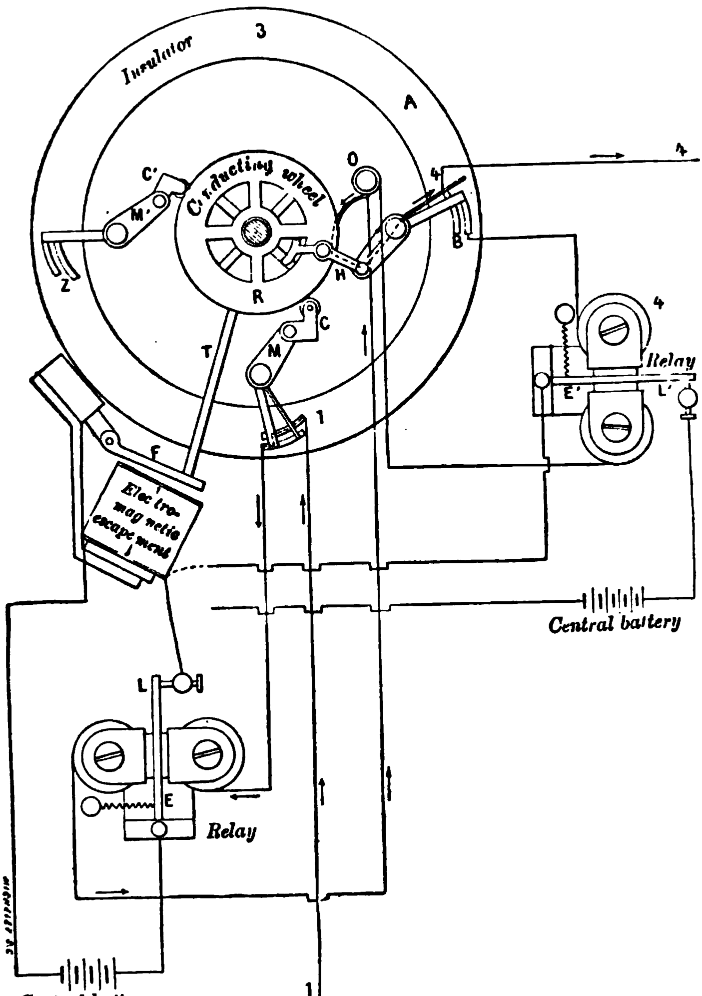


Fig. 76.—Automatic telephone (apparatus for communication between two subscribers).
(From La Lumière Électrique.)

lated. On this latter the small arm H which has been mentioned is fixed. In its normal position this small arm is maintained slightly obliquely to the circumference of the wheel; when the latter turns it can be made to incline on one side by moving a touch connection which it carries on the other side of the axis on which it is pivoted. Under normal conditions this touch connection places the arm H in communication with the lower wheel, and consequently with earth, but when the arm inclines by a certain quantity this contact is suppressed.

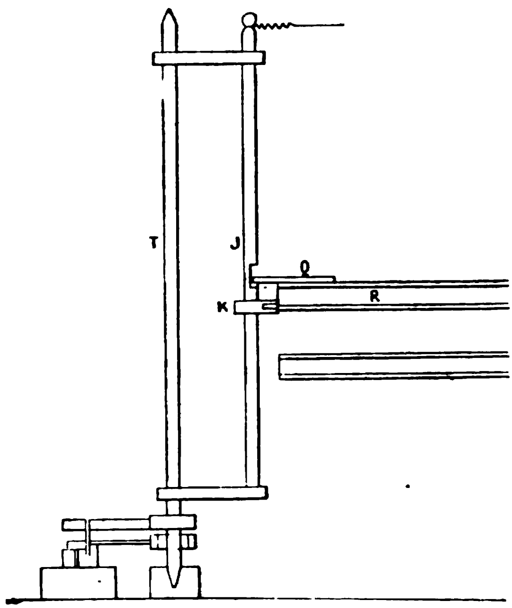


Fig. 77.—Automatic telephone (contact rods).
(*From La Lumière Électrique.*)

The contact rods are more specially represented in Fig. 77. Each of them consists of a rod T, pivoted at both extremities on insulated pieces and carrying on two transverse pieces a smaller rod J. In Fig. 76, where only the necessary apparatus for communication between two subscribers are given, two of these rods with their transverse pieces are represented at M and M′. A third is shown in contact with the arm H. In its lower part, each rod T carries two arms, the one insulated, the other communicating with the rod. The insulated arm can touch the two metallic contact-pieces fixed on the insulating ring S, and thus place the line in communication with the relay; or else the non-insulated arm can alone remain in contact with the line, and thus connect this latter with the contact rod. When a wheel R rotates, its arm H, having at its extremity a hollow of cylindrical form, catches on its passage all the rods J which it meets, and displaces them; but they take up again their original position under the influence of a spring, as long as the wheel continues to rotate. When the arm H has arrived at the corresponding rod, and the movement of the wheel is stopped, the rod in question is deviated from its normal position so that the arms of the other wheels can no longer catch it.

The central apparatus being in a state of rest, the line current of the caller enters, for instance, through the wire marked 1 at the bottom of Fig. 76. It arrives at the two contact-pieces 1 (which at this moment are connected by the insulated rubber of the corresponding rod), returns to relay E, traverses it, then following the direction indicated by the arrows, goes to the rod O, which carries a spring pressing against the upper disc of wheel R. At this moment the touch connection of arm H places the upper disc in communication with the lower disc, and the current, therefore, goes to earth through the main framė of the apparatus. This state of things is maintained as long as the wheel rotates. When it stops, the arm H gears in with the rod corresponding to the caller's line; the touch connection of H is now deviated and no longer makes contact with the lower disc of the wheel, and consequently the earth connection is suppressed. The current now passes through the arm H and the rod it has caught, and arrives at the contact-pieces B. In consequence of the movement of the contact rod, its lower branches take up such a position that the larger contact-piece alone is connected to the rod, and as this latter is in communication with the line, the current now passes into this line. From this moment connection is established between the caller and the subscriber he wishes to call, and the telephonic conversation can begin.

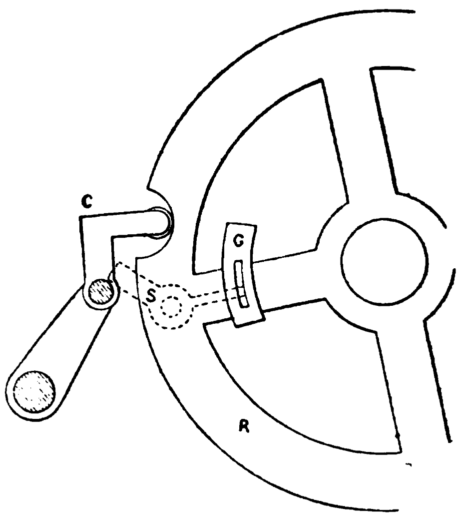


Fig. 78.—Automatic telephone (notched wheel).
(*From La Lumière Électrique.*)

During the rotation of the wheel, the arm H, as already mentioned, successively catches all the rods before arriving at the one with which it remains in definite contact. Whenever a rod gears in with the arm, this latter, together with its touch connection moves, and the earth connection is consequently suppressed; the current, therefore, passes for an instant into each of these lines, but this derivation does not interfere with the action of the relay.

When a rod is caught, it is deflected from its original position, and can no longer gear in with any other arm; the called line cannot, therefore, be accidentally short-circuited, but the caller's line must be put on the same footing. To this end every contact rod carries at the height of its line wheel a small lever terminating in a roller C, which presses against the insulator of the wheel. When the wheel is at rest, the roller C enters into a notch (Fig. 78), and the rod is held in a convenient position for being caught by some arm or other. But as soon as the wheel rotates, the roller leaves the notch, and the rod is sufficiently deflected from its position, so as no longer to be held in check, but yet not enough to break the connection between the two corresponding communications. Finally, the contact rod of a given line must not gear in with the arm of the wheel which corresponds to this same line; every contact rod carries, therefore, at the height of the wheel, a notch which allows the arm to pass without catching the rod.

The apparatus at the subscriber's house is represented in Figs. 79 and 80. Its principal part consists of a toothed wheel F, driven by a clockwork movement. The teeth of this wheel alternately raise and drop a spring V, whereby the line circuit, which is normally open, is intermittently closed, and the current destined for the central apparatus produced. This toothed wheel is covered by a graduated disc, on which numbers corresponding to the different lines are inscribed. The points where these figures are marked divide the disc into equal parts, and opposite each of them the disc is pierced by an opening into which a pin can be inserted. The toothed wheel carries a wedge M, which can press against the pin, and thus stop the wheel.

When the apparatus is at rest, the pin is inserted in the

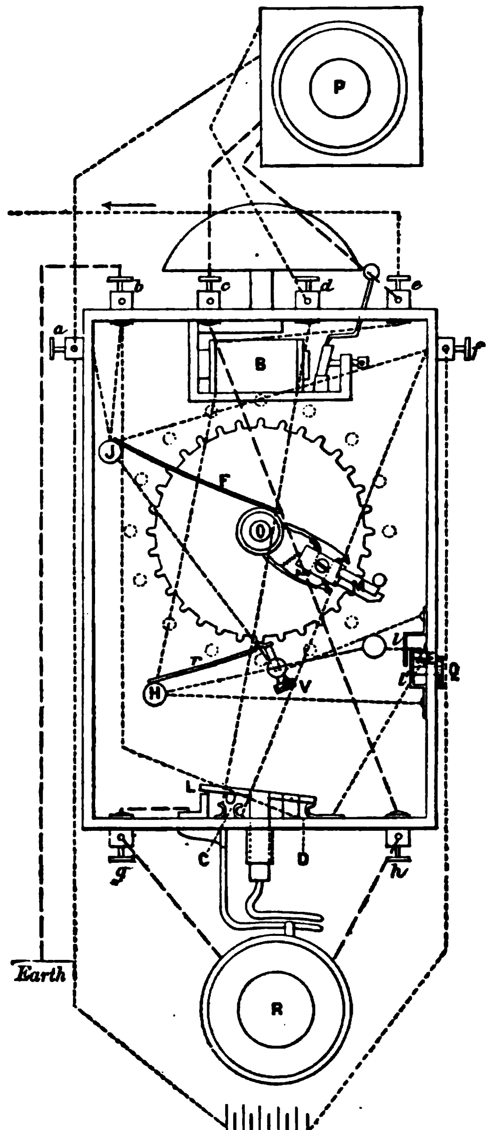


Fig. 79.—Automatic telephone (interior arrangement of subscriber's apparatus).
(*From La Lumière Électrique.*)

opening opposite the number assigned to the line which corresponds to this apparatus, and at the central station the wheel of this line occupies a corresponding position, that is to say, its arm H is opposite the notch of the contact rod of

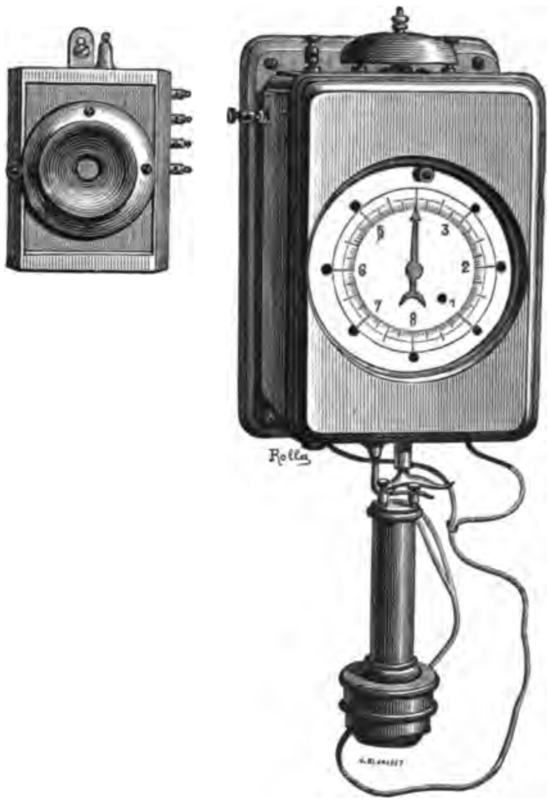


Fig. 80.—Automatic telephone (subscriber's apparatus).
(*From La Lumière Électrique.*)

the same line. If one of the subscribers wishes to correspond with another, he takes out the pin and inserts it in the opening opposite the number of this latter subscriber. The wheel can now move as far as the pin; consequently the corresponding wheel of the central station moves in the same way, and the arm H stops at the proper rod; the two subscribers are now in communication. But connected with the toothed wheel and moving with it is a special commutator, which presses at the same time as the wedge against the pin, is displaced by this movement, and changes the sense of the current. This change is necessary, for, if the current remained of the same sense for the subsequent operations, the relay would be affected anew by its passage, and the communication would be disturbed. In this way, the relay not being sensitive to the inverted currents, the communication can take place without interruption. In Fig. 5 this commutator is indicated, but its connections with the battery and the line are not given.

In a state of rest, the connections of each subscriber's apparatus are on the call-bell, that is to say, the apparatus is ready to receive a call from any one of the other lines.

When a subscriber is in communication with another, his first duty is to call his correspondent. This he does by pressing a stud Q, which acts as commutator, changes the arrangement of the connections, and transmits to the line a continuous current, which produces a call at the second subscriber's, previously placed in communication with the former. This stud must only be pressed when the spring *r* does not touch the screw V, and when there is consequently no connection with the line at this point.

When once the call is made, the called subscriber answers in the same way by pressing the stud Q of his apparatus. The current which produces the reply signal does not act on the relay of the called line, because this latter is not a circuit, neither does it act on the relay of the calling line, because it has not the requisite direction. It therefore does not affect this latter, which alone remains in the circuit.

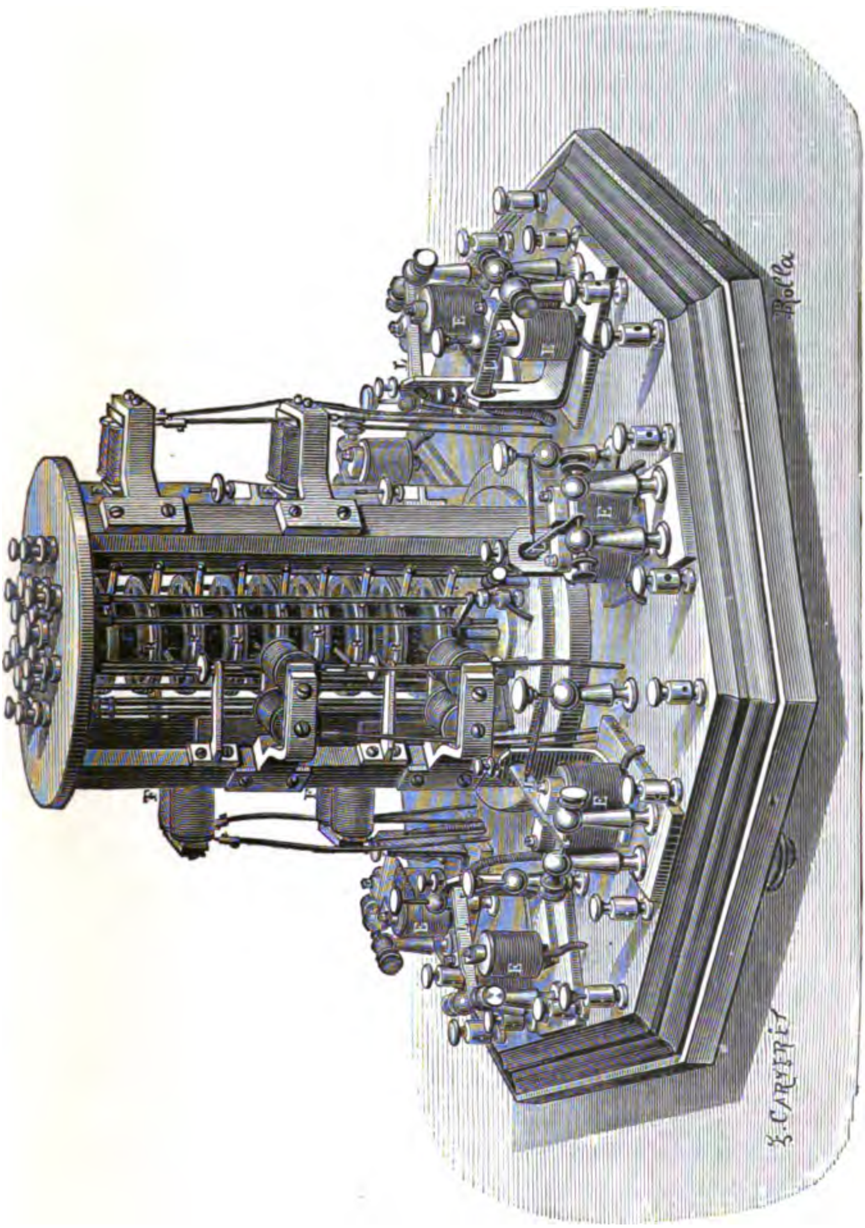


Fig. 81.—Connolly and MacTighe's automatic telephone (perspective).
(From La Lumière Electrique.)

The call and the reply being thus made, the two subscribers take each their receiving telephones R into their hands, which telephones are suspended from a double hook C. The act of taking up the telephone again changes the connections, and the conversation takes place by means of the two receivers P and the two transmitters R.

When the conversation is finished, the two correspondents have only to suspend again the telephones to their respective hooks. The one who has been called ought, besides, to replace the pin into its proper hole. The toothed wheel again takes up its original position; as soon as it commences to move, the arm of the commutator no longer pressing against the pin, the current resumes its original direction and can act upon the corresponding relay. The wheel R now moves, and the arm H coming back to its former position, the apparatus is ready for a fresh call. The opening of the disc into which the pin is inserted in the state of rest is a little further apart from the centre than the others, to prevent the pin from acting on the commutator.

It will be seen that the subscribers' apparatus are in all their details constructed like an ordinary telephonic post. The characteristic part which they contain is the toothed wheel and its accessories, intended to produce the movements of the wheels R in the central apparatus.

Connolly and MacTighe's system can, therefore, up to a certain point, replace an *employé*, but it can only be applied to a service restricted to about twenty subscribers. Beyond this number the apparatus would become too complicated, and this complication would be detrimental to its proper working.

Leduc's Automatic Telephone System.—We have seen that Connolly's apparatus is intended to constitute an automatic central station, working without any personal attendance, to place a certain number of subscribers in direct communication with one another.

Leduc's apparatus has a less general end in view. It aims at placing in communication with a central station, similar to those which exist already, a number of subscribers, forming a sort of secondary telephonic network grafted on the main service.

It enables, with the employment of one or two line wires—

1. The central station to correspond at will with each of the subscribers of the secondary network.

2. Each of the subscribers of the secondary network to correspond with the central station, and consequently with all the subscribers connected with it.

3. Any two subscribers of the secondary network to correspond with each other.

For this purpose all the subscribers' apparatus are connected, on the one hand with earth, and on the other hand, by means of the automatic apparatus, with the central station. The battery is placed in this latter station, and here also the clerk works the automatic apparatus to place in direct communication with the line, and isolate from the remainder of the secondary network, either the calling subscriber or the one who has been called from some point or other of the principal network.

The manipulator by means of which the clerk works the automatic apparatus is, as in the preceding apparatus, a manipulator for emission of successive intermittent currents. We shall describe it later on.

The automatic apparatus, or more exactly, the automatic commutator, is represented in Figs. 82 and 83. On an axis *a*, which a clockwork movement causes to rotate in the direction indicated by the arrow (Fig. 82), is fastened a toothed wheel R. A lever escapement, controlled by the movements of the armature A of an electro-magnet E, regulates the movements of the wheel R according to the currents transmitted to the electro-magnet by the manipulator of the central station. The same axis carries a rod terminating in an insulated contact finger *d* (Fig. 83), which is kept in position by a spring. The rod of the piece *d*, moreover, carries a contact screw *t′*, which, under normal

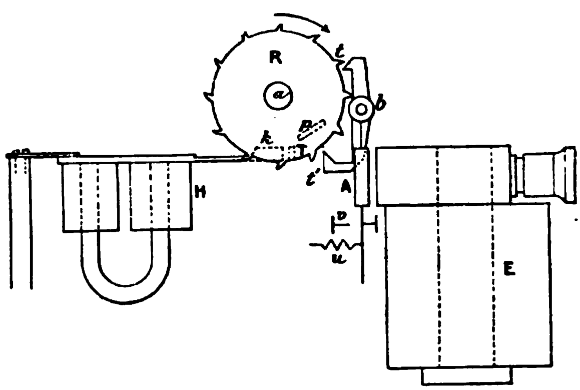


Fig. 82.—Leduc's telephone system (automatic commutator).
(*From La Lumière Electrique.*)

conditions, connects the upper movable part to the main frame. The result of this arrangement is that, as soon as the finger *d* meets with an obstacle on its passage, it is raised and interrupts the contact with *t′*.

Now, the extremity of the finger *d* moves along the circumference of an ebonite disc *c*, to which are fastened as many metallic studs *l*, *l* as there are teeth on the wheel R. Each of these studs is connected to one of the line wires of the secondary network, and they likewise communicate with the contact springs *g*, *g*.

When the wheel is at rest, the extremity *m* of the finger *d* pushes a lever which presses a plate *q* against all the contacts *g*. All these contacts, and consequently all the lines, now communicate with the finger *d*, and as this latter is at that moment on the stud L which raises it, the contact *t'* is broken, and all the lines are connected with the general circuit of the apparatus. From the finger *d*, the current passes to a small Hughes electro-magnet H, and thence

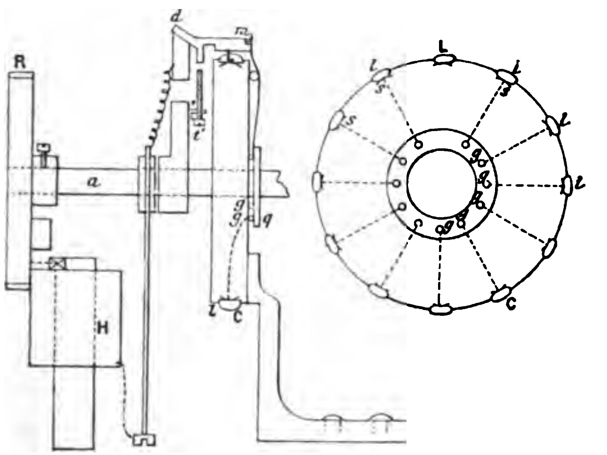


Fig. 83.—Leduc's automatic commutator.
(*From La Lumière Électrique.*)

to the electro-magnet E, Fig. 82, and subsequently to the line of the central station.

Consequently, if this station transmits a certain number of currents to line, there will be a release of an equal number of teeth of the wheel R, and the finger will pass over as many studs L; it will therefore be possible, by transmitting a convenient number of currents, to bring *d* on any stud required, and to place the central station in communication with any one of the secondary lines.

At the moment when this communication is established, the extremity *m* of the lever being no longer pushed back by the finger, the communication of this latter with the contacts *g* is suppressed, and the line on whose stud the finger is remains the only one in circuit.

In order to effect a concordance between the movements of the manipulator and those of the finger, the wheel R must always start from a fixed point, and come back to this point after each operation. For this purpose the wheel R carries a pin T, which in the position of rest abuts against a stop *k* forming the extremity of a Hughes electro-magnet H placed in circuit. This electro-magnet is constructed in such a way that it is only affected by currents of inverse sense to those which generally flow through the circuit. Now, the first current transmitted by the manipulator is a negative current, all the following ones being supposed to be positive. This first current, therefore, releases the wheel R, which begins to rotate, and, by the play of a piece *p*, brings the armature of H back into contact. In this way, when the telephonic conversation is finished, the clerk, by bringing his manipulator back into rest, will bring the wheel back into rest, and its pin will abut forcibly against *k*.

The manipulator is represented in Fig. 84. A handle M, in communication with the line, can be placed in contact with a series of copper blocks connected with one another underneath the socket to which they are fastened. These blocks communicate at the same time with a battery whose other pole is at earth. Between the first and second blocks is placed a spring, which the handle touches and which acts as a commutator. By this means, whenever the handle touches a block, a current is transmitted to line, which causes the advance of the toothed wheel R by one tooth; but the first current transmitted is inverted by the play of the commutator, and it is this current which releases the Hughes electro-magnet H and thus starts the wheel R.

In the perspective view (Fig. 85), the apparatus is represented in its latest form. At B is seen the clockwork movement which sets in motion the axis O (*a* of Figs. 82 and 83), the wheel *r* (R), and the finger *c* (*d*). E is the Hughes electro-magnet which controls the wheel *r*, but its armature, instead of acting on a lever escapement, controls a slide escapement

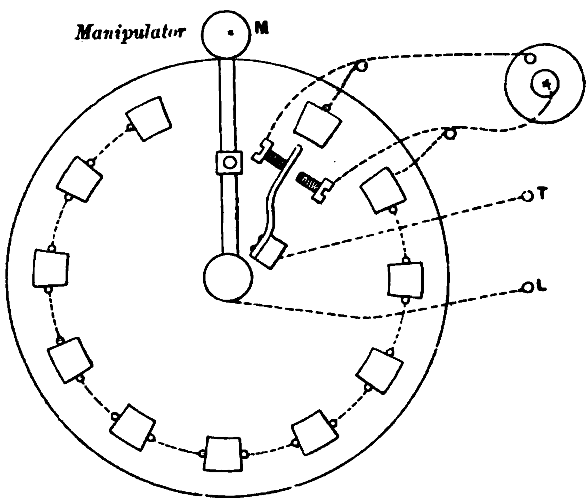


Fig. 84.—Leduc's telephone system (manipulator).
(*From La Lumière Électrique.*)

M H, which offers greater security. The contacts *g*, instead of being arranged in circular form round the axis, are placed in a horizontal line above the fixed disc, and a bar balanced by the piece J makes contact with them as soon as the finger is in a state of rest. D is an index, which follows the movements of the finger and indicates them on an external disc. In practice, the subscriber of a secondary network always calls the clerk at the central station, who puts him in communication with one of the subscribers of another

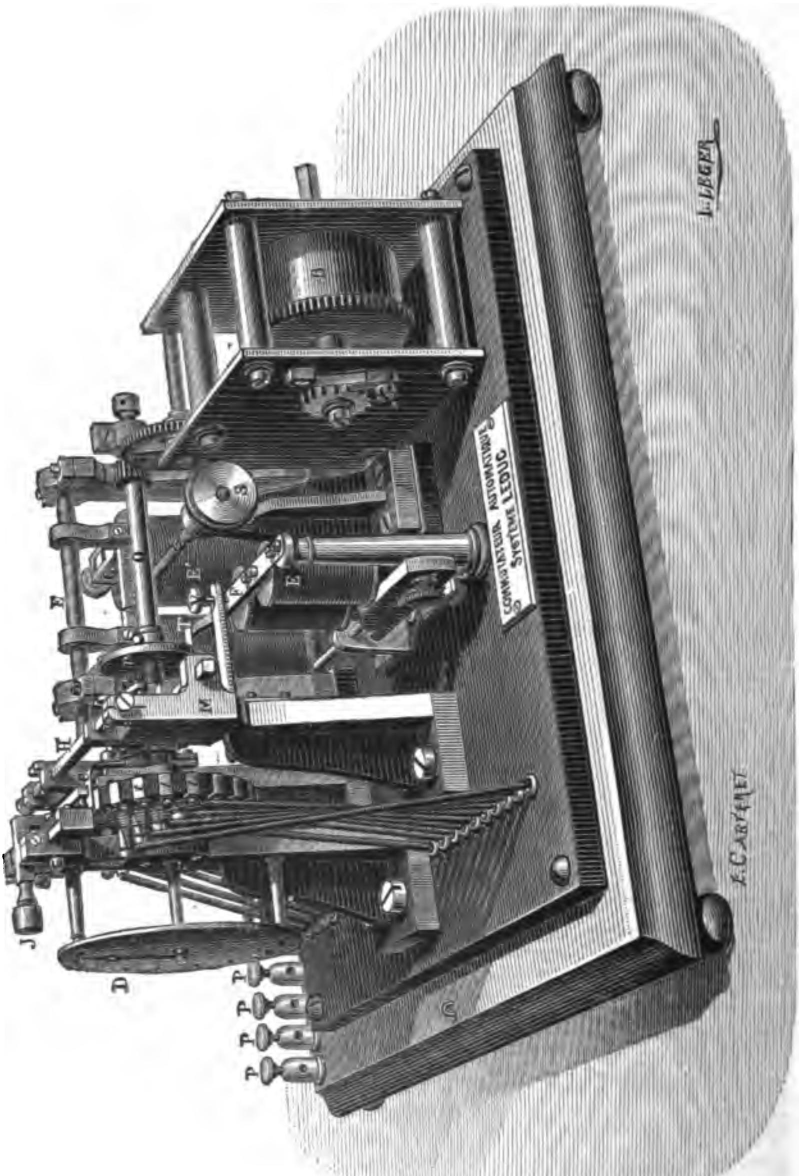


Fig. 85.—Leduc's automatic telephone.
(*From La Lumière Électrique.*)

secondary network. The conversation of a subscriber with another subscriber of the same network can be carried on by means of a single apparatus; the different lines 1, 2, 3, 4, are connected to earth through a relatively large resistance. If now, for instance, subscriber 2 wishes to correspond with subscriber 4, he requests the clerk at the central station to inform 4 that 2 wants him; 2 and 4, by taking up their telephones, are in short circuit, and can converse without being disturbed by the derivations of the other subscribers; but this method does not ensure secrecy of conversation. It is, therefore, preferable to employ two conjugate apparatus and a double wire. In this case, 2 requests the clerk at the central station to inform 4; the clerk calls 4, leaves 2 on the first apparatus, and places 4 on the second by establishing connection between them.

The second apparatus is no inconvenience; it allows, while 2 corresponds with one of the subscribers of B—2′ for instance—1, 3, 4, to converse with any other subscriber.

Leduc has, moreover, modified his apparatus, and has established a small movable commutator, by means of which the central station can make connection with one single apparatus between any two subscribers.

Theatrical Performances repeated by the Telephone.—Nothing could more forcibly illustrate the power and sensitiveness of telephonic communications than the repetition of theatrical performances at the Paris Electrical Exhibition. The performances at the Opéra, Opéra Comique, and Théatre Français could be distinctly heard in a room set apart for this purpose. Not only the voices of the actors and actresses, the songs and the orchestra, but all the incidents of the performance, the applause and laughter of the audience, and in some cases, alas! the voice of the prompter too, were faithfully repeated and listened to with intense pleasure by a never-tiring crowd of visitors.

The following was the arrangement for the telephonic repetition of the performance at the Opera:—

The conducting wires led from the Exhibition through the sewers to the stage of the Opera, where they were connected to a number of transmitters, which were nothing but microphonic transmitters with multiple contacts represented in Fig. 33, p. 64. There were ten transmitters of this kind at the Opera, which were placed on either side of the prompter's box along the footlights.

The receivers placed in the telephone-rooms of the Exhibition, were Ader's telephones, described on p. 29, and the installation of the batteries for the working of these multiple systems had nothing peculiar about it. They were placed wherever there was room for them, generally below the stage, but as polarization would take place to a serious extent if their circuit remained closed during a whole performance, they had to be renewed every quarter of an hour, and a commutator had to be installed to effect these renewals at once. This commutator consisted of a board, having as many springs as there were transmitters, and which served as an intermediary between these latter and the different batteries by which they were actuated.

The greatest difficulty which had then to be encountered was to render the transmitter more sensitive to the voice of the singers than to the predominating sounds of the orchestra. This difficulty has been overcome by M. Ader by the following contrivance:—

Let us suppose two microphonic transmitters placed on the stage at T and T′ (Fig. 86), and these transmitters separately connected by two distinct wires to two telephonic receivers R and R′, which are applied to both ears to hear the singer, whom we will suppose to be placed at A. It is easy to understand that, the distance of this actor from transmitter T being less than that from transmitter T′, his song will be more distinctly reproduced by transmitter T than by T′, and that the stronger impression will be produced on the left ear. If, on the contrary, the singer changes his position to A′, the opposite result will be obtained, and the right ear will receive the stronger impression. The sensation produced will, therefore, be a change of sonorous intensity from one ear to the other, consequent upon the displacement of sound or of the singer from right to left, and the same will be the case for several actors crossing one another on the stage.

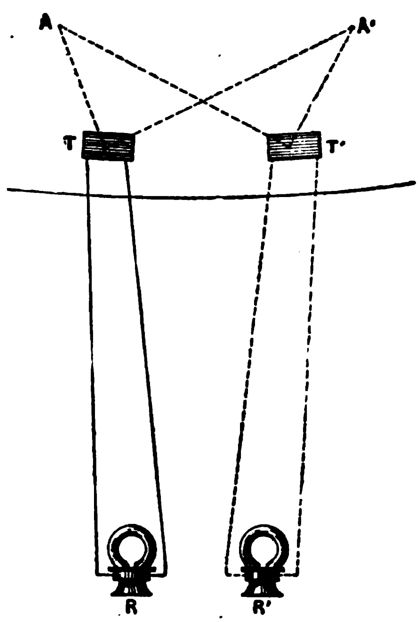


Fig. 86.—Transmitters and receivers for repetition of theatrical performances. (*From La Lumière Électrique.*)

Now, we have seen that on each side of the prompter's box, along the footlights, five transmitters had been installed. Each of these transmitters had its separate circuit, and consequently its underground cable. On arrival at the audience-room, the cables led each to eight receivers, but always in such a way that, for each member of the audience, the effects were quite distinct for each ear. Fig. 87 shows the arrangement of circuits for two transmitters, and it will be the same for all the others. It will be seen, on reference to Fig. 87, that on each board of the telephone-room there was always one telephone, that on the left, which corresponded to the transmitters on the left of the stage, and a telephone on the right which corresponded to the transmitters on the right. The telephones of each series were, moreover, arranged one after another in the same circuit.

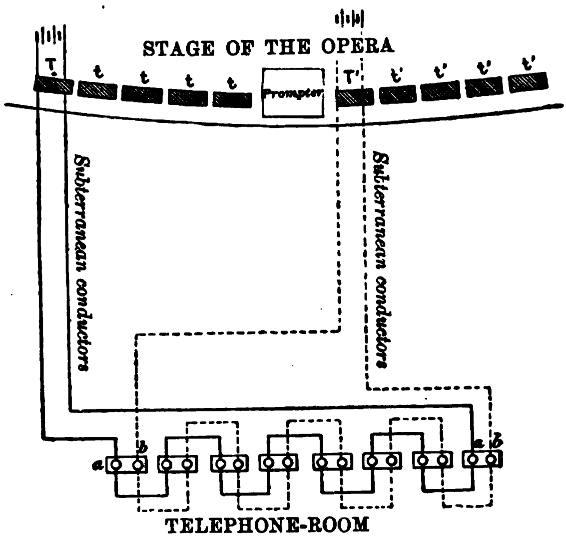


Fig. 87.—Diagram showing connections of stage and telephone-room. (*From La Lumière Électrique.*)

This arrangement is very ingenious, and although it might have been simplified with regard to the number of circuits employed, it was found to be necessary in order to obtain a satisfactory result for the forty-two pairs of telephones employed—a number which was by no means sufficient to satisfy public curiosity.

In London, too, the operetta *La Mascotte,* was telephonically repeated before a dinner-party assembled at a restaurant at a considerable distance from the Comedy Theatre, where it was performed.

Telephonic Communication between Towns.—It will be interesting to note a trial which has lately taken place between New York and Chicago, a distance of 1000 miles, and which proved a complete success. Previously the longest distance over which a telephonic message had been sent was 700 miles, between New York and Cleveland. The present result is not solely due to the telephone, although that possesses some novelty, but is mainly due to a different construction of the conductor. This consisted of a steel wire core, copper-plated, the electrical resistance of which to Chicago was only 1522 ohms, as against upwards of 15,000 ohms, the average resistance of ordinary iron telephonic wire. This new achievement may well be regarded as marking a new era in the development of telephonic communication.

Domestic Telephones.—The telephone can be applied to a number of domestic purposes, of which we will mention a few. In many-storied houses telephonic communication with the servants will be very much appreciated. A manufacturer can correspond from his office with the manager of his works, a business man from his house with his office, a newspaper editor with the printing-office, etc.

For all these applications, when the distances are not too great, which is generally the case, magnetic telephones are the simplest, with the addition of an electric bell worked by a few Leclanchés. Gower's telephone can also be used in certain cases when the rooms where the call is to be heard are not too noisy and are always occupied, as, for instance, an office.

The Telephone applied to Diving Operations.—The idea of this application belongs to Captain Des Portes, of the French Navy, who has made a large number of successful experiments on this subject.

A circular, rather flat telephone of six centimetres diameter, provided inside with two superposed magnets of spiral shape, of a total weight of eighty-eight grammes, had been fixed to the inside of a diver's helmet by means of two screws soldered inside the helmet level with the ear, at the same place where the vibrating plate of these sort of helmets generally is when they have an ordinary speaking-tube. A hole had been pierced in the speaking-tube for the insertion of the conducting wire leading to the telephone. One of the telephone wires was connected to a terminal screwed to the inside of the helmet, which thus served as earth plate.

The telephone transmitter was similar to that of the helmet. The receivers were of different kinds; those constructed by Gaiffe gave excellent results. The warning signal was given with a small bugle, eight centimetres long by two centimetres wide. The diver was called by blowing into the bugle and placing the ear-trumpet near the plate of the transmitter. This call was in *every instance* heard by the diver, in whatever position he was working. If the diver wanted to speak, he had only to say, "Attention!" and this call was likewise heard in every instance.

After the diver had been called, he was obliged, in order to hear comfortably, to take the precaution to press his hand against the air-escape valve, so as not to be disturbed by the noise. He answered that he was ready, and the conversation commenced. But as the air-pump continued to act, the conversation had to be interrupted after a few minutes, to enable the diver to get rid of the excess of air.

The greatest depth at which these experiments were made was fourteen metres; the results were equally satisfactory at various depths, in spite of the well-known fact that the hearing is materially affected by greater depth.

When using telephones which are hermetically closed, a small hole must be made in the plate of the telephone, otherwise this latter will be warped and stick against the magnet through excess of pressure.

Denudations on the conductor between the helmet and the transmitter have very little influence on the amplitude of the sounds transmitted.

Telephone Stations with Magneto-Electro Bells. — In America, magneto-electro bells, which require no battery, are used with Bell's telephone; all that is required is to turn a winch-handle, to generate in an apparatus, similar to Clark's machine, magneto-electro currents strong enough to work an electric bell at the receiving station.

Perrodon has constructed a very practical telephonic alarum for military purposes, in which the current of a small portative battery sent along the line throws the plate of a telephone at the opposite station into vibrations; a small hammer, similar to the hammer of a bell, produces intermittent currents.

Trouvé has modified the apparatus by making the hammer independent of the telephone, and placing it in the handle itself.

Siemens and Ducretet employ, as signals for their telephones, a small vibrating reed similar to Gower's.

Applications of the Telephone and Microphone to Medicine and to Scientific Research.

An instrument of such marvellous sensitiveness as the telephone was bound to find, and has actually found, several applications in medicine and physiology.

We will only mention here Ducretet's stethoscopic microphone and Boudet's microphone.

Ducretet's Stethoscopic Microphone.—We mention this apparatus first, because it was the first apparatus of the kind constructed. With it the observer can hear in several telephones at the same time the faintest pulsations, beating of the heart, of the pulse, and the arteries. This apparatus is very sensitive; its great sensitiveness is, perhaps, a defect.

Two of Marey's drums are joined to the microphone (Fig. 88). The one acts as sounder, the other as receiver. The faintest motion communicated to the drum T acts, by the intermedium of the connecting indiarubber tube, on the drum T′, and consequently on the microphone. This microphone is connected with a lever L, whose sensitiveness can be regulated by the counterpoise P O. It terminates in a pencil C of gas carbon or graphite, which rests on a plate of the same substance, fixed on the receiving drum. The whole forms a complete circuit, containing a battery of one to three Daniells or Leclanchés, and the telephones for hearing the beatings of the sounding-drum T′.

This microphone is capable of modifications; it marks an undoubted progress in physiological science. By substituting a small mouthpiece for the drum T, it can be used for transmission of speech.

Boudet's Microphone applied to Medicine.—A small and slightly concave plate of hardened indiarubber, five centimetres by two, with a round hole in its centre, forms the stand of the apparatus (Fig. 89). At one of its extremities

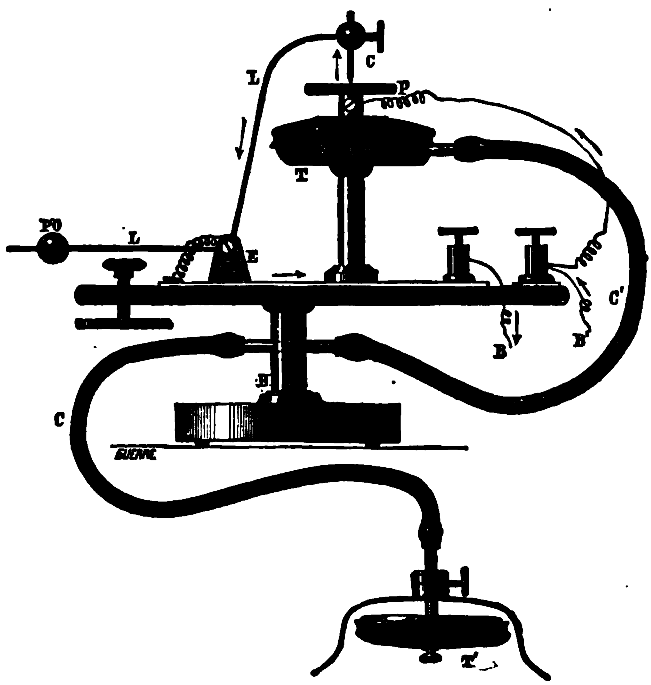


Fig. 88.—Ducretet's stethoscopic microphone.

stands a vertical rod A about three centimetres high, along which a very small copper waggon I is made to slide up and down by means of a regulating screw V; a carbon cylinder D, one centimetre and a half long and five millimetres thick, oscillates on a transversal axis between the uprights of the waggon. A small horizontal spring E, one end of which is fixed to the opposite extremity of the caoutchouc plate, abuts with its free end H against the carbon cylinder. This spring carries a small fragment of carbon, which touches the extremity of the oscillating carbon cylinder. Finally, underneath the first spring and parallel to it, as in Marey's sphygmograph, is another spring F terminating in a sounding-button K, which passes through the hole of the plate.

The least pressure exercised on the button is trans-

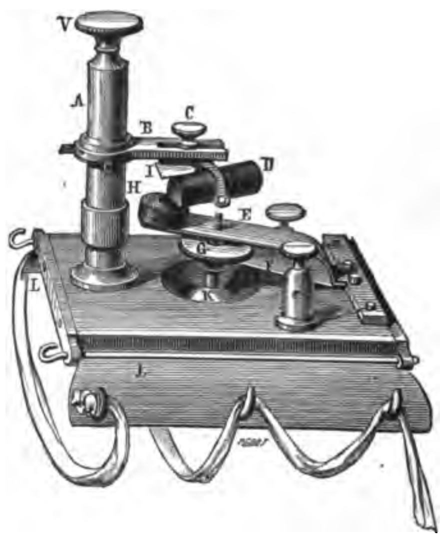


Fig. 89.—Dr. Boudet's microphone.

mitted, by means of the springs F and E, to the two carbon contacts, and causes a variation of intensity in the passing current. These variations are received by a telephone, which the observer applies to his ear. The mobility of the two carbons will account for the extreme sensitiveness of this microphone.

It is, however, necessary in these experiments to obtain a certain amount of initial pressure. This can partly be obtained by means of the regulating screw, which can press the oscillating carbon cylinder more or less close against the lower carbon. But this is not sufficient, for, on feeling a rather quick pulse, the motions communicated to the springs would suddenly raise the upper carbon and cause a breaking of the current.

Boudet has obviated this inconvenience by placing in the waggon, above one extremity of the oscillating cylinder, a small piece of paper bent in form of a V, which acts as a spring. The addition of this spring presents several advantages. Paper is a body of inferior but very perfect elasticity, as has been proved by Savard's experiments. It lends itself, consequently, much more readily than steel and caoutchouc to the successive interruptions and approaches of the carbon contacts, or rather to the variations of their reciprocal pressure. The apparatus thus constructed, when applied to an artery, indicates all the murmurs that take place inside the vessel, and with a little practice the observer can easily distinguish differences of rhythm, the breath-sounds, etc. The pulsation is very strongly accentuated, the normal dicrotism becomes perceptible; in one word, the tracings of the pulse are heard, such as they are registered by the sphygmograph. Applied to a muscle, the same instrument becomes an excellent myophone. It indicates the normal muscular sound, and when contraction takes place, the characteristic rumbling noise of this phenomenon is distinctly heard.

Chardin and Prayer have also constructed a sounding micro-telephone for sounding wounds. We refer our readers to No. 312 of *La Nature* (May 21, 1879), where this apparatus is described.

Scientific Applications of the Telephone.—Amongst the scientific applications of the telephone, Hughes' induction balance occupies an important place.

Hughes' Induction-Current Balance and its Application to Surgery.—This apparatus, which is represented at Fig. 90, consists of two tubes T, T′, each provided with a double induction coil A B, A′ B′, corresponding to two distinct circuits, in which are placed, on the one hand an interrupter (through the coils B, B′) and on the other hand a telephone, which can be replaced by a sonometer by means of a commutator X. One of the systems has an oscillating lever L, which regulates the distance of coil A′ from coil B′, so as to obtain two exactly equal induction effects.

Under these conditions, if the circuits are arranged in such a way that the induced currents produced in the coils A, A′ are of contrary sense, it is clear that the interruptions of the exciting current produced at P on the interrupter, will give no sound in the telephone O; but if a piece of metal is placed at P, the case will be altered, and the telephone will indicate the inductive disturbance caused by piece P, which will disturb the existing balance.

Let us suppose now that, instead of placing the metallic piece at P, it be placed above A; a similar effect will be obtained, but much less energetic, and it will be easy to ascertain the distance at which this piece has been placed if, above the second system of coils A′ B′, a similar piece is placed and is moved about until the sounds have died away in the telephone. If the two pieces are well in the axes of the two tubes T, T′, their distance from the coils A, A′ will be equal, and it will be sufficient to measure the one in order to know the other.

Having explained the general working of the apparatus, it will be easily understood how it can be arranged for finding a bullet which has gone astray in the interior of the human body. For this purpose the system A B has

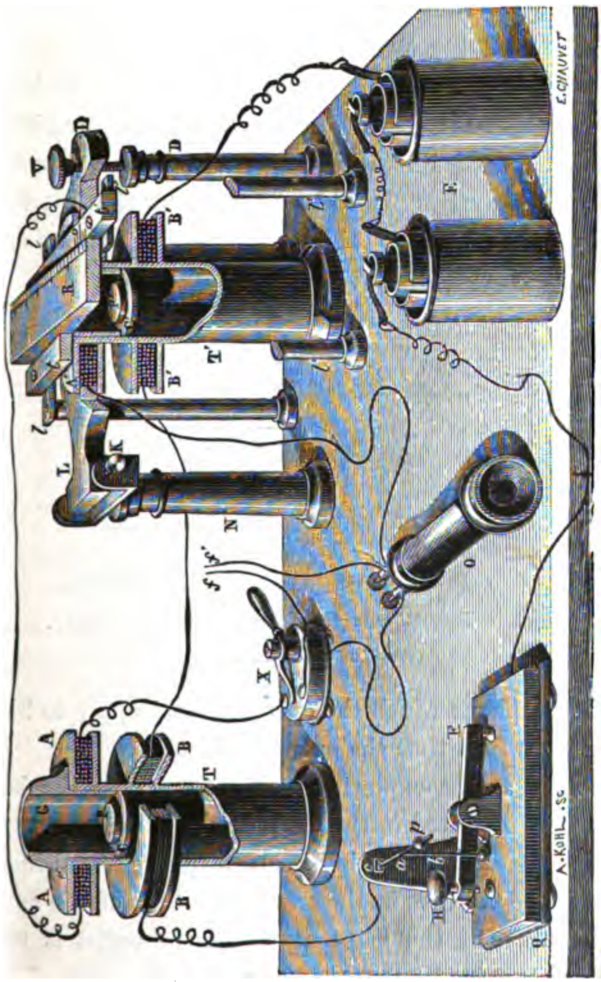


Fig. 90.—Hughes' induction-current balance.

(From La Lumière Électrique.)

only to be made movable, the tube to be cut at the level of the coils, and the connecting wires to be twisted into a sort of tensible cable, as shown in Fig. 91, so as to avoid any change of condition during the unavoidable displacements of the movable system. Care must, however, be taken that the coils of this system are in an inverse position to that of the fixed system A′ B′, since the action takes place in the inverse upward direction if the body on which the operation has to be performed is placed horizontally. In Fig. 91, E is the couple of movable coils which the operator holds in his hand, and with which he performs his explorations; B is the fixed system placed on a table near the interrupter I of battery P; C is the cable joining the two circuits; and

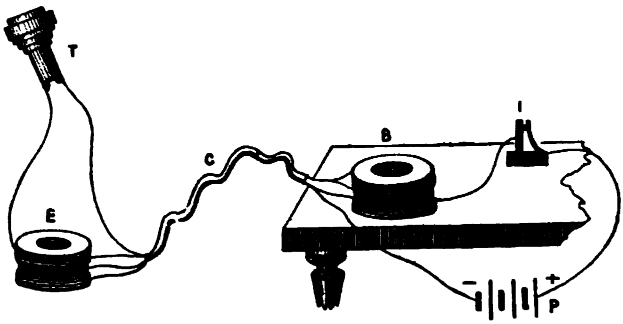


Fig. 91.—Hughes' induction balance applied to surgery.
(*From La Lumière Électrique.*)

T is the telephone which the operator must apply to his ear during the whole time the operation lasts.

As long as the exploring coils are not near the bullet, no sound is produced in the telephone; but as soon as they approach the bullet, warning is given by the sound increasing until the bullet is in the axis of the tube of the system. The direction of the point at which the bullet is lodged will be determined by a greater or lesser number of trials. For determining the depth, the method indicated above for the metallic pieces placed above the coils will be followed. A bullet of the same kind as the one which is supposed to be lodged in the body of the patient is placed on the top of the tube of the fixed system, and is withdrawn from the upper coil or brought nearer to it, until sound is no longer produced in the telephone. The distance of the trial bullet indicates the depth at which the bullet is lodged in the body.

It will be remembered that this instrument was used in the treatment of the wound of the late President Garfield.

McEvoy's Submarine Detector.—On the principle of Hughes' induction balance, Captain McEvoy has constructed an apparatus for detecting the existence of metal-cased torpedoes, sunken iron hulls, lost cables, anchors, or other metal objects, on the bottom of the sea.

The principle of the apparatus will be understood from Fig. 92, where P S and P′ S′ are the four coils of the balance, arranged in pairs separated from each other and connected by insulated wires. The coils P and P′ are joined together through a battery B and a key or interrupter I, thus constituting the primary circuit of the balance. The coils S and S′ are connected through a telephone T, and constitute the secondary circuit of the balance. The interrupter I may be either manipulated by hand or automatically, so as to give a continuous action. Whenever the primary circuit is closed by its means, a current traverses the primary coils P, P′, and induces a corresponding current in the secondary coils S, S′. This current is, of course, audible in the telephone T; but by reversing one of the secondary coils, say S′, the current induced by the primary

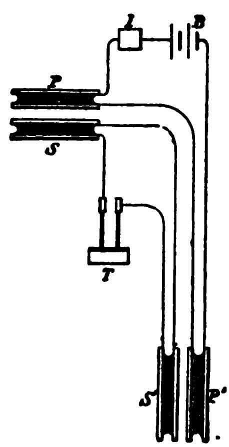


Fig. 92.—McEvoy's submarine detector (diagram illustrating the principle).

coil P′ in the coil S′ is made to oppose the current induced by the other primary coil P in the other secondary coil S, so that it is possible to cause these two induced currents to annul one another and produce silence in the telephone. In other words, it is possible to effect a practically perfect balance between the two induced currents.

This is done by making the two primary coils and also the two secondary coils alike in all respects, and placing the secondary S at the same distance from P that S′ is from P′. The final adjustment to produce silence in the telephone can be made by altering the distance between a secondary coil and its primary, say the distance of S from P, or it can be made by means of a small piece of metal adjusted near one pair of coils, as was originally shown by Professor Hughes. To employ this arrangement for detecting metal masses, it is only necessary to obtain a sufficiently good balance in this way, and explore the field where the metal is supposed to lie by moving about the pair of coils S′, P′. Then, if these coils come near a piece of metal, the inductive disturbance which its presence creates will upset the existing balance, and the telephone, before silent or nearly so, will give out distinctly audible sounds, owing to the predominance of the induced currents in the secondary S′ over those in the secondary S.

The apparatus is shown in Fig. 93, where A is a portable case containing the adjustable coils P S and the interrupter I (Fig. 92); B is a voltaic battery of two cells, which may be replaced by a small magneto-electric machine giving alternate currents; T is the telephone in the secondary circuit; C is an insulated cable conveying the wires connecting up the two pairs of coils; and D is the detecting or exploring case, containing the two secondary coils S′ P′ (Fig. 92). The coils

P S inside the box A are separated by a layer of soft india-rubber, and an ivory screw passes through both coils and

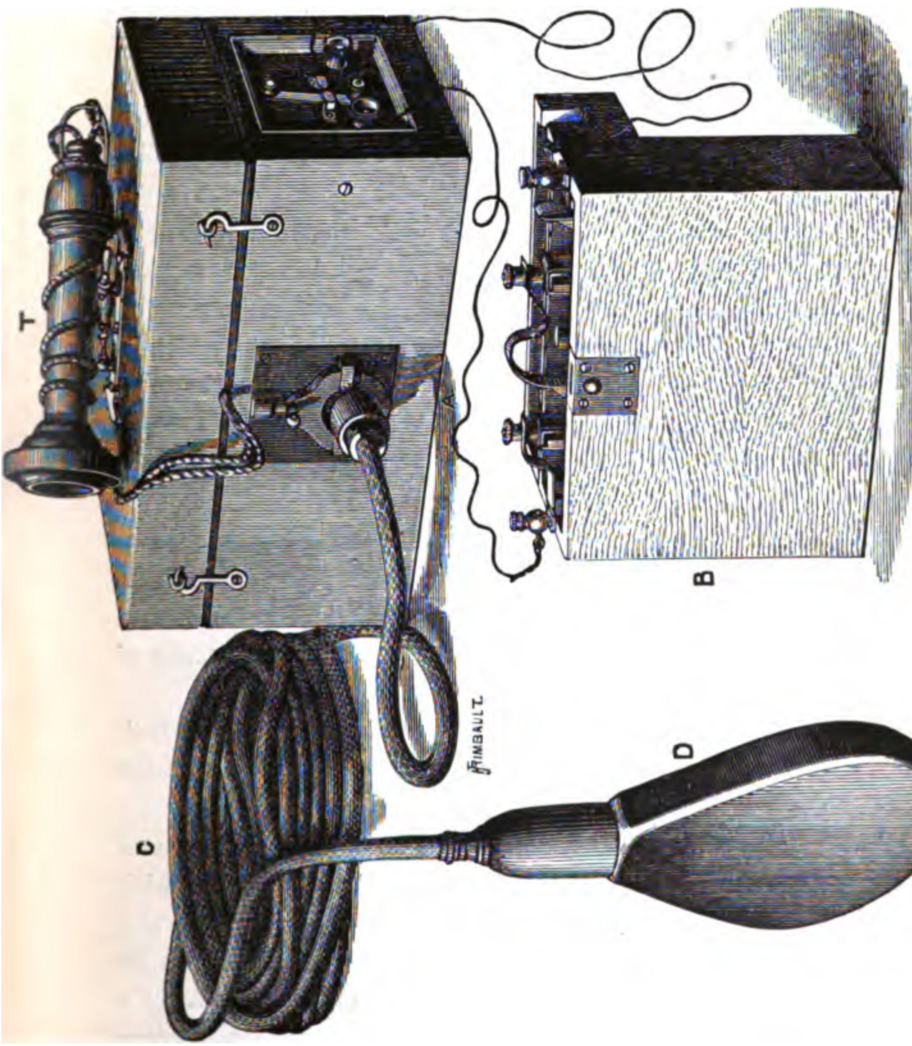


Fig. 93.—McEvoy's submarine detector.

the rubber washer between. An ebonite head to the screw is adjusted by hand so as to press the coils together or let them further apart by regulating the pressure between them and the indiarubber. This simple device adjusts the balance of induction and reduces the telephone to silence, or, as the inventor prefers it, to all but silence. When the ear has a slight sound to guide it, the notable increase of loudness in that sound, produced by the approach of the detecting case D to a metal body, is perhaps more readily observed.

The interrupter consists of a small iron reed or tongue kept in vibration by a small double-poled electro-magnet, and thereby interrupting the current a certain number of times per second, so as to give out a definite note, which is easily recognizable in the telephone, and cannot be mistaken. A switch E at the end of the box turns the current from the battery on and off the interrupter at a moment's notice.

The battery consists of two Leclanché elements in a portable case; a substitute for the battery and interrupter is also provided in the shape of a small magneto-electric machine such as are used in the medical applications of electricity.

The telephone is the ordinary speaking receiver of Bell, and it, as well as the magneto-machine, are packed inside the box.

The cable C is insulated with Henley's patent core, consisting of indiarubber having its pores filled up with ozokerit, or black earth wax, forced in under pressure, and when in a hot fluid state. It is further protected with an outer braided sheathing, and is fitted to the box A by a socket, which in an instant establishes connection between the corresponding primaries and secondaries and locks them together. The detecting case D is made of wood soaked in paraffin wax, and its peculiar powder-flask shape, as well as its material, were only arrived at after many trials. It is water-tight, and contains two exploring coils. When it is lowered into the water by the cable C, and moved about or dragged over the bottom, the instant it comes against a piece of metal, such as a torpedo-case, a chain, or a submarine cable, it disturbs the balance, and the noise heard in the telephone very faintly until now, becomes unmistakably loud and clear.

Carlo Resio's Telephonic Indicator of the Torsion and the Angular Velocity of the Driving Shaft, and consequently of the Work, of Machines.—This apparatus consists of two

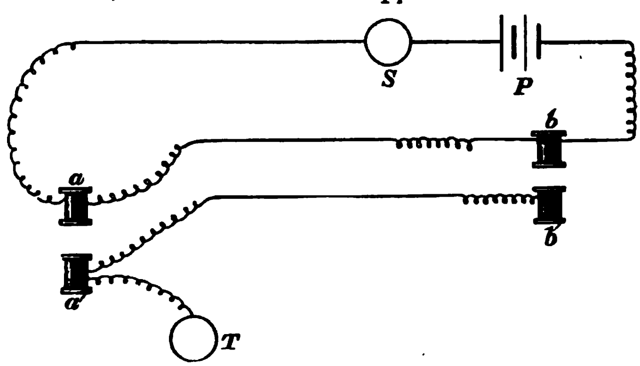


Fig. 94.—Carlo Resio's torsion indicator (diagram illustrating the principle).
(*From La Lumière Électrique.*)

parts, which are connected by an electric circuit—the one attached to the driving shaft forms the transmitter, the other placed at a distance constitutes the receiving apparatus. The principle on which the apparatus is based may be stated as follows:—

If in a circuit containing a battery P (Fig. 94) and a current-interrupter S capable of producing a sound, two identical coils *a*, *b* are placed in tension, whose respective wires are wound in different directions, the induction currents excited in two other coils *a′*, *b′* (secondary), equal in every respect and connected for tension in a circuit containing a telephone T, destroy one another, and, consequently, the telephone remains silent, if they are equidistant from the primary coils *a*, *b* and equally placed with regard to them; but the telephone will emit a sound if the distances of the primary from the secondary coils are not equal.

2. *Transmitting Apparatus.*—In machines where the driving shaft has rather large dimensions, the transmitter has the form indicated in Fig. 95. A tube B B′ E E′ of one and a half to two metres length surrounds the driving shaft M M′. At B B′ the tube is bolted on to the shaft, whilst at E E′ it merely touches it with slight friction. At the latter extremity the tube carries a fork which rises slightly above the cylindrical surface of the driving shaft M M′, and has between its prongs a wedge I terminating the short arm o I of the lever I o C, which is movable about the pivot o fastened vertically to the driving shaft, The longer arm o C of this lever passes beyond the metallic sector A A′, which is fixed to the shaft by its extremities and maintained in the plane of movement of the lever. The longer arm o C carries at its extremity a coil C. One of the extremities of the helix is attached to the small spring N *n* and to the insulated terminal N on the driving shaft, and this terminal is in metallic connection with the insulated grooved ring R; the other end of the helix communicates with the metallic part of the lever I C, and consequently with the driving shaft M M′.

Opposite the coil C, at a convenient distance and level with it, a secondary coil D is fastened to the shaft M M′; one of the poles of this coil is connected with the driving shaft, and the other with the insulated ring R′. Against a notch on the circumference of this ring presses a small rubber *m* or a small elastic rod, and between the teeth of the wheel R protrudes a spring L, arranged in such a way as to touch the teeth and to be slightly bent by the passage of each tooth, during the rotatory movement of the wheel.

If the motive force is applied above the wheel R and the movement takes place in the direction of the arrow,

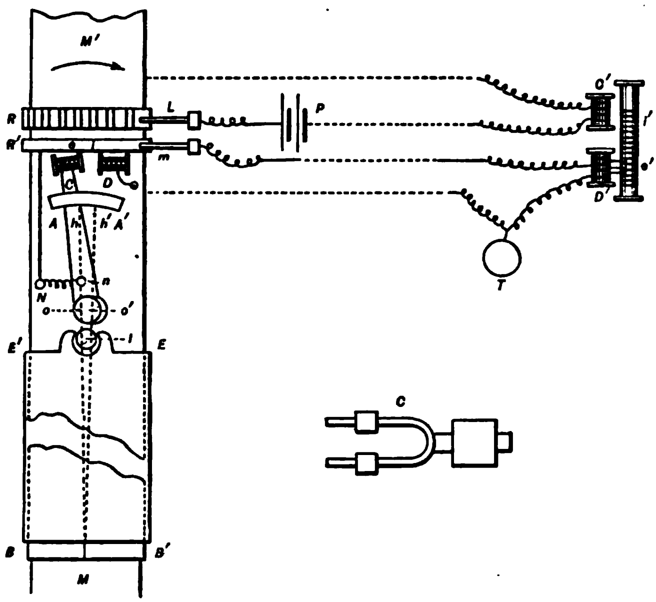


Fig. 95.—Carlo Resio's torsion indicator (transmitter and receiver).
(*From La Lumière Électrique.*)

the resistance being placed above the section B B′, the coil C will approach the coil D by an amount proportional to the force transmitted to the shaft. In fact, let us suppose, when the machine is at rest, the points M, I, *o*, *h* to be on the same generator. This will no longer be the case when the driving shaft is in motion; the tube B B′ E E′, which is only fixed to the shaft at B B′, is subject to no torsion, and the points M, I will always be contained in the section of the generator M I *o h;* but in the portion of the shaft surrounded by the tube, there will be a slight torsion, and the points *o*, *h* will be displaced in the direction of the rotation and take up the position *o'*, *h'*. Now, it is evident that the displacement of the coil C will be proportional to the displacement *o*, *o'* of the point *o*, and consequently proportional to the motive force; it is also clear that the coil C will approach the coil D if the rotation takes place from left to right, and that it will withdraw from it if the rotation takes place in the opposite direction.

3. *The Receiving Apparatus.*—The receiving apparatus is very simple. It consists of two coils C', D' identical with the coils C, D, and occupying the same relative positions. The secondary coil D' is fixed, and the primary coil C' is movable, and, by means of a screw or some other arrangement, it can be brought near or withdrawn from the coil D. A graduated ruler, on which this coil can slide, serves for measuring its displacements.

The primary coils C, C', the wheel R—which acts as interrupter, and which must have a considerable number of teeth (the more the less the velocity of rotation)—and the battery P are placed in the same circuit, which at each revolution of the driving shaft is opened and closed as many times as there are teeth on the wheel R. The coils C, C' are connected for tension, and arranged so as to excite currents of contrary sense in the secondary coils D, D'.

A telephone T is introduced in the circuit containing the two coils D, D', which are connected with a diapason G, and this completes the receiving apparatus.

4. *Action of the Apparatus.*—To understand the working of the apparatus, let us suppose the machine to be at

rest, but that the exciting current be interrupted from fifty to sixty times per second. Then the induction currents generated at the same moment in the coils D, D′ will be equal and contrary, if the distance *e i* of the coils C and D is equal to the distance *e′ i′* of the coils C′ and D′; consequently the telephone T will emit no sound.

If the machine by its rotation gave rise to no torsion in the driving shaft, the distance *e i* would always be equal to *e′ i′*, and the exciting current would be interrupted, at each revolution, as many times as there are teeth on the circumference of wheel R; but the induced currents generated at the same time in the coils D, D′ being still equal and contrary, they would have no action on the telephone, which would therefore remain silent. But as necessarily a torsion will be produced in the driving shaft, coil C will approach coil D by an amount proportional to the torsion, and consequently proportional to the force transmitted to the shaft. The distance *e i* being thus diminished, the induction currents generated in coil D will be of greater intensity than the currents developed in coil D′, and the telephone T will emit a sound whose intensity will be in proportion to the distances *e i*, *e′ i′*. By gradually bringing coil C′ near coil D′, the intensity of the sounds emitted by the telephone will gradually be weakened, and when it is silent we conclude that $e\,i = e'\,i'$. The measure of the distance *e′ i′* being given by the graduated ruler, the distance *e i* will be known, and consequently the motive force too will be known, if we know the ratio which exists between this force and the distance of the coils C and D. Now, this ratio can be determined experimentally in the following way:—A section of the driving shaft is permanently fixed below section B B′, and, by means of a dynamometer applied to the extremity of a lever arm H above wheel R, the force F, corresponding to each distance of the coils C and D, is measured.

For each of these distances it must be ascertained if in the receiving apparatus the telephone is silent when the coils C′, D′ are placed at the same distance. For this purpose the primary current is, by means of an interrupter, passed into the secondary coils and the coil of the receiver is displaced until the telephone is silent; then the distance $e' \, i'$ will be equal to $e \, i$ if the metallic masses which act on the coils C, D are equal and arranged like the masses acting on C′, D′. But as C and D might be influenced by the driving shaft, which exercises no influence on C′ and D′, the distance of these latter coils might not be equal to the distance of C and D when the telephone is silent. However, having determined $e \, i$ for different amounts of motive force applied to the driving shaft, these values are inscribed on the scale over which coil C′ can slide, and in this way the number inscribed on the scale at the point where the coil C′ reduces the telephone to silence, gives in kilogrammes the motive force applied to the shaft at the extremity of the lever arm H. To remove as far as possible the coils C, D from the action of the metallic mass of the driving shaft, they have been raised somewhat above its surface, and all the coils, both of the transmitter and of the receiver, are without a metallic core.

5. From the data thus determined the work of the machine for each revolution of the driving shaft can be calculated. This work is evidently represented in kilogrammetres by the formula $2\pi HF$; where H is expressed in metres and the force F in kilogrammes. If we want to find the work of the machine in a unit of time or in a given time t,

we must know the velocity of rotation of the driving shaft, or the number of revolutions which it performs per second. This result is obtained in the following manner, without adding anything to the mechanical arrangement indicated above :—Let n be the number of teeth of the ring R and also the number of double vibrations of the diapason G when the metallic masses placed on its arms occupy the position indicated in the figure. On displacing these masses, either to the left or to the right, the number of vibrations varies, and the scale marked on the two cams will indicate their number for each position of the masses, if we suppose this number to be inscribed on the arms.

Now it will be easy to understand how the experiment for determining the number of revolutions of the driving shaft in unit of time is performed.

The observer listens to the telephone (which gives a sufficiently strong sound without applying it to the ear), and the diapason G is thrown into vibrations. If it is in unison with the telephone, the number which corresponds to the position of the metallic masses is equal to the number of teeth of wheel R which, in one second, touch the plate L, or to the number of interruptions of the current of battery P if the unison does not exist. In this latter case the masses are displaced on the arms of the diapason until unison is obtained. Then the number n' is read off which corresponds to the position of the masses, and which will also be that of the teeth which passed before L in a second; the number of revolutions of the driving shaft in unit of time is therefore $\frac{n'}{n}$, and work—

$$T = 2\pi HF \frac{n'}{n}$$

per second.

On referring to what has already been stated, it will be seen that the receiver can be consulted at any moment, that this apparatus can be at any distance from the machine, and that the work of the latter can be measured by making the two following experiments:—Unison is established between the diapason G and the telephone T, and this gives us the number $\frac{n'}{n}$ of revolutions in one second of the driving shaft; the coil C′ is displaced until the telephone becomes silent, and we get from this the force F transmitted to the driving shaft. The value of these elements thus determined and substituted in the preceding formula gives the work of the machine in unit of time.

6. We have supposed that, for a certain position of the coil C′, the telephone ceases to emit sounds; this supposition requires the torsion of the driving shaft to be constant. Now, it is evident that this torsion can vary, not only whilst the experiment lasts, but at each revolution of the shaft. It can vary periodically, and then we get maximum and minimum values; in this case the coil is displaced until the telephone gives a sound of minimum intensity, and the force F which is read off on the scale will then express the average motive force, and consequently the formula will give the average work per second.

The transmitter which we have described cannot be applied to machines, if the driving shaft is not sufficiently long; but by modifying it in a convenient way it can be applied to any machine whatsoever. Let us suppose, in the first instance, the movement to be transmitted to the driving shaft by means of a driving belt. In this case the transmitter can be arranged in the following way:—

The driving pulley F F′ (Fig. 96) is fastened on the shaft, but at the same time connected with two equal arms H F, H F′ fixed to the driving shaft by means of two elliptical dynamometers F *d*, F′ *d′*, which at F, F′ are joined to the arms H F, H F′, and at *d*, *d′* to a pivot starting at right angles from the pulley. The primary coil *c* is fixed to the pivot *d*, and the secondary coil D to the arm H D, forming a rigid system with the arms H F, H F′. If the pulley F F′ rotates in the direction of the arrow, the two dynamometers which transmit the force to the driving shaft are elongated, and consequently the coil *c* approaches the secondary coil D, and the displacement will be proportional to the motive force. The coil *c* is placed in communication with a toothed wheel similar to R (Fig. 95), insulated on the shaft, and the secondary coil with a ring similar to R′, and this constitutes the convenient arrangement of the transmitter. As for the remainder, all is arranged as in Fig. 95, and the work of the machine is found in the same way.

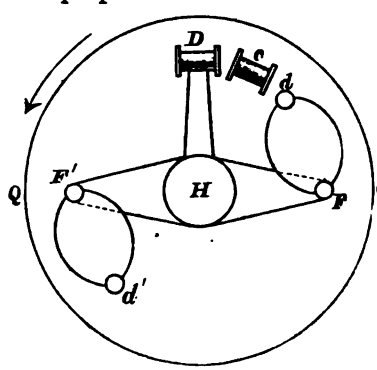


Fig. 96.—Carlo Resio's torsion indicator (transmitter for machine worked with driving belt).
(*From La Lumière Électrique.*)

The three arms H F, H F′, H D can be replaced by a pulley fixed on the driving shaft, and having an equal diameter to that of pulley F F′.

If the transmission of motive force to the shaft of the machine is not effected by means of a driving belt, and the shaft is not sufficiently long to apply to it the arrangement indicated in Fig. 96, the same result is obtained in the following manner:—

The driving shaft can be divided into two parts having a common axis. One of these parts terminates in a disc like F F′ (Fig. 96), and the other in the system of three arms H F, H F′, H D; the latter carries the secondary coil D, and the others, H F, H F′, are connected to the disc F F′ in the way already indicated. Now, if the coils C and D are placed in electric communication with a toothed wheel R and with a ring R′ insulated on the shaft (Fig. 95), we find ourselves again under the conditions indicated above, and consequently the elements of work can be determined in the same way as before.

The principle indicated at the beginning of this article can be applied to a number of cases—to the measurement of changes of the level of liquids, to observations of barometric pressure and of temperature.

For these purposes the transmitter need only be arranged in such a manner that a primary coil C approaches or withdraws from a secondary coil D for changes of level, of temperature, etc. The receiver would always have the same arrangement, but the diapason would be no longer required, the coils C′, D′ would be sufficient. In this case an interrupter would have to be introduced into the primary circuit.

The Telephone applied to the Indication of Electric Currents of very Feeble Intensity.—The following is D'Arsonval's own account of this interesting application:—

"It is clear that the telephone can only indicate the variations of an electric current, however feeble they may be; but I have, with the help of this instrument, found the means of indicating the presence of a continuous current, however feeble it may be. I have succeeded in doing this by a very simple method. I pass the supposed current into the telephone, and, in order to obtain variations, mechanically interrupt this current by a diapason. If the telephone is not traversed by any current, the instrument remains mute. If, on the contrary, the feeblest current exists, the telephone vibrates in unison with the diapason."

Various Applications of the Telephone.—The applications which the telephone has already found are innumerable: several volumes like this would not be sufficient to describe them all. Hughes' audiometer or sonometer, the measurement of resistances, Warren de la Rue's researches on the electric discharge of high-tension batteries,—these are the principal scientific applications of the telephone.

Telephonic communications in mines, workshops, and factories, the measurement of torsion in the axles of machines in motion, the analysis of metals by the induction balance, constitute the principal industrial applications.

Every day witnesses new experiments, new problems for the solution of which the telephone affords a means of investigation, a valuable help.

In other cases new difficulties arise from its application, but science as well as these applications profit by the researches rendered necessary to overcome these difficulties. Of this we will quote an example. When networks of telephone wires were established in the sewers of Paris, there arose, through the forced close proximity of the wires, a difficulty of so serious a character as to jeopardize the development of the system. It was a question of reciprocal induction of the different wires, producing a very Babel of conversations, and a noise which would render conversation very difficult, if not altogether impossible. If, on the other hand, telephone wires run side by side with telegraph wires, and the lines are widely spread, the emission of successive signals produces on the telephone wires sounds which closely resemble the crackling noise heard when using a frying-pan.

Several suggestions have been made for getting over this difficulty, and of these, Van Rysselberghe's experiments made between Paris and Brussels attracted a good deal of attention at the time. They were kept rather secret, but it appears that an attempt was made to send currents of the same undulatory nature as telephonic currents along the neighbouring telegraph wires, which would necessitate a particular arrangement of the telegraphic transmitters. Nothing has been heard for some time of these experiments, which were heralded in with a great flourish of trumpets.

Another experiment, which has quite lately been made by Mr. Lugo at New York, holds out a better promise of success. The cable employed, called *solenoid cable*, is composed of two wires corresponding to the sending and return wires of the current, and these wires are coiled round each other in portions of alternately inverse sense, so that the two opposite parts of the circuit always present themselves crossways one to the other in their straight parts—an arrangement which effectually prevents the reciprocal inductive action of two wires. The author mainly ascribes the results obtained to the very induction of the two wires, and thinks that the induction of the other wires would from this reason be annulled, or, in any case, if it still should produce a certain effect, the action alternately exercised on the two wires would tend to create equal and contrary currents, which, by destroying one another, would free the line.

Without being over-sanguine, we may confidently expect a complete solution of this vexing problem in the nearest future.

We have shown in the preceding pages how many technical and scientific questions of the greatest interest have been raised by the practical applications of the telephone, notwithstanding the recent date of its invention—only seven years ago.

The rapid development of the telephone since its discovery is unique in the annals of science; it shows the increasing importance of science for the progress of civilization and also the immense import of Professor Graham Bell's discovery.

PART II.

VARIOUS APPLICATIONS OF ELECTRICITY.

CHAPTER I.

METHANOMETERS, OR APPARATUS FOR INDICATING THE QUANTITY OF FIRE-DAMP IN COAL-MINES.

Liveing's Methanometer.—It is well known that, in order to avert the dangers of an explosion in coal-mines, no burning substance must come in contact with the surrounding air of the mine.

Davy's lamp and its different modifications, and quite recently the introduction of incandescent electric lamps, have partly solved this problem; but even with these precautions, a thoughtless act of the miner in any part of the working containing the explosive mixture of marsh gas and air, can cause a serious accident. It is therefore of the utmost importance to receive an immediate warning at the moment when the air begins to contain a dangerous proportion of hydro-carbon, so as to be able, by active ventilation, to avoid the danger of explosion.

The lengthening of the flame of a Davy lamp first served as a warning in this case; other apparatus have been constructed since with the object of obtaining more accurate indications, and even of ascertaining the quantity of explosive gas in the air. These apparatus can be divided into two classes—those founded on the physical properties of the gaseous mixture, and those founded on its chemical properties. The former are represented by Forbes' and Ansell's apparatus, but, as electricity has no part whatever in their working, they do not come within the scope of this book. The latter comprise the apparatus of Coquillon, Angus Smith, Liveing, Monnier, and Somzée. All these, with the exception of Angus Smith's apparatus, are founded on the use of electricity, and three of them—Liveing's, Monnier's, and Somzée's—were exhibited at the Paris Electrical Exhibition.

The principle of Liveing's apparatus is the following:—

A mixture of air and marsh gas containing less than five per cent. in volume of the latter gas, is not explosive. If, however, such a mixture comes in contact with a platinum wire which has been raised to a sufficiently high temperature, it will, by a phenomenon of condensation or perhaps of local combustion, raise the temperature of this platinum wire, and the more so the more marsh gas the mixture contains. If, therefore, we raise two platinum wires to the same temperature, and place the one in the air of the mine, and the other in an atmosphere free from hydro-carbon, the temperature of the former will rise in proportion to the quantity of hydro-carbon contained in the mine. The intensity of light of the platinum wire will increase with the temperature, and, by comparing this intensity with that of the other wire, we shall be able to determine the quantity of fire-damp in the mine.

The apparatus employed for this purpose is represented in section in Fig. 97, and in perspective in Fig. 98. It consists of a narrow wooden box A B about twenty centimetres in length; a glass plate C forms part of its cover, which is perforated by two tubes D and E for the admission and the outlet of the gas. At the two extremities of the box—at F and G—are two platinum spirals contained in the same circuit through which an electric current can be passed at the same time by means of a small magneto-electric machine enclosed in the lower part of the box. One of the spirals G is enclosed in a glass tube fixed to a

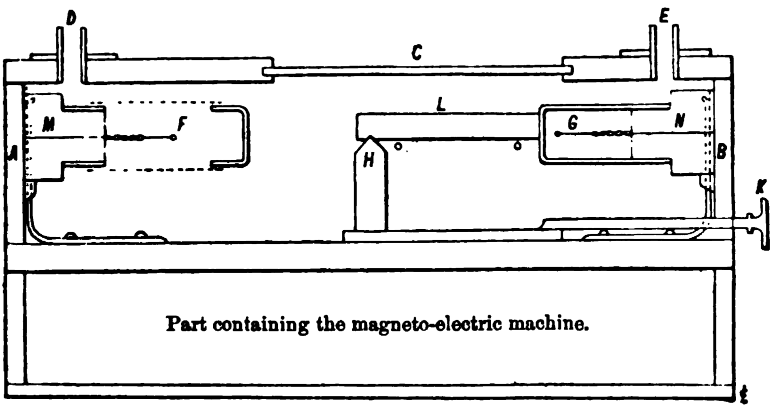


Fig. 97.—Section of Liveing's apparatus.
(*From La Lumière Electrique.*)

sort of stopper N. This tube contains ordinary air without any admixture of fire-damp. The other spiral is enclosed in a tube fixed to a similar stopper M, but which is only partly of glass at the end, the lower part being formed of metallic wire gauze, so that this tube is full of air having the same composition as the air of the box and consequently of the mine. When the current passes through the spirals, these spirals are, as long as the air contains no fire-damp, heated to the same degree, and have therefore the same luminous intensity; but as soon as the air contains any hydro-carbon, the spiral F becomes more brilliant, and its luminous intensity enables us, as we have said, to determine the proportion of fire-damp. This determination is made by means of a small photometer contained in the box. A square piece of wood, placed at an equal distance from the two spirals, is bevelled off at its upper end so as to present an inclined surface to the light of each spiral. These two surfaces are covered with white paper and their luminous intensity can easily be compared by looking through the glass C. By means of the screw K the rod H can be moved until the luminous intensity on both inclined surfaces is equal. A graduated scale L indicates the proportion of fire-damp corresponding to each position of H.

The scale is graduated experimentally, by introducing into the box mixtures of known quantities of air and hydro-carbon—assuming the composition of fire-damp to be CH_4, which is correct on the whole.

The annexed table shows the differences of intensity corresponding to different quantities of CH_4—

Quantity of CH_4.	Relative illuminating power of the spirals.	
	Covered spiral.	Open spiral.
Pure air	1	1·0
¼ per cent. of CH_4...	1	1·24
½ " " ...	1	1·65
1 " " ...	1	2·78
2 " " ...	1	5·1
3 " " ...	1	22·0
4 " " ...	1	64·0

The table shows the sensitiveness of the apparatus for quantities of inflammable gas exceeding two per cent.

Fig. 98 represents the exterior view of the apparatus. The magneto-electric machine, which is a sort of Siemens machine with permanent magnets, is enclosed in the lower protruding part of the box, which contains the tubes and the photometer. The box can easily be held in the left hand by pressing it against the chest, or in a recumbent position against the knees. At the same time, the handle is turned with the right hand and the photometer is observed. If there is a difference in the intensity of the two white surfaces, the observer ceases turning the handle, and slightly moves H by pulling K (Fig. 97); then he begins turning

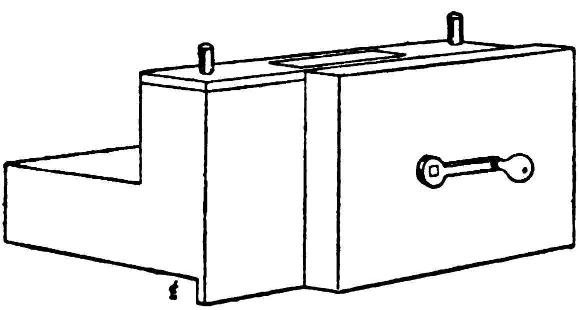


Fig. 98.—Exterior view of Liveing's apparatus.
(*From La Lumière Électrique.*)

again, and so on, until a uniform tint is obtained. The only thing to be done now is to read off the scale.

To introduce the air of the mine into the box, it is sufficient to remove the cover of the box for a few minutes; but when a particular mixture—the air contained in some fissure, for instance—has to be examined, indiarubber tubes are fixed to the openings E and D (Fig. 97), one of the tubes is introduced into the cavity, and the gas contained in the cavity sucked through the apparatus with the mouth.

The platinum spirals are mounted in such a way that they can easily be replaced; the wooden stoppers M and N which support them are provided with contacts which press against a spring placed at each extremity of the box. These contacts have the double function of establishing communication and keeping the pieces M and N in their place.

It will be seen that the apparatus is very portable, and can easily be entrusted to a workman who has to take observations in different parts of a mine.

Somzée's Methanometer.—Somzée has constructed a number of apparatus for indicating the presence of marsh gas in coal-mines, some of which do not require the help of electricity, and consequently do not come within the scope of this book. The most practical of his apparatus exhibited at the Paris Electrical Exhibition were the following:—

1. When a Davy lamp burns in an atmosphere containing a certain proportion of marsh gas, its flame is elongated, and at the same time acquires a much higher calorific power. A fixed point situated at a certain distance from the top of the flame will, therefore, when the atmosphere contains hydro-carbon, be raised to a much higher temperature, and this rise of temperature can be utilized to produce the closing of a circuit and to give an electric signal.

Fig. 99 shows a practical application of this principle. Externally the apparatus resembles an ordinary Davy lamp, but the socket contains, besides the lamp, a small Marié Davy battery and clockwork R. The current, after having traversed the clockwork, arrives on the one hand at the plate L, on the other at the screw G. Between the chimney C and the metallic wire gauze at A is an expansion apparatus formed of a flat zinc tube bent in the shape of a

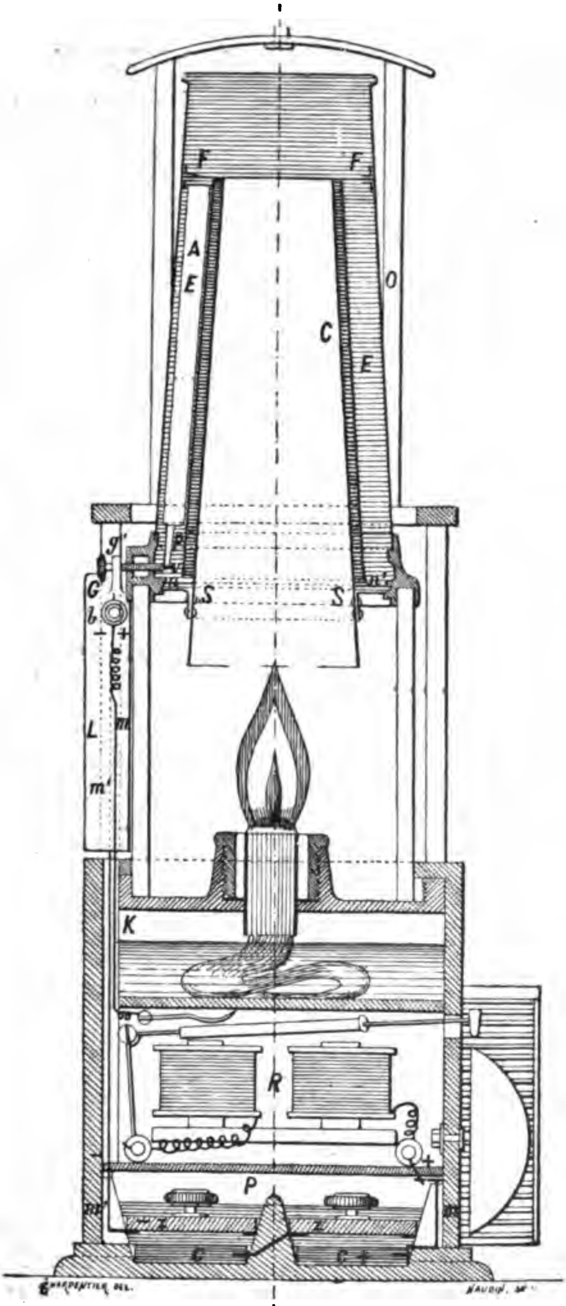


Fig. 99.—Somzée's apparatus (1) for indicating the presence of fire-damp in coal-mines.
(*From La Lumière Électrique.*)

reversed U. One of the branches of this U is filled with zinc filings, the other is empty. As long as the flame burns in a normal atmosphere, the heat produced does not sensibly affect this apparatus; but as soon as the air is charged with $\frac{1}{17}$ to $\frac{1}{16}$ of fire-damp, the flame is lengthened and fills the cylinder of the lamp. The expansion apparatus is then acted on, the empty tube expands more than the full one, and, as it cannot expand in length, it pushes the whole of the mass towards the contact point *p*, which closes the circuit of the clockwork. The signal is given, and as the mixture only becomes explosive for twice the quantity of marsh gas, there is plenty of time for ventilating and renewing the air of the mine.

Somzée employs various methods for protecting the expansion apparatus against the influence of the flame during normal combustion. In some cases calorific isolation is produced by surrounding the whole of the chimney with metallic wire gauze; in others by a glass cylinder also surrounding the chimney, which keeps the circuit of expansion in the dark, and prevents the heat-rays from passing through the glass.

2. Another kind of apparatus is founded on the different absorption of calorific rays by different gases. Two tubes T, T_1 (Fig. 100), closed at both ends by thick plates S, S′, and similar in other respects to those employed by Tyndall for his experiments, receive, by the aid of a mirror, the rays of the same source F. This source is nothing but an ordinary miner's lamp. One of the tubes T is full of normal air, the other T_1 is continually traversed by the air of the mine. The rays, after having traversed the two tubes, fall upon the two opposite faces of a Melloni thermopile P, in connection with a galvanometer G. As

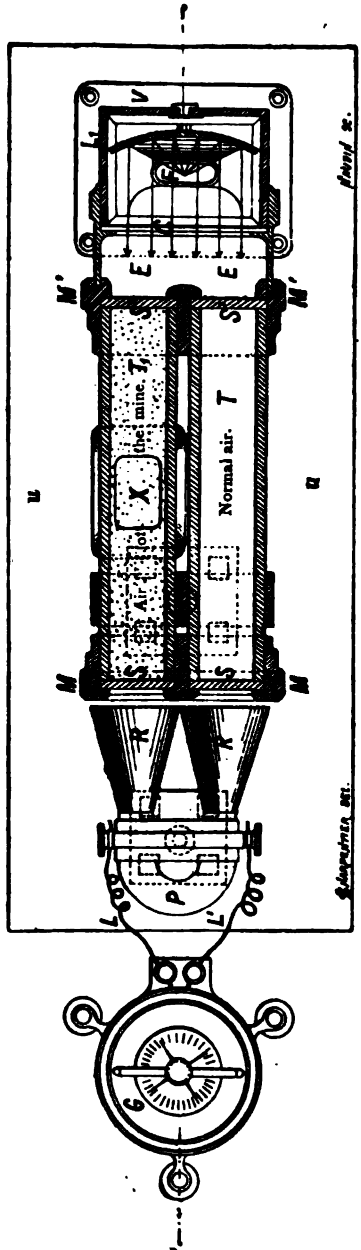


Fig. 100.—Somzée's apparatus (2) for indicating the presence of fire-damp in coal-mines.
(From La Lumière Électrique.)

long as the air is the same in both tubes, the galvanometer remains at zero, but as soon as the composition of the air in the two tubes is different, the tube containing the normal air allows the heat-rays to pass entirely, on account of the diathermancy of air for these rays, whilst the other tube, containing marsh gas, absorbs part of the heat-rays, and this absorption is proportionate to the quantity of explosive gas in the atmosphere. The result is a difference of temperature between the two faces of the pile, and consequently a deflection of the galvanometer, which indicates the quantity of fire-damp contained in the air.

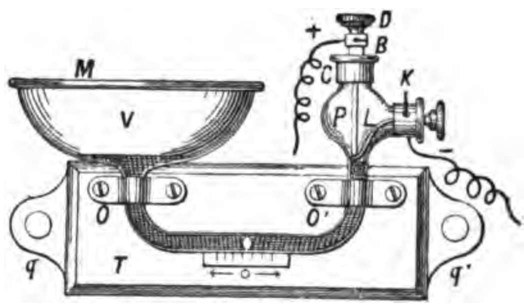


Fig. 101.—Somzée's apparatus (3) for indicating the presence of fire-damp in coal-mines.
(*From La Lumière Électrique.*)

This apparatus is very sensitive, but it is not portable. It can, however, be set up at a given point, and receive successively, by means of tubes, the air from different parts of the mine.

3. The third class of apparatus is based on the diffusion of gas through a porous medium. It is a well-known fact that the lighter a gas the greater its diffusive power. Marsh gas will therefore pass through a porous membrane much more quickly than atmospheric air. The apparatus represented in Fig. 101 is constructed on this principle. It consists of two vessels communicating by means of the tube

O O′. When the air contains a certain quantity of marsh gas, it penetrates through the porous plate M of the vessel V much more quickly than the air contained in the vessel can pass out; the pressure produced thereby in the vessel V acts upon the mercury contained in the tube of communication O O′. This mercury rises and establishes

Fig. 102.—Somzée's harmonica.
(*From La Lumière Electrique.*)

contact between the rod P and the spring L, and sets the bell ringing. A certain number of these apparatus can be placed in different parts of the mine, and ring either at a central station in the mine itself or at a station on the surface.

4. Another apparatus devised by Somzée, and called by him *harmonica*, is shown in Fig. 102. It is a flame burning in a glass cylinder; the draught is regulated in such a manner that in pure air the flame remains silent, but is transformed, under the influence of a certain proportion of marsh gas, into a singing flame. The flame, of course, is regulated so that the singing is produced before the mixture of marsh gas and air becomes dangerous.

Monnier's Automatic Methanometer.—Another very ingenious, but rather complicated, apparatus for indicating and determining the quantity of hydro-carbon in coal-mines has been constructed by Denis Monnier, Professor of Chemistry at the Geneva University.

It is based upon the oxidation of marsh gas (called *méthane* in French) by an excess of atmospheric air, under the agency of a high temperature produced by an induction spark or by red-hot platinum. This decomposition is represented by the following formula:—

$$CH_4 + O_4 = CO_2 + 2H_2O.$$

The carbon dioxide formed, unlike the water vapour, is not condensed, and acts on the level of the mercury in a manometer tube. The changes of level of the mercury produced by different quantities of carbon dioxide are electrically transmitted to a dial in the office of the engineer of the mine, and also ring an alarm-bell when the percentage of marsh gas in the mine threatens an explosion.

For the details of this interesting apparatus, we refer the reader to *La Lumière Électrique* of the 19th of October, 1881.

CHAPTER II.

FIRE ALARMS.

Bright's Street Fire-Alarm and District Telegraph.—This system was exhibited at the recent Paris Electrical Exhibition, and gained for its inventor the gold medal.

It differs from all other systems hitherto invented by the manner in which it indicates, at the receiving station, the station from whence the signal emanates. The method is purely electrical, and requires neither wheels, nor springs, nor any other intricate mechanism. The principal applications exhibited at Paris consisted of a street fire-alarm employed by the London Fire Brigade, and an automatic alarm for the protection of the interior of dwellings.

Let us first examine the general working of the system in its simplest form.

At the receiving station is a battery, one of whose poles is at earth, the other being connected to one end of each coil of a differential relay. This latter is constructed in such a manner that, as often as its needle is deflected, it closes a local circuit supplied by a few of Leclanché's elements. The free end of the wire of one of the relay coils is connected with a key, and through that key with the line; when the key is pressed down, the line circuit is interrupted. The free end of the wire of the other relay coil is connected with a rheostat of a resistance equal to that of the line wire, and also with a commutator, which, under ordinary circumstances—that is to say, when no signal is sent—is connected with the earth. In this way the differential relay is balanced by the current passing, on the one hand into the line, and on the other into the rheostat.

At those points of the line (pillar-posts or mural boxes, whence the signals are to emanate), handles are fixed with the inscription, "Pull." By pulling the handle, a small coil of definite resistance is brought into circuit. This increases the electrical resistance of the wire along the streets, which had been previously balanced by a corresponding resistance in a rheostat at the fire brigade station, and the needle of a galvanometer relay is deflected, until the commutator handle at the receiving station, on being turned, inserts an additional electrical resistance equivalent to that of the alarm-post whence the call has emanated. The locality of the post is shown on the dial of the commutator. In the interior of the pillar or of the mural box is a transmitter similar to those which are used in telegraphy, and the electro-magnet is formed by the resistance coil which has been mentioned, and which is called a localizer; this coil, of course, has a core of soft iron. In order to work this transmitter in answer to the person who has given the signal, the person in charge of the receiving station, as soon as he has ascertained from which station the call emanates, pushes the key which has been mentioned above; a rupture of the line circuit ensues, the armature of the electro-magnet is attracted, and the speaker acts.

In London, instead of a speaker, the armature carries a white disc moving over a red ground. As long as the

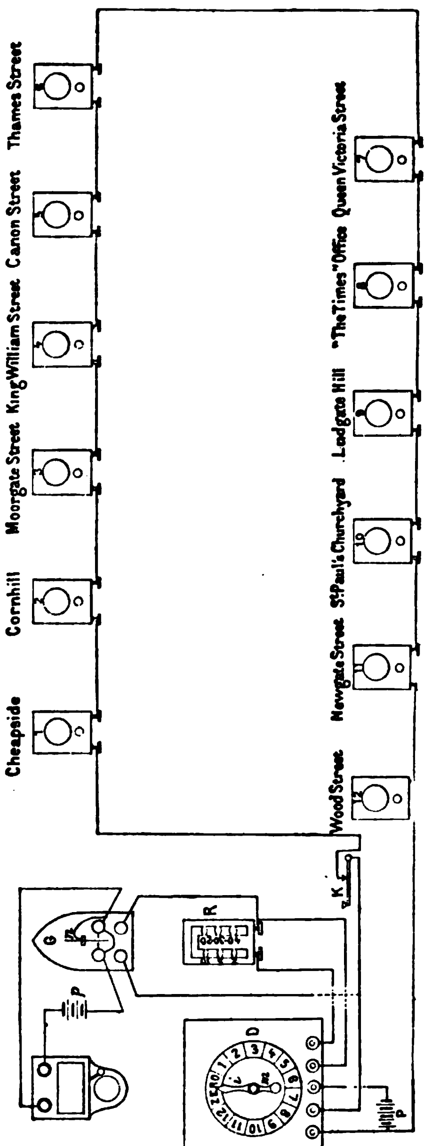


Fig. 103.—Diagram of the City stations of Bright's fire-alarm.
(*From La Lumière Électrique.*)

current passes, the white disc is withdrawn and shows the red ground; when the current is broken at the receiving station, the disc is detached and covers the red ground. In this way a simple signal can be sent, or, if the calling person understand the Morse alphabet, a few sentences may be sent by exercising longer or shorter pressures on the key. On his part, this person can answer by the aid of the handle at the station. Consequently, the same wire can be employed either for a simple call within reach of an inexperienced person, or as an ordinary telegraph. It is evident that the disc or the speaker, or even both, can be used for return signals; it is also clear that ordinary telegraphic or telephonic transmitters and receivers can, without any further modification, be added to the apparatus, in order to make it more complete and more perfect.

Another peculiarity of this system, besides the substitution of the disc for the speaker, and which is perhaps even more important, is an arrangement by means of which, instead of establishing an earth connection at each box, and only passing the current at the moment of call, the circuit remains constantly closed, and the current returns through a continuous line to the receiving station (Fig. 103). Under normal conditions, the current does not pass into the resistance coils, because it finds a shorter route; but by pulling the handle at one of the stations, the shunt is opened, and the current is obliged to pass through the coil placed at this point. This arrangement obviates the necessity of testing the apparatus or inspecting the line, for any defect announces itself by ringing the call-bell, which cannot, as in the case of a real call, be reduced to silence by turning the index of the commutator; it rings for every position of the index.

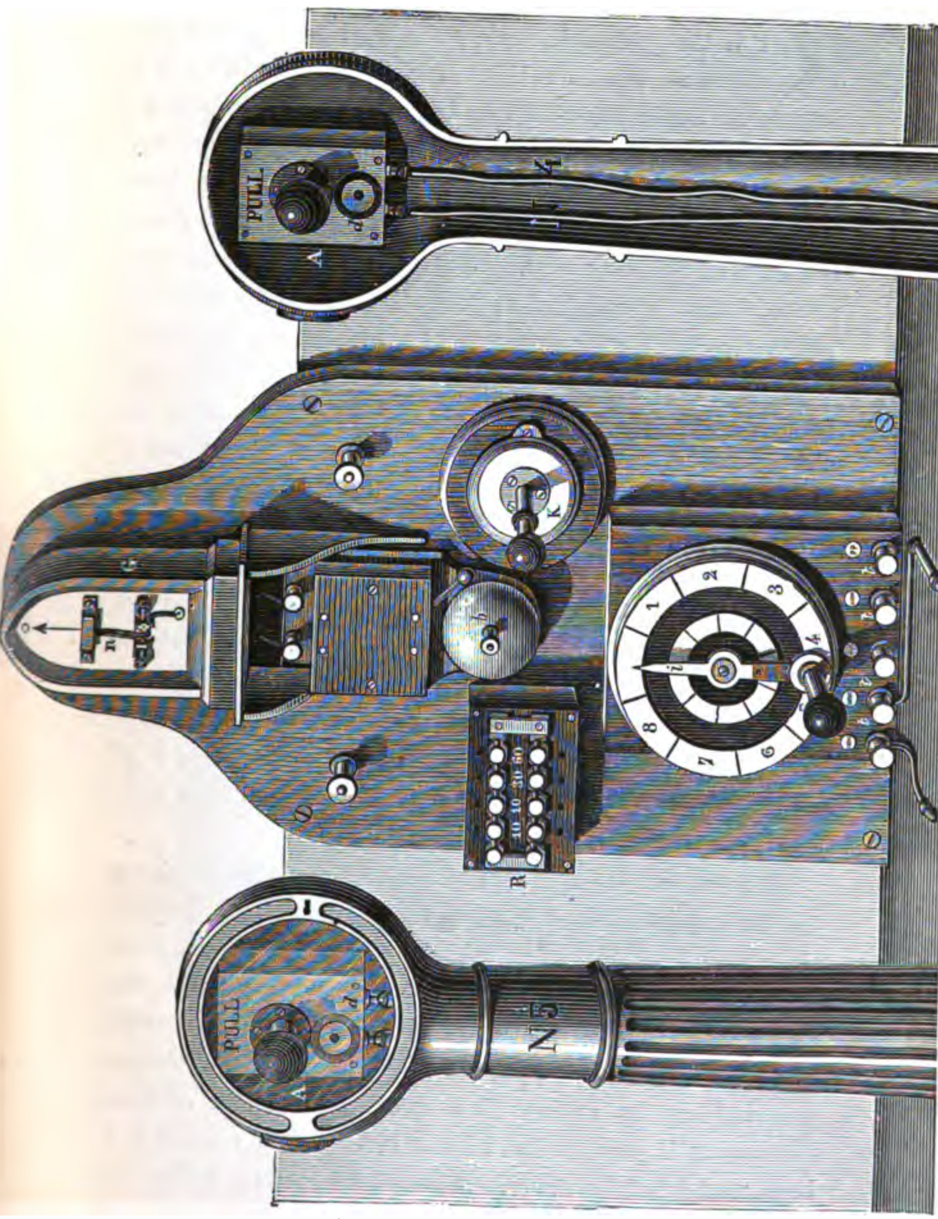


Fig. 104.—General view of the apparatus. Pillar-posts for call, and receiving station. (*From La Lumière Electrique.*)

Fig. 103 is a diagram of the circuit established in the City; P is the general battery, *p* the local battery, and the other letters correspond to those of Fig. 104. This latter is a view of the apparatus exhibited at the Palais de l'Industrie; G is the differential relay; *n* its needle which closes the local circuit and sets the call-bell *b* ringing on being deflected from one side to the other; K is the key for interrupting the current and transmitting signals to the call station, by the motions of the discs *d d;* R is the rheostat by means of which the circuit of the station is kept in balance with that of the line; D the dial of the commutator; *t, t, t, t,* are the terminals for connecting the apparatus of the station to the line of the battery. A A are call-boxes (Nos. 4 and 5 of the circuit) with their handles, and *d d* the discs mentioned above.

In the interior view of the call-box (Fig. 105), E E is the localizer, consisting of a resistance coil which forms an electro-magnet. A is the armature of this latter, which turns the disc, designated by K instead of *d;* L and L′ are the contact plates forming short circuit on the line,—they are separated when the handle is pulled. The wires F F′ and G G′ insert the coils into the circuit, and form connections at P and P′ with the line.

We pass now to the description of the automatic alarm for the interior of dwelling-houses and shops. Its description involves more general principles but less details than that of the foregoing apparatus. The principle of the apparatus is the combination of the preceding method with an improved bimetallic thermostat, adjustable for different temperatures by means of a screw. A section of this thermostat is represented in Fig. 106. When contact has been established by the expansion of the metallic spring, at the temperature for which it has been adjusted, the current passes into a localizer, exactly as in the case where the handle of the call-box is pulled. In this case, however, no

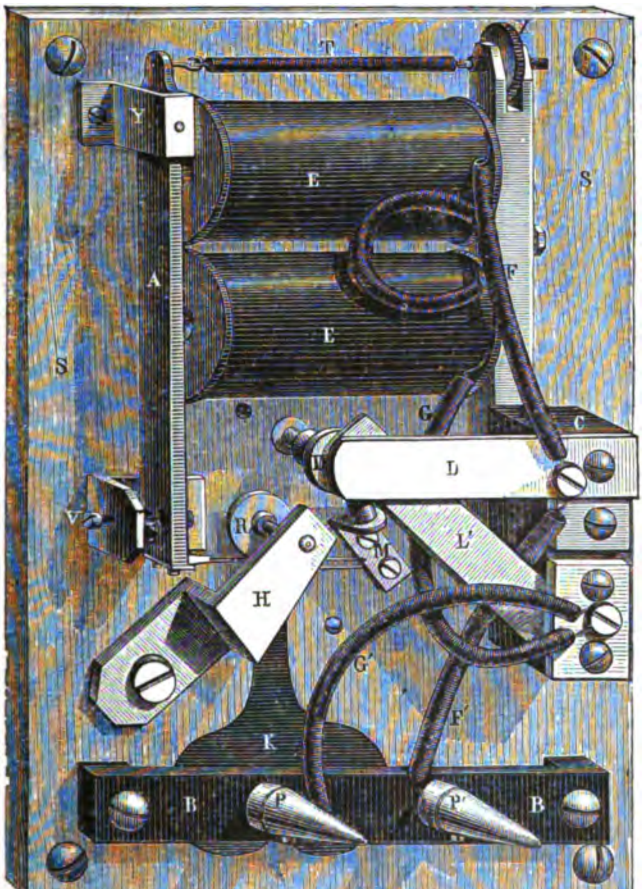


Fig. 105.—Interior view of a call-box.
(*From La Lumière Électrique.*)

answer is required from the receiving station, and the resistance coil has no longer the form of an electro-magnet, neither is it enclosed in a metal box, but simply in a wooden box, so as to be placed in a recess of the wall, close to the thermostat. This latter and the conducting wire attached to it can be enclosed in the wall or fixed at the top of it, and will last as long as the building itself. In houses where electric bells are already established, their wires can be used for the fire-alarm.

The same localizer can, however, as will easily be understood, be introduced into the circuit, either by a thermostat or by a handle, as the case may require. When the receiving apparatus is at some private office, and not at a fire brigade station, it is advisable to set up a telephone and a handle at the spot where the thermostat is placed. In that case, if a fire breaks out during the night, or when nobody is there to extinguish it, a warning signal is immediately transmitted to the office, and the signal can be transmitted to the nearest fire brigade station; at ordinary times the handle and the telephone can be used for business communications. The relay at the office can be arranged in such a manner that the alarm-bell rings at the same time at the office and at the fire brigade station, whilst during the day-time, the communication with the fire brigade station being broken, it only acts at the office, and serves for ordinary telephonic communications.

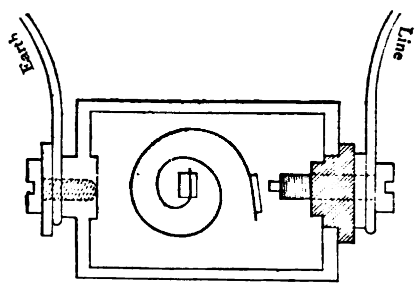


Fig. 106.—Thermostat for automatic fire-alarms in dwelling-houses and shops. (*From La Lumière Électrique.*)

Mr. Bright has invented some combinations which make it possible to distinguish between two calls made simultaneously at two different points of the same circuit, and also for an automatic movement of the index of the commutator. But these combinations have not yet been adopted in practice. Captain Shaw, of the Metropolitan Fire Brigade, prefers an apparatus where the operator is obliged to turn the index himself, to make sure of his attention. In fact, he considers two calls made at two minutes' interval such a rare occurrence that he thinks it useless to provide for this case. On the other hand, it is very easy, by the aid of existing arrangements, to distinguish between two calls made at less than two minutes' interval.

A police telephone and signal system, on the same principle as Bright's fire-alarm, has been introduced in several large American towns.

Bartelous' Automatic Fire-Alarm.—Bright's system, described in the preceding pages, consists of two distinct apparatus—an automatic apparatus for the interior of dwelling-houses, and an apparatus for communicating with a fire brigade station. Now, supposing that both these classes were generally established in a town, the call for help would comprise two distinct phases—an automatic warning of the inhabitants of a house, and a call at the station. Now, a certain time must necessarily elapse between these two operations, and, however short this interval may be, it is of the greatest importance to prevent the spread of a fire at the very outset. With this view, Bartelous has constructed his fire-alarm. It consists in directly uniting the automatic alarms at the station so that the alarm-bell is heard, not only in the threatened house, but also at the same time, and by the action of the same electric current, at the fire brigade station. This call is accompanied by signals produced by intermittent currents, which indicate the house in which the fire has broken out.

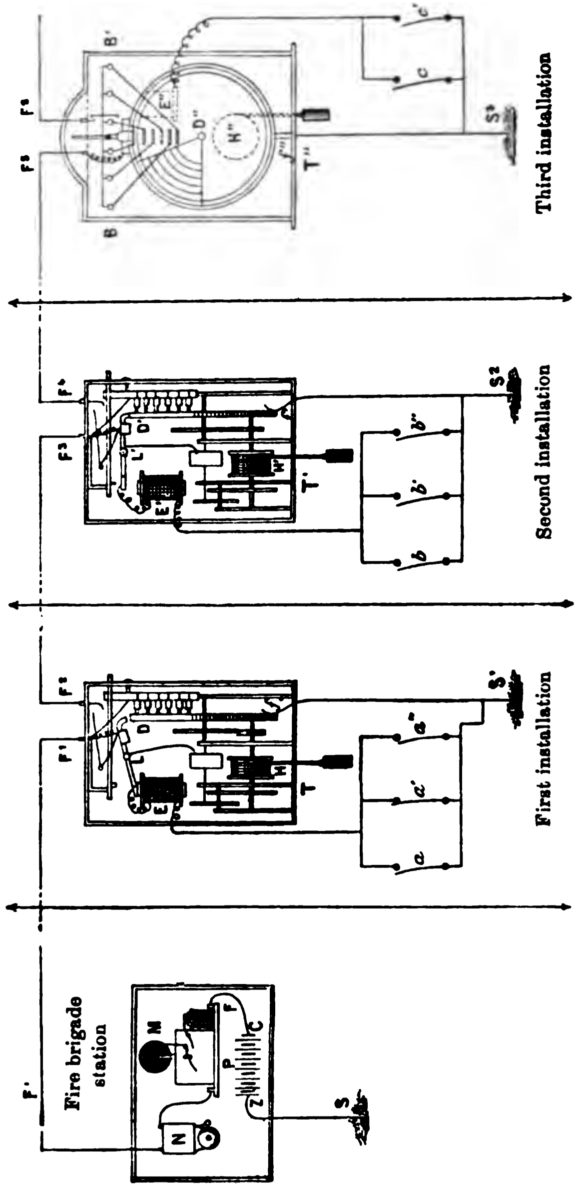


Fig. 107.—Bartelous' automatic fire-alarm.
(*From La Lumière Électrique.*)

Bartelous has altogether done away with local batteries, and works his automatic alarms with a central battery placed at the station. This central battery is represented at P in Fig. 107. One of its poles Z is connected to earth at S, the other C is in communication with the line wire F F^1, F^1 F^2, F^2 F^6, etc., which, in its turn, is connected, in the first instance, to a Morse apparatus M, with automatic release and a bell N, and further to certain pieces of all the transmitters T, T′, T″, etc., without having itself any earth connection. To the transmitter placed in a given house lead the wires which start from the fixed contact of the alarms installed in this house. The movable contact of these latter, whether a bi-metallic plate or any other mechanism, is in connection with earth at S^1, S^2, S^3, as is shown in Fig. 107, where the alarms of the first, second, and third installations are represented at *a*, *a′*, *a″*; *b*, *b′*, *b″*; *c*, *c′*. If one of these—for instance, alarm *a′*—is exposed to the action of heat, the electric circuit is immediately closed. The current then passes through the coils of the electro-magnet E placed in the transmitter T, and attracts its armature, which is mounted on a lever L. The other extremity of this lever, which oscillates round its axis, releases a disc D, which begins to turn under the action of a clockwork movement H. This disc, which is composed of alternate metallic and insulated parts, produces successive interruptions and closings of current, and their succession constitutes the signal received at the station.

The signals consist of dashes and points, as in the Morse alphabet, and they can be received by a telegraphic apparatus of this system or even by a simple bell. The dashes and the points inscribed by the Morse apparatus or the sounds of the bell constitute an easy system of numbering. By giving to the dashes the value of 5, and to the points the value of unit, a large number of receivers can be classified. If they are grouped in twelve series of thirty numbers each, 360 different and distinct indications can be inscribed on discs of fifteen centimetres, reserving at the same time one-fourth of their circumference for a call signal and for the conventional signals which will be mentioned presently. In practice this result need not be attained, and the signal can be repeated twice, if required, by a rotation of the disc.

The special arrangements of each transmitter are combined to produce the following effects:—

1. As soon as a transmitter has been energized by an alarm, and has commenced to act, the current necessary for the production of signals becomes completely independent of the alarm by which it has been actuated, in consequence of the existence of a contact *f* (Fig. 107), in direct communication with earth.

2. During the action of a given transmitter, all the apparatus placed behind it on the same network are, for the time being, unable to act; and can, therefore, not interfere with the signals which are being actually transmitted.

3. When the disc has made a complete rotation, which does not take more than a minute, the whole of the remaining electric circuit is re-established, and the other apparatus can act in their turn; moreover, the transmitter which has just been in action, and the whole installation depending on it, are short-circuited.

4. An indicating needle shows if the apparatus has acted or if it is ready to act.

5. A special stud, which need only be pressed, indicates fires which break out outside the radius of action of the alarms.

The way in which the closing and interruption of current is effected is shown in Fig. 107, where the first installation represents a transmitter during the rotation ot the disc; the second and third installations show the transmitter in a state of rest. The two former give a side view, and the latter a front view, of the transmitter.

The apparatus is, moreover, arranged in such a manner as to transmit other signals, for instance, call for medical help or for the police, simply by pressing a stud.

To this effect, one part of the surface of the disc comprised between two radii (third installation, Fig. 107) is occupied by a metallic piece divided into six or more arcs of concentric circles; these are each composed of a succession of alternate metallic and insulated parts, arranged so as to constitute in each circle a distinct signal.

The disc presses against six contact-rollers, in communication with six call-studs placed alongside each other on the horizontal line B B′. According as the one or the other of these studs is pressed, one of the six contact-rollers is placed in circuit, and consequently the signals inscribed in the concentric circle which passes under this roller are transmitted. The uppermost roller, however, is always in circuit, and serves for the automatic transmission of the alarm-signal in case of a fire.. The only effect produced by the pressure of the fire-stud is, therefore, the rotation of the disc.

The system can also be employed with a closed current by effecting a slight alteration in the transmitters and arranging the alarms in a special way (Fig. 108). It will be seen that a, a', a''; b, b', b''; c, c', c'', have double contacts. When at rest the movable plate presses against the first contact; the action of heat has the immediate effect of

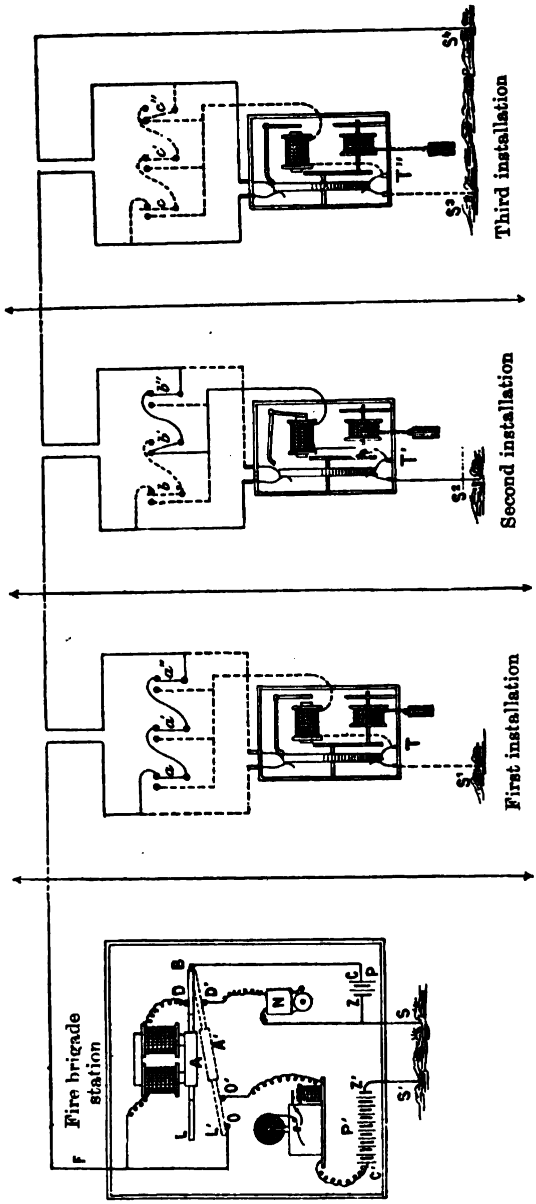


Fig. 108.—Bartelous' automatic fire-alarm.
(*From La Lumière Électrique.*)

breaking this communication, and immediately presses the plate against the second contact, as will be seen at *b'* and *c''*. All the alarms are in circuit, and the transmitters are out of circuit as long as they are not intended to act. The arrangement of the apparatus at rest is shown in the first installation of Fig. 108, where the circuit traversed by the continuous current is represented by full lines, and the shunts, not utilized at this moment, by dotted lines. If a wire breaks, or if some other accident happens to the apparatus, a simple rupture of current will ensue; if, on the contrary, a fire breaks out, the current, after a short interruption, will be immediately re-established by means of the second contact of the alarm, and will pass into a local shunt of the circuit. In this shunt is placed the transmitter T' corresponding to the alarm *b'* which has acted. This second contingency is shown in the second installation (Fig. 108), and the path of the current, as it is produced by the release of the disc and for the transmission of signal, is likewise represented by a full line in opposition to the dotted lines which represent its primitive circuit.

Finally, when a transmitter has acted, its disc is stopped shortly before it returns to its position of rest. Through this change of position, which modifies the conditions of passage of the current through the apparatus, the whole local installation connected with it is withdrawn from the continuous current, which follows its regular course through the remainder of the network. The path followed by the current in consequence of the action of an alarm *c''* and the corresponding transmitter T'', is shown in the third installation (Fig. 108), by the same arrangement of full and dotted lines for the two parts of the circuit.

It will be remarked that the transmitters of Fig. 108 are not represented in the same manner as in Fig. 107. The reason is that they show the arrangement of the apparatus when they are solely intended for the automatic transmission of fire-signals: in this case the necessary parts simply consist of an electro-magnet, a lever, and a disc. The closed current, however, is equally applicable to complete transmitters provided with call-studs: in this case the latter are placed in a closed box, and the opening of this box produces a rupture of the current, whilst a pressure of the stud effects the closing.

Fig. 108 also shows the modifications of the installations at the central station. The constant current can be produced by a very weak battery P, one of whose poles has an earth connection at S; the other pole C, before leading to the line wire F, first traverses an electro-magnet, whose armature it keeps in contact,—this armature is mounted on a lever B L, movable round the fixed point B. To this point B leads the conductor C, and the current of the battery passes through B D on to the electro-magnet. If the current happens to be broken, the armature A is no longer maintained, and the lever B A L assumes the position B A′ L′. By this change of position, the contact is broken at D and re-established at D′, and the current passes through C B D′ F and through a bell N. This bell, therefore, indicates any rupture of the current, which constantly passes through all the installations and goes to earth at the extremity of the network. But the same displacement of the lever also establishes, through piece L, a communication between two contacts O, O′. Point O is at the extremity of line wire F. From O′ starts a conductor which, traversing a Morse apparatus with automatic release, leads to pole C′ of a second battery, stronger than the first, whose other pole Z' is in connection with earth at S'. If, therefore, as we have shown above, an interruption of the current is the first result of the action of a fire on an alarm, the sequel of this action will re-establish this current through a transmitter, and the signals produced by this latter will be received by the Morse apparatus. The bell N will ring, until the attention of the man on duty is attracted; it is independent of the inscription of signals.

Instead of having a transmitter for each house, a single transmitter can be installed for a number of houses. In this case it consists of a series of discs placed alongside each other in the form of a cylinder. Each of these discs carries on its external circumference the contact-pieces intended to produce the signals which indicate the house corresponding to the disc. When a contact produced in some house or other brings about the release of the cylinder, this latter begins to rotate, and when it has performed an entire rotation, the disc whose signals have been transmitted is momentarily suppressed, and the apparatus is ready to transmit the calls of all the other houses with which it is in communication. As regards the signals for voluntary calls, they are produced by studs placed at one of the extremities of the cylinder, where a contact-roller, mounted on a traveller, receives the corresponding signal; this traveller automatically returns to its original position by the movement of the cylinder.

Dupré's Call-Stud for Fire-Alarms.—The great advantage of this system consists in the application of an automatic fire-alarm to the ordinary studs of an electric bell. For this purpose Dupré fastened on the lower contact-plate of the stud a small abutment piece provided with a piece of fusible alloy long enough to prevent, under normal conditions, the contact of the two springs of the interrupter. The bell-stud acts like an ordinary stud, until the piece of alloy fuses at a convenient temperature, generally about 37° C.; then the lower spring is released, rises, and is placed in continuous contact with the upper spring, and the bell rings continuously, thus preventing the place where the stud is from reaching a temperature of 37° C.

In Fig. 109, which shows an ordinary stud arranged after this principle, A represents the upper spring; B the lower plate, which is bent in form of a V to form a spring,

Fig. 109.—Dupré's call-stud.

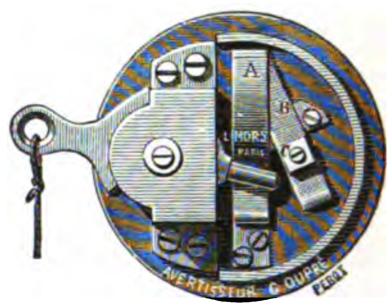


Fig. 110.—Dupré's bell-stud.

(*From La Lumière Électrique.*)

and which, when left to itself, would place itself in contact with A. The piece of fusible alloy is at C, and is fastened to the spring by a screw which traverses the plate B.

In Fig. 110, which shows a bell-stud controlled by a bell-pull, the arrangement is similar. The lower spring is at B, the piece of fusible alloy at C, and the upper spring A, bent in form of an S, is subjected to the effects of traction exercised on the bell-pull by means of a finger which is placed in the hollow of the spring. When the string is pulled, the finger rubs against the convex part of the spring, presses it against the lower spring, and, contact being produced, the corresponding bell rings. On the contrary, when the bell-pull remains fixed, and the fusible alloy disappears, the spring B comes into continuous contact with the spring A, and prevents any sudden rise of temperature.

This system is so simple that M. Mors, the constructor of the apparatus, has not even been obliged to raise the price of his bell-studs, which, in this way, fulfil a double function.

CHAPTER III.

ELECTRIC WATER-GAUGES.

Most of these apparatus are nothing but simple indicators with pointing needles, which are arranged in such a way as to act either with one or with two wires, but which are all actuated by a float controlling a current-interrupter, after longer or shorter periods of displacement, varying from one to five centimetres.

The two systems most commonly in use are those of Kempe and Hipp.

Kempe's Water-Gauge.—This apparatus, represented in Fig. 110, is much used in this country. The axle which carries the pulley of the float, instead of acting directly on the commutator, as in some of the other systems, only fulfils this function through the intermediary of two wheels R and R′ of nearly equal diameter, gearing into one another, and of a disc *c*, which is set in motion by the upper wheel by means of a pinion. In this way the movements of the float are amplified, and it is the disc *c* which actuates both the inverter and the interrupter. This effect is produced by a sort of triangular piece A, oscillating slightly above its centre of gravity and placed in such a manner that one apex is at the top. To each of the two other angles is fastened a strong click connected by a spiral spring which presses against a pin fastened to the disc *c*. The upper part

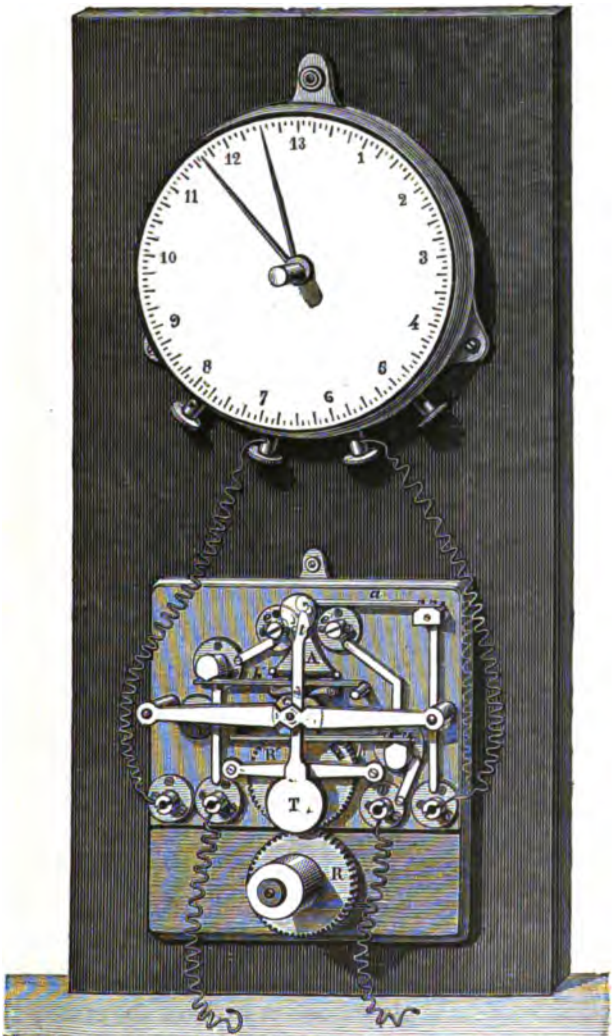


Fig. 111.—Kempe's electric water-gauge.
(*From La Lumière Électrique.*)

of the triangular piece has two contacts, which, in consequence of the inclination given to the piece in one or the other direction, meet two contact screws *e*, *e'* in connection with the positive and negative poles of the battery, and which can thus each constitute an inverter. A spring *a*, terminated by a roller which touches the apex of the triangular piece, presses the contacts against the screws of the inverter. On the other hand, an excentric fastened to the circumference of the disc produces, by acting on two horizontal springs *h* in connection with the line circuit and the inverter, the interruptions of current corresponding to the different variations of the water-level. The most interesting part, however, of this apparatus is a sort of turnstile T *t* fastened to the axis of the disc, which is composed of two arms of unequal weight, and which completes the action initiated by the movements of the float. As these movements are very much amplified, the least displacement acts on this turnstile, and when the heavier arm assumes a vertical position, it finds itself in a state of unstable equilibrium, which completes the movement and brings about the escapes of the inverter, and consequently a corresponding emission of current. In this way the current does not remain closed when the water-level corresponds to a position in which the circuit of the inverter is closed, and the slight oscillations of the float can have no effect upon the interrupter; in one word, the effect, once produced, cannot be altered again.

The receiver of this system employs only one ratchet-wheel, and the magnetized armature which acts on it through the intermediary of a forked brake is actuated by two electro-magnets placed one in front of the other; but, in order that the closing of the current in one direction should bring about a rotation of the wheel in the same direction, the armature in question had to be arranged in such a manner that it should assume, when at rest, an intermediate position between its two diametrically opposite positions, and this has been effected by means of cleverly contrived antagonistic springs. The ratchet-wheel itself and the clicks also show a particular arrangement. Thus the teeth of the ratchet-wheel, instead of being inclined in a certain direction, form regular angles, and the action of the clicks, arranged on a sort of hoop which surrounds the lower rim of the wheel, is ensured on the opposite side of the wheel by pins which afford additional safety. Finally, in order to narrow as much as possible the field of indications, the ratchet-wheel carries a pinion, which gears in with another wheel of a comparatively large diameter, whose axle carries the indicating needle.

Hipp's Water-Gauge.—In this system, the battery energizing the electro-magnets of the receiver is only active during the time strictly necessary for the transmission of indications. If, therefore, the water-level remains the same for a long time, the circuit remains open, and there is no waste of current power. Two wires connect the transmitter to the receiver—one for the indications corresponding to a fall, the other for those corresponding to a rise, of the water-level; the return current goes to earth or to the metallic conducting pipes of the reservoir.

Transmitter.—This apparatus is shown in side and front view in Figs. 112 and 113. According as the water-level rises or falls, float A, with the help of counter-weight B, causes a rotation of the drum *b* and its axis *c* in one or the other direction. A disc bolted on to axis *c*, carries four pins *f*, which can make contact with the extremity of spring *n*. Outside the frame of the apparatus is a lever *i* ending in a toothed sector which gears in with a pinion *k*.

This lever *i*, whose axis is at *v*, carries near its centre a tooth *g* of triangular form, which is met by a double arm *e* bolted on the axis *c* when this latter rotates in one or the other direction. Two strong springs, *x* and *x'*, acting through the intermediary of two levers with concentric

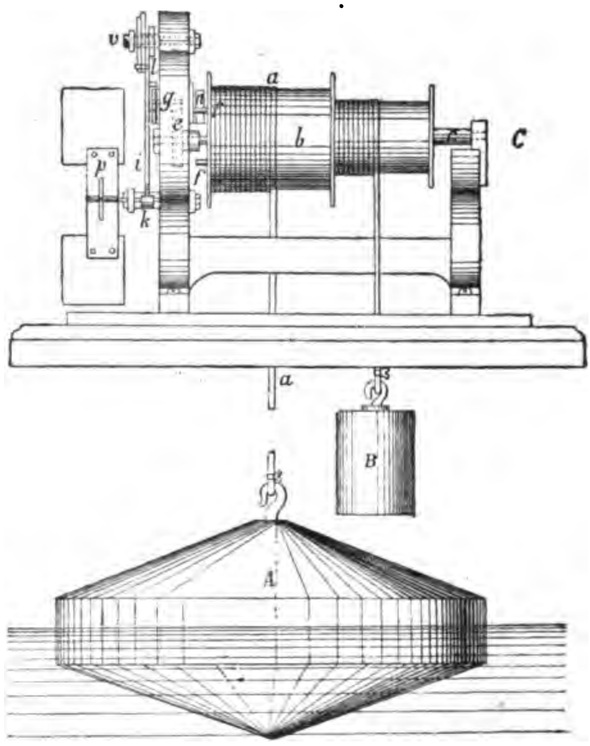


Fig. 112.—Hipp's water-gauge : transmitter (side view).
(*From La Lumière Électrique.*)

axes, and of a pin, maintain the lever *i*, and eventually bring it back to a vertical position. The lever *i*, finally, carries a pin *l*, which can make contact with the spring *m* or the spring *m'*, according as *i* is inclined to the left or the right. The relative position of the pins *f* and of the double arm *e* on the axis *c* is such that none of the pins *f* can touch the spring *n* as long as the pin *l*, participating in the slow ascending movement of the lever *i*, presses against either of the springs *m* and *m'*. On the other hand, at

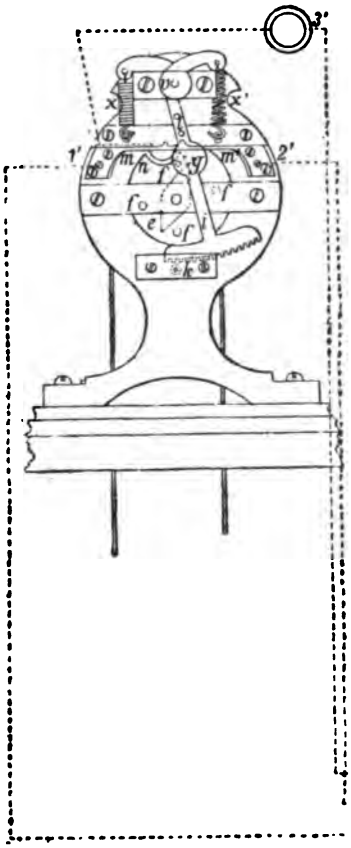


Fig. 113.—Hipp's water-gauge: transmitter (front view).
(*From La Lumière Électrique.*)

the moment of descent of lever *i*—a descent which is produced when the tooth *g* is released from the point of arm *e*—one of the pins *f* is in contact with *n* at the very moment when the pin *l* presses against one of the springs *m* and *m'*. Now, the interrupter *f n* is placed in the same circuit as one or the other of the interrupters *l m* or *l m'*, and *f n* and *l m* (respectively *l m'*) must therefore be closed *at the same time* for the current to pass. This simultaneous closing can only be produced during the fall of lever *i*, that is, during a period of time which is completely independent of the greater or lesser rapidity of variation of the water-level, and thus the problem is solved. The pulley *p*, mounted on the axis of the pinion gearing in with the toothed part of the lever *i*, regulates the rapidity of fall, and consequently the duration of contact. The spring *m* is connected to one of the wires leading to the receiver, and only acts under the variations of water in one sense; the spring *m'* is connected to the other wire, and transmits the indications corresponding to the variations in the other sense. The common interrupter *n* is connected to one of the poles of the battery, whose other pole leads to the return wire.

In Fig. 112, the diameter of the drum *b*, the number of pins *f*, and of points of the multiple arm *e* are such that a contact is produced for each variation of ten centimetres The details of the apparatus, of course, might be arranged in such a manner as to indicate variations of any height desired.

In his most recent apparatus, Hipp replaces the drum by a toothed wheel gearing in with a fall-chain, whose extremities carry, the one the float, the other its counterweight.

Receiver.—This may be simply an apparatus for indicating, or at the same time also for registering, different levels. Fig. 114 gives a front view of an apparatus of the latter kind.

The two wires coming from the transmitter are connected to the two horizontal electro-magnets *p* and *o*, which

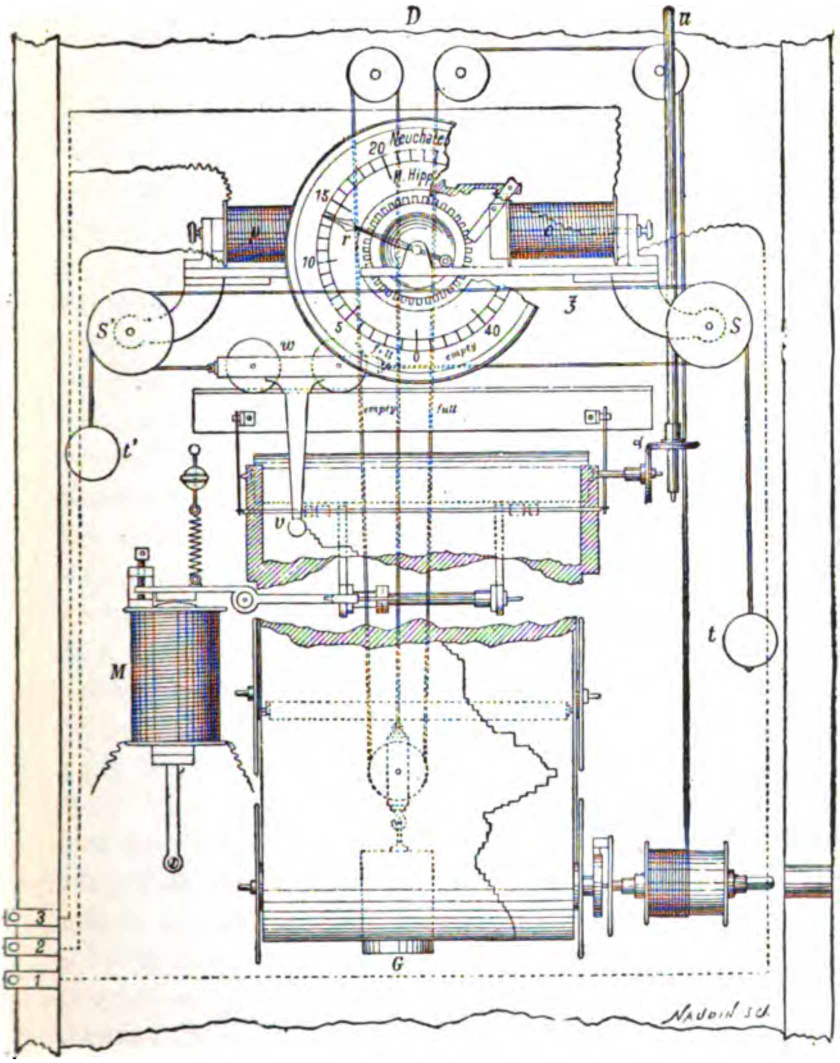


Fig. 114.—Hipp's water-gauge: receiver.
(From La Lumière Électrique.)

have a common wire connected to the return wire. Their armatures act, by means of propelling clicks, on a toothed wheel, to the axle of which is bolted the pointing needle *r*. According as the reservoir is emptied or filled, the needle turns in one sense or the other; indicating, on a graduated disc, the height of the water in decimetres or centimetres.

The axle of this same wheel carries a grooved wheel, on both sides of which passes a cord, whose extremities, after passing over the pulleys S and S′, are attached to a traveller *w*. This latter carries a stylus *v*, which can mark points on a strip of paper. These successive points form a curve, whose ordinates (perpendicular to the movement of the paper) give the height of the water-level, and whose abscissæ (parallel to the movement of the paper) give the time. The motor of the strip of endless paper is the weight G, and the rate at which it is unrolled is regulated by the conical wheels *a*, and the vertical axis *u*, in connection with the clockwork movement of a Hipp electric clock, placed above the indicator and not represented in Fig. 114. The electro-magnet M receives from the electric clock, every quarter of an hour, half-hour, or hour, currents which move the mechanism controlling the stylus *v*.

In his latest apparatus, Hipp has replaced the stylus *v* by a siphon tube which traces a continuous curve with red ink. The electro-magnet has been suppressed and replaced by a star-shaped wheel, controlled by the clock-train and marking on the edge of the paper dots and dashes, giving the time, and serving at the same time as a basis for measuring the ordinates of the curve indicating the level.

Hipp's gauge is extensively used, amongst other places, at Zurich, Geneva, Lausanne, Berlin, Ulm, Ratisbonne, Essen, etc., and is very much appreciated wherever it is used.

CHAPTER IV.

ELECTRIC APPLIANCES FOR NAVIGATION.

Kelway's Electric Log.—This log provides for the continuous registration on dials placed in the captain's cabin, chart-room, engine-room, etc., showing on each the distance run. In order that the condition of the log should be known, an arrangement is made to sound an electric bell every one-eighth of a knot. The position in which the log is placed is said to obviate many inaccuracies which arise in the use of other logs. In Fig. 115, A A shows the bottom of a vessel supposed to be going in the direction indicated by the arrow B. C is a sluice-valve bolted to the bottom of the vessel, shown open, and allowing the sea full access to the iron box D. This iron box D is bolted to the upper flange of the valve C, and is closed at its top by the metal plate E, which effectually prevents the ingress of water to the ship's hold. Through the stuffing-box F in plate E passes the metal rod G, the screw-thread on which raises or lowers the metal cage H. To the bottom of cage H is affixed the cylinder I, having its opening for the passage of water in a fore-and-aft direction, or in a line with the keel of the vessel. The passage of water through I causes the screw R to rotate with the spindle L. On the spindle L is an endless screw which revolves, by the intervention of a wheel, the vertical spindle M, which in its turn actuates a series of wheels in the box N. The last of these wheels (termed the "mile"-wheel) makes one revolution while the vessel passes through the water one nautical mile. On the spindle of this "mile"-wheel is affixed a second wheel having eight ratchet teeth, and these teeth, by moving a lever, cause an electric circuit to be completed—obviously eight times in the mile—the current passing through the electric cable O to the indicating dials and bells.

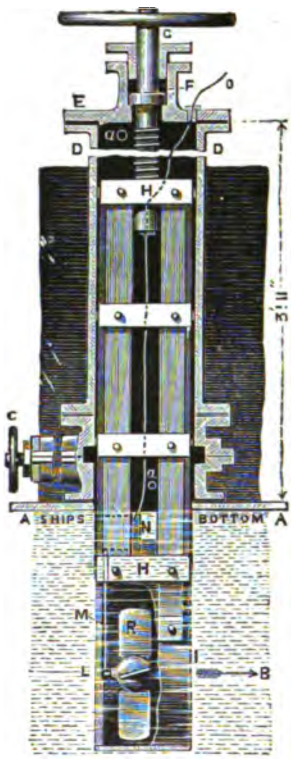


Fig. 115.—Kelway's electric log.

Fig. 116 shows the dial, which has eighty graduations on the outside circle, and, as the pointer in front of the dial jumps one graduation at each completion of the electric circuit, one revolution of the larger pointer represents ten miles. Ten revolutions of this pointer cause the small one to make one revolution—recording 100 miles. In fact, the mechanism of this improved form of log is similar to that used in the towing log, to which the inventor's electrical apparatus was affixed, and which was successfully tried on board several of her Majesty's ships.

Electricity as Motive Power for Vessels.—The first attempt to employ electricity as motive power for vessels dates back as far as 1838, when Professor Jacobi, of St. Petersburg, exhibited a boat on the Neva, the paddles of which were worked with an electric apparatus. The motor employed by him is represented in Fig. 117. It consisted of

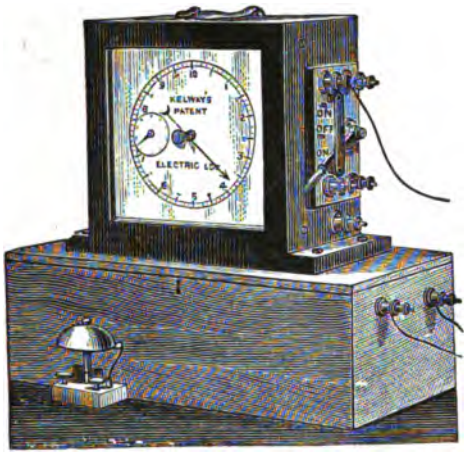


Fig. 116.—Dial of Kelway's electric log.

two circular rows of horse-shoe electro-magnets carried by two vertical supports. Between these two rows rotated, round

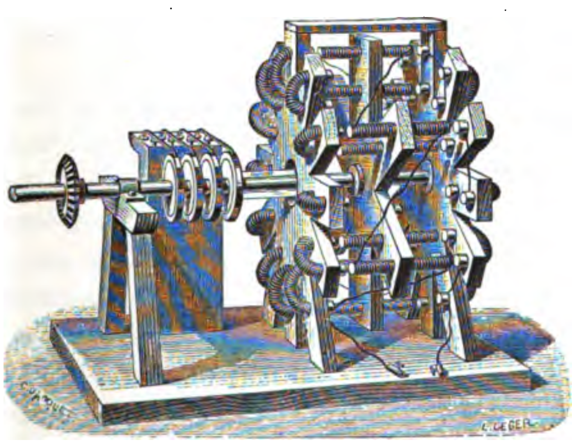


Fig. 117.—Jacobi's electric motor for vessels.
(*From La Lumière Électrique.*)

a horizontal axis, a sort of star with six arms carrying six pairs of straight electro-magnets. The axis carried a commutator formed of four wheels, which regulated the direction of the currents in the apparatus, so that when the straight bars happened to be between two consecutive poles of horse-shoe electro-magnets, they should always be attracted by one and repelled by the other—the change of direction taking place at the moment when the movable poles happened to be opposite the fixed poles.

The necessary current for actuating the motor had, in the first instance, been produced by 320 Daniell elements, and the speed attained had been 2·3 kilometres per hour. The following year this battery was replaced by 128 Grove elements, and the speed attained reached 4·17 kilometres per hour.

This experiment for which the Emperor Nicholas had supplied the necessary funds, amounting to 60,000 francs, excited at the time a good deal of curiosity. But the considerable quantity of noxious vapours which were given off by the battery compelled the inventor to discontinue his experiments.

During the Paris Electrical Exhibition, Trouvé exhibited an electric boat in the small basin surrounding the lighthouse. A double Trouvé motor, fixed to the upper part of the rudder, actuated, by means of an endless chain, a screw placed in the rudder itself. The current was supplied by two bichromate trough batteries, which could be employed either together or separately, and had a total weight of twenty-four kilogrammes. The boat was 5·5 metres long, and 1·2 metre wide; it weighed eighty-eight kilogrammes, and carried three persons. The speed of this little boat, when going against the current was 5·4 kilometres, and with the current, nine kilometres per hour.

The latest experiment was made on the Thames, in

September, last year, by the engineers of the Electrical Power Storage Company, in the presence of Professor Sylvanus Thompson.

The electric boat, which had received the name *Electricity*, was a small iron boat, 7·62 metres long by 1·52 metre wide. Two Siemens dynamos M, M′ (Fig. 118) were employed as motors; they were placed underneath the cabin, in the central part of the vessel. The driving belts of both machines acted on the same pulley P, which set in

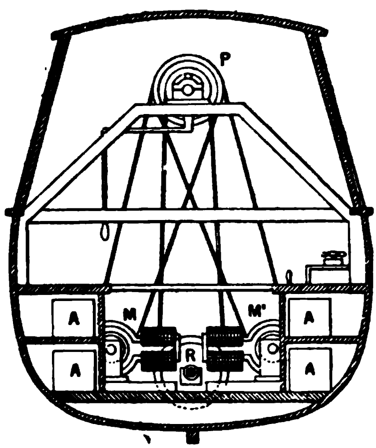


Fig. 118.—Electric motors on board the *Electricity*.
(*From La Lumière Électrique.*)

motion another pulley R, placed on the axis of the screw. This latter was constructed to make 350 revolutions per minute, whilst the Siemens dynamos made 950.

The current for the dynamos was supplied by forty-five Sellon-Volckmar accumulators A of forty plates and of 816·5 kilogrammes total weight. The total electro-motive force of the forty-five secondary batteries was ninety-six volts, and they were capable of supplying, during nine hours, a continuous current of more than thirty ampères, equivalent to four horse-power for six hours.

The apparatus was completed by a commutator for varying the number of accumulators; a simple arrangement permitted the exclusion of either motor. Finally, the motors were arranged in such a manner that the direction of their rotation could be reversed. To this effect, each of them carried two pairs of brushes, and, by the aid of a simple lever, the proper pair of brushes giving the desired sense of rotation were pressed against the collector. Every facility was given, in this way, for stopping and backing the vessel. The person who was stationed in the cabin for working the commutators also attended to the helm. The steam-whistle was replaced by a powerful electric bell, likewise actuated by the accumulators.

The *Electricity* could accommodate twelve persons, but for the experiment made on the Thames between London Bridge and Millwall, four only were on board. The average speed attained was nine miles per hour with the current, and eight miles against. This speed, although far below that attained by steamboats, nevertheless shows the possibility of employing electricity as motive power for small craft. But here again, as in the case of electric light, we may say that practical results in this direction depend upon the construction of better and less expensive storage batteries.

King's Electric Rudder.—This apparatus, which was invented by W. F. King, of Edinburgh, has been tried on one of the steamers running between London and Glasgow. Its object is to dispense with the helmsman and to work the rudder by the compass itself. The dial of the compass carries a metallic index, which is at first set in the direction of the course of the vessel. On each side of this index, at a distance of one degree, is a metallic wedge connected to a single Daniell element, and when the vessel deviates only by one degree from its course on either side, the index touches one of the two wedges. This results in the production of a positive or negative current, acting, in one sense or the other, on an hydraulic apparatus, which sets the rudder in motion. Provided the apparatus acts favourably in rough weather, it would constitute a most important improvement.

CHAPTER V.

ELECTRICAL APPLIANCES FOR METEOROLOGICAL OBSERVATIONS.

Van Rysselberghe's Meteorograph.—We may safely say that meteorology has only lately risen to the rank of a science, since accurate and coherent observations have been made by competent men. These observations of the thermometer, barometer, rainfall, direction and velocity of the wind, etc., easy as they may appear, require the greatest perseverance and accuracy. It is, therefore, of the utmost importance to substitute the inflexible regularity of a mechanical apparatus for the variable and fallible readings taken by an observer, and registering thermometers, barometers, and anemometers have been in use for a considerable time, and have contributed in no small degree to the progress of meteorology.

It was again the Paris Electrical Exhibition which showed the important services electricity can render in this particular branch of science, and amongst the instruments exhibited Van Rysselberghe's meteorograph deservedly occupies the first place.

Six observations have generally to be made to establish a basis for the forecast of weather. These are: (1) the height of the barometer; (2) the temperature on an ordinary thermometer; (3) the temperature on a wet-and-dry bulb thermometer, for determining the degree of moisture in the atmosphere; (4) the direction of the wind; (5) the velocity of the wind; (6) the quantity of rainfall. These readings have to be taken at stated and short intervals, say every ten minutes, and keep several observers employed at the meteorological station. The meteorograph replaces them all, and acts exactly like them. Every ten minutes it enters upon action, and notes successively the readings of the six instruments on the same sheet; this operation lasts one minute and a half, and recommences at every ten minutes' interval. This result is obtained by Van Rysselberghe in the following way:—

Two distinct instruments are employed for the purpose —a registering apparatus shown in Fig. 119, and a measuring apparatus represented in Fig. 120.

The Registering Apparatus.—It consists, in the first instance, of a vertical registering cylinder, coated with zinc-foil, and opposite this cylinder is the electro-magnetic system controlling the action of the tracing stylus. The electro-magnetic system is composed of an electro-magnet E, whose armature carries the stylus and is fastened to a movable screw nut on an endless screw, by means of which it can be lowered so as to point the stylus against different parts of the cylinder. The complete descent of this system is effected in a certain number of days, according to the length of the cylinder and the channel of the conducting screw, but at every ten minutes' interval it is slightly lowered, so that the tracings are regularly registered below one another. The registering cylinder is only set in motion after a release effected every ten minutes by a seconds clock, whose dials are shown at C and C′, and their movement only consists of one single complete revolution; it is effected slowly, so that the different tracings can be made successively, one after another, at the different points of

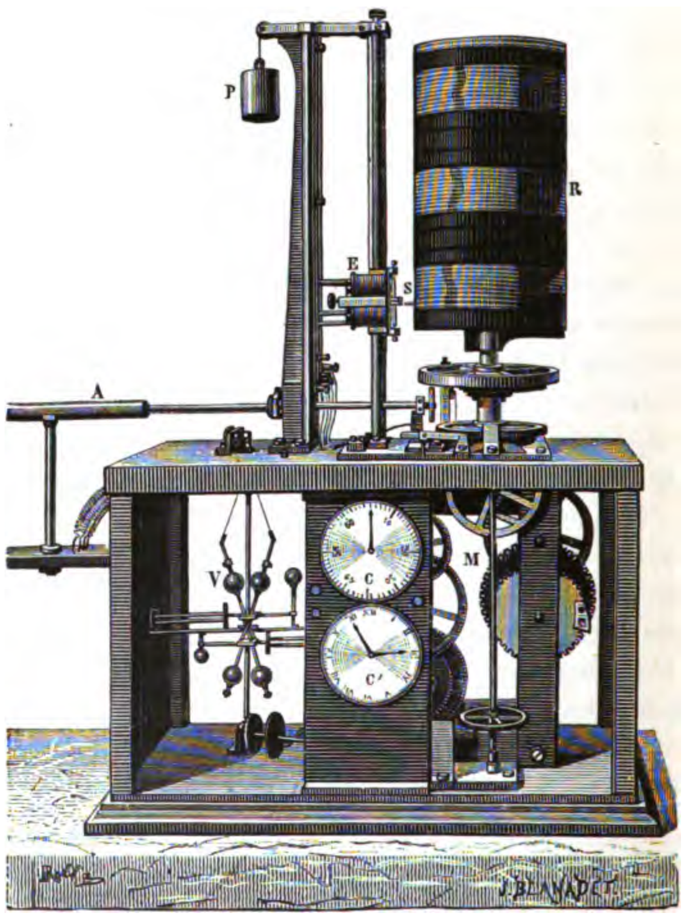


Fig. 119.—Van Rysselberghe's meteorograph (registering apparatus).
(*From La Lumière Électrique.*)

the circumference which present themselves successively before the tracing stylus. But the same mechanism which causes the rotation of the cylinder actuates, by a reciprocal movement and a rod A, the mechanism of the measuring instruments, causing them to perform, for each revolution of the cylinder R, two movements in an opposite direction, whereby they are brought back to the same starting-point, when once the reading has been taken. The stylus itself has a diamond point, and is, under ordinary conditions, held apart from the cylinder by an antagonistic spring, but approaches it and leaves a mark on the varnished zinc-foil of the cylinder when a current passes through the electro-magnet E.

We need not enter here upon a description of the mechanism which controls the movement of the cylinder and the tracing electro-magnet; an independent motor, ensuring the most perfect regularity of movement, and represented at V in Fig. 119, has been constructed for the purpose.

The registering apparatus, therefore, consists in its essential parts: (1) of a registering system R; (2) of a tracing system actuated by a clockwork movement M, under control of the regulator V; (3) of a seconds clock C C′ which releases every ten minutes the mechanism M; (4) of a transmission A which, by two successive movements of contrary direction, actuates the mechanisms of the measuring instruments. A counter-weight P brings back the tracing system to its starting-point when the descent is completely finished. We will now proceed to the description of the measuring instruments, and, for the sake of greater clearness, will suppose the axis of transmission of movement A to be continued to the system of toothed wheels, shown at the bottom of Fig. 119.

Measuring Instruments.—They are all enclosed in a large cupboard, as shown in Fig. 120, and set in action by the mechanism of the registering apparatus by means of axis A.

The barometer in this figure is at B B, and in the open part of the tube will be seen the platinum probe which touches the mercury. This probe is carried by the rackwork C″, which receives its movement every ten minutes from the axis A, through the intermediary of the wheels R″ and R′.

As in siphon barometers the oscillations of the mercurial column, read off on the shorter limb, take place in an inverse sense to the variations of pressure, the mercury rising when the pressure diminishes, and, as this might give rise to confusion and errors, the electrical arrangements have been made in such a way that, at the moment of each observation, the current is closed on the registering apparatus by a relay electro-magnet, whose armature establishes contact with the stud against which it rests, and produces interruptions of the current at the moment when the electro-magnet becomes active. Under these conditions, when the probe carried by the rackwork C″ touches the mercury of the barometer, the tracing stylus ceases to act, and this interruption continues until the rackwork, having attained the extremity of its course, begins its retrogressive movement; then a commutator adapted to the motor mechanism short-circuitsthe electro-magnet of the relay and the contact itself, so that during the retrogressive movement no tracing is made on the cylinder. In this way the tracings produced on the registering cylinder present themselves as the ordinates of the barometric curve, without any spark being produced on the surface of the mercury.

The thermometers are at T and T′; they are bent at their lower end, and traverse the back of the cupboard and the wall to which the latter is fastened, so as to expose their

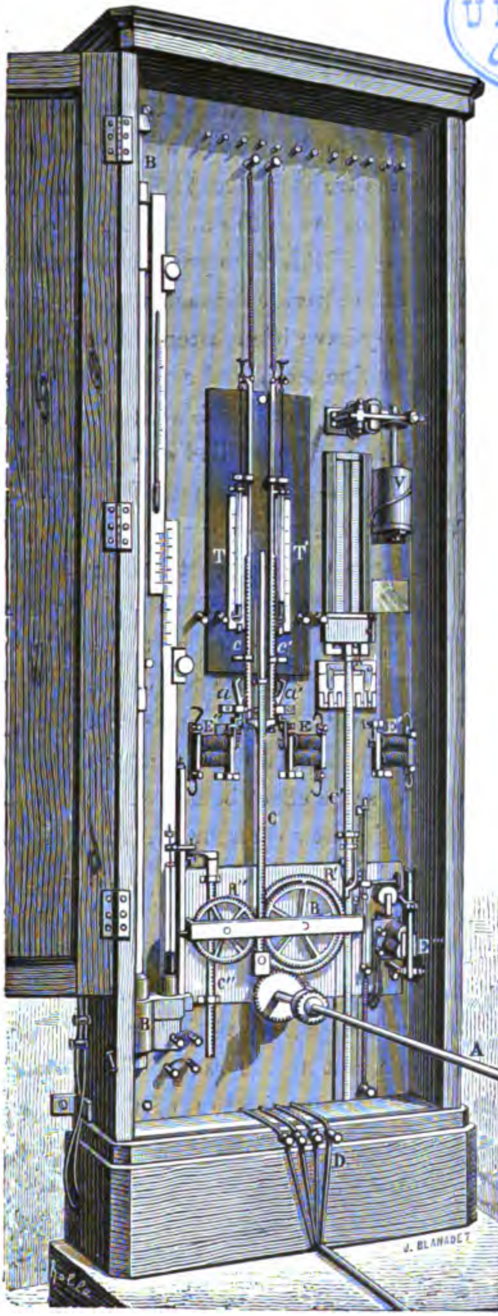


Fig. 120.—Van Rysselberghe's meteorograph (measuring instruments).
(From La Lumière Électrique.)

bulbs to the open air. One of these thermometers being a wet-and-dry bulb thermometer, the other an ordinary one, the mercurial columns are at different heights, and it has only been possible to employ, as in the first system, one and the same rackwork C to guide the two probes, by arranging them in such a manner as to provide for each an independent stop. For this purpose they have been fastened to two small rackworks *c*, *c'* with very fine teeth, and carried by the rackwork C. At the moment of descent of this latter, *c* and *c'* can be stopped by two clicks *a*, *a'*, controlled by two electro-magnets E', E", which at the same time form a relay, as will be seen further on. When, therefore, every ten minutes, the rackwork C has raised the two probes to the necessary height for taking the readings, and then brings about their retrogressive movement, one of the probes touches the mercury of one of the thermometers before the other, and the sooner the higher the temperature; the current is hereby closed, acts on the corresponding clamping electro-magnets, arrests the system, and, the same effect being produced on the other probe, the heights of the two mercurial columns are indicated by the position of the two probes.

To register these heights, the tracing stylus must now be set in action, and this result is obtained on the return of the rackwork C to the starting-point, that is to say, to the highest point of its course; for at that moment the electro-magnets E', E", by arresting the rackworks *c*, *c'*, have acted as relays. But as the combination of these relays is such that the local current is closed for the clamping of the wet-and-dry bulb thermometer, whilst it is open for the clamping of the ordinary thermometer, the consequence will be that this current, being closed in the first instance, will produce on the registering apparatus tracings which will only be interrupted at the moment when the rackwork C will have raised the probe of the wet-and-dry bulb thermometer; and this interruption will last until, the second probe having, in its turn, left the ordinary thermometer, the local current is again closed by the corresponding electro-magnet E′; a new tracing is now produced, indicating by the space which separates it from the first tracing the difference of height of the two mercurial columns.

The whole of the tracings will, therefore, give, as it were, a white wave of different thickness, which will represent in its upper part the curve of the thermometrical variations, and in its lower part the same curve modified by the moisture contained in the air.

The udometer is a sort of trough balance, placed above an ordinary funnel-shaped rain-gauge, which alternately inclines one way or the other, as soon as ten grammes of water have fallen into the troughs (the dimensions of the funnel are calculated in such a manner that this weight exactly corresponds to a thickness of water of one millimetre). Each oscillation closes a circuit corresponding to an electro-magnet which is to be seen on the right of the upper part of the apparatus, and which actuates a ratchet-wheel controlling the rotation of a cylinder V. A prominent spiral piece is coiled round this cylinder, and a metallic rod, guided by the rackwork C′, makes contact with the spiral piece, and brings about a closing of the current, and this results in the tracing of a curve on the registering apparatus, which represents the variations of height of the rainfall.

The direction of the wind is given by a vane, which carries on its axis an interrupting finger which, by rubbing over eight sectors corresponding to the eight principal winds, closes one or the other of the eight circuits which connect these sectors with a rectilineal commutator, composed of eight contacts. This commutator is attached to the measuring apparatus by the side of the contact finger. According, therefore, to the direction of the wind, the current passes through a certain sector, a certain plate of the commutator, and actuates the tracing stylus at the moment when the finger, in its ascension, touches this plate. A tracing whose position indicates the nature of the wind is marked on the registering cylinder.

The velocity of the wind is, as in almost all the registering apparatus of this kind, determined by means of "Robinson's cups," that is to say, by the number of rotations performed by the fan during an interval of ten minutes. The fan at each revolution sends a current which acts on the electro-magnet E‴ of an indicator which, in its turn, actuates the registering apparatus. But in order to prevent the current from remaining accidentally closed during a period of calm, an arrangement, shown in Fig. 120, above the electro-magnet E‴, mechanically completes the contact after it has once commenced. This arrangement consists of a double wheel actuated by an endless screw; the electro-magnet E‴ moves the latter by means of a ratchet-wheel. This double wheel carries a small rackwork provided with a finger, which it raises more or less according to the number of times the current is closed, and when the rackwork C′ is raised at each observation, a contact-piece which it carries meets, sooner or later, the finger of the small rackwork, and produces the electrical contact which acts on the registering apparatus.

The following is the order which has been adopted for the registration of the different phenomena:—

1. At the outset, and without any intermediary indi-

cator, the current passes through the tracing electro-magnet, and the marking commences.

2. The probe of the ordinary thermometer touches the mercury; the tracing stylus ceases marking.

3. The probe of the wet-and-dry bulb thermometer touches the corresponding mercury; the tracing stylus recommences marking.

4. The current is interrupted by the motor mechanism at a fixed moment, independent of the measuring instruments.

5. It is reconstituted by the passage of the rubber over the helix of the udometer; then it ceases.

6. It is reconstituted by the passage over the indicator of the vane, interrupted by the piece or the pieces which give the direction of the wind.

7. A second time the current is conveyed by the motor to the tracing electro-magnet; it ceases when the probe of the barometer touches the mercury.

8. Lastly, the current is reconstituted at the moment of registration of the velocity of the wind, and then ceases finally; the motor is clamped and the whole system returns to rest until the next period of observation.

As the sheet which receives the tracings is of very smooth varnished zinc, and the tracing stylus of steel, the tracings form a complete engraving. The marks are deepened by immersing the sheet for a moment in a solution of perchloride of iron, and an indefinite number of copies can now be taken from it, either directly or by galvano-plastic. These copies serve for communicating the observations to other meteorological stations, and this brings us to an important property of the apparatus, which is to transmit its own indications. All that is required for this purpose is to place on a telegraph wire, at different stations, electro-magnets provided with tracing pins and similar cylinders. They will reproduce all the movements of the first armature, provided this latter, on approaching its electro-magnet or withdrawing from it, establishes or breaks the circuit after the manner of a small Morse key: this is a well-known method of telegraphic translation. In this way the same observing apparatus keeps any number of stations informed. Each receiving station, reciprocally, can be in communication, at the same time, with several observing stations, and, by giving an electro-magnet to each, can at the same time register on the same cylinder the observations of each of them. The arrangements for regulating the time are so precise that perfect synchronism is obtained without any special electrical contrivance.

The results obtained with such a system must evidently be most remarkable. They realize the ideal of exact observations in any desired number and with instantaneous registration. Van Rysselberghe's system is worked between Brussels and a number of stations on the coast. That its general introduction would be accompanied by the most important results cannot for a moment be doubted.

Eccard's Barometrograph.—This instrument, too, was shown at the Paris Electrical Exhibition. Its purpose is to register at an observatory or some meteorological station the readings of a barometer placed at a distance. It consists of two parts—a transmitter directly influenced by the variations of the barometer, and a registering apparatus electrically controlled by the movements of the transmitter so as to inscribe barometric variations.

The registering apparatus (Fig. 121) consists of two cylinders mounted between two metallic plates. On the upper plate are two clockwork movements actuated each by a weight, which is represented in the figure. The clock-train on the right serves exclusively for the rotation of the cylinders. It first of all directly actuates the cylinder on the right, and then transmits, by a system of multiplying wheels to the cylinder on the left, a movement fifteen times less rapid than the former. Now, as the first cylinder makes

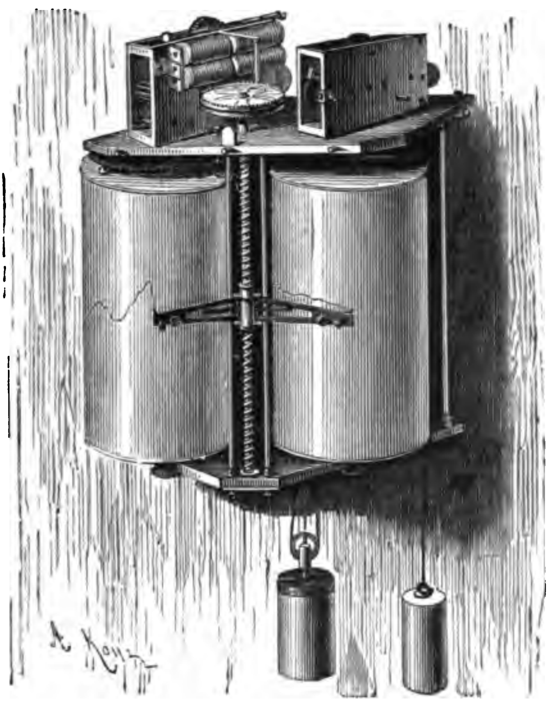


Fig. 121.—Eccard's barometrograph (registering apparatus). (*From La Lumière Électrique.*)

one revolution per day, the second makes one every fifteen days. The curves traced on the right-hand cylinder, therefore, represent diurnal variations, whilst that on the left-hand cylinder represents the half-monthly variations of the barometer. Between the two cylinders is a filleted rod, on which is screwed a collar carrying two pencil supports, and these latter are arranged in such a manner that they always press against the paper which covers the cylinders. The collar carries two lateral connections, which fit into two vertical supports forming slides, and therefore cannot turn, but can only move up or down. It will easily be understood that these vertical movements are produced by movements of rotation of the filleted rod, and are either ascending or descending movements, according to the direction of rotation of this rod. This rotation is produced by the clock-train with two toothed wheels on the left of the upper plate; the box which contains this mechanism carries outside two electro-magnets having the same armature. Supposing this armature to be attracted by one of the electro-magnets, it releases the clockwork movement, and causes the advance by one tooth of one of the two inverse toothed wheels which are carried by the filleted rod. If the armature is, on the contrary, attracted by the second electro-magnet, the release is produced in the part of the mechanism corresponding to the second toothed wheel, and the latter advances by one tooth, but in the opposite direction. The filleted rod turning at the same time as each of the toothed wheels, it will be seen that one of the electro-magnets, by the attraction of its armature, will cause the tracing pencil to rise, while the other will lower it.

The transmitter (Fig. 122) consists of a siphon barometer whose tube has an interior diameter of two centimetres. On the free surface of the mercury is a small iron float suspended to a wire which passes over a pulley and is attached to a winch by means of which the wire can be lengthened or shortened. The pulley is carried by the extremity of a lever, represented on the right of the figure, and when the float rises or descends, the action of the wire on the pulley causes a descent or a rise of the other extremity of the lever. This latter moves between two platinum contacts, and touches either the one or the other according to the direction of its movement.

The apparatus contains also two electro-magnets with

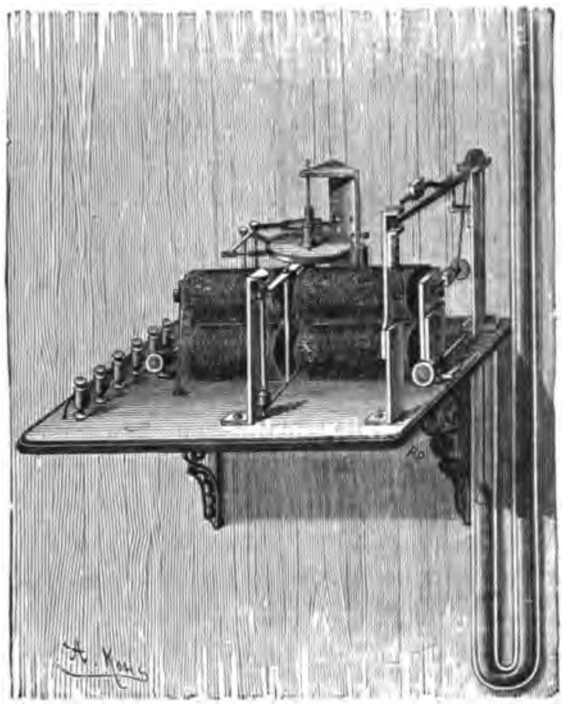


Fig. 122.—Eccard's barometrograph (transmitter).
(*From La Lumière Électrique.*)

a common armature. The movements of this armature causes the rotation, either to the right or the left, of a horizontal toothed wheel placed above. But this wheel is traversed by a filleted rod, so that, when the wheel rotates it raises or lowers this rod. This latter is in communication with the extremity of a lever placed behind the electro-magnets, whose other extremity carries the small winch for the adjustment of the wire. The movements of the toothed wheel consequently act, through the intermediary of the filleted rod, the lever, the winch, and the wire, on the pulley of the contact lever, and raise it or lower it as the case may be.

Let us now suppose that the float is lowered, which corresponds to a rise of the barometer; the lever will touch the upper contact, and will close a circuit comprising a battery, and that one of the electro-magnets of the registering apparatus which, by attracting its armature, raises the tracing pencils. But at the same time as the mechanism of the registering apparatus produces this effect, it establishes a contact which closes a second circuit. This circuit, mounted on a shunt of the same battery as the former, comprises one of the electro-magnets of the transmitter. This electro-magnet attracts its armature, and thereby causes the horizontal wheel to rotate in the required direction for raising the pulley of the contact lever and lowering the other extremity; the upper contact is broken, and, if the barometer continues to rise, the same movements are reproduced a certain number of times. If, on the contrary, the barometer falls, the mercury rises in the open limb of the tube, and the lever then touches the lower contact, thus establishing a circuit which comprises the other electro-magnet of the registering apparatus. This latter releases the movement of the second toothed wheel and lowers the tracing pencils; at the same time the clockwork movement establishes a contact which closes a second circuit, comprising the second electro-magnet of the transmitter. This latter attracts its armature, and causes the toothed wheel to rotate in such a direction that the contact lever is raised. If the fall continues, the same actions are again produced. In a state of rest, the lever of the transmitter is, therefore, always between the two contacts, and is always brought back to this position as soon as it acts in one direction or the other. Eccard's apparatus has been used in America for the last seven years, and has always given good results. It has the advantage of being simple, and will, no doubt, render important services in meteorology.

CHAPTER VI.

ELECTRO-SORTING.

As early as 1852, Chanot conceived the idea of utilizing the property of certain minerals and metallic oxides of becoming magnetic by their reduction, for the mechanical separation of these oxides from the impurities with which they occur mixed in nature. He recognized the important fact that metallurgical processes would be greatly simplified by the use of electro-magnetic apparatus, and constructed, in common with Froment, a machine of large size, which he called *electro-trieuse* ("electric sorter"), and which was conspicuous by the excellency of its construction and of its working.

Little attention, however, was at that time paid to electrical appliances, and Chanot's machines found no practical application. It was evidently the question of batteries which formed the obstacle, for when, twenty years later, Vavin constructed his magnetic sorter, in which he only employed powerful magnets, his machine was adopted for industrial purposes. Besides Vavin's machine, we have now also Edison's and Siemens' apparatus which deserve mention.

Vavin's apparatus only utilizes the magnetic action of some powerful magnets, and its description, therefore, hardly comes within our scope. For a description of it we refer our readers to *La Lumière Électrique*, 1881, No. 64.

Siemens' Electro-Sorter.—This machine, as remarkable for its simplicity as for its ingenious construction, is represented in section in Fig. 123. It consists of a cylinder inclined at an angle of 25°, set into rapid motion, and into which falls, from a hopper placed above it, the pulverized mineral which is to be sorted. The sorting is effected by means of a series of very thin circular electro-magnets, arranged alongside of each other in the interior of the cylinder throughout its whole length, and thus forming a sort of circular grating, each bar of which represents a magnetic pole. The coils wound on each of these electro-magnets have a very different number of spirals, which goes on increasing from the highest to the lowest part, so that the attracted magnetic particles do not encumber the outlet and adhere to the interior walls of the cylinder.

A sort of metallic trough, open at the top, is fastened inside the cylinder along its axis, and one side of this trough, by rubbing against the upper wall of the cylinder, performs the part of a sweeper. This trough contains an Archimedean screw, and ends in a cylindrical cavity, which surrounds the bearings on which the cylinder is pivoted; this cavity communicates, by means of a tube, with a box destined to receive the separated metallic particles. As the trough is fixed and the cylinder turns round it, the magnetic particles adhering to the cylinder are swept off from its upper part, and fall successively into the trough and into the reservoir destined to hold them; whilst the non-magnetic particles, on account of their weight, remain in the lower part of the cylinder, and graduallv fall out through the lower opening of the cylinder, into another box

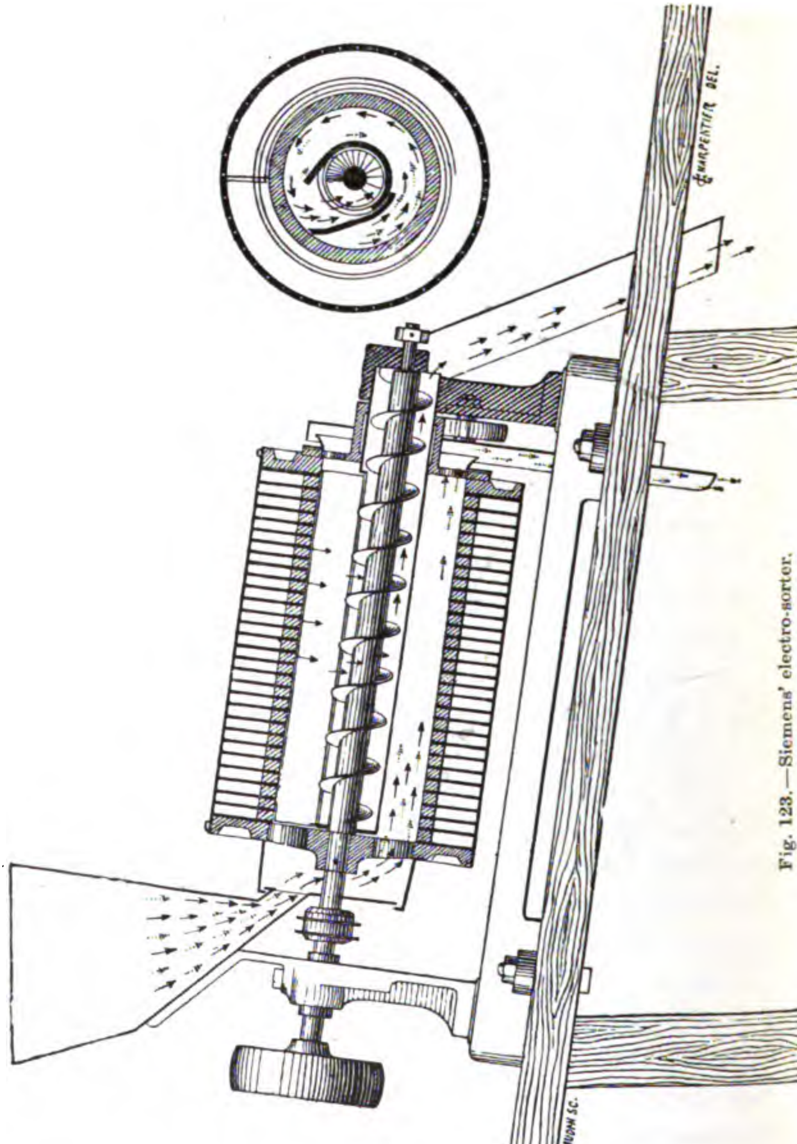


Fig. 123.—Siemens' electro-sorter.
(From La Lumière Électrique.)

arranged for the purpose. This apparatus can sort nearly twenty tons of pulverized mineral per day. It is very much used in Spain.

Edison's Electro-Sorter.—This apparatus, to which Edi-

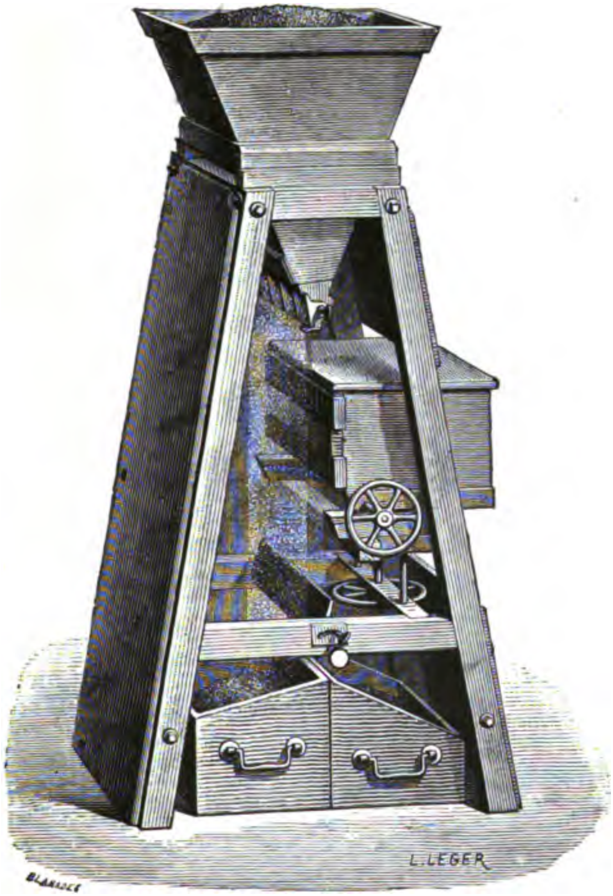


Fig. 124.—Edison's electro-sorter.
(*From La Lumière Électrique.*)

son has given the name of *magnetic separater,* is founded on a principle other than the preceding ones. The electro-magnets, instead of acting on the magnetic particles by contact, attract them from a distance, and under such conditions that the sorting is effected without effort. The mineral dust, which falls out of a hopper in the upper part of the apparatus, is acted on by the electro-magnet; the magnetic particles are, at the moment of their fall, drawn out of the vertical line, and thus separated from the gangue or other impurities.

In Fig. 124 the separating electro-magnet is enclosed in a box, which is shown in the lower part of the apparatus; its flat superposed limbs are flush with one side of the box where the pulverized mineral falls down. It will be seen that the apparatus is very simple. It is extensively used in America.

CHAPTER VII.

ELECTRO-METALLURGY.

The Electro-Metallurgy of Zinc.—Several attempts have lately been made to introduce electro-chemical methods into metallurgy. At the Paris Electrical Exhibition magnificent copper plates were shown, obtained by electrolysis on using the masses of copper to be refined as soluble electrodes in a bath of copper sulphate.

Similar attempts have been successfully made with zinc, with the object of extracting this metal from its ores. A special interest is attached to these experiments, because the metallurgical methods for the extraction of zinc from its ores are very expensive, and thus afford a favourable opening for the employment of electricity.

With the ordinary method, which consists in the reduction of zinc by carbon at a high temperature, the expenses amount to about £2 per ton of ore. To this has to be added a loss of one-sixth of the zinc contained in the ore, or about 16*s.* to 25*s.* per ton. The reduction of one ton of the ore, therefore, costs about £3, or 3*s.* per hundredweight, with an ore containing from forty to fifty per cent. of the metal. Besides, if the ore comes from Greece, Sardinia, or Spain, the freight amounts to another 25*s.* per ton. With the object of reducing the cost, the zinc of the ores has been transformed into a soluble salt, and subsequently reduced to the metallic state by electricity.

The two zinc ores used in practice are calamine or zinc carbonate, and blende or zinc sulphide; they are both insoluble, and must therefore be first of all transformed into soluble salts.

Both hydrochloric and nitric acids have been proposed as solvents, but the method lately indicated by Létrange seems to us the most practical, because it is the least expensive. Létrange transforms the insoluble blende into soluble sulphate by a very simple process, in which the sulphuric acid necessary for the formation of the sulphate is supplied by the ore itself.

It is well known that, by the roasting of sulphur ores, part of the sulphur forms a sulphate, whilst the remainder is given off in the form of sulphur dioxide. This latter can be converted into sulphuric acid in the usual way, and the sulphuric acid thus obtained can be used as solvent for the ore.

The ore, consisting of a mixture of blende and calamine, is roasted at a moderately high temperature, so as to obtain the largest possible quantity of zinc sulphate. The vapours of sulphur dioxide, converted into sulphuric acid, are used either for the solution of the calamine or of the roasted ore.

After the ore has been converted into sulphate, it is placed in large tanks and treated with water. The solution of zinc sulphate passes slowly into another series of tanks, where it is exposed to the action of the electric current. The liquid sulphate sinks slowly to the bottom of the tank, and the sulphuric acid, liberated at the positive electrode, gradually rises to the top, from whence it flows into another tank containing roasted ore or calamine.

A continuous reaction is thus established: the liquid current first passes through the dissolving tanks, where the acid dissolves the zinc contained in the ore to exhaustion, then passes into the precipitating tanks, where it deposits the zinc and changes back into acid, only to be employed again as a solvent.

The same liquid, however, cannot be used *ad infinitum*, because the ores contain oxides—lime, for instance—which do not part with their acids by electrolysis.

The electrodes employed in this method are not identical, the negative electrode consisting of a thin zinc plate, the positive electrode being formed of a leaden plate. On this latter the iron contained in the liquid is deposited in the form of oxide, which detaches itself and sinks to the bottom of the tank. As regards the lead, the silver, and the other metals insoluble in sulphuric acid, they remain in the residue, from which they can be extracted.

The electric current necessary for these operations is supplied by dynamo-electric machines; and Létrange uses, as much as possible, natural forces for driving them.

In this latter case the operations are reduced to placing the roasted ore in the dissolving tanks, removing the residue, and replacing the electrodes charged with zinc by fresh plates.

When a steam-motor is required, the quantity of coal used for the production of two hundredweight of zinc is the same as for one hundredweight with the ordinary method.

There is an enormous saving too in the original outlay, which for the ordinary method amounts to £40,000 for the production of 20,000 tons of zinc. The new process only requires, for the same production, from 200 to 300 horse-power, a corresponding number of dynamo-electric machines and a certain number of dissolving tanks. The outlay in this case would not exceed £20,000.

With the view of simplifying his process, Létrange causes the sulphurous acid directly to act upon the oxidized ore or the carbonate, without converting it into sulphuric acid; he thus obtains zinc sulphite instead of sulphate, but this salt is as readily decomposed by the current, and is, moreover, gradually converted into sulphate by the action of the air.

There can be no doubt whatever that this method has a great future.

Cobley's Method for Extraction of Copper from its Sulphides.—The cupric sulphate destined to form the electrolytical bath is obtained by the combined roasting of the sulphides and employment of André's method, which latter comprises: (1) the electrolytical extraction of the metals from their ores containing copper, cobalt, and nickel; (2) the employment between the electrodes of a frame filled with granulated metal, which precipitates one of the metals from the solution; (3) the use of rotatory conical positive electrodes in order to prevent polarization.

Blas and Miest's Method for Extracting Lead, Zinc, and Copper from their Sulphides.—These sulphides, when properly condensed, conduct the current, even when they are mixed with a large quantity of gangue. Besides, if a salt whose acid attacks these natural sulphides is electrolytically decomposed, employing these latter as positive electrodes, the metal of the sulphide is dissolved, whilst the sulphur is deposited on the anode.

Blas and Miest's method is founded on these properties of the sulphides, and simply consists of two operations: (1) the agglomeration of the metallic sulphides; (2) the electrolysis of a salt of the metal to be extracted, by employing as soluble electrode the agglomerated mineral.

In order to obtain thoroughly homogeneous and conducting electrodes, the mineral is formed into thick plates by the combined action of heat and pressure. The mineral is crushed so as to form grains of about five millimetres, is introduced into copper and steel moulds, and exposed to a pressure of about a hundred atmospheres; the moulds are then closed and heated in a furnace to about 600° C. The mineral is pressed again on leaving the furnace, and then rapidly cooled.

For electrolysis, the plates thus obtained are attached to iron bars connected by an iron conductor to the positive pole of a dynamo, and suspended in the bath. This bath is made with a neutral metallic salt: so for instance, for galena, lead nitrate; for blende, zinc sulphate, nitrate, or chloride, are used.

The cathodes are formed of metallic plates insoluble in the bath employed, and connected by iron conductors to the negative pole of the machine. The electrodes have a very large surface, and are as close together as possible.

Between the electrodes and the bottom of the vats a certain amount of space is left to receive the sulphur and the gangue which fall from the anodes.

The chemical action which occurs in this electrolysis is very simple. With lead, for instance, it is as follows:—

$$Pb2NO_3 = Pb + 2NO_3.$$
$$PbS + 2NO_3 = Pb2NO_3 + S.$$

Blas and Miest claim the following advantages for their method:—

1. The bath remains constant and neutral, and serves for an indefinite time apart from the losses inherent to the industrial manipulations.

2. The acid of the salt escapes the action of the current,

since it is only liberated from one compound to enter into another.

3. The sulphur is separated as such and can be easily extracted.

4. Generation of gas, the chief cause of polarization, is avoided.

It is stated, moreover, that a great economy is realized, not only over the common metallurgical processes, but also over other electrolytical methods. To establish a comparison with other electrolytical methods, the inventors compare the price of zinc manufactured by their method with that of zinc obtained by Létrange's process, for which they calculate the expenditure in the following way:—

The combination of metallic zinc with sulphuric acid—the sulphate of zinc remaining in aqueous solution—sets free 106,090 calories (thermal units) per equivalent (65·5) of zinc. Therefore, in order to decompose this sulphate by the galvanic current, this latter must perform work of at least 106,090 calories per equivalent of zinc precipitated on the cathodes, or 1620 calories per kilogramme (always supposing the acid to escape electrolysis, which is the most favourable case). The mechanical equivalent of heat being 424 kilogrammetres per calory (that is to say, that the work performed in raising 424 kilogrammes through one metre will raise one kilogramme of water through 1° C.), the work is 106,090 × 424 = 44,982,160 kilogrammetres, or for—

$$\text{One kilogramme of zinc} = \frac{44{,}982{,}160}{65{\cdot}5} = 686{,}750 \text{ kilogrammetres.}$$

One horse-power represents per hour: 75 × 60 × 60 = 270,000 kilogrammetres. To obtain one kilogramme of zinc per hour a theoretical force would be required of—

$$\frac{686{,}750}{270{,}000} = 2{\cdot}54 \text{ horse-powers.}$$

Now, a dynamo gives the maximum of available electricity in the external circuit when the interior resistance of the machine is equal to that of the circuit. In this case the efficiency is fifty per cent. On taking into account that part of the electrical energy is absorbed by the resistance of the conductors and of the bath, etc., and, on the other hand, that the work transformed into electricity is only eighty-five per cent. of the work applied to the dynamo, the efficiency will not exceed thirty per cent. *The available force of the motor will therefore be*—

$$2{\cdot}54 \times \frac{100}{30} = 8{\cdot}48 \text{ horse-powers}$$

for precipitating one kilogramme of zinc per hour.

The consumption of a good steam-engine being two kilogrammes of coal per horse-power per hour, Létrange's process will require, per kilogramme of zinc per hour—

$$8{\cdot}48 \times 2 = 17 \text{ kilogrammes of coal.}$$

This would give, for an ore containing forty-five per cent. of zinc, allowing for a loss of five per cent.—

$$427 \text{ kilogrammes} \times 17 = 7259 \text{ kilogrammes of coal}$$

per ton of ore.

For their process they calculate the expenditure as follows:—

The zinc sulphate is decomposed into metallic zinc which is deposited on the cathode, and into sulphuric acid which attacks the plate of the anode, dissolves it under formation of zinc sulphate and deposition of sulphur, as expressed by the equations—

(*a*) $ZnSO_4$ + galvanic current = $Zn + SO_4$; work absorbed: 106,090 calories.

(*b*) $ZnS + SO_4 = ZnSO_4 + S$; work produced: 106,090 − 41,880 calories.

The heat of formation of ZnS being 41,880 calories, the chemical work performed by the electricity is therefore 41,880 calories per molecule, or 637 calories per kilogramme of zinc (combining weight = 65·5); and this corresponds per kilogramme of zinc per hour (the efficiency being always thirty per cent.) to—

$$\frac{41{,}880 \times 427}{65{\cdot}5 \times 75 \times 60 \times 60} \times \frac{100}{30} = 30{\cdot}5 \text{ horse-powers.}$$

According to this, the motive force necessary for the treatment of a ton of ore yielding forty per cent. in twenty-four hours, would be—

$$\frac{3{\cdot}5 \times 400}{24} = 60 \text{ horse-powers.}$$

The consumption of coal would be—

$$60 \times 2 \times 24 = 2880 \text{ kilogrammes, or three tons,}$$

inclusive of the necessary fuel for manufacturing the plates.

But these calculations only give the necessary expenditure of coal for the production of the electric current; to this expense must be added in each case the cost of the previous treatment of the ore. Taking into account this cost, and also the fact that, by their process, Blas and Miest obtain a product of a certain value, namely sulphur, the following tables give a comparison between the final cost price of the metals by the different methods:—

PRODUCTION PER HOUR OF ONE KILOGRAMME OF METAL.

	Zinc.		Lead.	Copper.
	Method Létrange.	Method Blas-Miest.	Method Blas-Miest.	Method Blas-Miest.
Calories necessary	1620	637	92	287
Motive force, in horse-powers ..	8·48	3·50	0·50	1·50
Coal, in kilogrammes	17·00	7·00	1·00	3·00

TREATMENT OF ORES.

(Three tons in twenty-four hours.)

	Cost of treatment.		Difference.	Value of metal obtained.		Difference.	Value of sulphur obtained.		Advantages of the method Blas-Miest.
	Present metallurgical process.	Process Blas-Miest		Present method.	Method Blas-Miest		Present method.	Method Blas-Miest	
	frs.	frs.	frs.	frs.	frs.	frs.	frs.	frs.	frs.
Of zinc ..	40·00	46·00	− 6·00	156·60	165·60	+ 9·0	0	+ 18·0	21·0
Of lead ..	24·82	21·23	+ 3·59	270·72	277·92	+ 7·2	0	+ 12·0	22·8

These results would be very favourable if they were only confirmed by practice. We must, however, remark that if Blas and Miest have assured themselves, by laboratory experiments, that the principles on which their methods are based are correct, they do not state in their pamphlet that they have made any trial on a large scale, and it remains to be seen how their agglomerated plates will answer in practice.

Electricity applied to the Treatment of Gold Ores.—It is well known that gold is chiefly found in a free state embedded in quartz rock. To extract the metal the rock is pulverized, and then spread on inclined trays over which a continuous current of water is running. The trays are intersected by transverse vats containing mercury. When the pulverized material falls into these vats, the gold is taken up by the mercury and amalgamates with it. As soon as the mercury is sufficiently charged with gold, the two metals are separated by distillation, and the distilled mercury is used again. If the mineral were only composed of quartz and gold, the operation which has been described would present no difficulty; but most frequently the mineral contains sulphides of arsenic and other bodies, which soil the mercury of the troughs. When the surface is thus covered with impurities, the pulverized mineral can pass over the mercury without the gold being amalgamated. It is then necessary to distil the mercury, and this is a very great drawback, the more so as the least impurity—a few drops of oil, for instance, from a lubricator—is sufficient to render the surface of mercury inactive. Certain minerals which contain too many impurities are, from this cause, excluded from treatment. We may quote, for instance, a quartz containing 1·25 gramme of gold per ton, and from which no metal could be extracted.

Several chemical methods have been proposed to obviate this inconvenience, as, for instance, the treatment of the mercury with chlorine gas or with metallic sodium, but without much effect.

Mr. Richard Barker has succeeded, by an electrical process, in freeing the mercury from its impurities, and his method is based on the curious fact that, if the mercury is connected with the negative pole of a dynamo, and an electrode connected to the positive pole is immersed in running water, the impurities are attracted towards the latter, and the mercury is purified and recovers its activity. This process has been installed at Southwark for some time. Two iron bars in connection with the two poles of the battery run along the side of the wash-trays, and iron rods starting from the negative conductor plunge into all the mercury troughs. The positive conductor is in connection with a number of other bars which are placed across the tray above each of the troughs. From each of these bars start copper strips, twenty centimetres long by two and a half wide, which are stretched horizontally above the mercury at a distance of about six millimetres, and form above each trough a large comb immersed in running water. Above the combs are wooden rollers provided with rods passing between the teeth of the combs, and intended for stirring the surface of the mercury. The current of the machine passes thus from the combs to the mercury through the water, and the same transmission which sets the machine in motion also rotates the stirring rollers. As soon as the circuit is closed, the impurities are drawn towards the positive pole, and are collected in furrows arranged for the purpose, from which they can easily be removed. The mercury is thus left perfectly pure.

Copper-Plating of Iron and Steel.—Although this is not a new method (it was first employed ten years ago by Mr. F. Weil), it has lately acquired greater importance by the application of dynamo-electric machines instead of batteries.

In the baths employed by Mr. Weil, the alkaline cyanides, which are always dangerous and costly from the necessity of frequent renewal, have been replaced by organic acids and glycerine. The liquids require no renewal of organic substances, and act continuously, provided they are supplied with cupric oxide. Finally, the property possessed by the alkaline salts of organic acids—of discolouring the oxide of iron (rust)—renders the cleaning of the pieces perfect, for the bath itself effects this cleaning before depositing copper on the surface.

The copper-plating is done in three different ways, according to the local conditions, the dimensions and the various applications of the objects to be plated.

The first method consists in immersing the objects in the bath in contact with a zinc wire. The plating takes place immediately, and thus protects the metal against the action of the acid. According to the alkaline properties of the bath and the destination of the objects to be plated, it requires a time varying from a few minutes to several hours.

The second method, which has been employed with great success for the copper-plating of the candelabra of a large town, consists in placing porous vessels in the bath containing an organic double salt of an alkali and cupric oxide, and also the objects to be plated to average thickness. These porous vessels are filled with a solution of caustic soda, and contain zinc plates, which are connected by a stout copper wire with the objects to be plated. The caustic soda serves continuously, because, as soon as it is nearly saturated with oxide of zinc, it is treated with sodium sulphide, which forms again caustic soda and precipitates zinc sulphide, which can be sold advantageously. This copper-plating to average thickness, as suitable for candelabra, only requires a very short time.

The third method consists in plating the objects to any thickness required in the same sort of bath, by means of a dynamo. The bath, as already mentioned, only requires from time to time the addition of a certain quantity of cupric oxide. The nearly exhausted bath is titrated in the following way:—Ten centimetres of the bath are introduced in a white glass beaker; from thirty to forty centimetres of hydrochloric acid are added, and the mixture heated to boiling point; a titrated solution of protochloride of tin is then added until the yellow-brown liquid is completely discoloured. The quantity of the protochloride of tin employed exactly indicates the quantity of copper contained in the bath.

The bath consists of the copper salt of an organic acid, such as tartaric, citric, oxalic acid, or of neutral organic substances, such as glycerine and the alkaline salts of these acids with an excess of alkali.

Mr. Weil deposits other metals, such as nickel, cobalt, antimony, tin, etc., on iron and other metals, by a method analogous to copper-plating.

In another method, employed at Val-d'Osne, an acid solution, consisting of a double salt of an organic acid, with copper and an alkaline metal, is used for the bath.

CHAPTER VIII.

ELECTROLYTICAL METHODS APPLIED TO MANUFACTURING PROCESSES.

The Rectification of Alcohol by Electricity.—Naudin has successfully applied Gladstone and Tribe's zinc-copper couple, together with direct electrolysis, to the purification of alcohols; the process has been carried out on a large scale by M. Boulet, of Bapaume-les-Rouen, and has given most satisfactory results.

For certain alcohols the purification is completely effected by the zinc-copper couple; for others direct electrolysis is required in addition to the action of this couple. Naudin has combined the two methods, and his process may be divided into the following stages:—

1. Treatment of the distilled fermented liquor by the zinc-copper couple.

2. Electrolysis of the resulting liquor, with addition of acid, in a series of voltameters.

3. Neutralization of the liquid obtained by the second operation.

4. Rectification by the usual method.

The first stage of the process is effected in closed wooden or copper vats (Fig. 125), divided into a number of compartments by perforated wooden trays *a*, *a′*, *a″*, *a‴*, on which the zinc filings are placed. The zinc-copper couple is formed by the introduction of a solution of copper sulphate (five parts of the salt to a hundred parts of the solution) into

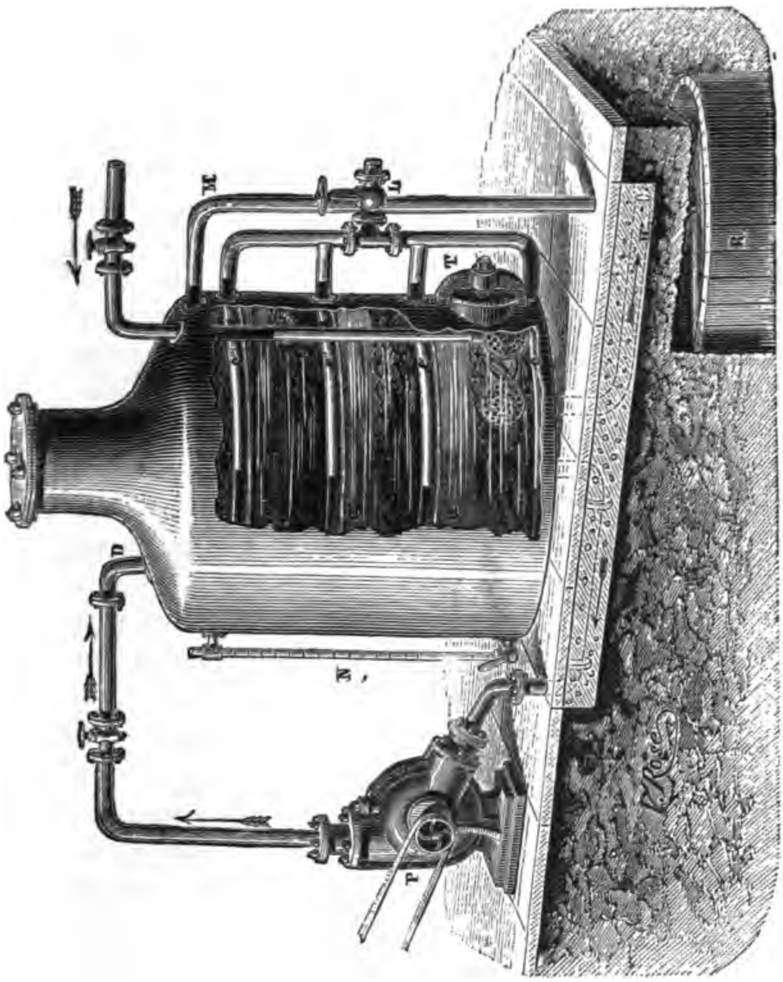


Fig. 125.—Copper vessel containing zinc-copper couples.
(*From La Lumière Électrique.*)

the vat. The discolouring of the liquid, which takes place at the end of about two hours, indicates the point at which the copper has been precipitated on the zinc; the solution containing zinc sulphate is now removed and replaced by the fermented liquor.

A spiral tube *c, c′, c″, c‴* surrounding the wooden trays allows the circulation of hot water through tap L. The fermented liquor enters the vat, in the direction of the arrows, through a tube on the right; as soon as the vat is full, the tap of the entrance tube is closed, and the tap of a tube D at the upper end of the vat, which is connected with a pump P, is opened. The liquid is kept in continual motion by the action of the pump, and thus brought into intimate contact with the hydrogen given off by the zinc-copper couple. During this time, the hydrogen generated by electrolysis and charged with alcoholic vapours keeps on bubbling through the tube M into the receiver R containing the unfermented liquor. The man-hole T allows the dismounting and cleaning of the battery when required. The tube N marks the level of the liquid in the vat.

After a certain time, the length of which depends on the greater or lesser purity of the fermented liquor, this latter is drawn from the vat through the discharge pipe H, is acidulated with one-thousandth of sulphuric acid, and introduced into the voltameters.

The voltameter (Fig. 126) is a long narrow glass cylinder A, with two tubulatures *t, t′* at the lower end; the upper end is hermetically closed by a strong glass plate held fast by a clip E. The tube B for the entrance of the liquor is closed at the top and perforated throughout its whole length; it is placed between two platinum plates serving as electrodes and connected to the dynamo. The current arrives through wires, which traverse the glass plate. The small holes through which these wires pass are stopped up with cork, thus fulfilling the function of safetyvalves in case one of the pipes should be accidentally stopped up during electrolysis.

The supply of liquor can be regulated by the tap R, and

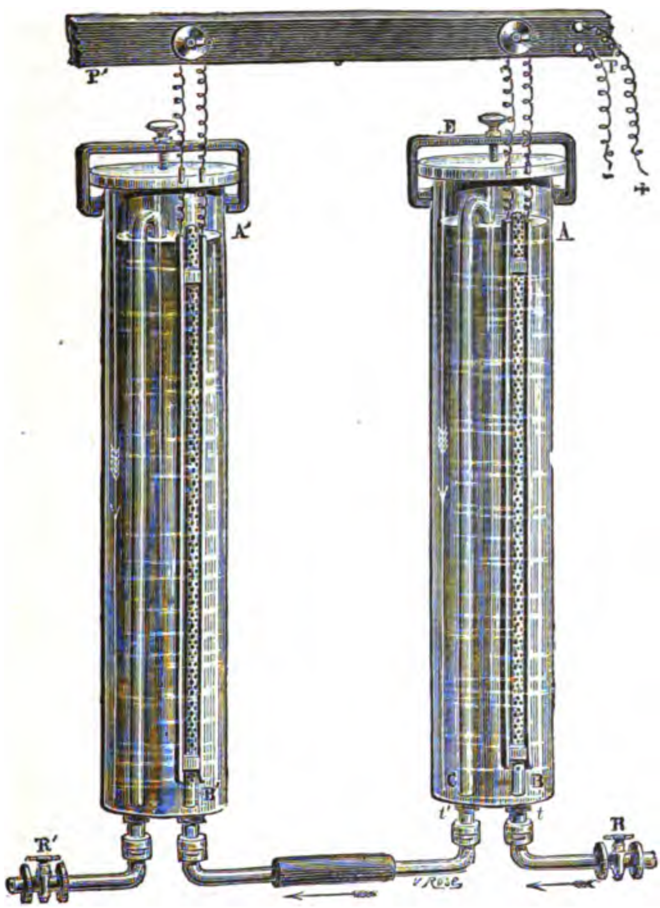


Fig. 126.—Voltameter for electrolytical treatment of alcohol.
(From La Lumière Électrique.)

the outflow by R'. The return pipe C, bent in form of a siphon, allows the gases to escape with the liquid current, and to bubble from one voltameter into the other.

Fig. 127 represents several of these voltameters arranged on the same supporting frame. The number of voltameters coupled for quantity naturally varies with the intensity of the action to be produced and the quantity of unfermented liquor to be treated. In practice, for a distillery treating 300 litres of unfermented liquor in twenty-four hours, twelve voltameters must be coupled for

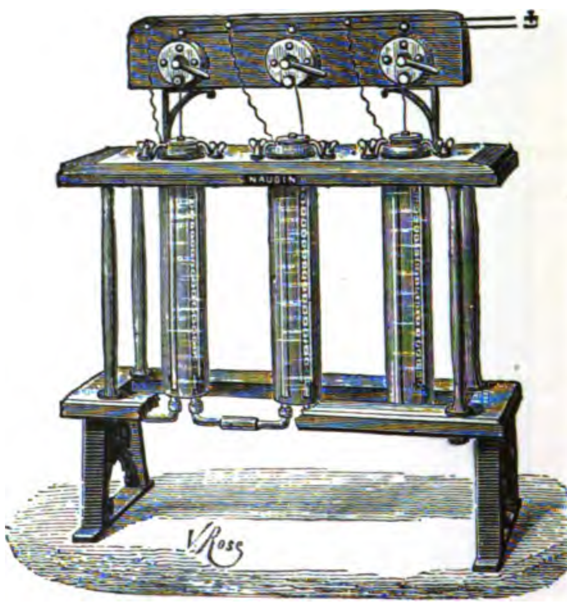


Fig. 127.—Supporting frame for voltameters with commutators.
(*From La Lumière Électrique.*)

quantity; the electrolytical action is then regulated, not by varying the intensity of the current, but by withdrawing from the circuit or adding to it a given number of voltameters by means of the commutator with which each of them is provided (Fig. 127). The liquor always passes into the battery of twelve voltameters, but is electrolyzed, at will, either in twelve vessels or in a smaller number. This electrolyzer is actuated by a dynamo. From the voltameters the liquor passes into troughs containing zinc or iron for the neutralization of the acid, and from thence into the ordinary rectifying still.

The most interesting practical result obtained by Naudin with his process is the manufacturing of pure alcohol from beet-root. It is well known that the alcohol hitherto obtained from beet-root is of very bad quality, and that it is next to impossible to purify it; Naudin's electrolytical rectification gave an alcohol of eighty per cent., and of a quality equal to that of alcohol prepared from grains.

Preparation of Aniline Colours by Electrolysis.—This method was discovered by Goppelsröder, who communicated it in 1875 to the Industrial Society of Mulhouse. At that time he had only prepared aniline black; since then he has succeeded in obtaining most of the other aniline colours by his electrolytical process. His general way of proceeding is to subject to electrolysis, water—if needs be, acidulated—containing in solution an organic substance or a mixture of organic substances, capable of producing a dye under the influence either of oxygen or of hydrogen. The colouring matter, therefore, is produced, sometimes at the positive, sometimes at the negative, and sometimes at both poles simultaneously.

The apparatus employed must, therefore, be arranged in such a manner as to avoid the mixture of the products formed at either pole, not only because these substances may both be useful, but also in order to avoid secondary reactions by diffusion.

The simplest arrangement which realizes all these conditions is also the one which has been adopted by most experimenters for the electrolytical preparation of different organic substances. It is represented in Fig. 128, and consists of an earthenware vessel, into which is placed a porous battery cell, both being filled with the liquid to be experimented on. A platinum plate L′, in communication with the negative pole of a battery, is immersed in the porous cell, and a second platinum plate L, of larger dimensions than the former, is immersed in the external vessel.

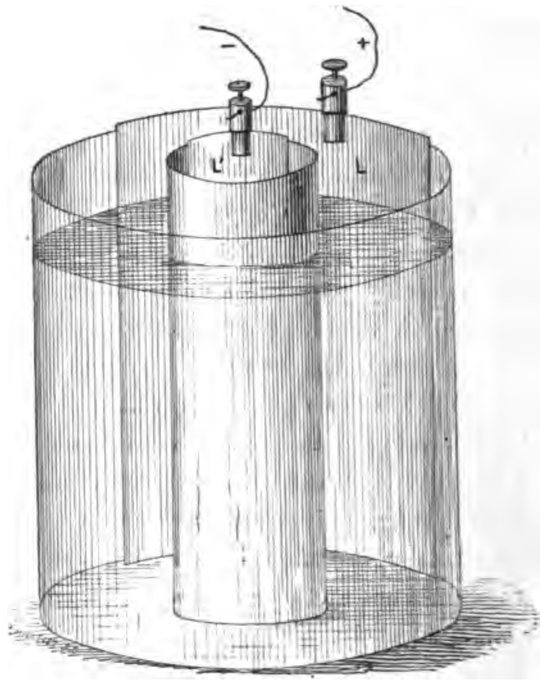


Fig. 128.—Earthenware vessel for electrolytical decomposition.
(*From La Lumière Électrique.*)

This latter is in communication with the positive pole, and on it the principal product is generally deposited.

In certain cases, in order to avoid still more completely the mixing of the compounds, the liquid is placed in two separate vessels, connected together by a cotton wick M or some other porous substance, covered with parchment paper where it issues from the liquid, in order to prevent evaporation (Fig. 129). L and L′ are the two electrodes, with their supports T and T′.

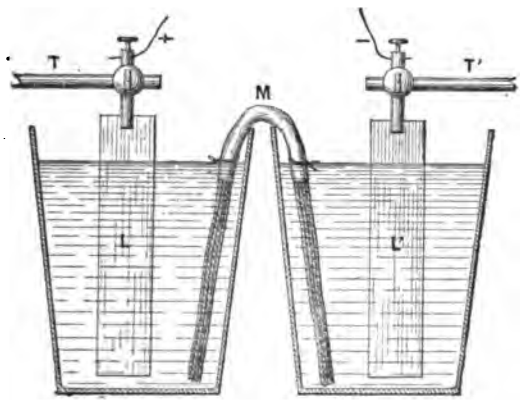


Fig. 129.—Vessels for electrolytical preparation of aniline colours. (*From La Lumière Électrique.*)

Another arrangement employed by Goppelsröder is shown in Fig. 130. Here the principal plate L is placed in

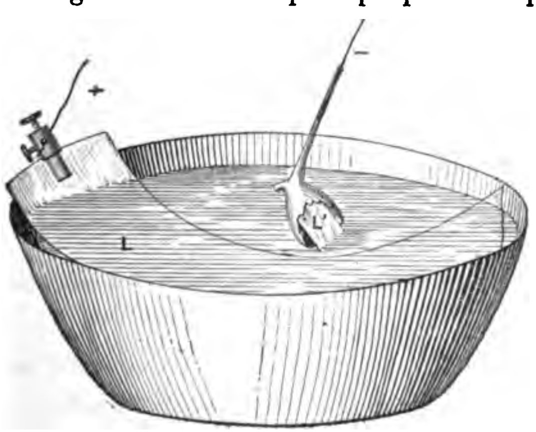


Fig. 130.—Porcelain dish for electrolytical preparation of aniline colours. (*From La Lumière Électrique.*)

a porcelain dish, and the other electrode L′ in the bowl of a pipe, through whose tube the wire passes. In this case, by fitting to the pipe an indiarubber tube through which the platinum wire passes, the gases generated on this electrode can be collected.

Another arrangement for collecting the gases is represented in Fig. 131. The wire corresponding to the principal electrode traverses the indiarubber stopper, and this latter carries a gas-conducting tube; the second electrode is

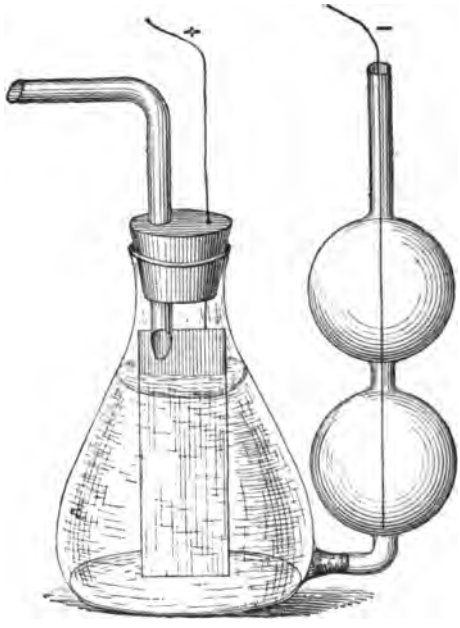


Fig. 131.—Flask for preparing aniline colours, with gas-collecting apparatus.
(*From La Lumière Électrique.*)

contained in the bulbs on the right of the figure, and these are separated from the principal vessel by a cotton plug.

Finally, when electrolysis has to be effected in a hot solution, a platinum crucible L′ is used as the principal electrode (Fig. 132). This crucible is placed on a sand-bath, and has two loops, to which are attached two wires coming from the same pole of the battery. The second plate L is immersed in the liquid of the crucible without touching this latter.

The electrodes employed are generally platinum plates, but they are sometimes replaced by carbon pencils. Thus, in an apparatus of larger dimensions, one of the electrodes is formed of a carbon pencil contained in a porous vessel,

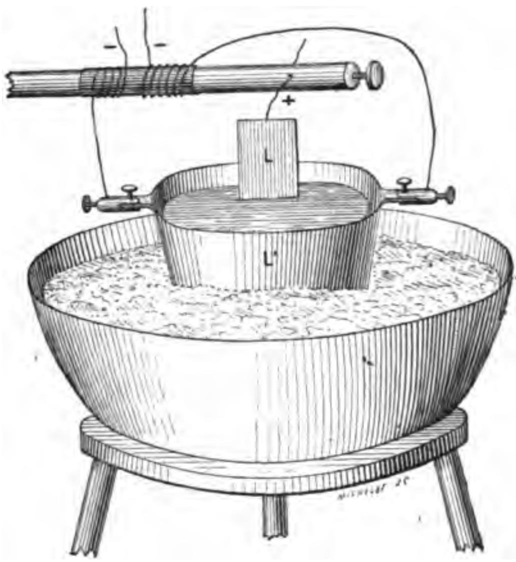


Fig. 132.—Apparatus for preparing aniline colours at a higher temperature. (*From La Lumière Électrique.*)

and the other of a number of similar pencils placed in circular order in an external vessel.

The bodies on which Goppelsröder has experimented are chiefly salts of aniline, of toluidine, and of their mixtures, those of methylamine, diphenylamine and methyl diphenylamine, phenol, and the salts of naphtylamine. The principal dyes prepared by him are the following:—

Aniline black—obtained at the positive pole, by electrolysis of an aqueous solution of hydrochlorate, sulphate, or nitrate of aniline, acidulated with a little sulphuric acid.

Various aniline blues—obtained at the positive pole, by electrolysis of hydrochlorates of methyl aniline, diphenylamine, and methyl diphenylamine.

Hoffmann's violet—obtained at the positive pole, by electrolysis of a solution of rosaniline salt under addition of methyl alcohol, a little sulphuric acid, and very little potassium iodide.

Alizarine—obtained at the negative pole, by electrolysis of a mixture of anthraquinone with a concentrated solution of caustic potash.

These are very important results, and though they were only gained by laboratory experiments, and no data are given as to quantities produced and probable expense of production, they hold out the promise of a new industrial application of electricity.

Application of Electrolysis to Dyeing and Printing.—The following methods, too, were invented by Goppelsröder and brought before the Académie des Sciences in July, 1882:—

1. To produce, for instance, aniline black on tissues or on paper, they are immersed in an aqueous solution of an aniline salt, generally hydrochlorate, and then placed on a metallic plate which is not chemically acted on, and is in connection with one of the poles of the galvanic battery or of a small dynamo. A second metallic plate, which carries in "relief" the design or writing to be reproduced, and is in contact with the other pole, is placed on the tissue or the paper. By applying the necessary pressure and passing the current, a copy of the design is obtained in black. Coins and medals have likewise been reproduced. It is also

easy to write with a metallic stylus which is not chemically acted on, or a conducting carbon, forming one of the poles, on the tissue or the paper impregnated with the solution of aniline salt and placed on a metallic plate, which forms the other pole. Wherever the stylus, under slight pressure, touches the tissue or the paper, the current passes, aniline black is formed and fixed in the fibre as effectively as by the ordinary methods.

This method might be employed in factories, for marking the pieces with a lasting black colour which resists the operations of bleaching, dyeing, and printing. It might also be used in commerce and in the custom-house for stamping without colour, by means of the current and of aniline salts. Instead of aniline black, any other colour which is formed by reduction or oxidation can be prepared and fixed in the fibre.

2. The same process can be employed for obtaining white designs on Turkey red or indigo blue. The coloured tissue is impregnated with a solution of nitrates—saltpetre, for instance—or chlorides, such as sodium or aluminium chlorides, which attack the colour and change it into colourless oxygen compounds, so that the points of the tissue which are in contact with the relief of the second plate are discoloured.

By choosing salts whose bases can act the part of mordants, new colours can be obtained on the discoloured spots by dipping the tissue into a fresh bath. It is also possible that certain higher and coloured oxides, liberated by current action, are fixed on the tissue, and impart to it their colour.

But there is yet another way of discolouring, forming and fixing colours, simultaneously. If the tissue (Turkey red or indigo blue) be impregnated with aniline hydrochlorate, there will be, at the moment of the passage of the current not only a discolouring, but at the same time a formation of black.

3. In some cases the negative electrode acts the principal part. If, during the process of printing, the negative electrode of a battery or of a dynamo be immersed in the vat containing the dye, and the contents of the principal vat be placed in communication with a second small basin containing the same dye or some conducting liquid, and in which the positive electrode is immersed, an oxidation of the colouring matter can be prevented. The communication is effected by means of a diaphragm of parchment paper or of porous clay, or by a simple tube. It is the hydrogen given off at the negative pole, in the midst of the colour used for printing, which prevents oxidation.

Several heavy and precious metals have lately been employed for printing; they can be precipitated in the fibre by impregnating the tissue with a thickened solution of a salt of one of these metals and allowing the negative electrode to act on this salt.

4. Finally, the current can be employed for preparing vats containing indigo, aniline black, etc., by making use of the hydrogen which is given off at the negative pole. The colouring matter is hereby reduced as effectually as by the action of the ordinary reducing processes. When the vats are prepared, their oxidation will be prevented by the action of the negative electrode of a feeble continuous current. The separation of the electrodes, in this case, must be as perfect as possible, and this presents no difficulty whatever.

Electrolytical Preparation of Chlorine and Caustic Soda.—Naudin, whose method for the rectification of alcohol by electricity has been described on p. 278, has also taken out a number of patents for the industrial application of electrolysis to the preparation of chlorine, chiefly for bleaching purposes.

Under the influence of the current, sodium chloride gives, on the one hand, chlorine and, by a secondary reaction, sodium hypochlorite; on the other hand, caustic soda. It might, perhaps, be difficult to collect the chlorine thus obtained, in gaseous form, but, with a well-contrived apparatus, the sodium hypochlorite produced might be isolated. Naudin thought that this hypochlorite and the nascent chlorine ought to be utilized in the apparatus itself for the bleaching of various tissues. The caustic soda which is formed can be used for boiling the tissues after bleaching, and Naudin has constructed an apparatus which performs the two functions indicated.

Unfortunately, operations which are based on the employment of electricity are generally expensive; but in the case in point, the fibres are so rapidly bleached by the nascent products, that this rapidity might to some extent compensate for the greater expense of the process.

Messrs. Dobbie and Hutcheson have also patented a similar process for the industrial preparation of chlorine by electrolysis of sodium chloride. Having been engaged in similar experiments, with a view to the practical application of electrolysis to the decomposition of sodium chloride, I made inquiries on the subject, and have been told on good authority that it would take 40,000 horse-power for twenty-four hours to produce one ton of caustic soda.

We may, therefore, safely conclude that, as long as we have no cheaper source of electricity than the present dynamos, these methods will not be found practicable.

CHAPTER IX.

ELECTRO-MEDICAL APPLIANCES.

Continuous-Current Apparatus.—Electricity is employed for medical purposes, either in form of a discharge when static machines are used, or in form of alternating currents of high tension when induction coils or magneto-electric machines similar to that of Chardin are used, or, lastly, in form of a voltaic current when batteries are employed. In spite of some means of regulation for currents of induction coils, the two former modes of application of electricity still preserve certain elements of insecurity, and the means for graduating the treatment remain to a certain point empirical. With voltaic currents, on the other hand, the intensity of the current employed can always be exactly determined, and this is the reason why continuous-current apparatus present more interest for the physician.

These latter apparatus have been in use for a considerable time. One of the first employed was Marié-Davy's mercuric sulphate battery (*vide* Vol. I. p. 22), arranged for medical purposes by Duchenne, of Boulogne, and Ruhmkorff. In this apparatus, which comprises forty-two elements, all the zinc and carbon plates, carried by an insulated ebonite disc, are only immersed in the beakers containing the exciting liquid at the moment when the battery has to be used. The apparatus is, moreover, arranged in such a way that the number of elements employed can be varied, and is also provided with a rheotome, which allows an intermittent application of the current.

Other apparatus, such as those of Gaiffe, Trouvé, and Dr. Onimus, show a similar arrangement, and are to be found in Vol. I. Part II. Chap. I. All these apparatus are portable to a certain degree, but lately much more bulky apparatus have been constructed, which form veritable pieces of furniture. Amongst them we have to mention Gaiffe's apparatus, composed of zinc chloride and manganese dioxide batteries, and Chardin's flower of sulphur batteries.

Chardin's voltaic elements are identical with Daniell's, in which flower of sulphur has been added to the liquid. It appears, according to Filipo and Matteucci, that this substance acts a useful part by producing sulphuretted hydrogen, capable of increasing, by secondary reactions, the energy and also the electro-motive force of the couple. The sulphur is introduced in the following manner:—The zinc, instead of being immersed in dilute sulphuric acid, is placed in a porous cell filled with a mixture of flower of sulphur and pumice-stone or charcoal powder, and this cell is immersed, in its turn, in a solution of cupric sulphate. The copper electrode consists of a copper cylinder provided with a grating for supporting the crystals of cupric sulphate, as in the first model of Daniell's battery.

Sixty elements of the kind described are placed in a sort of cabinet, and are connected to commutators on top of the cabinet, which serve for grouping the elements according to the requirements of the case. To these two Leclanchés are added for working an electro-medical induction apparatus with induced currents of different order; the latter is likewise enclosed in the cabinet, with its corresponding accessories, and the two Leclanchés are also connected to the commutators, so as to actuate a bell, in case there should be an accidental combination of two groups of elements.

In most of these apparatus the battery elements are of small dimensions. It seems to be a tendency in medical practice to employ elements of high resistance, with the erroneous notion thus to increase the tension of the battery. This notion is contrary to all the laws on electric currents, for, in reality, the total intensity of the current is diminished by increasing the total resistance of the circuit, and the same effect would be obtained by placing in the circuit a simple resistance bobbin. When the battery is applied to the human body, the resistance of the body being always of several thousand ohms, it is clear that the resistance of the battery may be neglected in proportion to that of the body. To increase, therefore, the intensity of current, the tension of the battery must be increased by increasing the number of elements, without considering the slight increase of resistance arising from this; but it cannot be concluded that an increase of resistance of the battery is necessary or even desirable. Let us call R the resistance of the part of the human body subjected to electric action, r the resistance of a battery element, E the electro-motive force of an element, and n the number of elements; the intensity I of the current which traverses the body is represented by—

$$I = \frac{nE}{R + nr}.$$

In this fraction, R being very large in comparison with r, an increase in the number of elements does not increase the denominator to any great extent, whilst the numerator is multiplied by n.

The intensity is, therefore, notably increased by multiplication of the number of elements, without the increase of resistance being sensibly hurtful; but, we repeat, it must not be inferred from this that the resistance ought to be purposely increased, unless this increase of resistance is compensated for by an increase of tension. Nor ought the intensity to be increased by diminishing the resistance of the battery unless its tension is increased. This is another error into which some medical men fall, and against which we must likewise protest. An examination of the above formula will show that this way of proceeding is as illogical as the first.

Moreover, the employment of a small number of elements of large surface has a tendency to produce an erosion or scar on the spot where the electrodes are applied, and this tendency almost disappears by using a battery of high tension whose resistance, from the number of elements employed, is in proportion to that of the body. It is, therefore, an advantage, in order to obtain a current of energetic action, to multiply the number of battery elements, and there is no objection to the employment of elements of high resistance. This multiplication of tension can easily be effected with the apparatus mentioned, which contain a large number of elements, but then they become very cumbersome. From this point of view, the following piece of apparatus will be found very interesting, because it is composed of a large number of elements of such small dimensions that it can easily be carried in the pocket.

It is an improvement of the well-known Pulvermacher's chain. Everybody remembers this series of small batteries formed of short wires arranged in perfectly regular order, and which adapt themselves easily enough to the forms of the body to be employed for local application.

In the latest form of these chains, the copper and zinc wires, coiled into flat spirals, separated from one another by cotton strings, and connected at given points to form a tension battery, constitute a sort of bracelet or belt of different dimensions, according to the parts of the body to which they have to be applied. Not only the polar extremities, but the elements themselves can be applied to the skin by means of an indiarubber band which passes through the interior of the spiral coils. In most of the cases, the moisture of the skin is sufficient to serve as exciting liquid, but, if greater intensity is desired, the chain can be dipped, before application, into water, salt water, or even vinegar.

Here we have already a high-tension apparatus, but chiefly intended for local applications of long duration, where it has for some considerable time rendered real services. But the apparatus to which we wish to call the particular attention of our readers is a transformation of these chains into a veritable battery. In this modification, also due to Pulvermacher, each element consists of a copper cylinder cut up by transverse grooves; each cylinder encloses a small zinc cylinder wound with cotton thread. Each copper cylinder is placed on a small insulating cylinder of cellulose, and from the former starts a tubular prolongation, which penetrates into the insulating cylinder of the following element. Each of the zinc cylinders likewise has a prolongation, which enters under friction into the tube coming from the next element; the communication between the elements is thus established, and the whole forms a sort of long chain.

To render this battery active it is sufficient to immerse it in a vessel containing the exciting liquid—vinegar, for instance—and since every element of the chain carries a little orifice which forms the upper end of the connecting tube, nothing remains to be done but to introduce in the orifice of the last element the pin of one of the electrode poles, and to place the other pin in the orifice corresponding to the number of elements which are to be employed.

An ebonite box which encloses the apparatus can serve for its immersion, and in this case two connections which traverse the side of the box establish communication with the electrode poles.

The inventor recommends the amalgamation of the zincs, and, when they are used up, they can easily be replaced by others. The battery consists of about one hundred elements.

Electric Thermometers for Medical Purposes.—For some considerable time past, medical men have, in most of the diseases, considered it of the highest importance to know exactly the temperature of certain parts of the body. They have recognized in the thermometer a powerful auxiliary for diagnosis, and this instrument is with them now one of daily use.

When it is a question of taking the temperature of a natural cavity, such as the mouth, the rectum, etc., or to take, as is often done, the temperature of the armpit, the determination presents, so to speak, no difficulty. A good graduated thermometer, giving tenths of degrees between 30° and 45° C., gives sufficiently accurate indications. But this is not the case when it is a question of determining, at different points of the body, the temperature of the cutaneous envelope and to determine, as doctors call it, local temperatures. If an ordinary thermometer is used for this purpose, it takes a long time (ten to fifteen minutes) for the mercury to get heated, and even then, only part of the thermometer bulb is in contact with the surface the temperature of which has to be taken.

To overcome these difficulties, recourse has been had to the electric thermometer; and the elder Becquerel's thermo-electric needles, perfected by Claude Bernard, are an admirable apparatus for taking local temperatures. But in this method, the difference between the temperatures of the two thermo-electric junctions constituted by the needles is indicated by the greater or lesser deflection of a galvanometer. A very accurate galvanometer established in a fixed position is required for this purpose, and the reading has to be taken by means of a mirror and a telescope. Moreover, on account of the variations to which the magnetism of the needles is subjected, the tables giving the relation between the deflections and differences of temperatures have frequently to be revised. If, therefore, the apparatus is excellent for scientific research, it is no longer practical in the sick-room, and several modifications of it have been constructed for the latter purpose. One of these apparatus, which deserves special mention, is due to Mr. Lombard, of London. He compares the temperatures of two points of the body by means of two Melloni thermopiles of special construction, and which act on a Thomson mirror galvanometer, provided with a reflection scale. Quite a system of resistances and commutators, interpolated between the batteries and the galvanometer, allows first of all the equalization of the currents produced by the two batteries when they are at the same temperature, and subsequently to regulate, according to the requirements, the sensitiveness of the apparatus.

But even this system is too complicated, and the

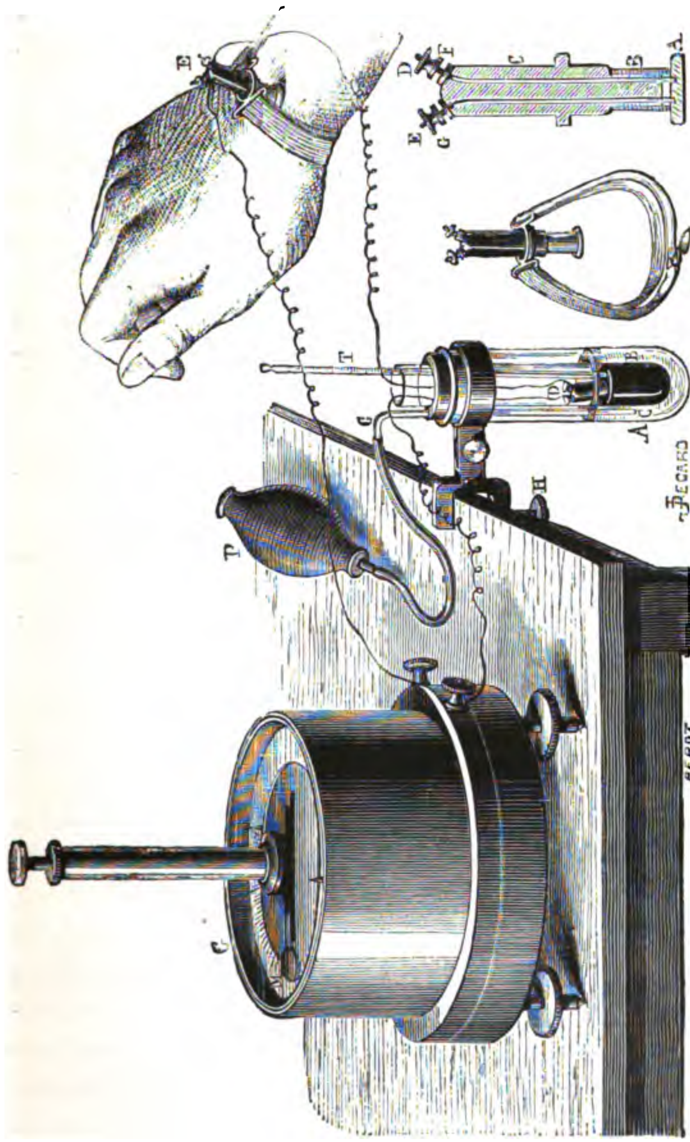


Fig. 133.—Redard's electric thermometer.
(*From La Lumière Électrique.*)

problem has been solved in a more practical manner by Dr.

Redard's apparatus, which we are now going to describe. This is nothing but a modification of Becquerel's thermometer for determining underground temperatures, and its principle is the following:—Given a circuit of two metals—copper and iron, for instance—if the two points of junction are at the same temperature, no current will pass, and a galvanometer placed on the copper wire will remain at zero. If now one of the junctions or solderings is placed in some locality whose temperature has to be determined, and the other junction is placed in a medium whose temperature is given by an exact thermometer, this latter medium can, by heating or cooling, be brought to such a temperature that the needle of the galvanometer is at zero. At this moment the temperature will be the same at both junctions, and the reading of the thermometer in the medium of variable temperature will give the temperature of the locality in question.

Fig. 133 shows the way in which Redard has applied this principle. G is the galvanometer, differing in its form and small size from the ordinary instrument. It consists of a sort of copper drum of nine centimetres diameter, covered with a smooth plate glass which permits the needle and the divisions of the graduated disc to be seen. At M is a mirror, which facilitates the reading of zero by eliminating the effects of parallax.

The astatic needle of the galvanometer is suspended, by a cotton thread enclosed in a copper tube, to a screw which allows the raising or lowering of the needle. Its sensitiveness is very great; for a difference of temperature of one degree it gives a deflection of from twenty to twenty-two degrees, and as it is easy to read off half-degrees, a difference of temperature of one-fortieth of a degree can be ascertained.

From the galvanometer start two German silver wires, which form two soldered junctions with the extremities of an iron wire. The particular form of these solderings is represented at the bottom on the right hand of the figure. A is an iron plate, with a socket B of the same material. A German silver wire starting from this plate arrives at the terminal E, to which is attached, by means of the binding screw G, one of the German silver wires coming from the galvanometer. An iron wire, likewise starting from plate A, leads to terminal D, and is connected, by the binding screw F, to one of the ends of the iron wire. A small insulating ebonite cylinder C surrounds these wires.

The circuit being thus established, one of the solderings is applied, as shown in the figure, to the part whose temperature has to be taken, and kept in position by straps, as represented at K. The other plate is placed in the apparatus of variable temperature, which is screwed on to the edge of the table by the clamp H, and is nothing but Becquerel's apparatus on a smaller scale; a tube B containing mercury into which a thermometer T and the thermo-electric plate are immersed, is itself enclosed in a larger tube A, containing methylated spirits. If the temperature of this apparatus has to be raised, a small deep basin containing water at 50° is held beneath it—and the tube plunged into the water for a few minutes; if, on the contrary, the apparatus has to be cooled, air is blown through it by the tube C and the caoutchouc bag P, and the evaporation of the methylated spirits produces the necessary cold. At the moment when, either in consequence of heating or by the effect of cooling, the needle of the galvanometer, which had been previously deflected, returns to zero, the thermometer T is read, and the temperature thus taken.

Application of Electricity to the Measurement of Luminous Perception in Vision.—This method is due to M. Aug. Charpentier, and was brought before the Académie des Sciences, in July, 1882. Although it cannot strictly be called a medical application, it will find its place here more appropriately than in any other part of the book. M. Charpentier has sought to determine the time which elapses between the appearance of a light before the eye and the production of a signal given by the experimenter as soon as he has perceived this light. It was an interesting question to decide whether the duration of perception was different for the centre and for the excentric parts of the retina, and also if training could modify this duration, and if this modification was confined to the trained part.

For the experiments, the eye, placed in the centre of a Landolt perimeter, is looking at the bottom of a large box covered with black paper, which has an aperture of about one centimetre square in the centre. This aperture is placed exactly opposite the eye and in front of a well-lighted window, and is closed by a plate covered with black paper. The heavy metallic plate is kept in position by the attraction of an electro-magnet, but not in actual contact with it, so that, as soon as a person placed behind the box interrupts the current which energized the electro-magnet, the obturating plate falls immediately, and exhibits the window to the experimenter's eye.

A current supplied by a Gramme laboratory machine, after having traversed the electro-magnet, actuates a small Deprez signal, whose stylus leaves its trace on a registering cylinder having a Foucault regulator. This signal immediately indicates the interruption of the current, and, consequently, the precise moment of the appearance of light.

The experimenter, immediately on perceiving the light, re-establishes the current of the signal by a shunt wire, by pressing a spring with the forefinger of his right hand, and a fresh mark is hereby made on the registering cylinder.

The interval which elapses between the interruption and the re-establishment of the current is measured by comparison with the vibrations of a Marcy's electric chronograph, and indicates in a direct manner the time required by the experimenter for perceiving and signalling the light. M. Charpentier simply calls this time, for the sake of shortness, the luminous perception.

By means of this method, the inventor has been able to study the different circumstances which influence the duration of luminous perception. He has found, amongst other things, that it varies for one and the same person by double the amount, and according to the individual from nine to fifteen hundredths of a second.

CHAPTER X.

PREPARATION OF PARABOLIC MIRRORS BY CENTRIFUGAL FORCE.

Latchinoff's Method.—Although this cannot be called an electrical method, yet the reflectors prepared by it are used for electric arc lamps and the apparatus is most conveniently worked with an electric motor.

It is well known that all the points of the free surface of a liquid rotating round a vertical axis acquire a constant angular speed, and that this surface assumes the parabolic form. If a liquid capable of rapid solidification is poured into a receiver, and this receiver rotated, in a continuous and regular manner round its vertical axis, until the liquid is completely solidified, a solid paraboloid is obtained, which can be utilized as a reflector. The most convenient substances are plaster of Paris or mastic specially prepared for the purpose. The receiver employed may have any shape, but, to avoid the use of too large a quantity of liquid, a vessel of hemispherical shape is preferred, closed by a glass cover through which the operation can be watched. A ring K K (Fig. 134), whose use will be explained further on, is fixed in the receiver close to its border.

If a fused substance is employed, it is advisable to surround the receiver with felt in order to retard the cooling. The form of the receiver does not in any way influence the form of the paraboloid. If the axis is not well centred, it will have no other effect than to give to the paraboloid a conical section, and this presents no drawback.

The principle of the operation consists in the regularity of the rotatory movement imparted to the body until it is completely solidified. A steam-engine would, therefore,

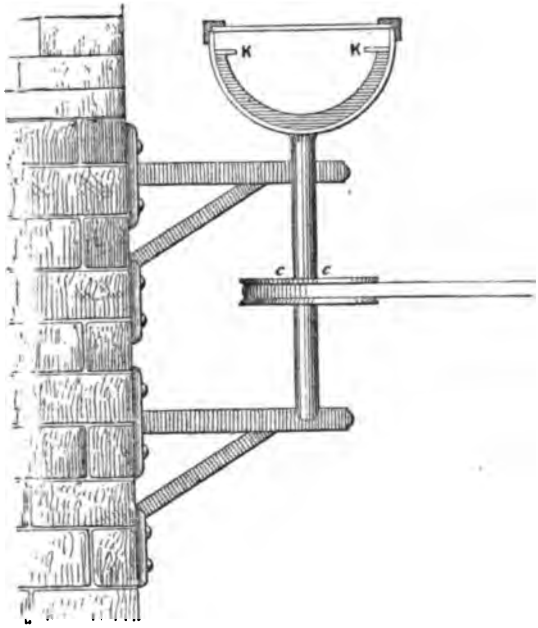


Fig. 134.—Apparatus for preparing parabolical mirrors.
(*From La Lumière Électrique.*)

not be practical as motor; an electro-motor would suit the purpose much better. A small Gramme or Siemens machine actuated by a Thomson battery would be the best to use; they give an intense and constant current during a relatively considerable time; three or four elements would be sufficient for obtaining the necessary movement by means of an endless strap (Fig. 134). The speed would have to be regulated by a convenient resistance introduced in the circuit. If a Deprez or Helmholtz regulator is added to the electro-motor, any battery can be used.

At the commencement of the movement, the liquid presents an irregular form on account of the difference of angular speed of its particles; but gradually, in consequence of molecular attraction, the particles acquire the same angular speed as the receiver, and the liquid assumes the form of a paraboloid, immovable as regards the receiver. The air of the receiver follows the movement, so that the contents remain in equilibrium as if the receiver were immovable. The axis must be perfectly fixed, and this can easily be obtained on account of the feeble speed which is given to the apparatus (about one revolution per second).

Fig. 134 represents one of these apparatus whose axis is maintained by a support which is solidly fixed to a wall. A vertical position is given to the apparatus by placing a spirit level on the surface of the pulley *c c*.

During the solidification of the substances employed, variations of volume ensue, and, on account of the unequal thickness of the different layers, there might be alterations in the surface of the reflector; in order to avoid this inconvenience, it is advisable to employ a substance which solidifies slowly—for instance, in an hour—and which passes through all the degrees of consistency. The slight differences which are produced in spite of this precaution would be corrected by the centrifugal force, because the mass only gradually loses its mobility. To obtain a paraboloid of constant thickness, it is necessary to employ the ring K K, which keeps down the liquid mass and renders the thickness of the sides of the bottom nearly equal.

Professor Mendelejeff, of the St. Petersburg University, has prepared a mastic which preserves its mobility until it has taken the temperature of the surrounding medium, and also presents after solidification a smooth and brilliant surface.

The paraboloids prepared in this way can be utilized in different ways.

1. A copper negative can be obtained by galvano-plastic which, by the same method, would give an iron or nickel positive. Iron precipitated by the galvanic current is not easily oxidized, and, as it has a very white colour, it might be used even without silvering, if it is kept under glass, as proposed by Tchikoleff; the nickel cast must be silvered and polished or platinized to become a good reflector.

2. An iron positive is prepared, into which a hard and easily fusible metal, like, for instance, type metal, is cast; a mould is formed, in which the reflector might be beaten out.

3. The paraboloid can be directly silvered as glass is silvered (a reflector of this kind must be preserved under glass). The drawbacks of this latter method consist in the fragility of the reflector and the loss of the mould.

Reflectors are generally constructed very deep, which renders a piercing of the sides necessary to place the luminous body or the electric carbons in focus. The object of the constructors in choosing this form is to direct the largest possible number of luminous rays on the sides of their reflectors, but both Latchinoff and Tchikoleff contest the accuracy of this view. By geometrical calculations upon which we cannot enter here, they have been led to the conclusion that, in parabolic reflectors for the illumination of distant objects, the depth ought to be equal to the focal distance. This would lead rather to a diminution than to an increase of depth, and the piercing of the sides would thus be avoided.

Tchikoleff's reflector, closed by a glass, must be of less depth than the focal distance; on account of the difficulty of constructing deep reflectors, he contents himself with an angle of 85°. With the process described, angles of 130° to 140° can easily be obtained, and this gives a depth which is not even found in Mangin's reflectors.

Latchinoff has calculated the speed of rotation corresponding to a given focal distance; we cannot follow him in his calculations, and must confine ourselves to the result obtained.

If n is the number of rotations per second, and d the focal distance, we have—

$$n = \frac{0{\cdot}352}{\sqrt{d}}.$$

The speed need not be too accurately calculated, because a slight difference in the focal distance does not present any serious inconvenience.

CHAPTER XI.

ETCHING ON GLASS BY ELECTRICITY.

Planté's Method—Amongst the experiments that Planté has made with his secondary battery, there are several which have led him to apply the electric current produced by it to etching on glass or crystal. He had, in fact, observed that, when a glass tube is traversed by a platinum wire serving as electrode of the battery, the glass of the tube instantly assumed a conical or funnel shaped form when placed in a voltameter containing a saline solution. Moreover, certain experiments on the luminous effects produced by these high-tension currents on the sides of a glass or crystal vessel moistened with a solution of common salt, had given him an opportunity of observing that the glass or the crystal was strongly acted on at the points touched by the electrode, and that the luminous concentric rings, formed all round, sometimes remained engraved on the surface of the glass of the voltameter. Finally, he had found that, by using potassium acetate as saline solution, a much smaller electro-motive force was required than with sodium chloride or other salts to produce luminous effects and etching. These observations have led him to his system of etching on glass, which he describes in the following manner:—

The surface of a glass or crystal plate is covered with a concentrated solution of potassium nitrate by simply pouring the liquid on the plate, which is placed horizontally in a shallow dish (Fig. 135). A horizontal platinum wire, communicating with the poles of a secondary battery of from fifty to sixty elements, is immersed in the liquid which covers the glass plate along the edges of the latter; the other electrode, consisting of a platinum wire surrounded, except at its extremity, by an insulating tube, is held with the hand against the glass covered with a thin layer of saline solution, at the points where the characters or the design are to be engraved, as shown in Fig. 135.

A luminous furrow is produced wherever the electricity

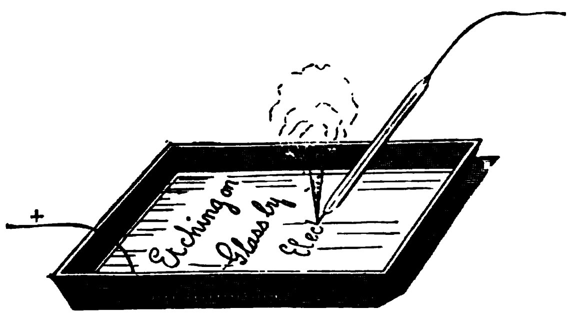


Fig. 135.—Etching on glass by electricity.
(*From La Lumière Électrique.*)

acts, and, however quickly the writing or drawing may be done, the strokes are deeply engraved in the glass, and their thickness depends on the diameter of the platinum wire serving as electrode; with a very fine point, exceedingly delicate lines are traced. The metallic conducting wire is thus transformed into a veritable stylus for glass, whose handling requires no effort on the part of the operator, in spite of the hardness of the substance to be operated on; for it is sufficient to pass the platinum wire lightly over the surface of the glass to obtain an indelible engraving. The corroding force is supplied by the combined calorific and chemical action of the current in presence of the saline solution.

The chemical action of the electric current under these conditions is very powerful, although it is being exercised on the surface of an insulating substance. It attacks vitreous substances even more energetically than hydrofluoric acid, for we have seen characters engraved on a plate of Lidot glass (an acid phosphate of lime specially prepared by M. Lidot), which is not affected by hydrofluoric acid. Either of the electrodes can be used for etching, but a stronger current is required when using the positive electrode, and the engraving is not so distinct.

Although these results were obtained with a secondary battery, it is clear that, for continuous work, any other electric source of sufficient quantity or tension, either a sufficient number of Bunsen elements or a Gramme machine, or even an alternating-current machine, ought to be used in preference.

CHAPTER XII.

ELECTRICAL APPLIANCES FOR RAILWAY INTERCOMMUNICATION.

The aim of all these appliances is to enable the passengers, in any and every compartment of the train, to communicate with the guard's van in front and at the end of the train, the signal being given by the ringing of a bell.

These two bells must be under the control of the two guards of the train, to enable them to communicate with one another, from one end of the train to the other, if occasion arises. The connections to be established for placing the carriages in electric communication with one another must be as few in number as possible; they must operate rapidly, simply, and must be of solid construction. One great difficulty used to be that the men employed for coupling together the carriages could not be relied upon for establishing a certain number of distinct connections. This difficulty has been lessened to a great extent by the use of continuous brakes, which, from the enormous increase of traffic, have become quite indispensable. The coupling of carriages now requires a junction of several tubes, and the proper attachment of the electric cable is, as a rule, no longer neglected; however, it is none the less necessary to reduce this operation to the minimum of time and of complication.

Finally, another function was required of the system of communication. It ought to signal automatically a rupture of the train. A few years ago, if the end carriages became detached, the front carriages had no direct means of ascertaining the fact. Electricity now fulfils this function automatically.

The system used on the French railways is that of Tesse and Prudhomme. It consists of two distinct equal batteries, one being placed in each of the two guards' vans. These batteries, of six Leclanchés each, are enclosed in special boxes, which at the same time contain the bells. The circuit is composed of two complete cables, one of which is insulated, the other connected to earth. This latter might undoubtedly be suppressed—a simple earth connection would be sufficient; but, in the first place, communications made at a single point of a vehicle are not safe, and, in the second place, this cable is necessary for the automatic action.

The two batteries are arranged in opposition, that is to say, they are connected by their poles of the same name. Under normal conditions, the batteries being equal, no current passes, but if any two points of the two cables are joined by a metallic connection, a shunt is created, the two batteries immediately enter into action, each half of the circuit is traversed by a current, and the two bells ring. It will be the same if, on part of the train becoming disconnected, the broken extremities of the insulated cable and the earth cable are joined, a complete circuit will be established and the signals are given. This result is obtained, in case of a partial disconnection of the train, by the very arrangement of the coupling-hooks, which constitute one of the interesting points of the system.

Each hook consists (Fig. 136) of a fixed frame and a movable bar B, which is held against the frame by a strong spring. The conducting cable, which runs beneath the carriage, is prolonged by a flexible conducting rope terminating in a brass ring C. For the purposes of coupling, the

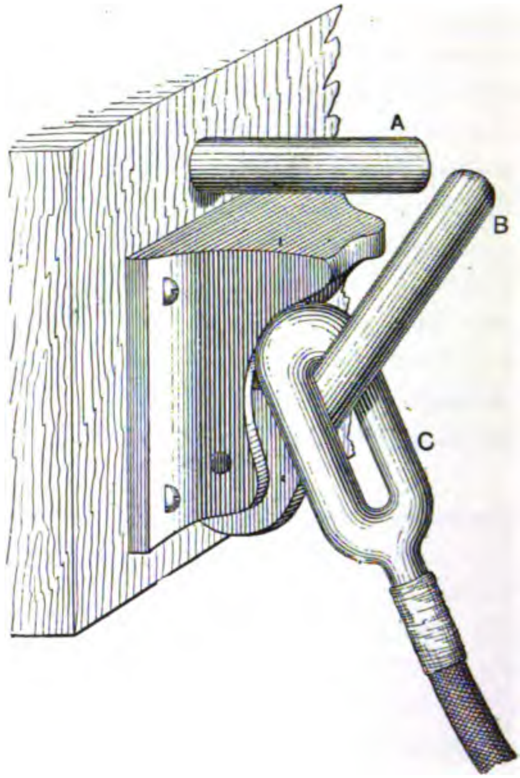


Fig. 136.—Coupling-hook for railway intercommunication.
(*From La Lumière Électrique.*)

ring is inserted between the movable bar of the hook and the frame, which remain separate by the ring. Contact is thus ensured, and in case part of the train breaks loose by accident, or if the cable is not unhooked when uncoupling the carriages, no damage will ensue, for the cable will be pulled back, will open the hook which falls back on the frame, and the connection will be broken. A particular arrangement now comes into play; the bar of the hook, pulled back by its spring, cannot go back as far as the frame, but falls back on the head of pin A. The frame and the bar belong to the insulated cable; the pin is connected to the earth cable, so that the contact of the hook with the pin, which is a conductor, establishes communication between the battery and earth, completes the circuit, and causes the bells to ring. This is how the apparatus acts automatically.

Each compartment receives two wires connected to the two cables, and if these two wires are joined a shunt is created and the signal is given. This junction is effected by making contact in the ordinary way; but in the bells a special arrangement has to be noted. If they were made in the usual way, the shocks of the vehicle would make them ring almost continuously. The armature which carries the hammer, therefore, carries a small stop, which is raised by the electro-magnet when this latter becomes active; the hammer is then set free, and can produce the signal.

This system has been in use for some considerable time on the Chemin de Fer du Nord; it answers the required conditions, is simple, and offers many advantages. It is, however, not without its defects. The chief drawback is that the contacts of the hooks are not absolutely secure; dust, and, what is still worse, soot, is deposited between the ring and the hook, or covers the head of the pin, and the apparatus cannot act. This drawback is so serious that the Chemin de Fer de l'Ouest, which had tried the system, has given it up.

The apparatus for connecting the carriages is represented in Fig. 137. The hook consists of two copper jaws, the lower one E of which is fixed; the upper one C is pressed against the other by a strong spring. The ring attached to the end of the cable H terminates in a straight bar A, and is, when not in action, suspended to the hook B; in order to establish connection between the carriages, it is pushed

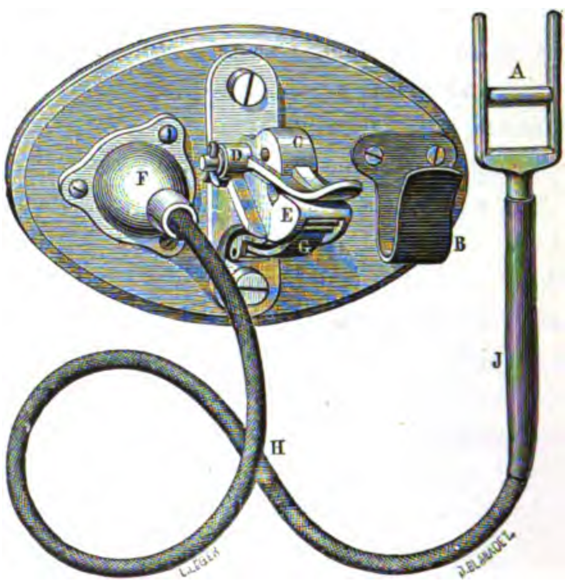


Fig. 137.—Connecting apparatus for carriages.
(*From La Lumière Électrique.*)

between the two jaws, which open, and naturally falls into a notch, where it is firmly held by the pressure of the spring, thus ensuring a contact which is guarded against the dust. It will be seen that the two lateral sides of the ring are prolonged beyond the terminal bar, and form a sort of fork. The object of this arrangement is to ensure a release of the ring in case of any of the carriages breaking loose. In this case, the cable, which is fastened to the carriage at F, is pulled in a horizontal direction, and raises the handle J of the ring; this latter then turns round the contact-bar, the two branches of the fork press on the two lateral pieces D, so that the whole forms a lever arrangement, the upper jaw is raised, and the ring escapes from the notch. The inconvenience of the rupture

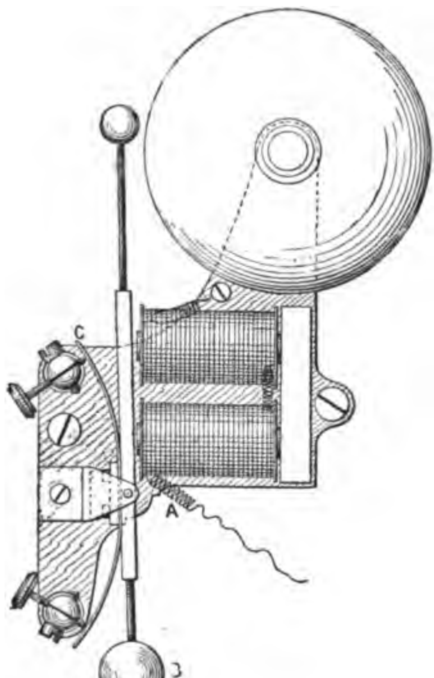


Fig. 138.—Alarm-bell.
(*From La Lumière Électrique.*)

of the cable in case of an accidental disconnection of the carriages is thus avoided. It is true that this arrangement no longer presents the advantage of an automatic closing of the circuit, as with Prudhomme's hook, but this property has become useless since the employment of continuous brakes.

The bell also has been simplified. To prevent it from ringing under the action of the movements of the train, instead of providing it with a movable stop, which necessarily complicates the system, the hammer has simply been suspended by its centre of gravity at A (Fig. 138), the weight of the upper part being balanced by a metal ball placed at B, and which can be raised or lowered by means of a screw-channel. The antagonistic spring has double the length, and forms a current-interrupter at point C, as in the ordinary arrangement.

Fig. 139.—Alarm-stud. Fig. 140.—Manipulator for guard's van.
(*From La Lumière Électrique.*)

The arrangement of the stud placed in the carriages for giving the alarm signal has likewise been modified. On the Chemin de Fer du Nord it is a ring placed between two mirrors in the wall separating two carriages; on the Chemin de Fer de l'Est, a box (Fig. 139) is used, which is fastened to the ceiling of the carriage. The signal is given by pulling a stud B; this pull turns the bottom of the box and makes contact by an interior spring. The stud, when once pulled, can only be put back in its place by a special manipulation, so that the guard can always find out from whence the signal has emanated.

Finally, special manipulators are placed in the guards' vans (Fig. 140). The handle B can serve for sending intermittent signals like a Morse telegraph, or else, by turning it towards the contact C, which is fastened to the insulating plate A, it closes the circuit altogether, and then gives the alarm signal by ringing the bell in a continuous manner.

CHAPTER XIII.

BOURDIN'S PLOUGH FOR LAYING ELECTRIC CABLES.

ELECTRIC communication, either by telegraph or by telephone, increases daily, and daily requires fresh installations of cables. These installations are for the most part air lines, which have the advantage of being more economical, simpler, and easier to control than underground lines, but are, on the other hand, exposed to the influences of weather and to wilful damage. The chief drawback of underground lines is their expensiveness. These cables require careful insulation, and their laying is a laborious process, as tedious as it is expensive. In certain cases—for instance, in war—underground lines would offer enormous advantages, but there is no time for installing them.

Instruments have been invented for accelerating and facilitating the laying of underground lines. These apparatus naturally assume the form of ploughs, and, although they cannot be called electrical appliances, they will not be considered out of place here.

The troublesome and expensive part of the operations for laying an underground cable is the opening of a trench of sufficient depth, and two ploughs were exhibited at the Palais de l'Industrie in Paris, intended for this purpose. One of them was in the German section. It was light, and could not attain a very great depth. It was principally intended for military purposes, where a provisory installation has to be rapidly made.

The other plough is Bourdin's, represented in Figs. 141

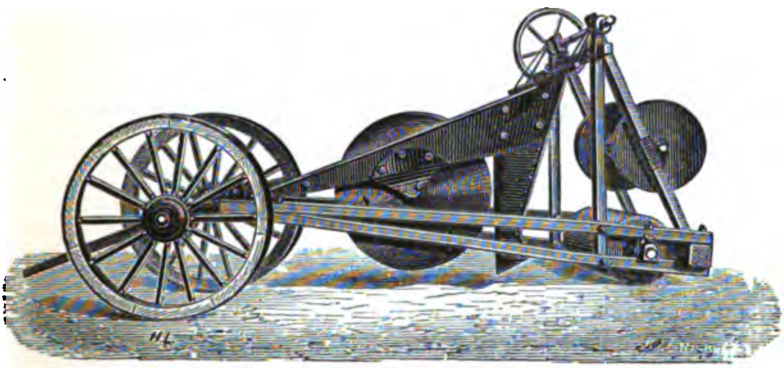


Fig. 141.—Bourdin's plough (at rest).
(*From La Lumière Électrique.*)

to 143. Its mode of working will be easily understood. A lenticular disc precedes the ploughshare, cuts the roots, and

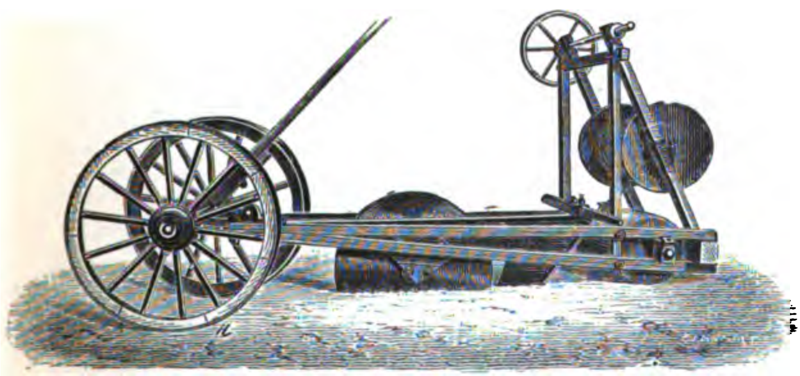


Fig. 142.—Bourdin's plough (in action).
(*From La Lumière Électrique.*)

opens the trench; behind the ploughshare is a bent tube, through which passes the cable, and the ploughshare itself places this cable at the bottom of the trench, which the hind roller closes. The machine carries a tressle for holding and replacing the wire coil, and requires but little personal attention. The width of the trench is reduced to a mini-

Fig. 143.—Bourdin's plough (plan).
(*From La Lumière Électrique.*)

mum, whilst the depth attained is about one metre. It appears that with three good horses, five kilometres (three miles) of wire per hour can be laid with this plough.

CHAPTER XIV.

SIEMENS' GALVANOMETERS.

It is not our intention to enter upon the question of electrical measurements. This is a subject which must be reserved for special treatment, and which would require a large amount of space, which we cannot assign to it in the present book. We only mention here a few galvanometers which were exhibited at Paris by Messrs. Siemens, and are most interesting apparatus of their kind. Fig. 144 represents an instrument for measuring the electro-motive force. It consists of a bell-shaped magnet suspended between two vertical bobbins coiled with fine wire. An index marks the position of zero of this magnet, and, when it is deflected by the action of a current, it is brought back to zero by acting on a spiral spring to which it is connected. The torsions are measured on a graduated glass disc, which forms the bottom of the case of the apparatus, and a table indicates the relation between the degrees of the graduated disc and the electro-motive force.

Under normal conditions, the apparatus can measure differences of potential between 0·01 of a volt and ten volts; but, by taking off a pin between the two terminals, the galvanometer is placed in a shunt, and electro-motive forces can now be measured varying between 0·1 and 100 volts.

This galvanometer must be handled with great care, because it is not easy to replace the thread when once broken.

Fig. 145 represents a non-vibratory galvanometer of very

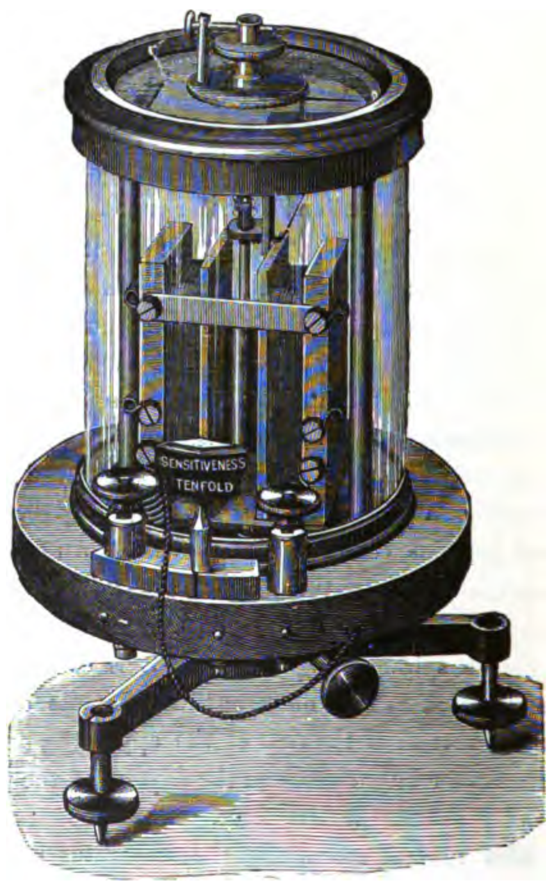


Fig. 144.— Siemens' galvanometer for measuring electro-motive force.
(*From La Lumière Électrique.*)

simple construction. It consists of two bobbins, and in the centre of the space contained between these two is a copper sphere, in which moves a bell-shaped magnet, as shown in Fig. 146. The rod of this magnet carries a small mirror,

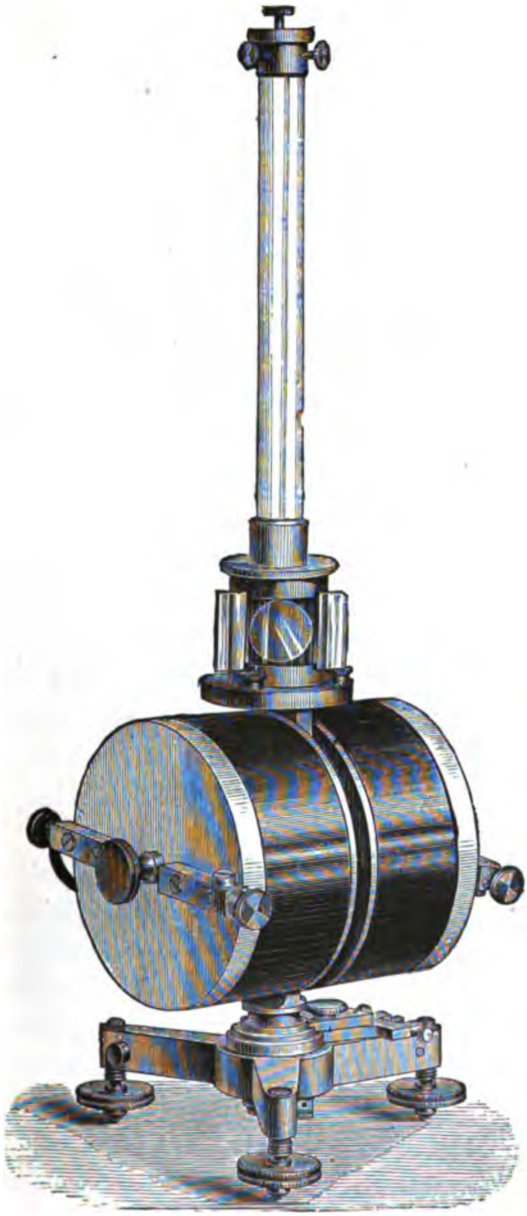


Fig. 145.—Siemens' non-vibratory galvanometer.
(*From La Lumière Électrique.*)

which is placed above the bobbins and moves in a glass case. The deflections are read off either by means of a reflection scale or a telescope. From the fact of its being provided with a copper "damper," this galvanometer has a non-vibratory movement, and does not require a directing magnet. It is specially intended for lecture experiments.

The last apparatus is a special form of Thomson's galvanometer, and is shown in Fig. 147. It has four bobbins, completely surrounded by a case. The magnetic system is astatic, and consists of two bell-shaped magnets suspended to long threads, and oscillating in copper tubes. The mirror is carried by the rod which connects the two magnets, and is fixed to that part of the rod which is between the two bobbins; the influence of shocks on the mirror is thus prevented. The suspending thread of the magnet turns in any direction, and the whole magnetic system is at rest when the apparatus is not used.

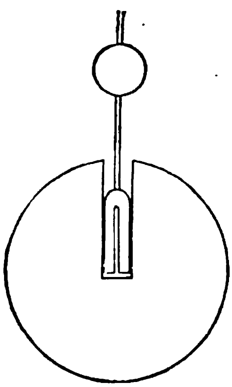


Fig. 146.—Siemens' bell-shaped magnet.
(*From La Lumière Électrique.*)

The socket of the galvanometer, formed of an ebonite plate, is perfectly insulated, and a small movable bobbin equalizes the difference of action which often exists between the two pairs of bobbins.

But the most characteristic part of this apparatus is the arrangement of the directing magnet. This magnet is composed of two straight lozenge-shaped horizontal magnets placed above the socket. They are superposed, and can turn in opposite directions round their common vertical axis, which coincides with the axis of the instrument. A lateral screw acting on a system of toothed wheels controls their movement. When they are superposed so that their poles of the same name coincide, their directing force is maximum; it becomes gradually weaker in proportion as they withdraw from one another. The arrangement of the wheels also enables the two magnets, in case of necessity,

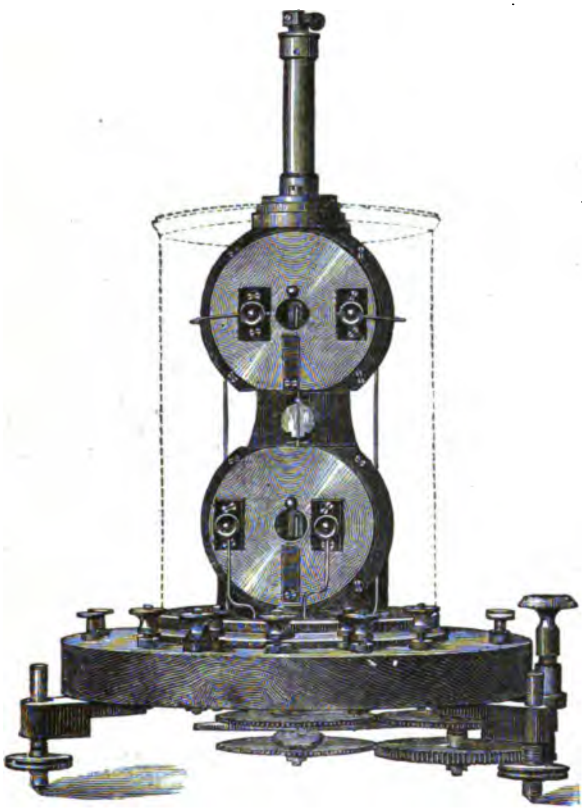


Fig. 147.—Siemens' galvanometer with special directing magnet.
(*From La Lumière Électrique.*)

to move at the same time, while they preserve their relative positions. The bell-shaped magnet employed in these three galvanometers is a special form adopted by Siemens; it has simply the form of a thimble with a longitudinal slit, and the poles are formed by the two halves of the thimble.

CHAPTER XV.

RAIMOND COULON'S PHOTOMETER.

THE increasing importance of electric light from an industrial point of view renders the construction of a good photometer requiring no delicate manipulations absolutely indispensable. Unfortunately, nearly all the instruments at present in use, and founded on the observation of the deflection of an index, have the serious defect of being influenced at the same time by heat and by light. Coulon's photometer has the valuable property of being acted on by luminous rays only.

The apparatus rests on the following two principles:—

1. *The luminous conditions remaining constant,* any radiometer whose temperature is raised turns in such a way that the brilliant side of the mica disc seems attracted by the surrounding bulb; any radiometer whose temperature is lowered turns in an inverse sense; any radiometer whose temperature is constant remains immovable.

2. *Any radiometer whose temperature is constant, turns under the sole influence of light.*

Coulon has tested the accuracy of these principles by a number of experiments, and, applying to his instrument the method of opposition of forces, has made of it a veritable balance.

Figs. 148 to 150 represent in elevation, section, and plan, the whole of the apparatus employed for producing a convenient action of the light on the beam of the photometric balance maintained in a medium of strictly constant temperature. Coulon soon found that the instrument had to be maintained at a temperature superior to that produced by the radiant heat of the luminous source to be measured; a temperature of 100° C. is sufficient in practice.

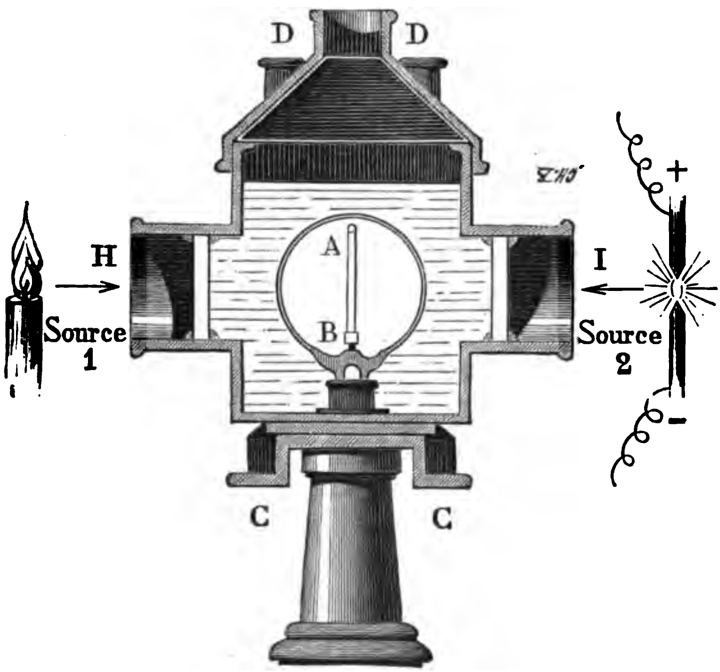


Fig. 148.—Raimond Coulon's photometer (elevation).
(*From La Lumière Électrique.*)

The photometric part of the instrument consists of a disc A B, which is pivoted about its vertical diameter. The semi-disc A is white on its two faces, the other semi-disc B is blackened on both sides. It is placed in an exhausted glass bulb on a socket in the centre of a metal box, which contains water or any other liquid that can be raised to boiling point and maintained at that temperature by means of the lamps C D placed at the four corners. Plates E placed on the side of the bulb protect it against the sudden action of heat and regulate the movement of the liquid.

This box carries four tubulatures closed by glass plates.

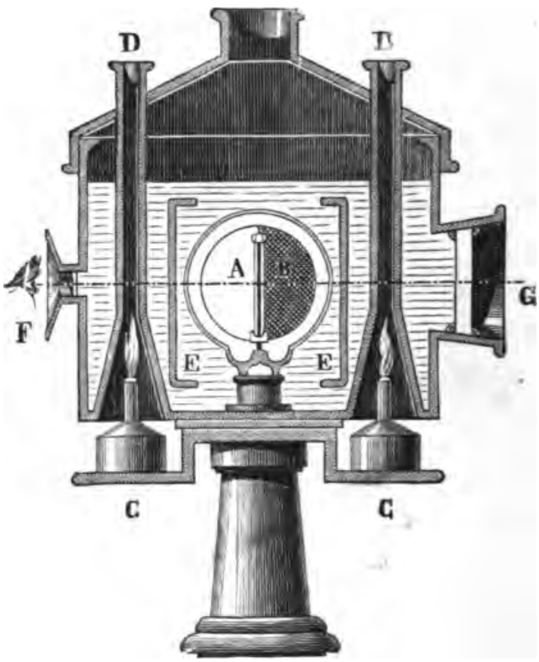


Fig. 149.—Raimond Coulin's photometer (section).
(From La Lumière Électrique.)

The tubulatures F, G (Figs. 149 and 150) serve for observing the movements of the disc. The tubulatures H, I open a passage for the luminous rays to be measured; they can be provided with objectives or condensers instead of simple glass plates. The socket K of the instrument can be fitted to a camp-stool.

The working of the apparatus will be easily understood. Let us suppose that source 1 and source 2 are to be compared. They are placed exactly in the prolongation of axis H I. If this is not possible, mirrors are used, and account of it is taken in the calculations, as it is essential for the working of the photometer that it should be perfectly hori-

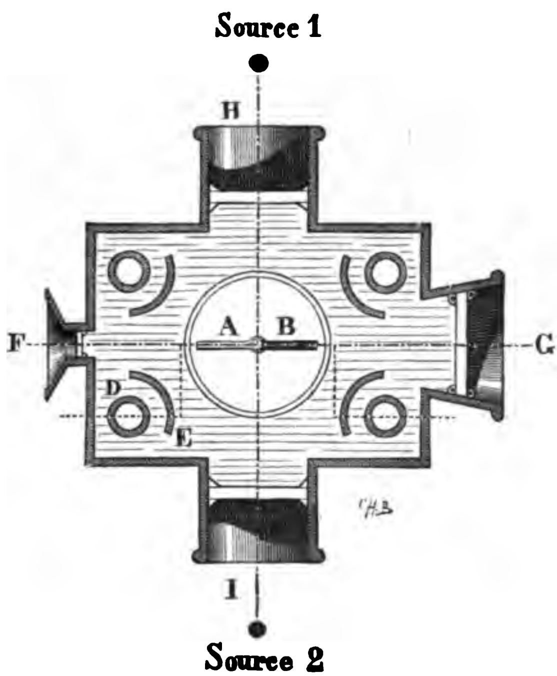


Fig. 150.—Raimond Coulin's photometer (plan).
(*From La Lumière Électrique.*)

zontal and that the luminous rays should be perpendicular to the axis of rotation of the disc. A screen of highly polished glass, and feebly illuminated, can be placed before the tubulature G, but it had better be stopped up altogether, the disc being always sufficiently illuminated by the rays of the sources 1 and 2.

The action of the apparatus is as follows:—Let us suppose the source 1 acting alone. Its luminous ray falls on the disc; it attracts the side A and repels the side B, consequently the whole disc turns until it finds itself in the plane H I. The observer, placed at F, now sees the disc in full, and he has the side A (white) on his left and the side B (black) on his right. If source 2 acts alone, it equally tends to place the disc crossways to axis F G, because it attracts the side A (white) and repels the side B (black). The observer, placed at F, will then see the disc in full, but he will have the white side on his right and the black side on his left. Finally, if the two sources act together and with the same intensity, their effects destroy each other, for the disc becomes the point of application of two equal couples of opposite directions. It can only be in stable equilibrium, whatever the intensity of the couples, if it is perpendicular to the direction of the four forces which act on it, and whose resultant is then equal to zero. In this case, the observer, placed at F, sees it edgeways. These three characteristic aspects of the disc are represented in Fig. 151.

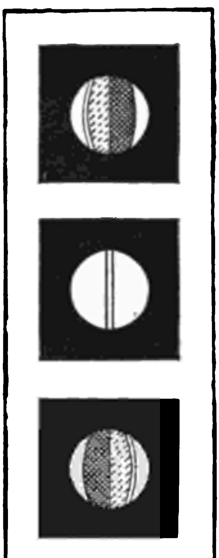


Fig. 151.—Aspects of the radiometer disc.
(*From La Lumière Électrique.*)

On withdrawing one of the two sources, this equality of the couples can always be obtained and the disc be brought to the positions indicated in Figs. 148, 149, and 150. When the equality of the couples is obtained, it is sufficient to measure the distances of the sources from the disc to find the relation of their intensities by ordinary calculation.

Instead of withdrawing the lights, a certain number of opaque diaphragms might be graduated beforehand, and thus veritable weights representing 10, 100, 1000, etc., luminous units, obtained. This would obviate the displacement of the luminous source, which is often attended with difficulties, and at the same time give sufficiently accurate results.

It is also advisable, in order to diminish the causes of error due to the want of homogeneousness of the surfaces of the photometric disc, to substitute source 2 for source 1, and *vice versâ*. When this substitution is not feasible, a slight turn of the hand causes the disc to make rather more than a semi-revolution. The action of the sources 1 and 2 continues the movement, and the black arm, originally directed towards G, is drawn towards F. This inversion of the faces of the disc is equivalent to the displacement of the sources of light. The apparatus is not patented, is inexpensive, very portable, and seems likely to render some services in industrial photometry.

PART III.

ELECTRIC MOTORS, AND ELECTRIC TRANSMISSION OF ENERGY TO A DISTANCE.

CHAPTER I.

ELECTRIC MOTORS.

MODERN physical science has established on an unassailable basis the principle of the unity of physical forces and the conservation of energy. Electrical phenomena, and the conversion of electrical effects into calorific, mechanical, or chemical effects, are so many proofs of the truth of this principle. The conversion of electrical into mechanical effects, and *vice versâ*, bids fair to become the leading problem which electrical science has to solve. For a long time it was not even contemplated practically to utilize electrical transmission for anything but the production of signals, as in telegraphy, by the agency of comparatively delicate and very light apparatus, and it is only quite lately that the question of transmitting energy to a distance, for the production, no longer of signals, but of continuous work, has been seriously entertained.

If we wish to produce motive force by means of an electric motor, our first consideration is to produce electricity, and our second to convey this electricity to a receiver which transforms it into motive force. We will examine these two questions separately.

1. **The Sources of Electricity.**—There was no thought of creating an electric motor capable of producing appreciable work, before the invention of Grove's battery, a few previous attempts excepted, which will be mentioned below. Jacobi's memorable experiment made on the Neva, in 1839, with a Grove battery of 128 elements, proved (*vide* p. 238) that a certain quantity of work could be produced by electricity. At that time the electrical efficiency of batteries and their mode of utilization were but imperfectly known.

The numerous researches on the voltaic battery made since, enable us accurately to determine the maximum work available in a given element, as well as the fraction of this work which can be utilized, according to the relative conditions of the battery, the circuit, and the electro-motor.

A given battery can be likened to a waterfall. Like this latter, it supplies a flow of a certain volume at a certain pressure during unit of time. The volume is the quantity of electricity which the battery can supply; the pressure is its electro-motive force.

The maximum work which our waterfall can supply during unit of time is equal to the product of the volume of the flow of water by the height of the fall. In the same way, the maximum work which a battery can supply is equal to the product of the quantity of electricity by the electro-motive force.

There is, therefore, already a theoretical limit which cannot be exceeded and still less be attained, for the losses of current in the conductor and the efficiency of the motor must be taken into account. This efficiency varies with the speed of the motor, and modifies to a very great extent the ratio between the electrical energy expended and the mechanical work produced. To this must be added that the battery consumes a very dear fuel—zinc, and that it consumes it but slowly.

It follows from this that the battery, considered from the point of view of electrical energy displayed, is very expensive, very heavy, and very cumbersome. This will sufficiently explain why electric motors set in motion by batteries—whatever may be their system—have up to the present not given the results which were expected of them at the beginning, and also why they have hitherto found but few applications for producing work not exceeding a few kilogrammetres.

We will quote a few instances of this.

If electrical accumulators are used as the source of electricity, the question assumes a different aspect. Where very small forces are required, at irregular intervals and with long periods of rest, representing altogether a very small amount of energy, accumulators can be employed. A series of accumulators weighing one hundred kilogrammes will feed a sewing-machine for a week, with an average work of from two to three hours per day. By charging these accumulators by means of dynamo-electric machines, and taking them, when charged, to the place where they are to act, the working will be found fairly advantageous from an economical point of view, provided that there exists a general system for the distribution of electricity. Accumulators can also be used where it is a question of utilizing natural sources of energy which vary at each moment, like wind and tide; in that case they act the part both of reservoir and of regulator. But this is a question of transport and distribution of energy to a distance, and no longer of a motor fed by an electrical source, and this question we reserve for future consideration.

2. **Electric Motors.**—If Figuier is to be believed, the first attempt to create electric motors dates back to 1831, and is due to the Abbé Salvator del Negro, of Padua. At that time, only single-liquid batteries were known, and Del Negro's motor could not give satisfactory results, were it only for the inconstancy of the source. The invention of Grove's battery, which provided a comparatively powerful electrical source, was the starting-point for new experiments, of which Jacobi's was the first in date.

In 1840, Messrs. Patterson brought before the Académie des Sciences an electric motor, to be used for printing a weekly paper, but which was in reality no good at all. In 1842, Davidson pretended to have worked a locomotive of eight tons, with a speed of eight kilometres (five miles) per hour on the line between Edinburgh and Glasgow, but the truth of this assertion is as little proved as Page's advertisement, in 1850, of a motor capable of producing work amounting to five horse-power.

A large number of motors invented since Page's experiments are described in Du Moncel's *Exposé des Applications de l'Électricité*. These motors only present a purely retrospective interest. In reality, none of them has produced work exceeding four kilogrammetres; they must be considered as electrical toys, for most of them only produce a fraction of a kilogrammetre.

Nowadays electric motors are employed under conditions much more favourable for their effective working. Thus, for instance, motors with reciprocating motion have been justly discarded, as they were not fitted for great speed. All modern electric motors are rotating. We take as a type Marcel Deprez's motor, which, for the production of small forces, has given very satisfactory results, considering its weight and its dimensions.

Marcel Deprez's Electric Motor.—The apparatus represented in Fig. 152 is nothing but a Siemens' bobbin B moving between the arms of a magnet. By placing the bobbin longitudinally between the arms of the magnet, instead of placing it transversely as Siemens has done in his machines, Deprez utilizes all the power of the magnet, and

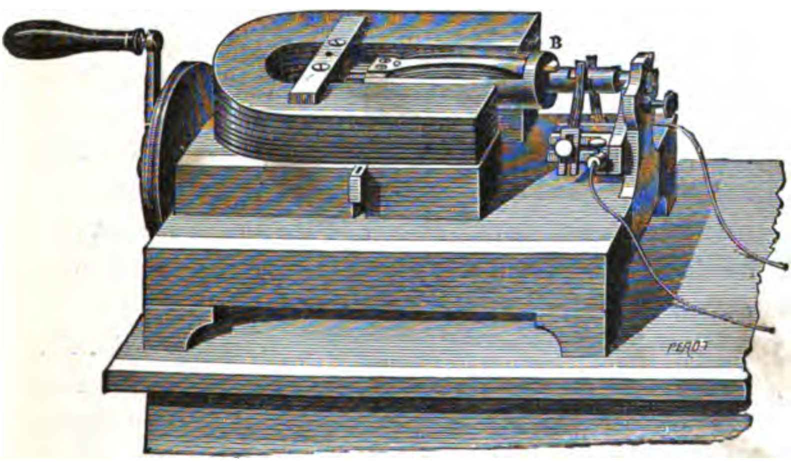


Fig. 152.—Marcel Deprez's magneto-electric motor.

makes the motor lighter and less expensive for equal power. The current of the source arrives at the contact pieces of the commutator by two brushes formed of very fine brass wire, as in Gramme's machine. The current which traverses the bobbin changes at each semi-revolution, at the moment when the poles which it polarizes pass before those of the magnet. The poles of the same name repel each other, those of contrary name attract each other, and the bobbin receives a rotatory motion depending on the sense of the passing current. The brushes are mounted on a support which can turn round the axis of the bobbin. The wedgings of the commutator and the speed of the motor can thus be changed according to the effect which it ought to produce. The model of Fig. 152 has a magnet of 1700 grammes, the bobbin weighs 400 grammes, and the weight of the complete motor is below four kilogrammes. For a speed of 3000 revolutions per minute it produces 2·5 kilogrammetres with eight flat Bunsen elements (Ruhmkorff's model). When the speed tends to become too great, a small spring, fixed by one of its ends to the wire of the bobbin and pressing with its other end against one of the contact-pieces of the commutator, is withdrawn from this contact by the effects of centrifugal force. The circuit is opened and remains open until the speed becomes normal again. In practice, the opening and closing of the circuit succeed one another so quickly that the variations of speed do not exceed $\frac{1}{100}$ of the normal speed.

Trouvé's Motor.—Deprez's motor is magneto-electric, that of Trouvé is dynamo-electric. A Siemens' coil revolves between the branches of a flat U-shaped electro-magnet. The exterior faces of the coil are slightly eccentric, which does away with the dead point. Trouvé has placed his motor on the helm of a small boat; the cords which direct the helm serve at the same time as conductors, and the current is supplied by a bichromate battery placed in the centre of the boat. The helix driven by the motor is placed on the rudder and turns with it, and the boat therefore performs its movements with the greatest ease.

Trouvé's motor has been applied by Journeaux to a sewing-machine; it is fed by three Faure accumulators.

The motor (Fig. 153) is placed vertically; its axle carries a pulley lined with indiarubber, which presses against the fly-wheel of the machine and drives it. The pressure of the pulley against the fly-wheel is regulated by means of a spring. The machine can be disconnected from the motor by means of a small square lever, which removes the motor; the contact between the pulley and the fly-wheel is broken, and the machine can be worked with the treadle. This is very useful if the accumulators are, for some reason or other, not charged. The commu-

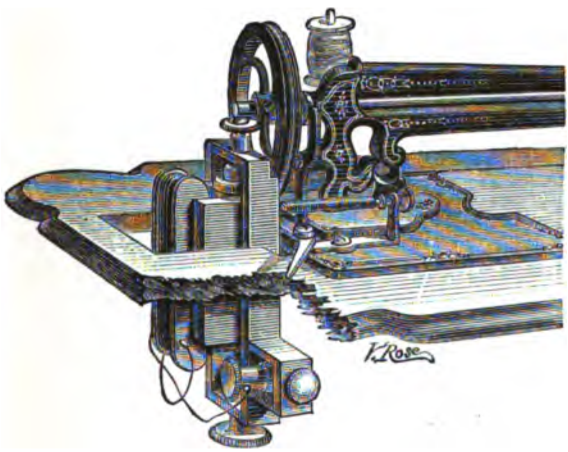


Fig. 153.—Trouvé's motor applied to a sewing-machine.

tator for setting the machine in motion or for stopping it is worked with the treadle.

The speed is regulated by exercising more or less pressure on the same treadle. This pressure produces a graduated pressure on a chain composed of a number of silver rings, which is interpolated in the circuit of the motor and of the electric source. A series of microphonic contacts is thus obtained, which, by their varying resistance, modify the intensity of the current and consequently the speed of the machine. This ingenious contrivance is due to M. E. Reynier.

Griscom's Motor.—This motor has been specially constructed for driving sewing-machines. Its length does not exceed ten centimetres, and its weight 1150 grammes.

It consists (Fig. 154) of a Siemens coil revolving between the two poles of an annular electro-magnet with consequent

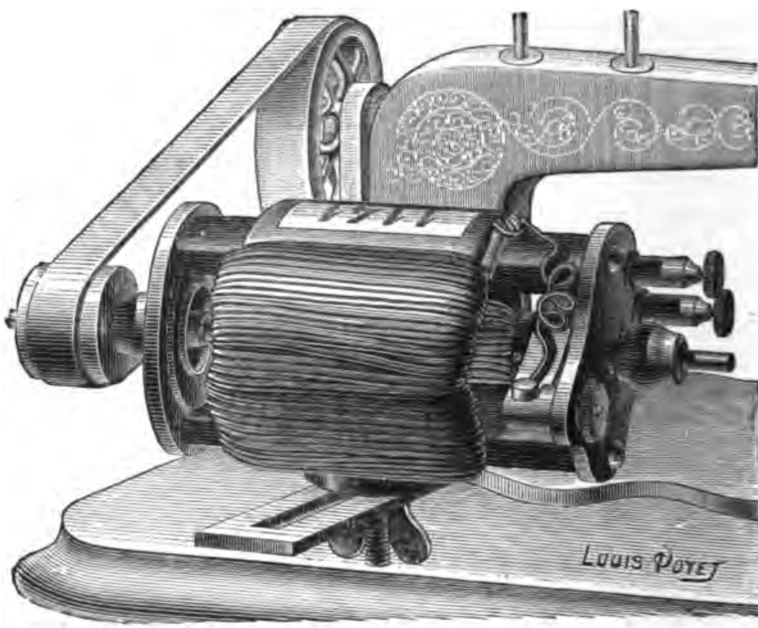


Fig. 154.—Griscom's electro-motor.

points; it is thus entirely enclosed in the inductor which protects it. All the pieces are of malleable cast iron, which has as feeble a coercive force as soft iron. This motor can easily be fixed on all existing machines by means of a small straight or square support, and a small screw-nut placed at the bottom.

The electric generator employed by Griscom is a bichromate battery of six elements. The speed of the motor is regulated by immersing the elements more or less into the liquid, by means of a pedal placed on the side of the box which contains the elements; a single charge is sufficient, according to Griscom, to do from 500 to 1000 metres of sewing, within a fortnight or six months of charging, at irregular intervals.

It would lead us too far afield to describe all the small motors which figured at the Paris Electrical Exhibition. The development of their applications seems to us altogether subordinate to the distribution of electricity.

Motors with Siemens' coil and their various modifications are very serviceable where inexpensive machines of feeble intensity are required. They, however, present a drawback which limits their employment to small forces. In these motors, the current supplied by the electric source is not continuous: it is interrupted at the moment when the current changes its direction in the coil; and likewise if the ferrules of the commutator are in very close proximity, a direct communication is established by the brushes at each semi-revolution, thus short-circuiting the electric source and increasing the expense at the very moment when it produces no work. In either case, the discontinuity of action is unfavourable to the efficiency, and all the motors we have described are therefore inferior, as regards their efficiency, to electro-dynamic machines acting as motors.

Gramme's Motor.—The field-magnets of the motor shown in Fig. 155 are flat, and the whole machine is very simple and of easy manipulation. It can be used as a light-machine as well as an electro-motor.

Reversibility of Electro-Dynamic Machines.—It is well known that, when an electro-dynamic machine is set in motion, it produces an electric current. Inversely, if a current passes into an electro-dynamic machine, it is set in motion.

In the first case work is transformed into electricity,

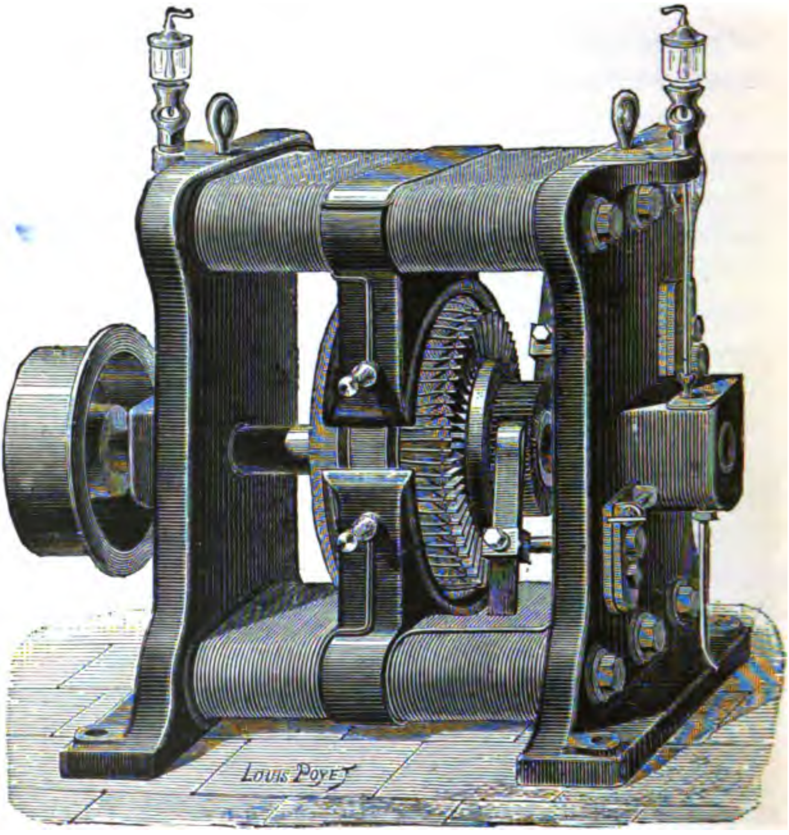


Fig. 155.—Gramme's electro-motor.

and in the second electricity is transformed into work. This fact is expressed by saying that electro-dynamic machines are reversible. It follows from this that, since dynamos with Gramme's ring produce continuous currents, they also expend a continuous current, and will be under the most favourable working conditions when supplied with a continuous current by the electrical source.

The principle of reversibility, introduced by Carnot, has not only simplified the electrical transmission of force to a distance, but has also rendered the methods infinitely more economical; there has hardly been time yet to appreciate these advantages.

CHAPTER II.

ELECTRICAL TRANSMISSION OF ENERGY.

It was again the Paris Electrical Exhibition which showed that electricity, contrary to a prejudice which had long prevailed, is eminently fitted for the production and transmission to a distance of mechanical work of any magnitude. A single instance will show the vast import of this application, which must ere long produce as great a revolution in industrial pursuits as the application of steam as a motive power produced years ago. Let us suppose a large natural source of energy to be available at a distance, say of fifty miles, from London. A number of electric generators are driven on the spot by this source, and the current produced by the generators is transmitted, by means of a cable, to the point in London where the motive force is to be consumed. At that point, another dynamo receives the current transmitted by the cable and supplies the motive force required. This is no longer one of "all the wonders that would be"—no longer a mere promise held out for the future; the problem has been actually solved by Marcel Deprez. Many were the sneers and great was the commotion when Marcel Deprez first made, two years ago, the startling assertion that—

It is possible, with two identical machines of type C, to transmit an available work of ten horse-power to a distance *of fifty kilometres, by means of an ordinary telegraph wire, the initial motive force being about sixteen horse-power.*

He evolved his theory from strictly mathematical premises, and has repeatedly proved its correctness by experiments within the last twelve months.

The vast importance which naturally attaches itself to this subject will justify us in giving a full account in Mr. Deprez's own words of the theoretical considerations which led him to this important result. Only the simplest physical principles and elementary algebraical formulæ will be employed in the demonstration, which the reader will easily be able to follow.

We must first of all explain what is meant by the term "energy:" it means work in all its forms. Strictly speaking, work is not energy, but is rather the process by which energy is transmuted, amount of work being measured by the amount of energy transmuted. Whenever work is done, it leaves an effect behind it, in the shape of energy of some kind or other, equal in amount to the energy consumed in performing the work, or, in other words, equal to the work itself. It is well known that all physical phenomena can be estimated in units of work—for instance, in kilogrammetres; chemical actions, calorific changes, etc., can be expressed in that way. The following important law can be deduced from these measurements:—Given a certain quantity of energy in measurable form, such as work employed for driving an electric generator, this work can be used, either totally for producing energy of a definite kind—such as heat, for instance—or for producing at the same time different forms of energy, such as heat, chemical action, motion; in any case, the sum of the energies produced is equal to the work expended. This is the well-known principle of the conservation of energy, which, after all, is nothing but a direct consequence of the laws of rational mechanics.

Definitions and Principles.

I. *Definition and Measurement of the Intensity of a Current.*

In the first volume of this book a short account is given of electrical measurements, which we will repeat and enlarge here, for the convenience of the reader and the better understanding of the subject to be treated.

We will first examine what is called *intensity*.

Amongst the actions which are produced on the passage of a current, chemical action has to be specially considered. The simplest examination shows that it is a function of the intensity of a current; we find it is produced more or less energetically according to the variations of this intensity. Without here precisely defining the relation between chemical action and intensity, it is evident that, to equal chemical actions, correspond equal intensities, and *vice versâ*. This phenomenon was the first which served as a mode of measuring electricity, and so it ought to have been, considering that chemical action was the first generator of dynamic electricity.

Faraday's Laws.—1. The laws which govern electro-chemical action were discovered by Faraday. The first of these laws is contained in the following proposition:—Given a circuit traversed by an electric current, whatever may be the nature and the arrangement of the successive conductors which enter into this circuit, the chemical work, and consequently the intensity—that is, the quantity of chemical action and of electricity—in unit of time is the same at all points.

2. This law is proved in the following way:—In the circuit of an electric battery are placed, one after another, a certain number of voltameters, unequal in dimensions as well as in conductivity (this latter condition can be obtained by acidulating more or less the water which they contain); in spite of these differences, the quantity of gas generated in each of them, in unit of time, will be the same.

3. The chemical work is the same, not only in the apparatus placed in the circuit, but also in the battery itself. To prove this, a battery is constructed by placing in acidulated water two plates, one of zinc, the other of platinum, this latter being covered with a bell-jar full of the water. On using this battery as a generator, the hydrogen will be given off at the platinum electrode in precisely the same quantity as that given off in the jars of the voltameters placed in the circuit; the battery, therefore, acts like any other apparatus subjected to the action of the current—the chemical action and the intensity at that point of the circuit where it is placed are the same as at any other point.

4. The experiment may be carried further still by using as generator a very interesting instrument—Grove's gas battery. This is a veritable voltameter whose bell-jars are respectively filled with hydrogen and oxygen. On joining the platinum wires immersed in these jars, a current is obtained. If a circuit is formed with a certain number of elements of this battery and a smaller number of voltameters, we find that the quantity of gas absorbed in each element of the battery is equal to the quantity which is given off in each of the voltameters. If, then, a certain

number of elements are withdrawn from the battery so as to give preponderance to the voltameters, these latter will, in their turn, become current-generators, and the action will recommence in an inverse sense. The quantities of chemical work produced in the same circuit are therefore always equal, whatever may be the locality or the direction, that is to say, whether they are positive and employed to create the current or negative and produced by current action.

5. The chemical action is proportional to the intensity of the current. To prove this, we place at one point of the current a voltameter V (Fig. 156); at another point we

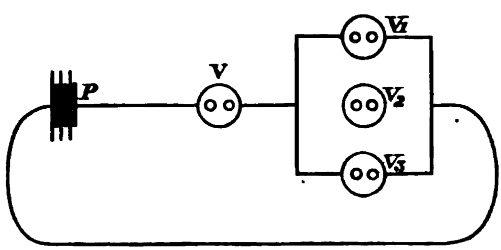


Fig. 156.
(*From La Lumière Électrique.*)

divide the current into three branches, on which we place three perfectly identical voltameters, V_1, V_2, and V_3; the current at this latter point is divided into three shunts of equal intensity, and which will each represent one-third of the total intensity. In each of the voltameters which receive the shunted currents the quantity of gas formed will be exactly one-third of that which is given off in the voltameter through which the whole of the current passes. This proves the law.

We have hitherto assumed that, throughout the whole extent of the circuit, only one and the same chemical reaction took place—that of oxygen on hydrogen, which, in our experiments, is active in one sense and passive in another. The law is true in the case where the current produces at the same time several different reactions; the weights of the chemical compounds which are formed in the battery and the weights of those which are decomposed by the current are then no longer equal, but proportional to the chemical equivalents of the bodies which take part in the action. Since batteries are generally used where the dissolved substance is zinc, this law, which is called "the law of electro-chemical equivalents," may be enunciated in these terms:—

In a circuit where a current produces various chemical actions, there are as many equivalents of zinc dissolved in each of the elements of the battery as there are equivalents decomposed in each of the electrolytical apparatus, the elements and the apparatus being placed in tension in the same circuit.

II. *Definition and Measurement of Electro-motive Force.*

The cause which sets the electricity of the circuit in motion is called the *electro-motive force.* It can be simply and clearly estimated by the number of battery elements employed, if these elements are placed in such a way as to be joined for action in one single circuit; they are then, according to the usual phrase, joined in series, or in tension.

Tension is a special attribute of electricity, and indicates a state of accumulation. Coulomb has studied its laws for static electricity; accurate experiments show that these laws are equally applicable to dynamic electricity: by the help of very sensitive apparatus we find, at different points of a circuit, tensions analogous to those which are to be met with in static electricity, only much more feeble. If we take, for instance, a Daniell element, with open circuit, we find between its poles the largest difference of electric tension this battery can produce; this difference of tension is then equal to what we call the electro-motive force of the battery. This electro-motive force is only known to us from the differences of tension which it produces, and which serve for its measurement. If the two poles of the battery are connected to earth, by following the wire which starts from one of them, tensions will be found which go on decreasing from the pole to earth, where the tension is zero. In this case we say, according to a modern term, whose mathematical signification expresses a perfectly definite function, that the different points of the circuit are at decreasing potentials; and the difference of potential can be determined by taking, for instance, as unit the potential of the battery with open circuit—what we call the electro-motive force of the Daniell battery. Electrical movement, or in other words, a current, can only exist between two points when there exists between them a difference of potential; we could not realize its existence between two points in the same electrical state, any more than we could conceive a current of liquid between two points situated at the same level. From this is deduced a direct means for measuring the difference of potential between two points.

Let us suppose that between the points M and N (Fig. 157), situated in the circuit A B, a current passes in the direction A B. Let us take between M and N a shunt circuit, M P N, in which we place some apparatus G for indicating the passage of a current. It will immediately show an action resulting from a shunt of the main current which flows in the direction M P N. We then interpolate in the circuit, at P, some Daniell elements tending to cause a current of inverse sense to flow through M P N, and we increase the number of these elements until there is no longer any current at G; then the battery current destroys the shunted current, that is to say, its electro-motive force exactly balances the difference of potential between the points M and N: it is therefore equal to it, and gives its measurement.

Now that we possess the means of measuriug an electromotive force, or difference of potential, we shall be able to

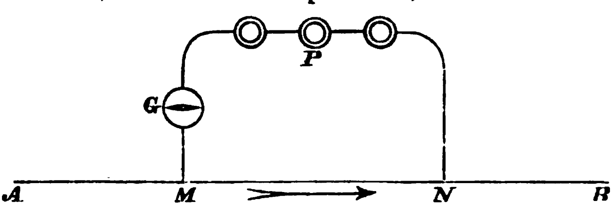


Fig. 157.
(*From La Lumière Électrique.*)

examine how a current varies according to its special conditions.

III. *Definition and Measurement of Resistance.*

In the circuit of a battery let us place a voltameter connected with it by a metal wire of known length; a certain volume of gas will be generated per minute. If we increase the length of wire between the two apparatus, the quantity of gas generated in unit of time will be diminished; and the same will be the case if we diminish the diameter of the wire: the opposite will take place if we shorten it or increase its section. The bodies through which the current flows constitute so many obstacles which vary its intensity; according to their dimensions and their nature, they act as more or less energetic *resistances*, and there is a certain relation between intensity, electro-motive force, and resistance.

1. Ohm has proved, by mathematical calculation, that this relation is the following:—

$$I = \frac{E}{R};$$

I representing the intensity, E the electro-motive force of the battery, R the total resistance of the circuit. We say "total," because it comprises, not only the resistance of the wires and the apparatus, but also that of the batteries. The batteries are, in fact, not distinct from the remainder of the circuit; they form an initial point; but for chemical action as well as for resistance they come under the general law and must count in the sum of resistances. We shall, however, for the sake of simplicity, neglect this resistance, which is called internal resistance, and only count the external resistance.

2. Ohm's law is more general than we have stated; it applies not only to an entire circuit, but to a portion of it, and then we get the equation—

$$I = \frac{e}{r};$$

I representing the intensity; e the difference of potential at the two ends of the circuit, measured as we have indicated above (§ II. 1); and r the resistance of this portion.

Œrsted's discovery of the action of a current on a magnetized needle has enabled us to demonstrate the existence of currents, and to measure them by phenomena more convenient than the chemical actions which we have used as a standard; and we will suppose that henceforth these apparatus, known under the general name of galvanometers, are always employed.

Special units have also been adopted for electro-motive force, resistance, and intensity, and are now in general use. We cannot enter here upon their precise definition, and must content ourselves with just giving their names and approximate value.

3. The unit of tension, or electro-motive force, is the *volt.* Its value is about 0·95 of the electro-motive force of a Daniell element.

The unit of resistance is called an *ohm.* It is represented by the resistance of a column of mercury of 1·05 metre in length, and of a section of one millimetre square; it is also approximately equivalent to the resistance of forty-eight metres of copper wire of one millimetre diameter.

The unit of intensity has received the name of *ampère.* It is an intensity capable of precipitating about four grammes of silver per hour.

According to Ohm's law, stated above, there is between these three units a relation which can be expressed in the following way:—

$$\text{Unit of intensity} = \frac{\text{Unit of electro-motive force}}{\text{Unit of resistance.}}.$$

TRANSPORT OF ENERGY.

IV. *Transport of Chemical Energy.*

Having established these preliminaries, we can now pass on to the study of the transport of chemical energy.

1. When we employ an electric battery for producing chemical action, there are necessarily actions of different sense—positive in the battery where they give rise to a current, negative in the apparatus where this current produces electrolytical decomposition. On referring to § I. 1, 2, 3, it will be found that these actions are equal at all points of the circuit, and in all the active elements, whatever may be their nature.

Let us more particularly consider the experiment in § I. 4, where some Grove gas batteries, arranged in tension, decompose the water of the voltameters. Let N be the number of Grove batteries, and n that of the voltameters. These two series of similar apparatus give rise to electro-motive forces of contrary sense. According to the definitions given in § II., the electro-motive force of an element being P, that of the N gas batteries will be NP, and that of the n voltameters nP; the ratio of these forces is—

$$\frac{nP}{NP}$$

or

$$\frac{n}{N}.$$

The chemical action being the same at all points of the circuit, there will be as much gas consumed in each of the elements of the gas battery as will be produced in each of the voltameters. If we call Q the volume produced in unit of time, the gas batteries will have absorbed NQ, whilst the voltameters will have furnished nQ. The ratio of these numbers $\frac{n}{N}$ expresses the proportion between the available work produced and the work expended; it will be seen that it is equal to the ratio of the positive and negative electro-motive forces. This number is what we call the efficiency of the apparatus; it expresses the necessary expenditure for the production of a certain amount of work.

It is evident that this number varies according to special arrangements. If we wished, for instance, to have this ratio equal to 1, we should have to make $n = N$, but in that case, the direct and inverse electro-motive forces being equal, there would be no work at all. If, on the contrary, we increase N in proportion to n, the work produced becomes more and more expensive. It is true that it is effected more and more rapidly, and that the quantity obtained in unit of time goes on increasing in proportion as the efficiency diminishes. We must not lose sight of the fact that, on account of the resistance of the circuit, there is always heat produced on the passage of the current; that portion of the work produced by the battery which is not recovered in the form of available work is expended in producing heat.

In the preceding calculation, the distance separating the active and passive apparatus, or the resistance of the circuit representing this distance, has not been taken into account. We have now to consider its influence.

Let us estimate the work expended and recovered. We have just stated that, on calling Q the quantity of gas collected in a voltameter or expended in a battery element, the available work was nQ, and the work expended NQ; but we know that the chemical action is proportional to the intensity (§ I. 5); therefore Q is proportional to I, and the work is proportional to NI. Now, we know I through Ohm's law—it is equal to the electro-motive force divided by the resistance. The electro-motive force in this current, where we have two opposite forces, will be the difference of these two forces, and is represented by NP — nP; the work expended in the battery is therefore—

$$N\frac{NP - nP}{R};$$

the work recovered—

$$n\frac{NP - nP}{R}.$$

Their ratio is, as we have seen, $\frac{n}{N}$; it is therefore independent of the distance. The value of both the work expended and recovered, on the contrary, depends on the distance, and if we vary it without changing anything in the arrangements of the system, the values of both + and — work will vary with it.

Under certain obtainable conditions, this will not be the case. In fact, the absolute chemical work produced in unit of time, as well as the efficiency, remain invariable, whatever may be the distance, provided the direct and inverse electro-motive forces vary in proportion to the square root of the resistance of the circuit.

To prove this, let us again take the preceding experiment (§ I. 4). In this experiment, the intensity of the current resulting from the difference of the opposite electromotive forces NP and nP was—

$$\frac{NP - nP}{R};$$

R representing the resistance of the circuit. The value of the efficiency was $\frac{n}{N}$. Let us suppose the distance, and with it the resistance, to become, for instance, twenty-five times as large, and instead of N and n elements, let us introduce in the circuit, according to the law we have stated, 5N gas batteries and 5n voltameters, 5 being the square root of 25. The intensity of the current will now be—

$$\frac{5NP - 5nP}{25R};$$

or

$$\frac{NP - nP}{5R}.$$

It will therefore be five times smaller than the preceding one; the chemical actions will therefore be, in each of the elements, five times less energetic; but, as there are on each side five times more elements than before, the total quantities expended and produced in unit of time, as well as their ratio, will remain the same.

These different theorems, established on the action of gas batteries, are applicable to every kind of chemical work; the quantities expended or recovered will cease to be identical; but, in virtue of the law of electro-chemical equivalents, they will not cease to be proportional to the same numbers, and the results will be the same.

Before summing up the conclusions to be drawn from these various theorems, a preliminary remark is necessary. We have found that the total positive and the available negative work are proportional to the quantities NI and nI, where I represents the intensity, N the number of positive and n the number of negative elements. It follows from this that the two kinds of work are likewise proportional to NPI and nPI, P being, as before, the electro-motive force of a battery element. NP then expresses the total positive electro-motive force, which we will call E; nP the total negative electro-motive force, which we will call e; and the expressions for the two kinds of work become EI and eI. These expressions, which are more general, give the measure of the work: EI is the measure of the total chemical work expended, eI the measure of the available chemical work produced.

And now we can state in a general way the conclusions to which we are led.

1. *The positive chemical work, representing the total work expended, is expressed by* EI; *for a given intensity it is therefore proportional to* E.

2. *The negative chemical work is expressed by* eI; *for a given intensity it is therefore proportional to* e.

3. *The efficiency is equal to the ratio between the negative electro-motive force and the positive electro-motive force.*

4. *The chemical work expended, the available chemical work, and the efficiency, remain constant, whatever may be the distance of transport, provided the positive and negative electro-motive forces vary in proportion to the square root of the distance.*

V. *Calorific Actions—Joule's Law.*

Production of heat is the inevitable consequence of the passage of an electric current. Joule has proved by experiment that the quantity of heat generated in a circuit is expressed by the equation—

$$Q = I^2R;$$

Q being the heat produced, I the intensity of the current, R the resistance of the circuit, provided there is no other external work done.

This remarkable law is a consequence of Faraday's law (§ I. 1), and of the law of the conservation of energy, as we shall show.

Let us first remark that, in a circuit where the current is entirely used for the production of heat, the heat produced is proportional to the total quantity of zinc dissolved in the battery; this heat being only the equivalent of the chemical potential energy expended.

If we now take a number of circuits, and in a first series maintain the resistance constant while varying the intensity, we find from Ohm's and Faraday's laws—remembering at the same time that the total quantity of zinc dissolved is equal to the product of the number of elements by the quantity dissolved in each—that the total quantity of zinc dissolved, or the heat produced, is proportional to the square of the intensity of the current.

In a second series we vary the resistance and keep the intensity constant, and find that the quantity of zinc dissolved is proportional to the resistance.

By combining these two results, it will be seen that, in circuits where resistance and intensity vary at the same time, the quantity of zinc dissolved and the heat produced are proportional both to the resistance and the square of the intensity, or to the product of these two numbers; and this brings us back to Joule's law, $Q = RI^2$. Substituting the value of I from Ohm's law, we get—

$$(a) \qquad Q = RI^2 = \frac{E^2}{R} = EI.$$

This equation, which applies to the totality of a circuit, is a special case of a more general formula. If we consider any portion of a circuit, of resistance r and difference of potential e at the commencement and end of the circuit (§ II. 2), the quantity of heat generated in this portion of the circuit is likewise expressed by the equation—

$$(b) \qquad q = rI^2 = \frac{e^2}{r} = eI.$$

It will be seen that no special notation is required for the intensity I; it is the same in a portion of the circuit as in the total circuit.

VI. *Transport of Calorific Energy.*

For the electrical transmission of calorific energy, an electric circuit must be constituted, and the heat generated at one point of the circuit must be collected and utilized. For instance, in a circuit of total resistance R, traversed by a current of intensity I, we take a special portion of the circuit of resistance r, and utilize the heat generated in it. Now, we know that the work expended is equivalent to the heat generated in the useful portion, and thence find the value of these two quantities. In fact, if we call E the electro-motive force of the battery, we have (§ V. a)—

$$Q = RI^2 = EI = \frac{E^2}{R};$$

and also, if we call e the difference of potential at the extremities of the useful circuit, we have (§ V. b)—

$$(c) \qquad q = rI^2 = eI = \frac{e^2}{R}.$$

The ratio of these two works, that is, the efficiency, is $\frac{r}{R} = \frac{e}{E}$.

The first expression, $\frac{r}{R}$, is of great practical value, because it enables us immediately to constitute a circuit of the required efficiency. It is clear that the available resistance must be as large as possible in proportion to the total resistance.

If we wish the available work q as well as the efficiency

$\frac{r}{R}$ or $\frac{e}{E}$ to remain constant, whatever may be the resistance, or, in other words, whatever may be the distance of transport, Q must also remain constant, and $\frac{E^2}{R}$ must be constant; that is to say, E must vary proportionately to the square root of R, but as $\frac{e}{E}$ is constant, e must vary in the same proportion.

We obtain, therefore, for calorific energy as well as for chemical energy, the following laws:—

1. *The positive calorific work, representing the total*

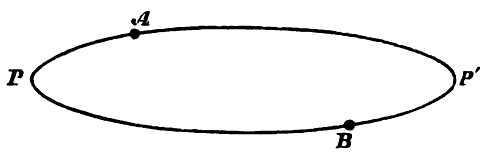


Fig. 158.
(*From La Lumière Électrique.*)

expended work, is expressed by EI; *for a given intensity it is therefore proportional to* E.

2. *The negative calorific work is expressed by* eI; *for a given intensity it is therefore proportional to* e.

It must be remarked here that a difference of potential is not a distinct quantity of what we call electro-motive force.

In fact, in a closed circuit P A P′ B (Fig. 158), if we only say that there is between the points A and B a difference of potential e, it is impossible to determine *à priori* in which direction the current will flow, nor whether this difference of potential is due to a positive electro-motive force placed at P, or to a negative electro-motive force placed at P′, or to a combination of both; the difference e between A and B is in itself, so to speak, what we call an electro-motive force, the only difference between them is that of cause and effect. In reality, we do not know the electro-motive force, although we must continue to use this convenient term; in calculation we only admit a difference of potential.

Consequently, in the law which we have just formulated in § V. 2, the difference of potential is nothing but a negative electro-motive force, and this law, although expressed differently from the one we have found for chemical action, is still the same.

3. *The efficiency is represented by the ratio of the negative difference of potential and the positive electro-motive force.*

4. *The expended calorific work, the available calorific work, and the efficiency, remain constant, whatever may be the distance of transport, provided that the positive electro-motive force and the negative difference of potential vary proportionately to the square root of the total resistance of the circuit.*

VII. *Transport of Mechanical Energy.*

In the preceding paragraphs we have had to estimate the work produced in the circuit of an electric current, and we found, both in the case of chemical energy and calorific energy the same expression for the quantity of work produced, $Q = EI$. We are now going to show that this formula is absolutely general.

Let us consider (Fig. 159) a circuit in which are placed a battery P of a certain number of elements n, a galvanometer G for measuring the intensity of the current, and moreover, between the points H and B, a series of apparatus

c, c', c'', expending the current, either in heat, or in chemical action, or in mechanical work. Under these conditions, the current has an intensity I indicated by the galvanometer, in each battery element a quantity of zinc Z is consumed, and consequently a quantity nZ in the whole battery.

Let us now suppress the apparatus c, c', c'', and replace them by a simple wire H D B, whose length we vary until the current is brought back to its original intensity I. The electro-motive force has remained E, the quantity of zinc dissolved per element is always Z, and the total quantity nZ; the total quantity of energy produced, which is

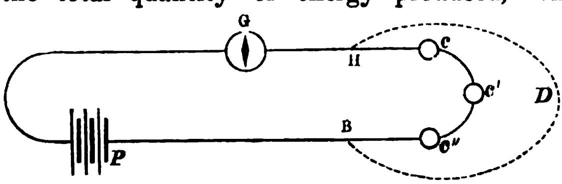


Fig. 159.
(*From La Lumière Électrique.*)

measured by the quantity of zinc consumed, has not been altered. Now, in the circuit P H D B, we know that it is represented by EI; this expression, therefore, also gives its value for the circuit P H c c' c'' B.

Moreover, in the circuit P H D B, we can calculate from Ohm's laws the potential at H and at B, as well as their difference e, and we know that the quantity of energy which can be recovered in the circuit H D B is represented by eI. If we re-establish the circuit P H c c' c'' B, nothing is changed in the portion H P B; the potential at H and at B as well as their difference e remain the same; the portion of the total work produced in H P B has not varied either; therefore the available energy in the circuit H c c' c'' B is still expressed by eI.

We have to remark here that, if we wish to measure the work in kilogrammetres, according to the units mentioned in § III. 3, E and e must be expressed in volts, I in ampères, and the product must be divided by the quantity $g = 9{\cdot}81$. From this demonstration it follows that an active resistance can in any case be replaced by an inert resistance. The value of this resistance is easily determined: if E is the positive electro-motive force, e the negative electro-motive force, and R the resistance, we get—

$$\frac{E - e}{R} = \frac{E}{R + x};$$

and from this—

$$x = \frac{eR}{E - e};$$

by suppressing e and introducing x, the condition of the circuit is not changed.

Transport of Mechanical Work.

Let us apply these considerations to the case when, in an electric circuit, only two sorts of energy—calorific and mechanical energy—are developed.

Let us call E the electro-motive force of the electric generator which is constant, as well as all those forces which might come into play in one sense or another. If the currents were not constant, or at least approximately so, as in Gramme's, Siemens', and similar machines, the following arguments could only be applied during infinitely short periods of time, and the solution of the problem would require the employment of integral calculus.

If only the two energies mentioned are produced in the circuit, we get from the principle of the conservation of energy the following equation :—

$$EI = RI^2 + T;$$

where EI represents, as we have just stated, the total work produced; RI^2, according to Joule's law, expresses the quantity of heat produced; and T the mechanical work to be utilized. The intensity I is a variable quantity, which depends on the value of T, and therefore if $T = 0$; that is to say, if the current only produces heat, we have again $EI = RI^2$, or $E = RI$ (Ohm's law). The intensity I can be determined as a function of the other quantity by solving the following equation, which results from the preceding expression :—

$$RI^2 - EI + T = 0$$

$$I = \frac{E \pm \sqrt{E^2 - 4RT}}{2R}.$$

Let us examine the different values of I for different values of T. The expression has the double sign $\pm$; we will first take the sign $+$.

If we make $T = 0$, we find $I_0 = \frac{2E}{2R} = \frac{E}{R}$. This is, according to Ohm's law, the intensity which would be developed in an ordinary circuit without any apparatus producing mechanical work, and it is the maximum intensity which can be obtained in the given circuit.

If we gradually increase T, the value I will go on diminishing, but it will be seen that T cannot exceed a certain limit, since the quantity under the radical sign cannot become negative. The maximum of T will therefore be obtained for $E^2 - 4RT = 0$, whence $T = \frac{E^2}{4R}$. For this maximum value, the value of I will be $I_1 = \frac{E}{2R} = \frac{I_0}{2}$. The intensity corresponding to work zero is therefore reduced by one-half when this work becomes maximum.

Between these two values, the intensity I can be considered as maximum intensity I_0 diminished by a certain quantity which we can express by—

$$I = I_0 - i.$$

I_0 is, as we know, equal to $\frac{E}{R}$; we can represent the variable i by $\frac{x}{R}$, and have—

$$I = \frac{E}{R} - \frac{x}{R} = \frac{E - x}{R}.$$

It will be seen that the quantity x represents a negative electro-motive force which we will, as before, design by e, then we get—

$$I = \frac{E - e}{R};$$

a formula which we have previously obtained, in studying the transport of chemical and calorific energy.

The value of e is easily found from the equation—

$$\frac{E - e}{R} = \frac{E \pm \sqrt{E^2 - 4RT}}{2R}$$

$$e = \frac{E \mp \sqrt{E^2 - 4RT}}{2}.$$

It will be seen that the principles with which we are acquainted naturally, and without any experimental evidence, lead us to the conclusion that the presence of an electric motor in a circuit is equivalent to the presence of a negative electro-motive force—a fact with which we have been acquainted for a long time.

Let us take again the general formula $EI = RI^2 + T$. From this we get $T = EI - RI^2$; EI being the total work produced, the ratio $\frac{T}{EI}$ is the total efficiency K. And now we have—

$$K = \frac{T}{EI} = \frac{EI - RI^2}{EI} = 1 - \frac{RI}{E},$$

or

$$R = 1 - \frac{I}{\left(\frac{E}{R}\right)}.$$

Now, $\frac{E}{R}$ is nothing but I_0; therefore $K = 1 - \frac{I}{I_0}$.

We also have $I = \frac{E - e}{R}$, and consequently—

$$K = 1 - \frac{\frac{E - e}{R}}{\frac{E}{R}} = \frac{e}{E}.$$

This again brings us back to a formula which we have already previously obtained, and we find that, whatever may be the nature of the transported energy, the efficiency is expressed by $\frac{e}{E}$, or the ratio of the negative electro-motive force e developed in the production of the available work to the electro-motive force E necessary for the production of the total work expended.

We can now calculate, not only the efficiency, that is to say, the ratio of the + and − works produced, but also their absolute value.

We have in fact—

$$\text{Total work, } T = EI = \frac{E(E - e)}{R}.$$

$$\text{Work, } T_m = KEI = eI = \frac{e(E - e)}{R}.$$

$$\text{Quantity of sensible heat, calorific work, } C = RI^2 = \frac{(E - e)^2}{R}.$$

We must not lose sight of the fact that these different works are produced in unit of time, and that their expression must be divided by $g = 9{\cdot}81$ if we wish to express them in kilogrammetres.

These different values can also be expressed as a function of the efficiency $K = \frac{e}{E}$, and in that case we get—

$$T = (1 - K)\frac{E^2}{R}.$$

$$T_m = K(1 - K)\frac{E^2}{R}.$$

$$C = (1 - K)^2\frac{E^2}{R}.$$

If we wish the efficiency K, as well as the work recovered and the work expended, to remain constant, whatever may be the resistance R or the distance of transport, it is sufficient that the quantity $\frac{E^2}{R}$ should remain constant, that is to say, that E should vary as the square root of R. It is scarcely necessary to remark that, $\frac{e}{E} = K$ being constant, e must vary in the same way. And this brings us again to the law we have found before for the transport of chemical and calorific energies.

Conclusion.

The laws for the transport of mechanical energy may be thus formulated:—

1. *The positive mechanical work, representing the total expended work, is expressed by* EI; *for a given intensity, it is therefore proportional to* E.

2. *The negative mechanical work is expressed by* eI; *for a given intensity it is therefore proportional to* e.

3. *The efficiency is represented by the ratio of the negative electro-motive force to the positive electro-motive force.*

4. *The available mechanical work and the efficiency remain constant, whatever may be the distance of transport, provided that the positive and negative electro-motive forces vary in proportion to the square root of the resistance of the circuit.*

These laws are, therefore, the same for the transport of any form of energy.

It will be remembered that, in the discussion of the values of I derived from the equation $I = \frac{E \pm \sqrt{E^2 - 4RT}}{2R}$, we have only considered the different values for the sign $+$.

Let us now examine these values for the sign $-$. If we make $T = 0$, we get $I = 0$ and $e = E$. The case was the same with chemical energy; the efficiency is equal to unit, the two opposite electro-motive forces destroy each other, and nothing is produced in the circuit, neither work nor electric current.

If we increase T up to the value $\frac{E}{4R}$, which, as we know, gives the maximum, we find a series of values of I increasing to $I = \frac{E}{2R} = \frac{I_0}{E}$.

We find, therefore, that for each value of T there are two values—the one obtained for the sign $+$, the other for the sign $-$; that is to say, that a given available work can always be obtained with two different intensities, corresponding to different electro-motive forces.

MAGNETO AND DYNAMO ELECTRIC MACHINES.

Having now given a full account of the laws governing the electrical transport of energy, before proceeding to Marcel Deprez's experiments, which finally proved the correctness of these laws, we must say a few words on the theory of magneto and dynamo electric machines, by means of which this transport is effected.

We must, first of all, give a definition of several terms we are going to use.

Both the terms "magnet" and "magnetic action" are known to everybody, and require no explanation.

We call a "magnetic field" a region subject to magnetic action; the intensity of a magnetic field at a given point can be measured by the deflection of a magnetized needle placed at this point. The position taken up by this needle indicates the direction of the resultant of the magnetic actions at this point, and the lines along which the needle sets are called "lines of force."

Magneto-Electric Induction.—If a conducting wire moves in a magnetic field, it will be traversed by an electric current during the whole time of movement, and the direction of the current depends on the nature of the current and the direction of movement of the wire.

1. The electro-motive force in each element of the magnetic field is proportional to the length of this element.

2. It is proportional to the velocity of movement reckoned perpendicularly to the lines of force of the magnetic field.

3. Lastly, it is proportional to the intensity of the field.

Inversely: 4. If a current is made to pass through a wire placed in a magnetic field, this wire will be urged in a contrary direction to the one in which it would be necessary to move it to obtain the same current by the inductive action of the field.

These are, in a few words, the laws governing magneto-electric induction. Electric generating machines utilize this phenomenon. They are, to all intents and purposes, apparatus constructed with the view of rotating, in as rapid and continuous a manner as possible, a conductor or a series of conductors in one or several magnetic fields and of collecting the currents thus produced.

The magnetic fields in these machines can be due either to a permanent magnet, and the machine is then called magneto-electric; or to an electro-magnet, and the machine is then called dynamo-electric. In this latter case, the current which produces the magnetization of the electro-magnet can be derived from an external source, and the machine then acts like a magneto-electric machine; or else, and this is more frequently the case, the magnetization can be produced by the current of the machine itself, and the intensity of the magnetic field then depends on the action of the machine alone.

Let us assume that we have a machine which gives currents that can be considered constant. In every case the machine comprises a system, either of magnets or of electro-magnets, producing a magnetic field, and this system we know under the name of "inductors," or "field-magnets." In this field revolves a movable piece in the shape of a ring or a coil, carrying the conductor in which the current is developed, and called the "armature;" this latter only constitutes a single conductor coiled in such a manner that its various parts pass successively and continuously through the magnetic field.

The laws which regulate the action of these machines when used as generators are the following:—

1. The electro-motive force of a given machine is proportional to the intensity of its magnetic field.

2. It is also proportional to the linear velocity with which the wires traverse this field, and consequently to the angular velocity of the revolving ring and to the distance of the wires from the centre.

3. It is likewise proportional to the number of convolutions of the wire of the armature coil.

These laws are simply the general laws of induction, and in no way depend on the previous electrical condition of the armature.

If machines are used as motors, a fourth law manifests itself.

4. The mechanical action (the product of the tangential effort by its distance from the centre) for a given machine is proportional to the magnetic field and to the intensity of the current; it is independent of the velocity imparted to the ring.

A fundamental experiment proves this law.

Let us first consider some sort of generating machine; to its ring is applied a Prony brake carrying a constant weight, so that, when the ring revolves, it is subject to a constant resistance, and gives per revolution a constant quantity of work. Now, we pass into this apparatus the current from a battery, taking care to place in the circuit a galvanometer for measuring the current which passes. If the number of battery elements is first of all small, the current will be insufficient to overcome the resistance of the brake, and the machine will not stir. By gradually increasing the number of elements, the intensity indicated by the galvanometer will increase; by a certain number of elements the machine will be set in motion, and from that moment the intensity of the current will remain constant, whatever may be the number of elements introduced in the circuit,—the speed of rotation alone will vary. A constant intensity of current, therefore, corresponds to a constant mechanical resistance, determined by the weight put on the brake, and in a general way we obtain the important result that, in a machine employed as motor, a definite mechanical resistance, and only one, corresponds to a certain intensity of current.

Let us now constitute a real transport of mechanical force—that is to say, place two machines in one circuit, the one acting as generator, the other as receiver; and let us, for simplicity's sake, suppose the two machines to be identical. The former is connected with some sort of driving engine, the latter is in connection with a tool machine or with a brake interposing a definite mechanical resistance and demanding a constant amount of work per revolution. The first machine commences its movement, gradually increases its speed, producing a gradually increasing electro-motive force and intensity up to that moment when the second machine is energized, begins to revolve in its turn, and commences to produce work. From that moment the intensity remains constant, as we have proved above, and if the speed of the first machine is increased, that of the second machine will follow suit and will increase at the same time. The two machines being identical and traversed by the same current, which is also constant, the mechanical effects produced and the work per revolution are equal,—the velocities alone are different. The work produced by the first machine is measured by the product of its velocity and of the work per revolution; the work produced by the second is likewise the product of its velocity and of the same work: the efficiency is therefore measured by the ratio of these velocities. But whatever may be these velocities, the current is constant; the resistance being constant, the difference of the electro-motive forces which produce the current must also be constant. Now, the magnetic field being the same in both machines, the respective electromotive forces are measured by the velocities of rotation; the difference of these velocities, therefore, will be constant. We know that the efficiency is measured by the ratio of the two velocities whose difference is constant, and we have, therefore, every cause for giving to our machines the highest possible speed in order to improve the efficiency.

We can, therefore, consider the transport of mechanical work by electricity as a veritable transmission by means of a visible mechanism, such as a driving belt connecting the two machines, which are supposed to have equal pulleys. *The mechanical effect is effectively transmitted in its entirety, as if there was a real connection between the two apparatus;* only the supposed belt slips, and hence a difference of velocity will manifest itself between the generating and receiving machines. The velocity of this slipping movement is constant, and the difference of velocity between the two apparatus remains constant during the whole time of work; —it depends on the quantity of electricity transmitted to the second machine.

By a numerical application of the foregoing laws, for which he took the results of some experiments made at Chatham with the Gramme machine C as his starting-point, Marcel Deprez arrived at the following conclusion:—

That it is possible, with two identical machines of type C, to transmit an available work of ten horse-power to a *distance of fifty kilometres (about thirty miles), by means of an ordinary telegraph wire, the initial motive force being about sixteen horse-power.*

We need not follow him in these calculations. We have explained all the principles and considerations leading up to the result obtained, and we are now going to give an account of the experimental proofs lately obtained by Marcel Deprez of the correctness of his views.

1. *Transport of Force between Miesbach and Munich (sixty kilometres).*—This experiment was made in October last year, at the Munich Electrical Exhibition, and we give the official report signed by the president and secretary of the committee appointed for the electro-technical department.

"By means of two dynamo-electric machines (system Gramme) M. Marcel Deprez has transported to Munich, a distance of fifty-seven kilometres, through an iron telegraph wire of 4·5 millimetres diameter, the work produced at Miesbach. The receiving machine placed in the Exhibition building (the Munich Crystal Palace) has worked during eight days a centrifugal pump which fed a cascade of about 2·5 metres in height.

"The dynamo-electric machines were first set in motion on the 25th of September, at seven p.m., and, according to the measurements taken by M. Datterer, the engineer appointed by the committee, the receiving machine at Munich revolved with a speed of 1500 revolutions per minute; the brake for measuring the work was weighted with 1·5 kilogramme.

"A series of accidents, due to the fact that the machines were constructed for laboratory experiments and not for practical use, interrupted after eight days the working of the machines, which, up to that date, had been completely satisfactory. The hoops which surrounded the ring of one of the machines broke and the wires of the ring, of 0·44 millimetre diameter, were damaged in consequence, and had to be insulated afresh. In the neighbouring hamlet of Miesbach repairs could only be executed with great difficulty, and required on the part of M. Marcel Deprez's co-operators a good deal of patience and perseverance.

"On the 9th and 10th of October, when the committee commenced to take measurements, a speed of 1600 revolutions only could be attained with the machine that had been repaired; the results attained were consequently much less favourable than they would have been with the normal speed of 2000 revolutions obtained at first.

"For a few minutes only the speed of 2000 revolutions per minute could be attained, and unfortunately, at the very beginning of the experiments one of the brushes of the machine became detached, which produced an extra current and completely destroyed the machine.

"Even under these unfavourable conditions, *the available work for the transport of energy was* 0·433 *horse-power, and* 38·9 *per cent. of the total electric work,* the speed of rotation at Miesbach being 1611 revolutions per minute, and at Munich 752 revolutions per minute."

2. *Marcel Deprez's Experiments on the Chemin de Fer du Nord.*—The length of transport in this case, between Paris and Bourget, was 8·5 kilometres; the wire had a diameter of 0·4 millimetre; the generator was a special machine constructed by M. Marcel Deprez; the receiver was a large Gramme machine modified for the purpose. The resistances of the two machines were respectively fifty-six and eighty-three ohms. In each experiment the number of revolutions of both machines were simultaneously determined every

minute, by means of special instruments. All the electric measurements were taken by Dr. Hopkinson, F.R.S., with a series of instruments invented by Sir William Thomson. The following were the results obtained:—

Generator.			Receiver.			Mechanical efficiency. — Per cent.
Speed. — Revolutions per minute.	Work expended (transmission deducted). Kilogrammetres per second.	Horse-power.	Speed. — Revolutions per minute.	Available work (recovered on the brake). Kilogrammetres per second.	Horse-power.	
553	408·9	5·45	315	131·25	1·75	32·1
571	414·2	5·52	345	144·0	1·92	34·8
580	406·5	5·42	362	150·75	2·01	37·1
596	454·75	6·06	369	153·75	2·05	33·8
608	474·4	6·32	384	159·75	2·13	33·7
633	469·83	6·26	418	174·0	2·32	37·0
646	478·4	6·33	426	177·5	2·37	37·4
662	483·2	6·44	448	186·75	2·49	38·6
705	531·5	7·08	488	203·3	2·71	38·2
741	559·0	7·45	528	220·0	2·93	39·3
754	556·0	7·41	561	234·0	3·12	42·0
767	579·5	7·72	548	228·25	3·04	39·4
792	588·3	7·85	578	240·8	3·21	40·9
806	607·9	8·10	608	253·25	3·38	41·7
814	618·0	8·24	620	257·5	3·43	41·7
876	662·6	8·83	650	270·8	3·61	40·8
883	667·3	8·90	663	276·0	3·68	41·3
910	699·0	9·32	726	302·5	4·03	43·3

These results were brought before the Académie des Sciences by M. Tresca, at the meeting on the 19th of February this year, and a committee was appointed, consisting of Messrs. Bertrand, Tresca, Coran, F. de Lesseps, and De Freycinet, to examine and report upon further experiments to be made by M. Marcel Deprez.

The experiments were made on the 4th of March, and lasted from one o'clock till six, all the members of the committee being present with exception of M. de Lesseps, who was represented by M. Mourette and M. Papinot. The mechanical efficiency obtained was nearly forty-five per cent., while the electrical efficiency rose to seventy-three per cent. The speed of rotation of the generator was 1024 revolutions per minute, and that of the receiver 797 revolutions.

There can be no further doubt that the problem of the electrical transmission of energy is successfully solved, and it is now only a question of practical application to increase the mechanical efficiency up to sixty per cent., the amount M. Marcel Deprez expects to obtain.

Of the many important practical applications of the transmission of force to a distance, we will only mention two —electric ploughing and electric railways.

Ploughing by Electricity.—A public trial of this application was made at Sermaize, on the 22nd of May, 1879. Fig. 160 represents the principal features of this interesting experiment.

Two four-wheeled trucks placed on each side of the field receive the electricity, supplied by Gramme's machines by the aid of conducting wires.

A commutator sends the electricity alternately into the two trucks. These trucks are each moved by two Gramme's machines of the type represented in Fig. 161. This machine consists of a very strong cast-iron frame, which protects all its parts against external shocks and internal dislocations. The machine has four poles and four brushes. It weighs 500 kilogrammes, and allows the transport to a distance of five to eight horse-power. Each of these machines has a pulley surrounded by a caoutchouc ring, which presses against a fly-wheel with a polished surface, and carries it along; the pressure between the fly-wheel and the ring is regulated by a spring connected with the movable supports of Gramme's machine. The trucks guide in turns one plough with four ploughshares, two of which work in one direction; the cable of steel wire which pulls the plough is wound up on one side, while it unwinds itself on the other, and *vice versâ*. When the double furrow is made, the two trucks are moved by trans-

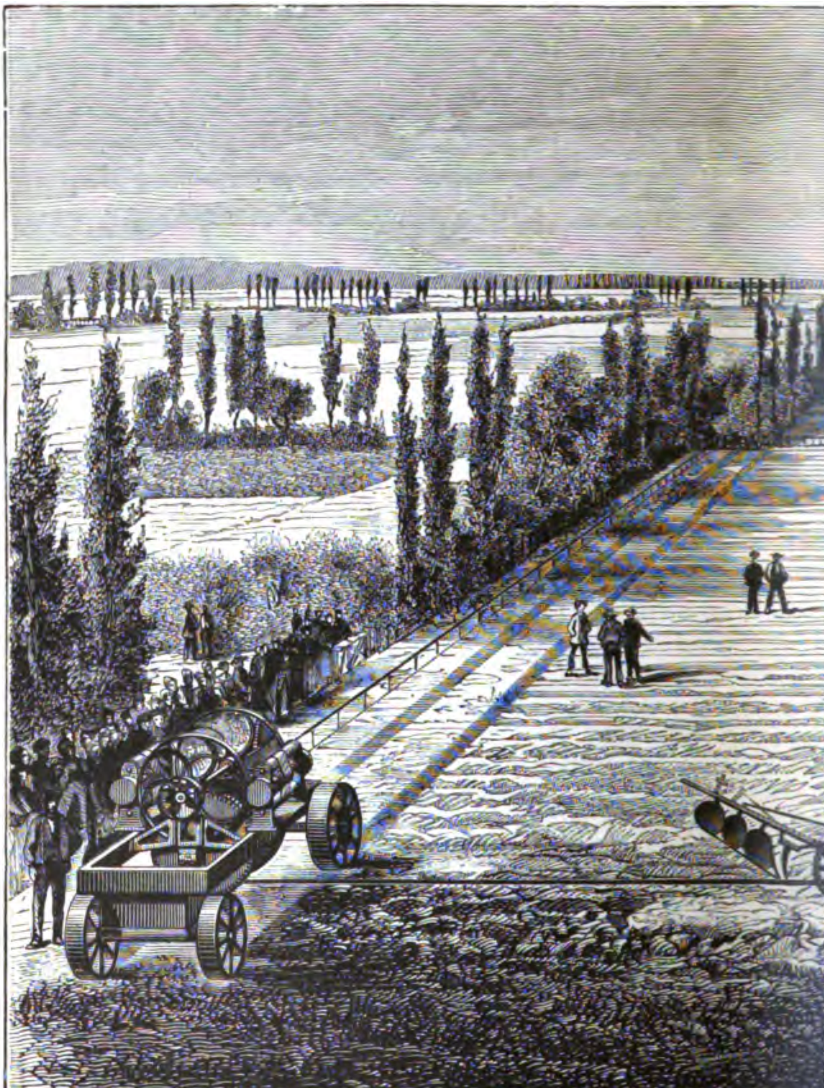
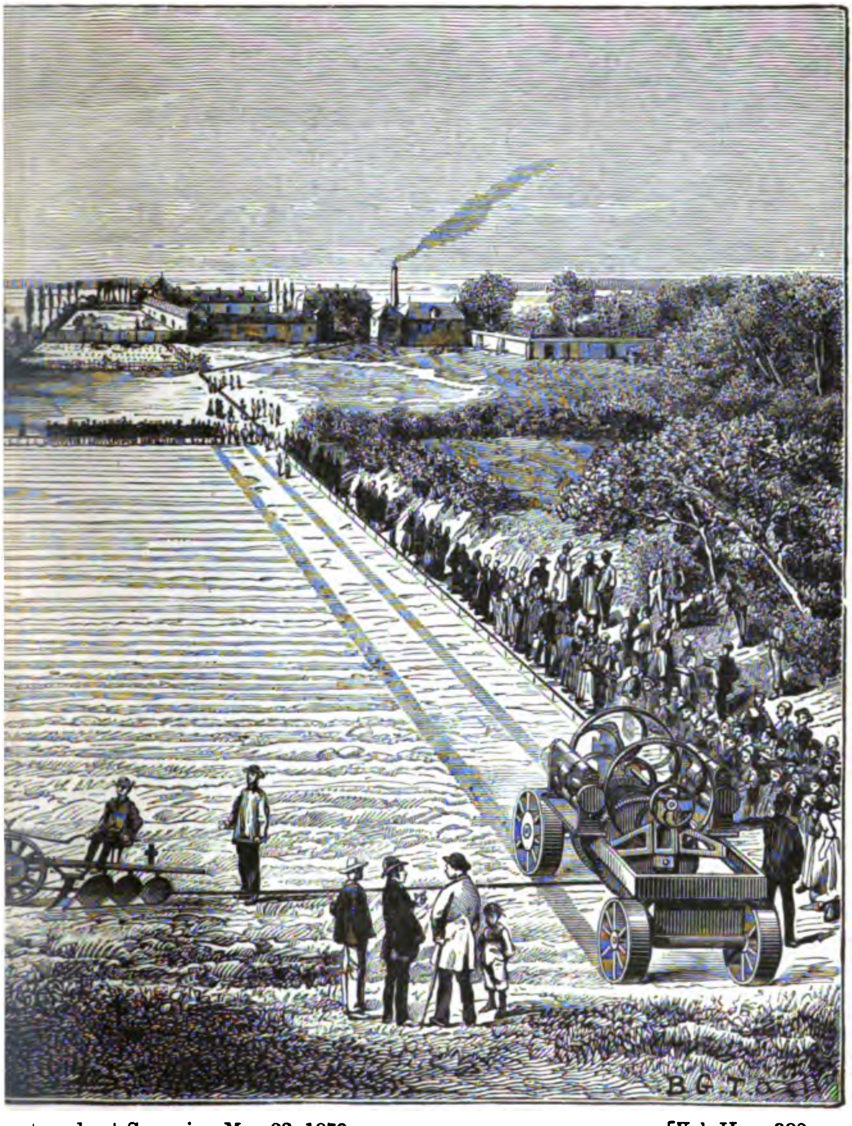


Fig. 160.—Electric Ploughing. Experi



ıent made at Sermaize, May 22, 1879.

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ferring the action of the Gramme's machines from the plough to the hind wheels of the trucks, which then take up a fresh position ready for making a fresh double furrow. This experiment proves that motive force can be transmitted to considerable distances by electricity.

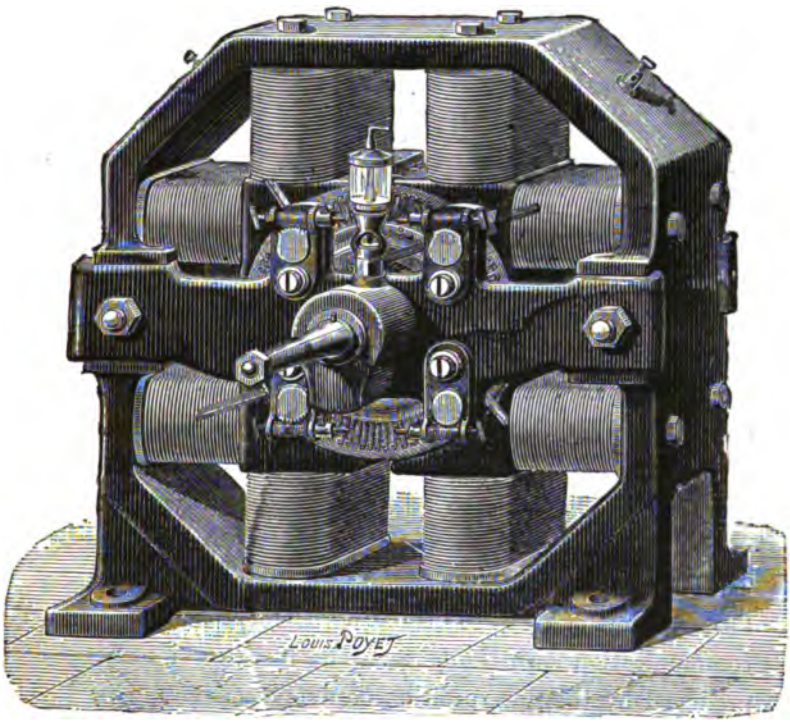

Fig. 161.—Gramme's electro-motor.

This application will prove most advantageous where an inexpensive motive force is supplied by water-power, as is the case in Menier's electrical works, at Noisiel. The available mechanical work can, under these conditions, be utilized for ploughing and other kinds of agricultural labour. In the neighbourhood of certain factories—sugar refineries, for instance—where steam-engines stand still for a great part of the year, it will be most advantageous to use electrical ploughs to utilize the engines. In cases where special machinery is required, the advantage seems to us very problematical.

Electric Railways.—Electric railways entirely depend upon the distribution of electricity by means of convenient electrical centres. The experiments made in 1879 at Berlin, and last year at Paris, show that the question is practically solved; in fact, an electric railway has lately been established at Berlin.

The problem was completely solved at the Paris Electrical Exhibition by MM. Boistel and Sappez, the engineers of Messrs. Siemens. In the preliminary experiments made at the workshop in the Rue Pictot, they made use, as conductors, of a brass tube electrically connected with the carriage by a traverser, the function of which we shall explain; the wheels and rails will serve as return wire. This system worked well at the workshop. In practice a special difficulty was encountered. The dirt sticking to the rails and felloes of the wheels formed a sort of crust so insulating as to prevent adequate communication with the earth. The increase of resistance produced by this interposition of finely conducting bodies was often sufficient to arrest the vehicle. The remedy was happily beside the evil, and a second conductor was established parallel with the first, in communication with the second pole of the generator, on which runs a second traverser identical with the former. These two cars follow on their respective tubes the movements of the vehicle, and ensure a good and constant communication between the electrical generator and the motor. At the height of the knife-board are two conducting tubes supported at certain distances by posts, and in the intervals by iron wires like the floor of a suspension bridge. The carriage is exactly the same as the ordinary tramway car. The motor is placed underneath the feet of the inside passengers; it is a Siemens dynamo-electric machine with horizontal inductors. The distance traversed was about 500 metres, and was accomplished in one minute. The work expended reaches eight horse-power in the curved part; on a level straight run it does not exceed three and a half horse-power. The transmission of motion to the wheels is effected by means of a fall-chain. By a happy coincidence, which belongs to the very nature of the electric motor, the static effect is maximum when the motor is in repose. This renders the starting very easy, and no difficulty is met with from this point of view. To regulate the speed, resistances are introduced into the general circuit, which reduce the intensity of the current, and consequently the work of the motor; this operation is very simply effected by means of a lever placed at each end of the carriage. For stopping, the current is broken, and at the same time an ordinary brake is applied.

As to the mode of communication of the conductors with the carriage, we have said that it is effected by means of two identical traversers; it will suffice to describe one of them. It is composed of a rectangular frame, bearing in its centre a wheel, of which the groove is semi-cylindrical, and is applied against the exterior part of the conductor, formed of a brass tube twenty-two millimetres in diameter, and slit on its lower part along all its length to a breadth of about one millimetre. In this tube slides a cylindrical core twelve centimetres in length, on which are fixed,

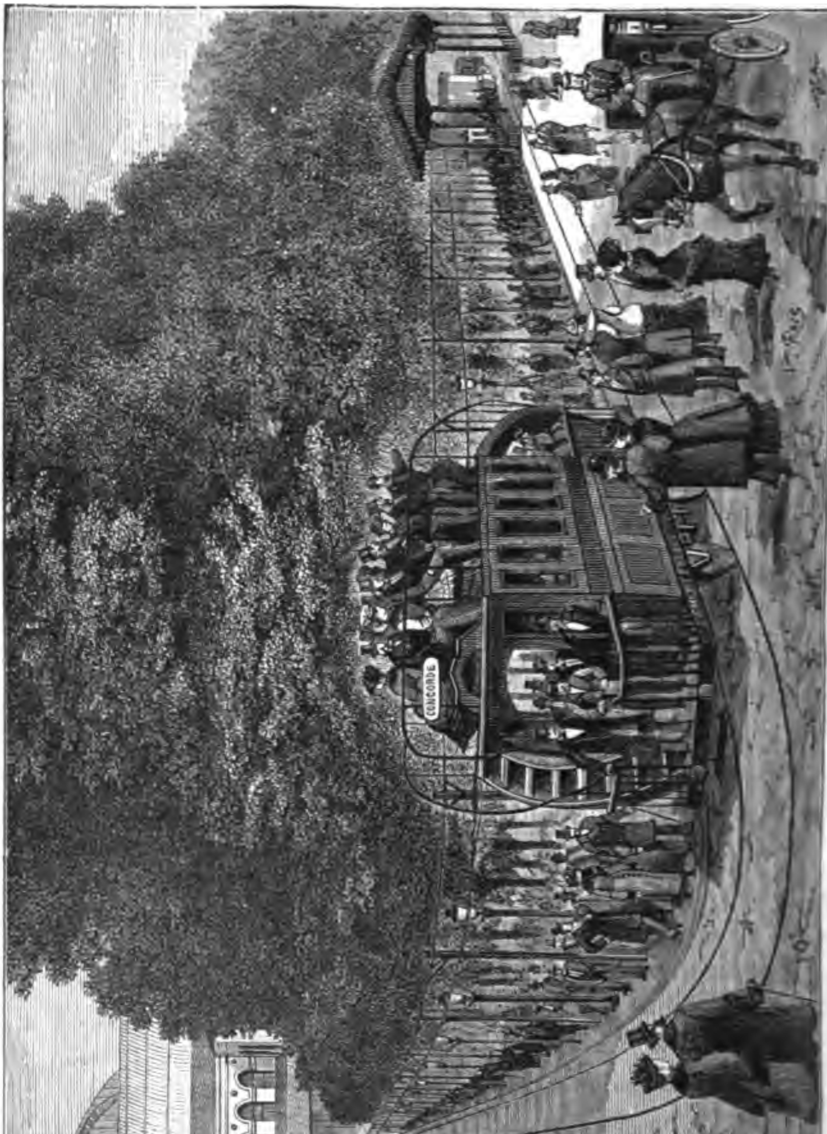

Fig. 162.— Siemens' electric railway at the Paris Exhibition.
(From La Lumière Électrique.)

at its extremities, two vertical shafts, which support the wheel or roller. Two springs supported on these vertical shafts press the wheel against the tube, and maintain an elastic contact between the tube and the wheel. The carriage may then be moved; the wheel runs against the tube; the core glides in the interior, without the communication ceasing to be, if not perfect, at least quite sufficient for the purpose. Only at times a few sparks are seen at the moment when the carriage passes the coupling of the tubes; these sparks are due to small instantaneous ruptures of the current, which do not affect the working of the system. The experiment shows that the wear and tear scarcely affects the tube; but nothing is easier than to replace a core. The current reaches the machine by a copper conductor. The traction of the carriage is effected by cords, according to the direction.

The electric railway of the Palais de l'Industrie presents (Fig. 162) the first practical solution of an electric traction in the case of a tramway. Of course, it is easy to see how this application of electricity is capable of the greatest development, and that by modification of details the principle might be applied to railways.

Ayrton and Perry's Electric Railway.—In Siemens' electric railway both the ordinary rails were used as the return wire, and the going wire was a third insulated rail rubbed by the passing train. This system works very efficiently if the ground is dry and the wires are short, but if the ground is moist and the wires are long, the leakage of electricity is very considerable. To overcome this difficulty, Ayrton and Perry, instead of supplying electricity to one very long and not very well-insulated rail, lay by the side of their railway line a well-insulated cable which conveys the main current. The rail which is rubbed by the moving train, and which supplies it with electric energy, is subdivided into a number of sections, each fairly well insulated from its neighbour and from the ground, and only the section or sections in the immediate neighbourhood of the train are connected with the main cable, the connection being, of course, made automatically by the moving train. As, then, leakage to the earth of the strong propelling electric current can only take place from the sections of the rail in the

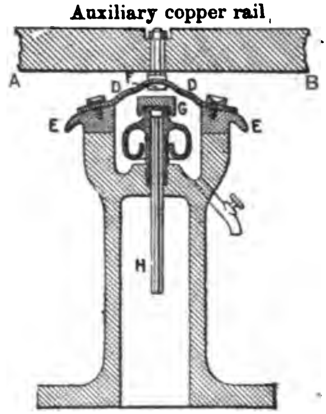

Fig. 163.—Ayrton and Perry's electric railway (contact-box). (*From La Lumière Électrique.*)

immediate neighbourhood of the train, the loss of power by leakage is very much less than in the case of a single imperfectly insulated rail.

For the purpose of automatically making connection between the main well-insulated cable and the rubbed rail in the neighbourhood of the moving train, various means have been devised, one of which is seen from Figs. 163 and 164.

A B is a copper or other metallic rod resting on the top of and fastened to a corrugated steel disc D D, which is fastened to a thick ring E E, made of ebonite or other insulating material. The ebonite ring is itself screwed to the circular cast-iron box, which latter is fastened to the ordinary railway sleepers. The auxiliary rail A B and the corrugated steel discs D D have sufficient flexibility to enable two or more of the latter to be simultaneously depressed by an insulating collecting brush or roller carried by one or by all of the carriages. Depressing any of the corrugated steel discs brings the stud F, which is electrically connected

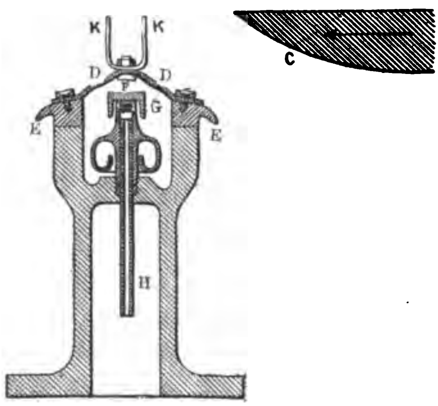

Fig. 164.—Ayrton and Perry's electric railway (contact-box).
(*From La Lumière Électrique.*)

with the rod A B, into contact with the stud G, electrically connected with the well-insulated cable H.

As only a short piece of the auxiliary rail A B is at any moment in connection with the main cable, the insulation of the ebonite ring E E will be sufficient even in wet weather, and the cast-iron box is sufficiently high to prevent the flooding of the line or the deposit of snow from affecting the insulation. The insulation, however, of G, which is permanently in connection with the main cable, must be far better. For this purpose the guttapercha or indiarubber covered wire coming from the main cable is led through the centre of a specially formed telegraph insulator, and it is caused to adhere to the inside of the earthenware tube forming the stem. And as, in addition, the inside of each contact-box is dry, a very perfect insulation is maintained for the lead coming from the main cable. Consequently, as all leakage is eliminated except in the immediate neighbourhood of the train, this system can be employed for the very longest electric railways. Fig. 164 shows a modification of the contact-box, where the auxiliary rail, instead of extending all along the line, is replaced by a short contact-piece C, which is carried by the train, and by its motion presses forwards and downwards a metallic fork K K on the contact-box, thus making contact between F and G.

The existence of these contact-boxes at every twenty to fifty feet also enables the train to graphically record its position at any moment on a map hanging up at the terminus, or in a signal-box or elsewhere, by a shadow which creeps along the map of the line as the train advances, stops when the train stops, and backs when the train backs. This is effected thus: As the train passes along, not only is the main contact between F and G automatically made, as already described, but an auxiliary contact is also completed by the depression of the lid of the contact-box, and which has the effect of putting, at each contact-box in succession, an earth-fault on an insulated thin auxiliary wire running by the side of the line. And just as the position of an earth-fault can be accurately determined by electrical testing at the end of the line, the moving position of the earth-fault—that is, the position of the train itself—is automatically recorded by the pointer of a galvanometer moving behind a screen or map, in which is cut out a slit representing by its shape and length the section of the line on which the train is. In addition, then, to the small sections of twenty feet or more into which the auxiliary rubbed rail is electrically divided, there would be certain long blocked sections, one mile or several miles in length, for each of which on the map a separate galvanometer and pointer would be provided.

Various Applications.—Among the various applications of transmission of electrical force to a distance, exhibited at Paris, we have to mention the apparatus for the piercing of rocks, either by percussion or rotation, the hoisting apparatus for mining and quarrying, the pumping of water by means of Greindl's and Dumont's rotative pumps, electric lifts, the working of the ventilators in the telephone-rooms, etc.

According to the force required and the nature of the work to be performed, the forms and dimensions of the machines have to be modified.

The question of transmission of electrical force simply resolves itself into a question of expense, whether it be cheaper to generate electricity at a distance and convey it to the consumer, or to produce it on the spot by means of some motor or other.

CHAPTER III.

THE DISTRIBUTION OF ELECTRICITY.

THE infinite variety of applications to which the electric current so easily lends itself, daily adds fresh importance to this comparatively new question. We give in the following lines a brief account of the actual state of this question, and of the future in store for the distribution of electricity.

It is well known how readily electrical energy produces, according to individual requirements, light, work, chemical effects, and even heat, especially very high temperatures.

As soon as practical and inexpensive methods shall have been introduced for supplying the energy to the consumer in any desired quantity and for instantaneous use, as water and gas are distributed nowadays, the number of electrical appliances will increase with a rapidity without precedent in history. The problem not only is capable of being solved, but has been partly solved already.

Generally speaking, this problem resolves itself into one of canalization, or of establishing a network, fed by a number of electric generators, which are set up at different points of the area to be supplied, and arranged in such manner that each electric receiver—electric lamps, motors, bells, galvano-plastic troughs, lighters, electric stoves, etc.—receives the necessary quantity of electricity, and under the most favourable conditions of electro-motive force. The stoppage at any moment, or the working of an indefinite number of receiving apparatus must in no way affect the electrical circulations in all the other apparatus which are in active work. This will be the case when all the apparatus of the system work with electro-motive forces E and intensities I of different value for each of them.

No system of distribution employed at the present time solves the problem thus generally put; that it is capable of being solved we shall show presently. The simplest case is where all the apparatus are identical, that is to say, are worked under the same conditions of volume and difference of potential. The division of light affords several examples of this case. The arc lamps of Brush, Gramme, Siemens, Weston, Berjot, and the incandescent lamps of Lane Fox, Edison, and Maxim, present partial solutions, to which we need not refer again.

In the case of a variable expenditure of energy, each apparatus must be supplied with a quantity of electrical energy equal to the product of the volume by the electro-motive force, that is to say, equal to EI.

The problem is simplified by having one of the two factors constant, and varying the other according to the requirements of the case. Hence we have two large general systems of distribution—

1. Distributions by constant electro-motive force.
2. Distributions by constant volume.

Distribution by Constant Electro-motive Force.—Let us suppose that, by some method or other, we can maintain between two points, A and B, a constant difference of potential. An indefinite number of circuits may branch off between these two points. Each of them will be traversed by a current of an intensity expressed by Ohm's formula—

$$I = \frac{E}{R};$$

E being the difference of potential between the two points A and B, R being the resistance of the circuit.[1]

Let us suppose, for instance, the pressure between A and B to be 100 volts; by introducing an incandescent electric lamp between these two points, the intensity of the passing current will be—

$$I = \frac{100}{100} = 1 \text{ ampère.}$$

If, on the other hand, we interpolate an arc lamp with a total resistance of only four ohms, the intensity of the current will be—

$$I = \frac{100}{4} = 25 \text{ ampères.}$$

The electro-motive force will be the same in both cases, but the energy expended by the arc lamp will be twenty-five times as great as that of the incandescent lamp, because the intensity of the current will be twenty-five times as great. By maintaining a constant electro-motive force, and conveniently varying the resistance of the receivers, we have therefore a means of varying the consumption of each receiver. For an electric bell, for instance, we lead off to an electro-magnet with an excessively long wire of great resistance; the expended energy will then be very feeble, and the bell can be worked by the main current of the system. This system, therefore, requires all the apparatus branching off from the main current to be placed on shunts between the two points A and B, and these shunts must have a constant

[1] We must sometimes—in the case of an electro-motor, for instance—take into account the antagonistic force developed in the receiver. We merely mention this point here, the introduction of this factor would complicate our explanation.

difference of potential. In practice, all the shunts need not be taken from the two points A and B.

By combining the resistances of the apparatus, and connecting two main conductors of sufficiently large size to the points A and B, the shunts can be taken from any part of the conductors without sensibly affecting the results.

The problem consists in maintaining the electro-motive force constant between the points A and B.

Lane Fox's system, which was patented in 1878, and has been described in Vol. I. p. 480, satisfactorily solves the question, as far as incandescent lighting is concerned, and also Edison's and Maxim's systems partly realize these conditions for lighting with the incandescent lamp.

Let us now pass on to the systems proposed for a general distribution. The most rudimentary is the one proposed by Gravier, in April, 1880. Gravier employs no current regulator. He excites a number of machines separately, and mounts them all for quantity to diminish the interior resistance. Theoretically speaking, if there were no interior resistance in the generators, an indefinite number of circuits might lead off from these generators without affecting the intensity of circulation in the remaining circuits. This is a method of distribution which was worked with favourable results at the Paris Electrical Exhibition, with a limited number of circuits, but it is not a general solution of the problem.

Finally, the most recent solution by constant electro-motive force was proposed by Marcel Deprez, and carried out at the Paris Electrical Exhibition, for distributing energy to a number of motors of different power. In this highly ingenious system no mechanism for regulation is required, the regulation being effected automatically and instantaneously by the introduction of new shunts into the circuit. For this purpose the dynamos placed on a common shunt have inductors coiled with two distinct wires. One of the wires is placed in the circuit of a special exciting machine, the other is in the general circuit. The intensity of the magnetic field in which the armature revolves depends, therefore, not only on the constant current supplied by the exciting machine, but also on the variable current of the general circuit. The increase of intensity of this current for each additional shunt introduced into the circuit, increases the electro-motive force of the quantity required for maintaining the available electro-motive force, which is perfectly constant between certain limits.

This elegant solution is thoroughly effective in the case of one single distributing workshop; it remains to be seen how it will act in the case of a general system of distribution with a number of workshops.

Distribution by Constant Volume.—This system was originally proposed by Cabanellas, in December, 1880. All the receivers are placed, one after another, in the same circuit. The main current, of constant volume, traverses them all. There is a regulator at the central workshop for varying the electro-motive force of the generators, in order to maintain this volume constant. It is clear that less initial electro-motive force is required when the circuit is short, and only a few apparatus are interpolated in that circuit, than when all the apparatus are at work, and also that the methods for stopping or setting in action a given receiver must naturally be the very reverse of the methods used for the systems which employ shunted currents or constant electro-motive force. In the one an apparatus is suppressed by breaking the circuit; in the other, on the contrary, this operation is performed by establishing a direct communication between the two terminals, that is to say, by short-circuiting the receiver. The current then passes directly into the shunt, without traversing the receiver. At the central workshop, an automatic mechanism introduces or suppresses the individual machines as occasion requires, increasing thereby or diminishing the initial electro-motive force, and thus maintaining a constant volume. Cabanellas thus establishes a series of separate and closed circuits, going from house to house, from story to story, to supply the various apparatus of his system. Each circuit, naturally, has its own regulator, absolutely independent of that of all the others.

Advantages and Drawbacks of the Two Systems.—Distribution by constant electro-motive force more effectively ensures the independence of the individual circuits, for there is no common connection between the apparatus as in the system employing constant volume, where they are placed one after another in the same circuit.

In fact, the least accident to the conductors or to a receiver in a given circuit deprives all the receivers in the same circuit of their current power. This is a most serious drawback, a drawback which does not occur with constant electro-motive force, because each shunt is entirely independent of the others. Numerous contrivances, however, have been invented for localizing the accidents which might occur. Of these we will only mention Edison's safety-box, described in Vol. I. p. 469.

The shunt system requires comparatively thick conductors, especially at the point of departure from the central workshop. The thickness of these conductors must, from the outset, be adapted to the probable number of shunts required, in order not to be obliged to disturb the canalization in the case of an increased consumption. But this system allows us to work with electro-motive forces which are of comparatively feeble intensity, and therefore less dangerous, and which also require a less perfect insulation of the conductors than in the system with constant volume, where the conductors are charged for a high potential, and constitute a permanent source of danger.

It is impossible, at the present moment, to assign any marked preference to either of the two systems; the question of distribution of electricity is still in its infancy, and the future alone can decide this point.

Electric Transformers.—Whether the distribution be effected by constant electro-motive force or by constant volume, all the apparatus cannot be indiscriminately adapted to this indispensable constant factor. Thus, for instance, if a distribution is effected by constant electro-motive force, with an available fall of 200 volts, this initial fall will be too great for the supply of an arc lamp of average intensity or for galvano-plastic; nor will it be possible, with the current supplied, to feed Jablochkoff's candles, which require an alternating current.

All apparatus which enable us to change the qualities or the nature of the currents supplied by a system of distribution, for the purpose of adapting them to the exigencies of the receivers, are transformers. All secondary batteries, for instance, are transformers. They have been described in Vol. I. Part I.

Cabanellas' Electric Tap.—Let us suppose, at a subscriber's house, an electro-motor of a certain power, supplied by the system. This electro-motor, in its turn, can drive an electric generator which, according to the special requirements, will give a continuous current of large volume for galvano-plastic, or a high-tension current for Geissler's tubes, or an alternating current for Jablochkoff's candles. Such a transformer has only one defect—the transformation is effected by the intermedium of work, and serious loss is the consequence. To diminish this loss, Cabanellas has constructed much simpler transformers, which do away with this intermediate stage of work, and fulfil the functions both of dynamo-electric machines and of induction coils. By means of these transformers, whatever may be the mode of distribution adopted and the elements of distribution, it will always be possible to feed a receiver of any kind, provided the transformer expends a quantity of electrical energy slightly superior to that which is consumed by the receiver.

We have had to content ourselves with casting a rapid glance over a number of interesting problems connected with the distribution of electricity, and its manifold applications. The enumeration of these applications alone would occupy a considerable space. We only wished to show that the question is ripe, and that there are no insurmountable obstacles in the way of a complete solution.

In a few years electricity will have penetrated into our houses, bringing with it innumerable and undreamt-of comforts, and thus keeping pace with the ever-increasing requirements of modern civilization. The nineteenth century will not come to its close without witnessing an enormous development of the applications of electricity, and its general distribution for domestic purposes. Our grandchildren, in token of their gratitude for the progress of a science born with the century, will then justly call it, "The Century of Steam and of Electricity."

INDEX OF INVENTORS' NAMES.

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