Goodwin & Co., for the loan of apparatus and other favors, and to Mr. Thos. H. McCollin for his valuable services in taking the photographs from which the illustrations of the carbon points were made.

ROBERT E. ROGERS, EDWIN J. HOUSTON,
PLINY E. CHASE, ELIHU THOMSON,
ROBERT BRIGGS, THEO. D. RAND,
WASHINGTON JONES,
SAMUEL SARTAIN,
J. B. KNIGHT, *Chairman.*

ERRATA.—In the table on p. 302, this vol., the weight of wire in the Gramme machine should be: on armature, 9½ lbs.; and on field-magnets, 57½ lbs.

THE TELEPHONE.

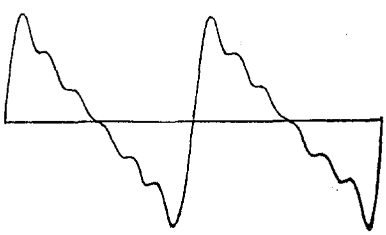
By BROWN AYRES.

Probably no invention ever attracted more universal and interested attention than the telephone, and it is safe to say that none was ever more deserving of it, whether we regard the instrument in its intrinsic interest from a scientific standpoint, or whether we look at it in its purely practical bearing. The public, by a legion of newspaper articles and public lectures, has become moderately familiar with the general construction and operation of the instrument, but no one seems as yet to have considered it in its theoretic aspects, nor to have given to the public many very remarkable facts that can hardly have failed to have attracted the attention of any one who has worked to any considerable extent with the instrument. An outline of this theory, and a few of these facts, it is the purpose of the writer to present in the present paper, with the hope that it may at least stimulate others more fully prepared for the task to give the subject more thorough attention.

The complete understanding of the action of the telephone, covering, as it does, some of the most refined portions of Dynamics, would require mathematical processes of the greatest complexity and difficulty; but a clear understanding of the general principles of the operation of the instrument, with enough of the quantitative relations involved to give us definite ideas in regard to its action, need not be inconsistent with a limited knowledge of the higher mathematical processes.

In attempting to form a conception of the action of the telephone, we must keep constantly before our minds the mutual relations of pitch, intensity, and quality in the sensations of sound, and their relations to the corresponding amounts of energy involved in the various transformations through which the energy of the sound wave passes between its initial and final states as kinetic energy of atmospheric vibration. We may, to give breadth to our view of the subject, regard the instrument in a generalized form. As such, we shall find that it consists of three essential parts: Firstly, the mechanism which receives the energy of the vibrating air, *e. g.*, the plate; secondly, the mechanism for transforming the energy of sound motion so received into an equivalent of electric and other energy, or for regulating the development of electric energy in an external source, and lastly, the mechanism for reconverting the electric energy into aerial undulations. I have pictured the instrument thus in its generality, because in special points the various telephones differ, and the present method of construction can hardly be expected to be rigorously adhered to.

Fig. 1.



The requirement for an articulating telephone is that the working margin of the electric current and the action of the mechanism shall be so related that the sound given forth at the distant end of the line shall be in relative pitch, intensity and quality, an accurate reproduction of the sound initially produced. In all forms of telephone yet devised, as we shall directly see, the strength of the transmitted current is in direct proportion to the kinetic energy of an air particle engaged in the production of a given sound, and is independent of the pitch; so that for the purposes of this paper we may say that the requirements of an articulating telephone are that at any moment the working margin of current strength shall be directly proportional to the loudness of the sound (physically considered) and independent of its pitch. To convey a more concrete conception of this, we may draw a curve (Fig. 1), whose ordinates will represent intensities of sound, while the abscissæ will represent periods of time. Any such curve, if it be harmonic in its character, may represent a musical sound. Now the requirement of a speaking telephone is that this same curve should represent the varying current strengths if the ordinates be currents while the abscissæ are times, as before.

These conditions are fulfilled by several different instruments to a greater or less degree of approximation. The various telephones yet devised may be classified as follows:

Class I. Telephones by induced currents (produced by the relative motion of a conductor and magnet).

(*a*). Those in which the magnet moves relatively to the conductor.

(*b*). Those in which the conductor moves relatively to the magnet.

(*c*). Those in which both move simultaneously.

Class II. Telephones by *variation* in a Voltaic current. A variation, according to Ohm's law $\left(I = \frac{E}{R}\right)$, can only be produced by varying E or R. Hence of this class there are:

(*a*). Those that vary the electromotive force.

(*b*). Those that vary the resistance of the circuit.

Class III. The Electrostatic telephone of the writer, to be directly described.

The equation of the motion of a particle engaged in the production of any simple tone,[1] is

$$y = a \sin\left(\frac{2\pi t}{\tau} + \alpha\right), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where a and τ are the amplitude and period of the vibration respectively, and α is a constant depending on the time that has elapsed from the commencement of the motion until the moment we begin to reckon. The variable velocity of the particle is

$$\frac{dy}{dt} = a. \cos\left(\frac{2\pi t}{\tau} + \alpha\right)\frac{2\pi}{\tau}. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

For our purpose a sufficiently exact expression for the kinetic energy of the vibrating particle while producing any note can be reached

[1] Donkin, "Acoustics," p. 47.

as follows: The total energy of the vibration at any time consists of two parts, kinetic and potential, the sum of which is constant. The whole of it will be manifested as kinetic energy as the particle passes its point of equilibrium. At this point $y = 0$, hence

$$\sin\left(\frac{2\pi t}{\tau} + \alpha\right) = 0,$$

$$\therefore \cos\left(\frac{2\pi t}{\tau} + \alpha\right) = \pm 1,$$

$$\text{and } \frac{dy}{dt} = \pm \frac{2\pi}{\tau} a.$$

But the kinetic energy is $\frac{1}{2} m v^2$

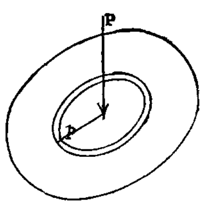
$$\therefore \tfrac{1}{2} m v^2 = 2 m \frac{\pi^2 a^2}{\tau^2}. \qquad (3)$$

Then the whole force exerted by any collection of particles vibrating synchronously will be

$$\Sigma \frac{m v^2}{2} = \Sigma \frac{2 m \pi^2 a^2}{\tau^2}.$$

From which we see that with a given mass of vibrating particles the kinetic energy varies as the square of the amplitude divided by the square of the period; or, what is the same thing, as the square of the product of the amplitude by the number of vibrations in a unit of time.

Fig. 2.



In all telephones yet devised, the aerial undulations are received on a flat disc of thin elastic substance—such as mica, rubber, or iron—and hence this portion of the theory is common to all forms. The complete investigation of the relations between the applied forces and the resultant action of the plate in the telephone forms one of the most complex dynamical problems in the whole range of science, but an expression for the relation between the variables, sufficiently exact for our purpose, may be reached in the following manner. Let us treat the problem as one of shearing stress, Fig. 2:

Let $P =$ applied force,
$\Delta =$ deflection of plate,
$\rho =$ variable radius,
$t =$ thickness of plate,
$e =$ coefficient of transverse elasticity.

Then[i] according to the law of shearing stress,

$$P = 2\pi t e \rho \cdot \frac{d\Delta}{d\rho}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

whence we have

$$d\Delta = \frac{P}{2\pi t e} \cdot \frac{d\rho}{\rho};$$

and integrating between the limits r, the radius of the plate, and r_1, the radius of the area on which the force is applied, we have

$$\Delta = \frac{P}{2\pi t e} \cdot \log \frac{r}{r_1}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

From equations (3) and (5) we see that within the elastic limit of the plate, the deflection will be proportional to the kinetic energy of the sound wave.

"It can be shown that no forced vibration can have any harmonic component of a period which does not exist amongst the periods of the harmonic component of the imposed motions or forces."[ii] The plate then must follow every motion of the alternately condensed and rarefied air particles. Though I have only given an expression in equation (3) for the kinetic energy of a single note, it will readily be perceived that in the case of a complex motion, at any given moment, the energy will be represented by that expression. The discussion of the general equation would be too lengthy for insertion here, but can easily be found by those interested. (See Donkin's "Acoustics" and Rayleigh's "Theory of Sound.")

The theory of the three divisions which I have made in the first class of telephones, is the same; hence an exposition of the theory of the Bell Telephone will answer for the other two. By the Bell Telephone we will understand that arrangement of a vibrating plate of magnetic matter before the pole or poles of a magnet—temporary or permanent—around which pole or poles wire is wound after the manner of an electro-magnet. In a general way the explanation of its action could be given somewhat in this wise: The motion of the plate, by disturbing the distribution of the magnetic field, causes a motion of the magnetic lines of force, which, cutting across the wires of the helix, cause a current to be induced in these wires. This current, passing over the line, causes a variation in the force with which the

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[i] Wood, "Resistance of Materials," p. 215.

[ii] Donkin, "Acoustics," p. 89.

plate at the further end is attracted, and the variation imparts to the plate a motion depending on the varying strengths of the incoming current. The motion of the lines of force can be readily observed if we cover the poles of a rather powerful horse-shoe magnet with not too fine iron filings, and move the armature to and fro before the poles. It can also be readily shown by means of the floating magnetic needles described by Prof. A. M. Mayer, in the *Am. Jour. Sci. and Arts*, for April, 1878.

The theory of the action is as follows:[1]

If m be the magnet strength, and the induced magnetism of the plate, which, of course, is a function of m, be $q\,m$, where q is some constant, then the attractive force between them will be

$$\frac{q\,m\,.\,m}{p^2}=\frac{q\,m^2}{p^2},$$

where p is the distance between the poles of the magnet and plate. Now if the plate be moved to any new position, p_2, from its initial position, p_1, work will be done by or against the attractive force.

This work $$=q\,m^2\int_{p_2}^{p_1}\frac{d\,p}{p^2}=q\left(\frac{m^2}{p_2}-\frac{m^2}{p_1}\right);$$

but $\frac{q\,m^2}{p_1}, \frac{q\,m^2}{p_2}$, are the values for the potential at the positions p_1, p_2, respectively; hence

$$\text{Work}=q\,(V_2-V_1);$$

or the work done will be manifested by a variation in the potential.

The potential at the time will evidently depend on the state of the magnetic field.

$$V=f(\gamma)=M\gamma.$$

But on the difference of potential at any two instants will depend the electromotive force of our induced current:

$$V_2-V_1=M_2\gamma_2-M_1\gamma_1=E=IR,$$

hence $$I=\frac{V_2-V_1}{R}=\frac{M_2\gamma_2-M_1\gamma_1}{R}, \quad . \quad . \quad . \quad (6)$$

or, the strength of the induced current will be equal to the difference

[1] For a more complete discussion see Cumming, "Theory of Electricity," p. 210; Maxwell, "Electricity and Magnetism," Vol. II, p. 176.

in the potential of the system at two given instants, divided by the resistance of the circuit. The quantity $M\gamma$ can be interpreted as the number of lines of force passing through the coil, M depending for its value on the position of the coil and plate with reference to the magnet, and γ being the number of lines of force in unit area of the equipotential surface at unit's distance from the pole at the instant that the quantity $M\gamma$ is observed. It will readily be seen that γ depends on the magnetic strength, while M depends on the arrangement and adjustment of the instrument as well as the intensity of the sound wave impinging on the plate. With any given arrangement of magnet, coil and plate, any change in $M\gamma$ will be dependent on the position of the plate, that being the only movable portion of the instrument. Hence if A be the position of the plate at any instant

$$M\gamma = f(A) = k A$$

and

$$M_2\gamma_2 - M_1\gamma_1 = k(A_2 - A_1), \quad . \quad . \quad . \quad (7)$$

or, the variation in the potential is proportional to the amplitude of vibration, hence the strength of the induced current will be proportional to the amplitude of vibration, and therefore proportional to the kinetic energy of the sound wave.

This current traversing the wire will cause a variation in the magnetic strength of the distant telephone, either by augmenting or diminishing it according to the direction of the current. The variation will be sensibly proportional to the strength of current, as will be shown later. Hence a force will be exerted on the distant plate proportional to the kinetic energy of the initial wave of sound. The intensity of the emitted sound will therefore, at any instant, be in direct proportion to the initial sound. It will be observed that in the above discussion no notice is taken of the pitch of the note, whatever it might be, except where it enters the expression for the kinetic energy of the initial sound wave; but it will readily be seen that whatever be the motion, if the distant plate is at every moment attracted with a force varying as the motion of the first plate, all the conditions for the transmission of sounds, however complex, are fulfilled. It remains for us to examine what are the requirements in the receiver that its plate may have a force exerted on it directly as the strength of the incoming currents.

Let m be the magnetism of the magnet, which, if produced by a current, will be directly proportional to it, $= a\,\gamma$.

Let $K=$ induced magnetism of the plate $=f(m)=q(m)$.

Assume the initial distance of the centre of magnetism of the plate from that of the magnet $=p$. Then the attractive force $F=\frac{q\,m\,.\,m}{p^2}=\frac{q\,m^2}{p^2}=\frac{q\,a^2\,\gamma^2}{p^2}$; or the attraction is as the square of the current, as was demonstrated by Joule.

Suppose m to undergo any variation $\overline{\Delta\gamma}$, due to a variation in γ,

then $$F_1=\frac{q\,a^2}{p^2}(\gamma+\overline{\Delta\gamma})^2=\frac{q\,a^2}{p^2}(\gamma^2+2\,\gamma\,\overline{\Delta\gamma}+\overline{\Delta\gamma}^2).$$

hence, $$\overline{\Delta F}=\frac{q\,a^2}{p^2}(2\,\gamma\,\overline{\Delta\gamma}+\overline{\Delta\gamma}^2).$$

If $\overline{\Delta\gamma}$ be very small, $\overline{\Delta\gamma}^2$ can be neglected without appreciable error, in which case

$$\overline{\Delta F}=\frac{2\,\gamma\,q\,a^2}{p^2}\overline{\Delta\gamma}. \qquad (8)$$

From which we conclude that while the total strength is proportional to γ^2, the variation, if small, is proportional to $\Delta\gamma$; or, in other words, if the magnet is entirely magnetized and demagnetized by the incoming currents, the attractive force will be proportional to the square of the current; while if it be a permanent magnet, whose strength is varied, it will be proportional to the current. But if $\Delta\gamma$ be large, so that $\overline{\Delta\gamma}^2$ will have an appreciable value, the force will be augmented by the term $\overline{\Delta\gamma}^2$. Now in an articulating telephone, in order that the relative loudness of the component tones of a sound be preserved, the attractive force must vary as the current. Hence, for the receiver of an articulating telephone, a permanent magnet must be used; and, in order that $\Delta\gamma$ shall be sufficiently small, the permanent magnet should be as near saturation as possible. Hence loudness, arising from large margin of attractive force, will be fatal to perfection of articulation. In the Bell telephone, these requirements are beautifully fulfilled by the use of the same instrument as sender and receiver. This result also explains to us the imperfect working of the original form of Bell's instrument—with the electro-magnet. The magnet was too far from saturation by the constant current; hence the attractions more readily followed the law of Joule, than that of simple proportion, and the articulation was correspondingly imperfect.

The second class of articulating telephones consists of those which operate by a variation in the strength of a voltaic current. The strength of a current is, by Ohm's law,

$$I = \frac{E}{R};$$

hence, any variation in I must be caused by a variation in either E or R. We know of no method by which the electromotive force of a battery can be varied continuously; and since a discontinuous variation could hardly be made so gradual as to produce waves in the current capable of carrying the more delicate shades of quality, we are forced, for the present, to regard that telephone which varies the electromotive force to be possible only in theory. The Voltaic telephones, then, reduce to one class—those which vary the resistance of the circuit. A type of this form is what has been called the "Hydro-electric Telephone," described by Prof. Bell, in his paper read before the American Academy of Arts and Sciences, in May, 1876. This consists of a membrane, to which is attached a platinum wire dipping into water or other highly resisting liquid. The motion of the plate to and fro causes the wire to be more or less submerged in the liquid, and hence the resistance, between it and a wire projecting upward from the bottom of the containing vessel, is varied. If v be the resistance of the liquid between the extremities of the wires, R the external resistance, and E the electromotive force in circuit, then

$$I = \frac{E}{R + v}.$$

Let the plate vibrate so that the extreme values of the resistances of the liquid are v_1 and v_2, then

$$\Delta I = \frac{E}{R + v_1} - \frac{E}{R + v_2} = \frac{E\,(v_2 - v_1)}{R^2 + R\,(v_1 + v_2) + v_1 v_2}.$$

Now if R is small, compared with v, we may, to reach an approximate solution, neglect R; then

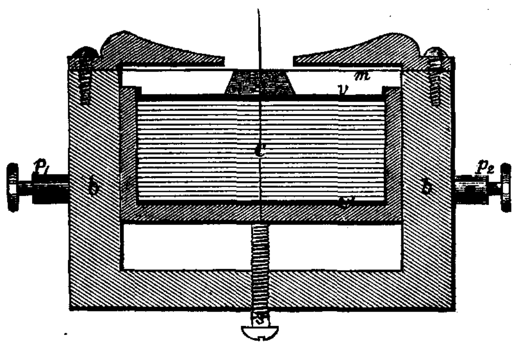
$$\Delta I = E\left(\frac{1}{v_1} - \frac{1}{v_2}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

or the variation in current strength, for that amplitude of vibration will be proportional to the variation in conductivity of the circuit. To reach this result we have been forced to consider $R = O$. But this can never be the case in a practicable arrangement; but the smaller is the internal resistance of the battery and conducting wires, and the larger the value of v_1, the nearer will the instrument approach to theoretical exactness.

In the form of instrument devised by Mr. T. A. Edison, where advantage is taken of his discovery of the variation, in resistance, of graphite or lampblack under pressure, the current is passed through the primary of an induction coil, while the secondary goes to line, and the current induced by variation in strength of the primary is utilized for actual transmission to line. If the resistance of the plumbago varies inversely as the pressure, then this instrument has the same difficulty to contend with as the "Hydro-Electric Telephone," and in the same degree.

The third class is represented, at present, so far as I know, by one instrument, the "Electrostatic Telephone," of the writer, Fig. 3.

FIG. 3.



This consists simply of an insulating box of wood or rubber, *b*, in which is placed a small condenser, *c*, the sides of which are connected by binding posts, p_1, p_2. This condenser is constructed of tinfoil, as usual, insulated by discs of thin sheet rubber, such as is used by dentists. On either end of the condenser is placed a thin piece of vulcanite, v, v_1, the upper one of which is attached to a piece of cork, *k*, which bears against the ferrotype or mica plate, *m*, while the lower rests on a screw, *s*, by means of which the instrument can be adjusted. One side of the condenser is kept at a nearly constant potential by means of a large number of small cells, while the other side is connected to line. The vibrating plate which bears on the condenser, by its motion, increases and diminishes the pressure, and hence the distance between the leaves. The principle of operation is as follows:

The capacity of the condenser varies inversely as the distance between the plates, and when the capacity is varied by the varying distance, of the leaves apart, a current is set up momentarily in the line, which depends for its direction on whether the condenser is under- or super-saturated for that value of its capacity. The general theory will be understood from the following. For convenience, we may consider any two contiguous sheets. Since the lines of force between the sheets cut them at right angles, the value of the force does not vary with distance, and since the electrostatic force is measured by the rate of change of potential, we have:

$$F = \frac{V_1 - V_2}{t},$$

where t is the distance between the plates. But the force near any electrified surface is $4\pi\rho$ where ρ is the density,

$$\therefore \quad \frac{V_1 - V_2}{t} = 4\pi\rho.$$

Hence, $$\rho = \frac{V_1 - V_2}{4\pi t}.$$

If S be the area of the plate then ρS will represent the total charge.

$$\therefore \quad Q = \frac{V_1 - V_2}{4\pi t} S.$$

Hence for any variation in Q,

$$\overline{\Delta Q} = \frac{V_1 - V_2}{4\pi} S\left(\frac{1}{t_0} - \frac{1}{t_1}\right) \quad . \quad . \quad . \quad . \quad . \quad (10)$$

or the variation in charge will be proportional to the change in *thinness* of the dielectric, since the reciprocal of the distance between the plates may be called the thinness. This thinness may, within the small limits with which we have to deal, be considered as proportional to the applied force. Then the variation in thinness will be proportional to the amplitude of vibration of the plate. Experiments made thus far with this instrument are encouraging, though its interest is more purely scientific than practical.

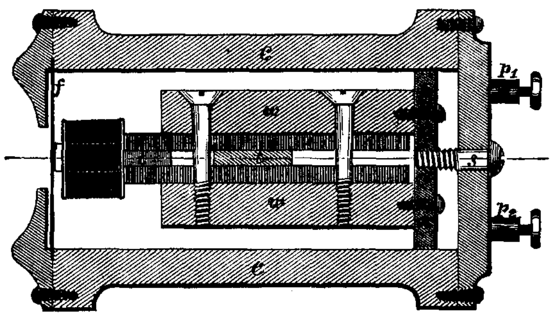
We have now examined the theory of a typical instrument of each class, and have found in each case, with varying degrees of approximation: (1.) That the amplitude of vibration of the plate was proportional to the kinetic energy of the sound wave. (2.) That the current on the line was proportional to the amplitude of vibration of the plate. (3.) Assuming the attractive effect of the current as directly proportional to it, the amplitude of vibration of the receiving plate is proportional to the strength of the current. (4.) That the kinetic energy of the sound emitted by the receiving plate is proportional to the amplitude of vibration of that plate, and hence the kinetic energy of the sound emitted is directly proportional to the kinetic energy of the initial sound. No time functions enter into any of equations (6), (8), and (10). Hence the action in every case is independent of the pitch of the note.

In equation (6) we see that the current depends on the change in $M\gamma$. As we have before remarked, this quantity may be considered as expressing the number of lines of force which pass through the conductor at any moment. Hence, to increase the current, the conductor should be so placed as to cut the greatest possible number of lines of force, and to allow of the greatest variation in the number of cutting lines for any given magnet strength. The electromotive force of the induced current will be proportional to the number of windings in the coil; the quantity to the electromotive force and conductivity of the circuit jointly, by Ohm's law.

The writer has experimented a great deal with the different forms of telephone, but more from a scientific than a practical point of view. Still in the course of his experiments some facts have been reached that are worthy of notice. He has devised a form of instrument differing in construction from the ordinary Bell Telephone, and having the advantage of greater ease and cheapness of manufacture. This instrument has been used by many scientific men who have visited the Stevens Institute, with the nearly unanimous opinion that it compared very favorably with the best yet constructed.

A sectional view of this instrument is shown in Fig. 4. The wooden case *c*, $4\frac{1}{4}$ inches in length by $2\frac{3}{4}$ in diameter, is, in the instrument made by the writer, of mahogany. Through this cylindrical block is bored a hole, 2 inches in diameter. Into this is fitted snugly the arrangement of magnets and coils tight enough to prevent its rattling about, but not so tight as to prevent its adjustment by means of the screw *S*. Two horseshoe magnets are used; they are 3 inches long and can be bought at any toy store at a cost of about fifteen cents apiece. A compound magnet is formed by superposing them, like pole over like, having a piece of wood *T*, $\frac{1}{8}$ inch in thickness, between them. A small piece of round iron or iron wire *I*, $\frac{3}{16}$ inch in diameter and $1\frac{1}{4}$ inches in length, is filed flat on two opposite sides to within about $\frac{5}{8}$ inch of the end—somewhat over half. One of the pieces is placed between the superposed like poles, and the whole is held tightly together by means of two screws passing through and into two pieces of wood *w*, *w*. On the ends of *w* is screwed a strip of brass, *b*, which, by means of a screw thread in its centre, allows the whole arrangement to be moved in and out by the screw *S*. On the pieces of round iron *i*, are slipped bobbins (which I have made of postal card, boxwood, or hard rubber), whose dimensions are: length, $\frac{9}{16}$ inch, diameter, $\frac{1}{2}$ inch, and core just large enough to fit snugly on *i*. They are wound with No. 38 wire, or for short lines coarser wire can be used. Connections are made in the ordinary way to binding posts p_1, p_2, and a disc of thin ferrotype, *f*, is placed over the end,

FIG 4.



and the magnets brought as near as possible without touching when the plate vibrates. The mouthpiece is like that of any ordinary telephone. One great advantage of this form is the ease with which a strong magnet can be made, and strength of magnet is an essential in the telephone. My instruments have a resistance of about 80 ohms, and I have worked them very satisfactorily on actual wires up to 75 miles and with resistances much higher. There is considerable choice in the ferrotype plates one meets with; the best that I have found is an imported article, of a maroon color, and very thinly coated with varnish. The ordinary black American plates do very well, but the varnish is rather thick and they are not as satisfactory as the French. Of course the dimensions can be varied at pleasure, but the plate should not depart far from the size given, for if so, the fundamental tone of the plate will interfere with distinctness of articulation.

The writer has also experimented to some extent with a telephone which is a type of the second division of the first class of telephones. Two horseshoe magnets were placed about $\frac{1}{4}$ inch apart, with the opposite poles facing each other, and a circular coil of such a size as to move easily between them, and whose diameter was such that the upper portion was between the upper poles of the two magnets, while the lower was between the lower poles. This coil was attached directly to a mica membrane, and when sounds were uttered before the membrane the coil was thrown into vibration in the magnetic field, and the motion of the coil across the lines of force induced a current in the coil. Very fair results were obtained with this arrangement. This was also combined with the regular Bell telephone (Fig. 4), by attaching the coils to the ferrotype plate and allowing them to vibrate to and fro on the round iron as a piston. In this case the coil was pushed across the lines of force, at the same time that the lines of force were drawn across the coil. The articulation of this arrangement was the best that I have yet heard on any telephone, though in my experiment it was not so loud as the regular form alone, probably owing to there being a want of sufficient freedom of motion in the coils, thus damping the vibration.

In the experiments made with the electrostatic telephone, I used some 200 cells, of small test tube battery of simple zinc and copper plates in dilute sulphuric acid. The instrument had a capacity of about $\frac{1}{10}$ microfarad. While the results reached were not great enough to warrant more extensive investigation, they were sufficient to show that we had here a new means by which articulate and other complex sounds could be conveyed.

While experimenting on a wire of the Virginia Telegraph Co., the writer had occasion to notice more particularly a very curious fact which from previous experiments he had suspected before, that is, that the telephone seems to work more satisfactorily on a leaky line than on one perfectly insulated. His experiments were made on four wires. No. 1 was a wire of the Western Union Telegraph Co., from Staunton to Charlottesville, Va., a distance of 40 miles. No. 2, a wire of the same company, from Staunton to Covington, Va., a distance of 70 miles. No. 3, wire of the Virginia Telegraph Co., from Staunton to Harrisonburg, a distance of 25 miles, and No. 4, one of the Baltimore and Ohio R. R., between the same points, 25 miles. On Nos. 1, 2 and 4, which were all excellently well insulated, the earth current was very marked, in some cases almost entirely drowning the sound of the voice, while on No. 3, a miserably insulated line, the earth current was comparatively insignificant, and conversation was carried on with the greatest ease. When this line was so nearly dead grounded, that it was nearly impossible to work with the Morse system over it, the telephone worked to a charm. The writer has sought to explain this as follows, which, be it remarked, is only provisional, for the subject deserves more attention than he has been able to give it.

It would be difficult to choose two points, at any considerable distance apart, which would be at so nearly the same potential that when they were connected by an insulated line, no current would pass. If the line were perfectly insulated the electromotive force of the earth current would be proportional to the difference of potential of the points; hence, if this difference were great the current would be great. On the other hand, if the line were leaking, this would allow of the readier equilibration of the potential at the terminus of the line and the leak, and of the difference between any two leaks, so that the earth current arriving at the distant telephone would principally be that due to the difference of potential of the nearest leak to the distant terminus and that terminus. The telephone current, of course, will lose in strength by being divided into so many branches, but being harmonic in its character, the successive currents reinforce the motion of the plate, hence a difference in the incoming current is not so readily perceived, and by adjusting, nearly as loud sounds can be obtained as if the line were insulated.

This observation agrees with the fact observed by others, that two wires could be buried in the ground and yet a telephone circuit made through them. Prof. A. M. Mayer has experimented on a railroad track, using the two rails as conductors and badly insulated and connected at switches as they were, good results were still reached. The writer has conversed with some ease between different floors of the same building, using the gas and water pipes as conductors. The same facts were observed with Mr. Edison's so-called "Etheric force;" and in fact many observations point to a close analogy between these telephonic currents and the "Etheric force," both being rapidly reversed currents. It should be noted that in the above experiments, Nos. 1 and 2 ran northeast and southwest, while Nos. 3 and 4 ran essentially northwest and southeast. No. 4, though well insulated, was much better than 1 or 2. Such experiments give us some idea of the infinitesimal character of the currents active in this instrument, which, though escaping at every point almost, still arrive at a distance of twenty-five or fifty miles with sufficient strength to operate the telephone satisfactorily. One of the telephones used in these experiments when the plate was pressed in with the finger and held, gave, on a high resistance Thomson galvanometer, a deflection of only 1°. This points to the use of the telephone as a delicate electroscope, especially valuable where reversed currents are to be observed, as in Mr. Edison's "force," and with it very accurate measurement could be made, placing it in the cross of the "Wheatstone Bridge," or winding it differentially and balancing until no "click" was heard in the instrument at closing and breaking circuit. In fact, this is only one of the many uses to which it can be applied other than as a transmitter of speech or music, and from its wide adaptation, its beautiful simplicity, and the marvelous minuteness of the forces involved, it deserves to be classed, as it undoubtedly will be, among the greatest and most interesting inventions.

STEVENS INSTITUTE OF TECHNOLOGY,
Hoboken, N. J., March 30th, 1878.

ON THE EROSIVE AND ABRADING POWER OF WATER UPON THE SIDES AND THE BOTTOM OF RIVERS AND CANALS.

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[Continued from Vol. lxxv., page 338.]

Dubuat also pursued the inquiry somewhat further, and observed what became of the sand after it had started. His Sec. 72, Vol. 1, is very interesting on this point. Says he: "When the velocity on the bed of the stream is great enough to cause bodies heavier than water to roll or slide along, these bodies are not moved along with uniform velocity, but they travel, as it were, by relays. Let us take the sand for example. When the bottom of the channel is composed of sand, a little coarse and well visible, and the velocity there is 0·67 or 1·00 ft. per second, its appearance resembles that of what is known as Hun-