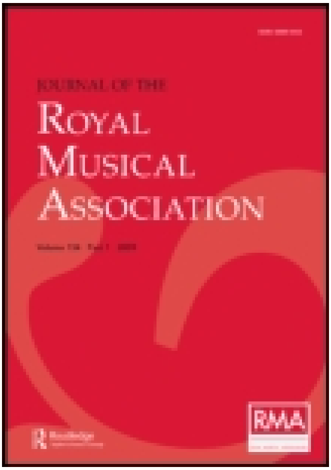

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THE RECENT INVENTIONS FOR REPRODUCING THE SOUND OF THE HUMAN VOICE.

By SHELFORD BIDWELL, M.A., LL.B.

NOT much more than a year ago the world was startled by the announcement of Professor Graham Bell's marvellous invention—the electric telephone—which rendered it possible to talk by telegraph.

The successful solution of a problem which had hitherto baffled all attempts excited universal interest, and has had the effect of directing considerable attention to the science of acoustics, particularly to that part of the subject which relates to the human voice.

The telephone has been followed by the discovery of other means of artificially producing articulate speech, and among the latest instruments devised for this purpose may be mentioned the phonograph, the microphone, and the aerophone. Of the last-named instrument we at present know little, except that it is said to be capable of imparting articulation to the sound of a steam-whistle. By its means, therefore, words may be uttered (so to speak) with such power as to be audible at a distance of several miles. No specimen of this instrument, nor any details as to its construction, have yet reached us from America. Our attention will therefore be confined this evening to the consideration of the telephone, the microphone, and the phonograph.

I need not remind you that all sound is primarily due to vibration. Sometimes the vibratory origin of a sound can be clearly distinguished by the eye. Thus, if you strike a tuning-fork and hold it up to the light you will see that so long as it gives out any considerable sound the outlines of the prongs are hazy and badly defined. This is, of course, owing to their rapid to-and-fro motion. The same thing will be observed if you pluck a stretched string or strike a bell. Many sounds, however, such as those of a whistle or an organ-pipe are caused by the vibration of a body of air, and since air is in-visible its vibratory motions are of course not apparent, but their existence can frequently be detected by the sense of touch. Now, all sonorous bodies with which we have to do are surrounded by air, and air is the medium through which sound is conveyed across the intervening space to the organs of hearing. When we remember that air is not really a uniform homogeneous mass, but is made up of an almost infinite number of little particles very near to each other, but prevented by certain repulsive forces inherent in them from actually touching, the theory of the transmission of sound becomes easily intelligible. It is shortly and simply this: The vibrating sonorous body communicates its vibrations to the particles of air in immediate proximity to it: these vibrations are then passed on from particle to particle of air, each one communicating its motion to its neighbours, until at last the wave of motion reaches certain particles which are in contact with a delicate drum-like membrane within the ear. Their impact against this sensitive organ produces certain physiological effects which result in the well-known sensation of sound.

The nature of the vibratory motions performed by every link in the chain of air-particles, from its origin to its termination, will depend upon those of the sounding body. If the vibrations of the sounding body are rapid, all the air-particles, from the first to the last, will vibrate with equal rapidity. If the rate at which the sounding body vibrates is slow, the air-particles will perform their vibrations at a corresponding slow rate. Again, the amplitudes of the vibrations performed by the air-particles will be large or small in correspondence with those of the sounding body, though it must be observed that inasmuch as each particle gives up its motion not to one only of its neighbours, but to several, among which it is equally divided, the length of the swing performed by any individual particle will decrease rapidly as the distance from the origin of the sound increases.

Every sound has three distinguishing characteristics—pitch, intensity, and quality. The first depends upon the rate of the vibration, slow vibrations producing a sound of low pitch and rapid vibrations a sound of high pitch. The *intensity* of the sound is dependent upon the amplitude or length of the vibration: the sound will be loud or feeble according as the vibrations take place through a large space or a small one. The *quality* of a sound is that characteristic which enables us to distinguish one *kind* of sound from another. Every one knows the difference between the sound of a flute and that of a violin. Every one recognises a distinction between the sound *ah* and the sound *oh*, even though both may be of the same pitch and the same loudness. Between all the various vowel sounds there is a well-marked and unmistakable difference. But though we are all quite conscious of such differences, we are unable without special education to say what is their exact nature. This matter, which was for a long time an incomprehensible mystery, the object of vague guesses and ingenious speculations, is now thoroughly understood; and it is to the complete explanation of it by Helmholtz that the telephone and the phonograph owe their existence.

To render this explanation clear it will be convenient to make use of a ball suspended by a string, forming a simple pendulum. Upon consideration you will see that the oscillations of a pendulum might have one other distinctive characteristic besides the rate at which they are performed, and the distance which they traverse. You will observe that the velocity at which the ball moves between the extreme limits of its course is variable. In the middle of its course it is rapid, then the speed gradually diminishes until the ball stops altogether. Instantly it resumes its journey in the opposite direction, slowly at first, but steadily increasing in pace until it attains the middle point, when once more its speed is diminished and the whole process is repeated.

Though from mechanical necessity this is invariably the kind of motion which is performed by a pendulum—rapid in the middle, slow at the two extremes—there is, of course, no reason why the motion of a particle between two extreme points might not possibly vary in any conceivable manner, while still the period of each complete oscillation remained unaltered. The particle might, for instance, travel quickly at the extremities of its journey, and slowly in the middle; or its course might be broken up into unequal portions, some of which might be performed quickly, others slowly. In fact, the conceivable variety is infinite.

Now it has been ascertained that the air-particles when conveying sound do not, except in very rare instances, perform the simple oscillations of a pendulum; their vibrations are generally of the most complex description, and it is upon the particular form of the vibration that the *quality* of the sound depends.

Several instruments have been devised for giving graphical representations of these vibrations, the best known of which is Scott's Phonautograph. In this instrument the sound to be examined is concentrated upon a small drum of india-rubber or goldbeater's-skin, to the centre of which is connected a long and light strip of wood having a point at the end. The air-waves beat upon the drum and cause it to vibrate in exactly the same manner as the particles of air themselves; the vibrations of the drum are communicated to the strip of wood, causing the pointed end of it to perform the same motions on a larger scale. If now a piece of smoked glass or paper is drawn under the vibrating point, a peculiar wave-like curve will be traced upon it, the exact form of which will depend upon the nature of the vibrations.

I have here an enlargement of some tracings which were obtained in this manner. The first is the simple sinuous curve produced by a pure musical sound; the air-particles in this case performed motions exactly like those of an ordinary pendulum. The others were produced by singing into the instrument the vowel sounds *oo*, *o* and *a* in succession, care being taken that the sound was in each case of the same pitch and as nearly as possible of the same loudness. You will see that they are all more or less complicated in form and that each of them possesses a well-defined character peculiar to itself. When the conditions are unaltered, the same sound always produces the same curve, and the curves traced by two different sounds are never alike.

In order to ascertain from such curves what was the exact nature of the motions of the air-particles concerned in producing them, we must eliminate that component part of them which is due to the motion of the smoked glass or paper. Knowing the velocity at which the glass or paper moved, this is a problem which may be solved by a simple geometrical method. Without troubling you with the details of the process, I will exhibit by way of example what may be called a translation of the first two of these hieroglyphics—those produced by the pure musical tone and by the vowel sound *oo*.

Upon the screen is projected a spot of light which is intended to represent a particle of air. By means of a suitable mechanical arrangement there is imparted to it a motion of the kind denoted by the hieroglyphic which was traced by the pure musical tone. It is, as you will have foreseen, a simple backward and forward oscillation, rapid in the middle and slow at the two extremes, like that of a pendulum. I now substitute an arrangement intended to interpret the hieroglyphic corresponding to the sound *oo*. The motion of the spot of light is in this case of a totally different character. There is no longer a gradual acceleration as the spot approaches the middle of its course, and a gradual retardation towards the two ends. It appears to be governed by no law whatever, sometimes starting forward with a jerk, then suddenly slackening and even moving in a retrograde direction more than once in the course of its oscillation. This is a very fair imitation on a large scale and at a reduced speed of the movements performed by every particle of air which assisted in conveying the sound of that vowel *oo*.

All other vowel sounds excite in the air-particles vibrations which are equally irregular in appearance, though their details are in every case more or less varied.

The cause of the complexity of these motions is very shortly this. No sound, with perhaps the single exception of that of a tuning-fork when excited in a particular manner, is a *simple* one. What we are accustomed to regard as simple elementary sounds are in fact more or less complicated *chords*. The fundamental note is always accompanied by other higher notes of varying pitch and intensity, and it is the admixture of these higher notes which determines the character or quality of the sound. Were the higher notes or "overtones" to be in every case eliminated, we should be unable, as Professor Tyndall tells us, to distinguish the sound of a clarinet from that of a flute, or the sound of a violin from either. All voices would be exactly alike, and no distinction between the various vowel sounds would be recognisable. In short, we should be universally afflicted with an incapacity closely analogous to colour-blindness, quality—or "clang-tint" as it is sometimes called—being to sound very much what colour is to light. The human voice is very rich in overtones, as many as eighteen having been distinguished in certain cases. Such overtones are always present when the voice leaves the larynx, but in comparison with the fundamental tone, they are generally weak. We have however the power of bringing one or more of them into greater prominence than the others, by merely altering the form of the cavity of the mouth, so as to reinforce by resonance the particular overtone or overtones necessary for the quality of the sound which we desire to utter.

If I strike a tuning-fork and hold it up in the air, the sound which it emits is so weak that it cannot be heard at any distance. I now hold it over the end of a brass tube, the capacity of which can be altered by dipping it into a vessel of water, and you will observe that when the empty portion of the tube is of one particular length, the intensity of the sound is so much increased that it may be heard all over the room. If the capacity of the tube is either increased or diminished, the sound at once becomes weaker. To reinforce the sound of a tuning-fork of a different pitch, it would be necessary to immerse the tube up to a different but equally definite point; and if we had two or more tuning-forks all vibrating at once over the mouth of the tube, we might reinforce the sound of any one of them which we chose to select, by simply immersing the tube to the proper depth.

In the same sort of way we are able to select and, by suitably adjusting the cavity of the mouth, to reinforce any one or more of the overtones which are present in the voice, and this process, though unconsciously performed, is rendered by long practice easy and certain.

A, then, is a chord; *e* is another different chord; the other vowel sounds are others. Helmholtz has determined the constituent notes of every vowel sound of a certain pitch, and by properly exciting sets of tuning-forks corresponding to those notes, he has succeeded in obtaining from them the sounds of all the vowels.

Now each single note in these chords is itself a pure musical tone, and if acting alone, would produce in the air-particles simple vibrations, like those of a pendulum. But when several such notes of different pitch and different loudness exist at the same time, each of them will tend to make the particles move in a different manner; and under the combined influence of these several sets of forces, all tending to produce a different motion, the particles will perform the complicated vibrations denoted by the curves which you have seen.

This then is the method in which vibrations corresponding to vowel sounds are produced by the human voice, and no instrument can be made to imitate the voice which is not capable of producing, by direct or indirect means, vibrations of a precisely similar character.

In the earlier attempts at constructing an electric telephone sufficient attention was not paid to this point, and it was endeavoured to reproduce the sounds of the voice by simply exciting at the distant end of a telegraph wire a series of vibrations resembling in *period* only those which acted upon the transmitting instrument, no regard whatever being had to the form of these vibrations. The result was that, though the tones of the voice were to a certain extent imitated, articulation was entirely absent. The best known of these instruments is that invented by Reiss, a specimen of which was to be seen in the Loan Exhibition of 1876.

A modified form of such a telephone is now before you. The transmitting instrument consists of a small drumhead of very thin iron which is electrically connected with one pole of a galvanic battery. About $\frac{1}{50}$-inch distant from its centre is the point of a carbon pencil to which the line-wire is connected. The receiving instrument contains a similar drumhead of iron, very near which is placed a small electro-magnet having one end of its coil joined to the line-wire coming from the carbon point, and the other end connected either directly or through the medium of the earth with the second pole of the battery.

When a note is sung at a short distance from the thin iron diaphragm of the transmitting instrument, the vibrating particles of air which convey the note communicate their vibrations to the iron, every single vibration bringing the iron into momentary contact with the carbon point. Now every contact between the iron and the carbon closes the electric circuit, thereby causing a momentary attractive power in the electro-magnet of the receiving telephone, and a consequent movement of the iron plate in that instrument. If we suppose that the note sung is that known to musicians as "middle C," the number of vibrations produced in a second will be 256; 256 currents of electricity will in the same time pass through the coil of the electro-magnet, and 256 to-and-fro movements will occur in the adjoining iron plate. The iron plate will thus become the origin of a new sound which will exactly correspond in pitch with the note—middle C—which we supposed to have been sung.

The great defect in this instrument as in all others constructed on a similar principle is its inability to reproduce the qualities of the sounds which it is intended to transmit. For this purpose it is clearly necessary that some other method should be adopted of supplying electricity to the electro-magnet in the receiving instrument than that of simply closing a galvanic circuit. For when that is done there can be no means of graduating the strength of the current, and thus causing the power of the electro-magnet to vary during each vibration in such a manner as to produce in the second diaphragm motions precisely corresponding with those of the air-particles. The instant that contact is made the full power of the electricity is brought into play: no sooner is contact broken, than in the twinkling of an eye all trace of electricity disappears. Between the maximum power of the electro-magnet and its minimum power there is no mean: at one moment it attracts the diaphragm with the utmost force of which it is capable, the next moment not at all: although, therefore, it can cause the diaphragm to vibrate, it is utterly incompetent to mould its vibrations into those delicate forms upon which the various qualities of sound depend for their distinctive characters.

After years of study and experiment Professor Bell at last succeeded in producing an instrument which perfectly fulfils all the necessary conditions. Beginning with a most complicated machine, which was intended to comform to certain theories enunciated by Helmholtz, Professor Bell gradually simplified, and at the same time improved his apparatus, until at length it attained the "ridiculously simple"* form which is now familiar to every one.

At the end of a trumpet-shaped wooden case is a funnel-like mouthpiece, immediately behind which is a disc of thin iron. Just so far away from the other side of the iron disc as not to interfere with its free vibration, is a bar-magnet, upon the end of which is mounted a small wooden bobbin, having a quantity of insulated copper-wire wound round it. The two ends of this wire are connected with brass binding screws for joining them on to the line-wires. In this arrangement the transmitting instrument and the receiving instrument are identical in form; in fact, it often happens that there is only one instrument at each end of the line, which serves the purposes both of a transmitter and of a receiver, being used in the manner of an ordinary speaking tube. The usual and more convenient

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* Sir William Thomson.

practice is to have two instruments at each end, one of which is applied to the mouth, and the other to the ear.

Now every deflection which the impact of sound-waves causes in the diaphragm of the transmitting instrument will induce in the coil of wire a momentary current of electricity, the strength of which will be proportional to the extent of the deflection. This current travelling along the line-wire will vary the attractive power of the magnet in the receiving instrument in a degree proportional to its strength; and, under the influence of this variation in the attractive power, the second diaphragm will undergo deflections similar in every respect except amplitude to those of the other. The vibrations thus set up will originate a new sound of the same pitch and character as that by which the transmitting instrument was excited, but it will be far less intense.

It will be noticed that with this apparatus no battery whatever is used, the electricity being generated simply by the action of the voice, which, by causing the diaphragm to vibrate, produces electric currents in the coil of wire. The original source of energy is therefore very small; and when we consider the number of transmutations which this energy undergoes before it reappears as sound, each transmutation involving an immense amount of waste, it is not surprising that the sound when reproduced should be extremely feeble. It has, in fact, been calculated that, with the best instruments and a short circuit, not more than $\frac{1}{1000}$ part of the original sound is given out by the receiving telephone.

Its deficiency in power is the one grave defect under which this otherwise nearly perfect instrument labours. Seated in solitary silence with the instrument applied closely to your ear, a conversation with a distant friend may be easily and comfortably carried on. But when persons are talking near you, when machinery is working, or carts and carriages are passing outside, it becomes extremely difficult to follow the telephonic communication, and if you should happen to remove the instrument a few inches away from your ear you will hear nothing at all.

No great improvement in this respect can be hoped for so long as we have no more powerful source of electricity than the mere sound of the voice. If, instead of relying upon the voice itself for the generation of the required energy, we could devise an instrument for enabling the voice to control and regulate the energy derived from another and more powerful origin, such as a galvanic battery, we should have a much more satisfactory telephone. By way of illustration, we may liken the ordinary Bell's telephone to a piano, and the more perfect telephone, yet to be invented, to an organ. In a piano the energy which produces the sound is derived solely and entirely from the fingers of the performer, and the amount of sound so generated is clearly limited by the performer's physical strength. A strong man could extract more sound from the instrument than a delicate young lady; but no ordinary human being could make a piano, of whatever construction, give out tones of very great power.

With the organ the case is different. The organist has nothing whatever to do with the generation of the sound-producing energy. This energy is supplied by another man, the blower, or sometimes by several men, and occasionally, as in the large instrument in the Albert Hall, by a steam-engine. The sole function of the organist is to control and regulate the flow of the energy which is supplied to him, so as to produce the desired musical effects, and he is thus enabled, with the least amount of physical effort, to fill with powerful strains of music such vast spaces as the Albert Hall or St. Paul's Cathedral, where the tinkling notes of a piano would be utterly lost.

What we desire is to construct a telephone on a similar principle, using a galvanic battery as a source of energy, and having a suitable regulating apparatus analogous to the keyboard of the organ, to be acted upon by the voice, instead of by the fingers. If this could be done there would be hardly any limit to the loudness with which a telephonic message might be repeated. A mere whisper breathed into the transmitting instrument could, if necessary, be transformed by the receiver into a shout loud enough to be heard by a large assembly.

Until very lately no one thought that this would ever be done. It seemed absolutely impossible that the strength of direct battery currents could ever be regulated with sufficient delicacy to produce articulation. But a few months ago the first step towards the solution of the problem was taken by Professor Hughes. He has devised a little instrument even more "ridiculously simple" than the telephone, which by means of a battery current transmits articulate speech with great distinctness. This instrument, which has been named the *microphone*, is peculiarly sensitive as a transmitter of sound, being capable of conveying words which are spoken at a distance of several feet from it. At present, however, the sounds as reproduced at the distant station are little if any louder than with the older instrument; but since the invention is still in its earliest infancy we may reasonably look for great improvement.

A specimen of one form of the microphone is now before you. The essential parts of it are three small pieces of gas carbon, two of which are in the form of rectangular blocks, and are fixed one above the other on an upright board, the third being a little cylindrical pencil which is pointed at both ends and loosely pivoted in an upright position between the two blocks. To each carbon block a copper-wire is attached, and the transmitting instrument is complete. For the receiving instrument an ordinary electro-magnet with a disc of thin iron fixed before its poles may be used, but a telephone of Bell's form is found to be far more sensitive.

A current of electricity from a battery is conveyed by means of a wire to the upper carbon block; thence it passes through the carbon pencil to the lower block, and thence along another wire to the distant telephone. The circuit is completed by a wire connecting the telephone to the other pole of the battery. Thus, when everything is at rest, there will be a constant uniform current of electricity circulating through the microphone, the connecting wires, and the telephone. An ear applied at the telephone would now hear nothing, because, the stream of electricity being uniform, there would be nothing to disturb the equilibrium of the thin iron disc. If, however, the resistance to the passage of the electric current were to be suddenly increased or diminished in any part of its course, a click would be heard in the telephone at the moment of such change. For the variation in the current would cause a corresponding variation in the attractive power of the telephone magnet, and a consequent movement of the iron disc. Now Professor Hughes has discovered that the resistance to the passage of an electric current presented by an arrangement of carbon blocks, like that before you, may be made to vary by extremely small causes. The mere impact of sound-waves upon the carbon pencil is sufficient to produce such variation; and more than that—the variation from one point of time to another will correspond precisely with the phase of the sound-wave, however complicated the wave may be. The apparatus is therefore suited to take the place of Bell's form of telephone for the transmission of articulate speech, one of Bell's telephones still being used as a receiver: but since the difference between the maximum and the minimum variation is not very great, the sounds heard at the receiving telephone will not be materially louder than with a pair of the original telephones connected in the usual manner.

The generally accepted explanation of the microphone is this: Increase of pressure, whether caused by the impact of an air-wave or otherwise, brings the carbon conductors into better contact, thus decreasing the electrical resistance. Diminution of pressure tends to separate the conductors, and so to increase the resistance to the passage of the electricity. It is probable, however, that the matter has not yet received its final explanation.

The most remarkable property of the microphone, and that from which it receives its name, is its extreme sensitiveness to the vibrations of very small sounds, particularly when they are excited by actual contact with the instrument. Thus when a feather is dropped upon the stand the unassisted ear cannot detect the slightest sound at the distance of a few inches. Yet with the assistance of a battery current and a telephone the fall of a feather can be distinctly heard many miles away. A gentle tap with the finger-nail or a light touch with a camel's-hair brush are magnified into very loud sounds, and under suitable conditions the footfall of a fly as it walks across the board is easily distinguished. Unfortunately, the sound cannot be heard by more than one person at a time, and the powers of the instrument cannot therefore be exhibited to an audience.

A further advance towards perfection has been made in the carbon telephone of Mr. Edison. The principle of this instrument is exactly the same as that of the microphone, imperfect contact being made between a button of carbon and a small disc of platinum. The carbon is however attached to a somewhat stout diaphragm of iron, which exposes a larger area to the action of the sound-waves; and the whole arrangement is conveniently mounted in a case resembling that of Bell's instrument. Speech transmitted by one of these telephones is said to have been heard by several hundred persons at once.

We come now to the consideration of one of the most singular pieces of mechanism which has ever been contrived by human ingenuity—Mr. Edison's phonograph. Its object, like that of the telephone, is the reproduction of sound, and particularly of the complex articulate sound of the human voice. But the agency employed is purely mechanical: there is no electricity, no magnet, no galvanic battery; nothing but a comparatively simple arrangement of mechanism. By the telephone a sound is reproduced at sensibly the same instant when it occurs. The phonograph however can repeat words which have been spoken into it, at any subsequent period, it may be a hundred years later, and the words so stored up can be repeated by it, not once only, but as many as ten or even twenty times. But the phonograph accomplishes its object in the same kind of way as the telephone—by causing a stretched membrane to perform certain very complicated vibrations.

It will easily be seen that vibrations of a certain form may be caused by very simple mechanical means. Here is a piece of steel spring, which has a short point attached perpendicularly to one end. The spring is held at the other end, and a file is drawn across the point. Now, on the face of the file are a succession of little ridges and furrows, and these passing over the point cause the spring to vibrate. The *rate* of the vibrations so produced will depend upon the rate at which the file is moved; their *form* will depend upon the form of the ridges and furrows over which the point travels. Now, these vibrations of the spring stir up similar vibrations in the surrounding air, and produce a sound; but since the surface of the spring is small the number of air-particles exposed to its influence is comparatively few, and the sound consequently feeble. In order to increase the vibrating area we connect the spring by a piece of twine to the centre of a small drum. If the spring is held so that the twine is taut, all the vibrations of the spring are communicated through the twine to the drum. This exposes a larger vibrating surface to the air, and the amount of sound produced on drawing the file across the point is much increased.

The outline of the ridges and furrows upon the face of the file would, if greatly magnified, be represented by a zigzag line something like the teeth of a saw. Suppose now that we were provided with a file having upon its face ridges and furrows whose outline, instead of being a simple zig-zag, resembled one of the sinuous lines which we saw just now—that corresponding to the vowel *oo*, for instance. When such a file was drawn over the point the resulting vibrations of the spring and drum would produce a noise as in the former case; but this noise, instead of being altogether inarticulate, would closely approximate to the vowel sound *oo*, because the vibrations stirred up in the air would be similar in form to those produced by the voice in saying "*oo.*"

So too we might have a file cut in such a manner as to cause any other desired form of vibration, when drawn across the point. Sound of any quality whatever could thus be obtained, and if we wished to make the sound continuous, we might cut the proper ridges and furrows upon the surface of a grindstone, instead of upon the file, and the sound would continue as long as the handle of the grindstone was turned. Lastly, if we wished to produce not merely a continuous vowel sound, but a succession of words or even sentences, we might elongate our grindstone into a drumlike cylinder, and mount it upon a screwed spindle, so that at each turn a fresh surface might be exposed to the point. Ridges and furrows suited to produce sentences of considerable length might then be cut in a spiral line upon the cylinder, and we should have a very remarkable talking machine.

The only obstacle in the way of carrying out this idea is the utter impossibility of cutting such ridges and furrows with sufficient accuracy upon either a file, or a grindstone, or a cylinder.* This difficulty has been surmounted by the phonograph, which enables the voice itself to cut the proper ridges and furrows.

Here is a small brass cylinder mounted upon a screwed

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* On the 27th of February, 1879, an instrument was exhibited to the Royal Society by Messrs. Preece and Stroh, containing a series of small brass wheels, upon the peripheries of which were cut such indentations as above described: when these wheels were made to rotate successively under a spring connected with a diaphragm, all the vowel sounds were very accurately reproduced.

axle, and having upon its surface a spiral groove of the same pitch as the screw on the axle. At a short distance from the cylinder and perpendicular to its surface is a steel point which is attached to a spring in the same way as the one which was used with the file. One end of the spring is fixed, the other is connected by a piece of silk or a rod of pine to the centre of a parchment drum. By means of a screw-nut we can bring the steel point up to the groove on the cylinder, and if we turn the handle the point may be made to travel in a spiral course from one end of the cylinder to the other without ever leaving the groove. Now if only the bottom of the groove were indented with suitable ridges and furrows, the point in passing over them might be caused to vibrate in such a manner as to produce the sound of any desired words. The way in which the exceedingly complex ridges and furrows necessary for this purpose are formed is wonderfully simple.

On the opposite side of the cylinder is the apparatus for doing it. This consists of a mouthpiece like that of a speaking tube, the object of which is to concentrate the sound of the voice upon the back of a stretched membrane, which is generally made of thin iron. Upon the other side of this membrane a short steel point is fixed perpendicularly. This point can, like the other, be brought into the groove on the cylinder, and be made to travel from end to end without leaving it. But before using the instrument, the cylinder is covered with a sheet of stout tinfoil, which prevents the point from entering freely into the groove. When the point is screwed up so as to press upon the tinfoil and the handle is turned, a smooth groove is scored upon the tinfoil; but if while the handle is being turned we say *oo* into the mouthpiece, the groove then formed will no longer be smooth, but will be indented with a succession of little undulations. The existence of these undulations is plainly visible to the unassisted eye, and if we could conveniently examine them with a microscope we should see that their outline very closely resembled the curve corresponding to *oo* which was traced by the phonautograph. The characters are in each instrument formed in precisely the same manner, the only difference being that whereas those of the phonautograph are traced upon a flat piece of glass or paper, those of the phonograph are embossed perpendicularly upon the yielding surface of a sheet of tinfoil.

The sounds spoken into the mouthpiece cause the iron membrane to vibrate in a particular manner, the nature of the vibrations depending upon the quality of the sound. The point of course vibrates with the membrane, and in so doing punches indentations upon the moving tinfoil against which it presses. Thus there is formed upon the cylinder a succession of little hills and valleys suitable for causing the spring on the other side to vibrate in such a manner as to reproduce the original sound. Having withdrawn the point which made the indentations, I place the point of the spring at the beginning of the indented furrow and then turn the cylinder so that the indentations pass under the point; the spring is thereupon made to vibrate (just as it was by the file), its vibrations are communicated by the silk thread or wooden rod to the parchment drum, and by the parchment drum to the surrounding air: and a sound is produced which you will recognise as a feeble but evident reproduction of the sound *oo* which was originally spoken into the mouthpiece.

It is, of course, theoretically possible to use a single diaphragm both for the production of the indentations and the reproduction of the sound; and indeed many instruments have been constructed on this principle. But, for reasons which it is not difficult to imagine, the arrangement just described is found to give the best results.

The phonograph is not a perfect instrument, and from its nature probably never will be. The extremely delicate details of the vibrations upon which the distinctive quality of different sounds depends must necessarily be injuriously affected by the resistance of the tinfoil, which impedes the free vibration of the iron membrane.

But the invention is nevertheless a very marvellous one, and its articulation, though somewhat muffled and metallic, is generally quite intelligible.