CHAPTER IV.

HISTORY OF THE PRODUCTION OF GALVANIC MUSIC.

This chapter will be devoted to the history of the production of galvanic music, and to the reproduction of sounds by electricity, from the experiments of Page, in 1837, to those of Gray, in 1874. The authorities quoted are given in chronological order.

[1] The following experiment was communicated by Dr. C. G. Page, of Salem, Mass., in a recent letter to the editor. From the well known action upon masses of matter, when one of those masses is a magnet and the other some conducting substance, transmitting a galvanic current, it might have been safely inferred (*a priori*), that if this action were prevented by having both bodies permanently fixed, a molecular derangement would occur whenever such a reciprocal action should be established or destroyed. This condition is fully proved by the following singular experiment. A long copper wire, covered with cotton, was wound tightly into a flat spiral. After making forty turns, the whole was firmly fixed by a smearing of common cement, and mounted vertically between two upright supports. The ends of the wire were then brought down into mercury cups, which were connected by copper wires with the cups of the battery, which was a single pair of zinc and lead plates, excited by sulphate of copper. When one of the connecting wires was lifted from its cup, a bright spark and loud snap were produced. When one or both poles of a large horseshoe magnet are brought by the side or put astride the spiral, but not touching it, a distinct ringing is heard in the magnet as often as the battery connection with the spiral is made or broken by one of the wires. Thinking that the ringing sound might be produced by agitation or reverberation from the snap, I had the battery contact broken in a cup, at considerable distance from the field of experiment; the effect was the same as before. The ringing is heard both when

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[1] C. G. Page, Silliman's Journal, vol. xxxii., p. 396, July, 1837.

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the contact is made and broken; when the contact is made, the sound emitted is very feeble; when broken, it may be heard at two or three feet distance. The experiment will hardly succeed with small magnets. The first used in the experiment consisted of three horseshoes, supporting ten pounds. The next one tried was composed of six magnets, supporting fifteen pounds by the armature. The third supported two pounds. In each of these trials the sounds produced differed from each other, and were the notes or pitches peculiar to the several magnets. If a large magnet supported by the bend be struck with the knuckle, it gives a musical note; if it be slightly tapped with the finger nail, it returns two sounds, one its proper musical pitch, and another an octave above this, which last is the note given in the experiment.

ON THE DISTURBANCE OF MOLECULAR FORCES BY MAGNETISM.

[1] A short article on this subject appeared in the last number of this journal under the caption, "Galvanic Music." The following experiment (as witnessed by yourself and others not long since) affords a striking illustration of the curious fact, that a ringing sound accompanies the disturbance of the magnetic forces of a steel bar, provided that bar is so poised or suspended as to exhibit acoustic vibrations. An electro-magnetic bar four and a half inches in length, making five or six thousand revolutions per minute, near the poles of two horseshoe magnets properly suspended, produces such a rapid succession of disturbances that the sound becomes continuous and much more audible than in the former experiment, where only a single vibration was produced at a time.

TONES PRODUCED BY ELECTRICAL CURRENTS.

[2] Mr. Page was the first to discover that an iron bar, at the moment it became magnetic through the galvanic current, gave a peculiar tone, and this fact has since been confirmed by Mr. Delezenne.

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[1] C. G. Page, Silliman's Journal, vol. xxxiii., p. 118, October, 1837.

[2] W. Wertheim. Annalen der Physic and Chemie. LXXVII., June, 1849.

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Without being aware of this discovery, I published, in 1844, a treatise in which I dealt with several questions relating to this subject. In this work I attempted to prove:

1st. That the electrical current causes a temporary weakening of the coefficient of the elasticity of iron.

2d. That likewise the magnetization is accompanied by a very slight decrease of the coefficient of the elasticity of the iron, which diminishes only partially when the magnetizing current is interrupted, and that this result does not manifest itself at once, but only upon the continued action of the currents.

The production of sound through the outside current (that is, a current which passes through a helix in whose axis is an iron bar or extended iron wire) was first accurately noticed by Mr. Marrian.

According to these physicists, the sound produced was identical with that obtained by striking the rod on either of its ends in the direction of its axis. Striking the rod sideways, however, did not give the same result.

Mr. Marrian also noticed that other metals, under the same conditions as iron, did not give any sound, and that the sounds from rods of the same dimensions, whether of iron, tempered steel or magnetized steel, were identical.

Mr. Matteucci has repeated these experiments with wires as well as iron bars, attempting especially to establish the relation between the strength of the current and the intensity of the sounds. He has, however, been in some doubt as to the character and value of the sounds.

Messrs. De la Rive and Beatson individually made the discovery that the current which passes directly through an iron wire produces a sound therein. In one of his later treatises, Mr. De la Rive has given a minute description of a series of experiments with various combined currents on different metals and under different conditions.

Mr. Guillemen made an interesting experiment, the result of which confirms my experiments already mentioned. He found that a weak iron bar which, surrounded by a helix, is fixed at

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one of its ends in a horizontal position and at the other end is loaded with a light weight, visibly straightens itself when a current passes through the helix. Mr. Guillemen attributes this movement to a temporary increase of the elasticity of the iron effected by magnetization.

At the same time I delivered to the academy a short note, in which, without entering into the details of the experiments, I explained the results which I had obtained, and how, according to my opinion, the sounds were to be accounted for. The present treatise contains developments and proofs to sustain the opinions given by me at that time. It seems superfluous to repeat here the discussion which occurred at the time of writing this note, between Messrs. De la Rive, Guillemen and Wartmann. I desire simply to say that the last named scientist was the first to notice that a current passing through a wire may produce a sound without there being, in the wire, a resistance of any amount to oppose. Sound may therefore be produced as well in an iron bar as in an extended iron wire, heat having only an insignificant part to play in the phenomenon.

Later on Mr. De la Rive sent a treatise to the Royal Society, in London, which dealt with a part of this subject. After admitting that no sound is produced by a current passing through any metal, other than iron, he goes on to describe a new class of facts.

All conductors, when exposed to the influence of a powerful electro-magnet, give, at the moment of the passage of an interrupted electrical current, a very distinct sound, similar to that of Savart's cogged wheel. The influence of magnetism on all conducting bodies seems to consist in its imparting to the latter, similar properties to those possessed by iron in itself; thus developing in these conductors the property of emitting sounds which are similar to those given by iron and other metals without aid from the action of a magnet.

VIBRATIONS OF TREVELYAN'S BARS BY THE GALVANIC CURRENT.

[1] The vibrations of Trevelyan's bars by the action of heat is an experiment more interesting than familiar, and one which

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[1] Silliman's Journal, 1850. Vol. ix., p. 105.

has been variously and vaguely explained by most authors. It will not be necessary for me to recapitulate the several descriptions and solutions of this phenomenon, as the novel experiment about to be detailed will embrace substantially the whole subject.

About a year since, while exhibiting to a class the vibration of these bars by heat, it became inconvenient to prolong the experiment, as the vibration ceases as soon as the temperature of the bar is somewhat reduced, and I was induced to seek for some method by which the vibratory motion could be produced and continued at pleasure without the trouble of reheating the bars for each trial. After various fruitless efforts, I obtained a most beautiful result by using the heating power of a galvanic current. Fig. 62 shows the mode of performing the experiment with the battery. A and B are the two forms usually given to Trevelyan's bars, which, when to be vibrated by the action of heat, are made of brass, and weighing from one to two pounds, and after being sufficiently heated are placed upon a cold block of lead, as seen in fig. 63. The two bars may be placed upon the same block, though the vibrations are apt to interfere when two are used. When the bars are to vibrate by the galvanic current, they may be of the same size and form as shown, and of any kind of metal—brass, or copper, or iron, however, seeming to be most convenient. One or both of the bars may be placed at once, without reference to temperature, upon the stand, as in fig. 62, the bars resting upon metallic rails E F,

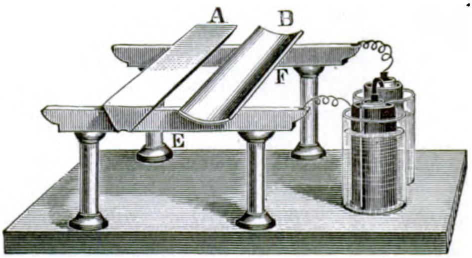

Fig. 62.

which latter are made to communicate each with the poles of a galvanic battery of some considerable heating power. Two pairs of Daniell's, of Smee's, or of Grove's battery of large size are sufficient. The battery I employ consists of two pairs of Grove's, with platinum plates four inches square. The vibration will proceed with great rapidity as long as the galvanic current is sustained.

In fig. 63 one pole of the battery is connected with the metallic block, and the other pole with mercury in a little cavity in the centre of the vibrating bar. The experiment succeeds much better with the rails as in fig. 62, and quite a number of bars may be kept in motion by increasing the number of rails, and passing the current from one to the other through the bars resting upon them.

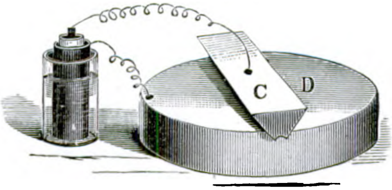

Fig. 63.

The rails are best made of brass wire, or a strip of sheet brass, though other metals will answer—the harder metals which do not oxidate readily, however, being preferred. A soft metal, like lead, is not so favorable to the vibrations in this experiment, although in Trevelyan's experiment lead seems to be almost the only metal that will answer to support the bar, which is usually made of brass.

Prof. Graham and other authors have attributed the vibration of Trevelyan's bars to the repulsion between heated bodies, and others have classed the phenomenon with the spheroidal state of heated bodies. I do not consider that any repulsive action is manifested or necessary in either of these cases, nor do I know of any instance in which a repulsion has been proved between heated bodies. It is obvious some other solution is required for this curious phenomenon, and it appears to me that the motion

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is due to an expansion of the metallic block at the point of contact, and, upon this supposition, it appears plainly why a block of lead is required. That is, a metal of low conducting power and high expansibility is necessary, and lead answers these conditions best. In a future communication I will analyze this matter and explain more fully.

The size of the bars may be very much increased when the galvanic current is employed, and some curious motions are observed when long and large cylinders of metal are used. If they are not exactly balanced, which is almost always the case, they commence a slow rolling back and forth, until finally they roll entirely over, and if the rails were made very long they would go on over the whole length. An inclination of the rails is required in this case, but it may be so slight as not to be perceptible to the eye.

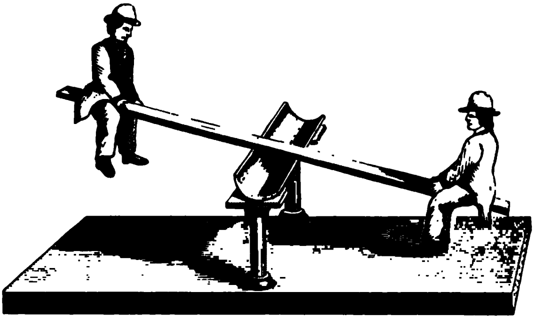

Fig. 64.

If a long rod of some weight be placed across one of the bars, as shown in fig. 64, the vibrations will become longer, and by way of amusement I have illustrated this with a galvanic see-saw, as it may be termed.

It is well known that where mere contact (without metallic continuity) is made by metals conveying the galvanic current, the metals become most heated at the points of contact, and if the current be frequently broken the heat at these points is still more augmented. It is for this reason we are able to use various

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kinds of metals for the experiment, without reference to their conducting powers and expansibilities.

VIBRATORY MOVEMENTS AND MOLECULAR EFFECTS DETERMINED IN MAGNETIC BODIES BY THE INFLUENCE OF ELECTRIC CURRENTS.

[1] Mr. Page, an American philosopher, had observed, in 1837, that on bringing a flat spiral, traversed by an electric current, near to the pole of a powerful magnet, a sound is produced.

M. Delezenne, in France, also succeeded, in 1838, in producing a sound by revolving a soft iron armature rapidly before the poles of a horseshoe magnet. In 1843, I myself remarked that plates or rods of iron give out a very decided sound when placed in the interior of a helix whose wire is traversed by a powerful electric current; but only at the moment when the circuit is closed, and when it is interrupted.

Mr. Gassiot, in London, and Mr. Marrian, in Birmingham, had also made an analogous experiment in 1844. Attributing this singular phenomenon to a change brought about by the magnetism in the molecular constitution of the magnetized body, I went through a great number of experiments, in order to study this interesting subject.

It is above all things important, in order to obtain a numerous series of vibrations, to be provided with a means of interrupting and of completing, many times in a very short space of time, the circuit of which the wire that transmits the current forms a part; in other words, to render a current discontinuous or continuous. With this view, I made use of one of the numerous apparatus called rheotomes, or cut-currents, and which are intended, when placed in the circuit, to render a current discontinuous. One of the most convenient (fig. 65) consists of a horizontal rod, carrying two needles, inserted perpendicularly and parallel with

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[1] Treatise on Electricity in Theory and Practice, by Aug. De la Rive. 1853. Vol. 13; pages 300 to 321 inclusive.

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each other, so arranged that when they are immersed simultaneously in two capsules filled with mercury, and insulated from each other, the circuit is closed; and when they are not immersed, it is open. A clock work movement, or simply a winch moved by the hand, gives a rotatory movement to the axis; whence it follows that, in a given time, a second for example, the circuit may be closed or interrupted a great number of times. The apparatus of fig. 65 presents four needles instead of two, and consequently four compartments corresponding with the four needles. We shall have occasion hereafter to see the use of the second system of two needles; for the present, a single one is sufficient; and, consequently, in all the experiments that will follow, in order to place it in the circuit, we shall employ indifferently either the one that is nearest to the clock work movement or the one that is most distant. There is a risk of the mercury being projected when the movement is too rapid; to prevent this inconvenience, we must cover the capsules, the needles, and the axis that carries them, with a small glass shade. When the current is very powerful, the mercury is oxidized by the effect of the sparks that occur at the moment when the needles emerge; in this case it is necessary to remove the oxide, or to change the mercury. We may do without mercury, and supply its place by two elastic metal plates resting on a cylinder, or on the circumference of a varnished wooden or ivory wheel, in the edges of which are inserted small pieces of metal, in metallic communication together. When the elastic plates, by means of the rotation of the cylinder or of the wheel upon its axis, come in contact with the metal part of the surface, the cir-

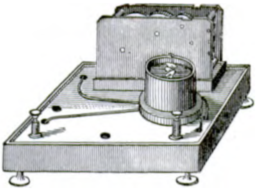

Fig. 65.

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cuit is closed; when the contact with this metal part ceases, which occurs when the contact is with the wood or ivory, the circuit is open. It is necessary in this case that the two plates, as were the mercury cups in the preceding case, shall be in the course of the circuit, that is, to traverse the wire of the helix, and shall press strongly against the circumference.

We may also interpose in the course of the current merely a toothed wheel and an elastic metal plate, which presses upon the teeth of the wheel (fig. 66). By giving the wheel a movement upon its axis, we cause the plate to leap from one tooth to another; each leap produces a rupture in the circuit, which is closed again immediately afterwards. The musical tone given out by the plate, when we have no other means of measuring it, gives us exactly the number of times that the circuit has been opened and closed, that is to say, interrupted, in a second. I have dwelt upon these several kinds of rheotomes because we frequently make use of one or the other of them. For the present, we shall apply them to the study of the vibratory movement experienced by magnetic bodies under the influence of discontinuous currents.

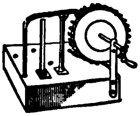

Fig. 66.

When we place a magnetic but unmagnetized body, such as iron or steel, in the interior of a bobbin, this body experiences very remarkable vibratory movements, as soon as we pass a series of discontinuous currents through the wire with which the bobbin is encircled. These movements are made manifest under the form of very decided and varied sounds, when the body has a cylindrical, or even an elongated form. The sound is less decided, but more sharp and more metallic, with steel than it is with soft iron. Whatever be the form or the size of the pieces of soft iron, two sounds are always to be distinguished; one a series of

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blows or shocks, more or less dry, and very analogous to the noise made by rain when falling on a metal roof; these blows exactly correspond to the alternations of the passage and the interruption of the current; the other sound is a musical sound, corresponding to those which would be given by the mass of iron, by the effect of the transverse vibrations. We must take care in these sounds to distinguish those that are due to the simple mechanical action of the current upon the iron—an action which, being exercised throughout the entire mass, may deform it, and consequently produce, by its very discontinuity, a succession of vibrations. However, this is not sufficient for the explanation of all the sounds; and we must admit that there is, in addition, a molecular action, namely that the magnetization determines a particular arrangement of the molecules of the iron, a rapid succession of magnetizations and demagnetizations gives rise to a series of vibrations. How, for example, can we otherwise explain the very clear and brilliant musical sound given out by a cylindrical mass of iron 4 inches in diameter, and weighing 22 lbs., when placed in the interior of a large helix (fig. 67), while traversed by a discontinuous current? Rods of iron half an inch and upwards in diameter, when fixed by their two extremities, also

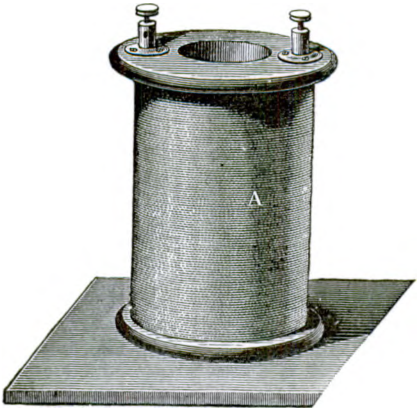

Fig. 67.

give out very decided sounds under the same influence. But the most brilliant sound is that which is obtained by stretching upon a sounding-board well annealed wires, one or two twentieths of an inch in diameter and a yard or two in length. They are placed in the axis of one or several bobbins, the wires of which are traversed by electric currents, and they produce an assemblage of sounds, the effect of which is surprising, and which greatly resembles that to which several church bells give rise when vibrating harmonically in the distance. In order to obtain this effect it is necessary that the succession of the currents be not too rapid, and that the wires be not too highly strained. With a wire 5 feet 2 inches in length, and $\frac{7}{100}$ inches in diameter, I found that the maximum of effect occurs when it is stretched by a weight of from 57 lbs. to 117 lbs., if it is annealed; and from 64 lbs. to 126 lbs., if it is hardened. Beyond these limits, in proportion as the tension increases, the total intensity and the number of different sounds notably diminish; and, at a certain degree of tension, we no longer hear the sound due to the transverse vibrations, but simply that arising from the longitudinal vibrations. The reverse occurs when the wire is slackened.

Sounds entirely analogous to those we have been describing may be produced by passing the discontinuous electric current through the iron wire itself. We remark, in like manner, a series of dry blows, corresponding to the interruptions of the current, and stronger and more sonorous musical sounds, in some cases, than those that are obtained by the magnetization of the wire itself. This superiority of effect is especially manifested when the wire is well annealed, and of a diameter of about one twelfth of an inch; for greater or less diameters, the magnetization by the helix produces more intense effects than those which result from the transmission of the current. Moreover, the same circumstances that influence the nature and the force of the sound in the former case, exercise a similar influence in the latter. The transmission of the discontinuous current produces sounds only when transmitted through iron, steel, argentine, and magnetic bodies in general; but in different degrees for each,

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depending on the coercitive force that opposes the phenomenon.

Wires of copper, platinum, silver, and, in general, any metals, except the magnetic, do not give forth any sound, whether under the influence of transmitted currents, or under that of ambient currents, such as the currents that traverse the convolutions of a wire coiled into a helix around a bobbin. The sound that is produced when a discontinuous electric current is made to pass in an iron wire, explains a fact that had been for a long period observed, and had been described as far back as 1785, by the Canon Gottoin de Coma, a neighbor and a contemporary of Volta. This fact is, that an iron wire of at least ten yards in length, when stretched in the open air, spontaneously gives forth a sound under the influence of certain variations in the state of the atmosphere.

The circumstances that accompany, as well as those that favor the production of the phenomenon, demonstrate that it must be attributed to the transmission of atmospheric electricity. This transmission, in fact, does not occur in a continuous manner, like that of a current, but rather by a series of discharges. Now, Mr. Beatson has demonstrated that the discharge of a Leyden jar through an iron wire causes this wire to produce a sound, provided it does not occur too suddenly, but is a little retarded by passage through a moist conductor, such as a wet string.

The sounds given out by iron wire and by magnetic bodies, under the circumstances that we have been describing, seem to indicate, in an evident manner, that magnetism produced by the influence of an exterior current, as well as by the direct transmission of a current, determines in them a modification in the arrangement of their particles, that is to say, in their molecular constitution. This modification ceases and is constantly produced again by the effect of the discontinuity of the current; whence results the production of a series of vibrations, and consequently different sounds.

A great number of observations, made by different philosophers, have in fact demonstrated in a direct manner the influence

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of magnetization upon the molecular properties of magnetic bodies. M. de Wertheim, in an extensive work on the elasticity of metals, had already observed, that magnetization produced by means of a helix whose wire is traversed by the electric current produces a diminution in the coefficient of elasticity in iron wire and even in steel; a diminution which, in the latter at least, remains in part even after the interruption of the current. M. Guillemin has also remarked more recently, that a bar of soft iron, fixed by one of its extremities whilst the other is free, and which, instead of remaining horizontal, is curved by the effect of its own weight, or by that of a small additional weight, immediately raises itself, when the current is made to pass in the wire of a helix with which it is surrounded, which helix is itself raised up with the bar, all the movements of which it follows, since it is coiled around it. This experiment possesses this important feature,—it shows the magnetization determines a modification in the molecular state of iron; for it cannot be explained by a mechanical action, which could only occur if the helix is independent of the bar.

Furthermore, an English philosopher, Mr. Joule, succeeded in determining the influence that magnetization can exercise over the dimensions of bodies. By placing a soft iron bar in a well closed tube, filled with water and surmounted by a capillary tube, he first satisfied himself that this bar experienced no variation of volume when it was magnetized by means of a powerful electric current, which traversed all the coils of an enveloping helix. In fact, the least variation of volume would have been detected by a change of the level of the water in the capillary tube; now not the slightest is observed, however powerful the magnetization may be. This result is in accordance with what M. Gay-Lussac had discovered by other methods, and with what M. Wertheim had also obtained by operating very nearly in the same manner as Mr. Joule. But if the total volume is not altered, it is not the same for the relative dimensions of the bar, which, under the influence of magnetization, experiences an increase in length at the same time as it does a diminution in

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diameter, at least within certain limits. It was by means of a very delicate apparatus, similar to the instrument employed in measuring the dilation of solids, that Mr. Joule discovered that a soft iron bar experiences a decided elongation, which is about $\frac{1}{720000}$th of its total length, at the moment when the current by which it is magnetized is established, and a shortening at the moment when it is interrupted. The shortening is less than the lengthening, because the bar always retains a certain degree of magnetism. It would appear that the lengthening is proportional, in a given bar, to the square of the intensity of the magnetism that is developed in it. When we make use of iron wires instead of bars, it may happen that it is a shortening, and not a lengthening, that is obtained at the moment of magnetization. This change in the nature of the effect is observed when the degree of tension to which the wire is subjected exceeds a certain limit.

Thus an iron wire, 12½ inches in length by $\frac{1}{5}$ inch in diameter, distinctly lengthens under the influence of the magnetism, so long as it is not exposed to a greater tension than 772 lbs.; but the less so, however, as it approaches nearer to this tension. Setting out from this limit, and for increasing tensions, which in one experiment were carried up to 1764 lbs., the wire was constantly seen to shorten at the moment when it was magnetized. Tension exercises no influence over highly tempered steel; so there is never any elongatior, but merely a shortening, which commences when the force of the current exceeds that which is necessary to magnetize the bar to saturation.

M. Wertheim, on his part, at the close of long and minute researches, succeeded in analyzing the mechanical effects that are manifested in magnetization. He found that, when an iron bar is fixed by one of its extremities, and the bobbin is so placed that its axis coincides with that of the bar, no lateral movement is observed, but merely a very small elongation, which rarely exceeds .00078 inch. This elongation is the greater as the bobbin is situated nearer to the free extremity of the bar, and diminishes in proportion as it approaches the point by which it is

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fixed. When the bar ceases to be within the axis of the bobbin, the elongation still remains; but it is accompanied by a lateral movement in the direction of the radius of the bobbin. The bobbin that was employed by M. Wertheim was 9.84 inches long, and 7 inches in interior diameter; glasses of a magnifying power of about 20 diameters, and containing two steel wires, were used to measure the elongation and the lateral displacement. This displacement, or, what comes to the same thing, the versed sine of the curvature of the bar, measured at its extremity, was determined for different intensities of current; and it appeared that it was in general proportional to this intensity, but it varied for each position of the bar in the interior of the bobbin. However it may be, we are able to find for each of these positions the mechanical equivalent of the unit of the intensity of the current, namely, the weight which, when applied at the extremity of the bar, would produce the same versed sine. Thus, for example, by calling the length of the part of the radius, comprised between the axis of the bar and the axis of the bobbin D, the versed sine of the curve *f*, the weight that would produce the same versed sine P, the following results have been obtained by acting successively upon three bars of iron, the respective masses of which were 100, 40.5, and 25.5:

NO. OF BARS.	FOR D—80.		FOR D—50.	
	f	P	*f*	P
1..............	.4386 feet.	98.92 grs. Tr.	.2385 feet.	53.86 grs. Tr.
2..............	3.0632 "	41.26 "	1.5573 "	23.04 "
3..............	1.5249 "	22.57 "	.9360 "	12.55 "

We calculate P from the formula $P. = \frac{f\,g\,b\,c^8}{44^8}$, in which *f* is the versed sine of the curvature, *g* the coefficient of elasticity, which is 27,122,653 lbs. avoirdupois per square inch for soft iron, *b* and *c* the width and thickness of the bar, and L its length from its fixed point to its free extremity. From the preceding table we deduce the value of the mechanical forces that are between

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them: for D=80, as 100 : 41.71 : 22.81; and for D=50, as 100 : 40.50 : 23.34. So we may conclude, since the masses of the three bars are together as 100 : 40.5 : 25.5, that the effect, which is here an attraction, is proportional to the mass of iron upon which the current is acting. We, in like manner, find that it is proportional to the intensity of the current; which would render it an easy manner to construct upon this principle a very sensible galvanometer, by employing a prismatic bobbin and a wide and thin iron band.

Thus, all the experiments that we have been relating lead us to recognize that there is produced, by the effect of magnetization, a mechanical traction, due to a longitudinal component and to a transverse component; that the latter becomes null when the bar is situated in the centre of the helix; that they are both proportional to the intensity of the current and to the mass of the iron.

It is a more difficult matter to verify the effect of the transmitted current than that of the exterior current, by which magnetization is produced. In fact, in the former case, the mechanical effect of the current is very difficultly separated from its calorific effect. However, it follows, from some of Mr. Beatson's experiments, that an iron wire, at the instant it is put into the circuit, appears to undergo a small sudden expansion, and one very distinct from the dilatation that results in it, as in other metals, from the heating produced by the passage of the current.

These mechanical effects being once well studied, we can return, with greater knowledge of the cause, to the study itself of the sounds that accompany both magnetization and the transmission of currents.

M. Wertheim has in a perfectly accurate manner verified the existence of a longitudinal sound in an iron or steel bar when placed in the centre of helices traversed by discontinuous currents. This sound, which is similar to that produced by friction, is due, as is proved by direct experiment, to vibrations actually made in the direction of the axis. With wires substituted for bars the effects are the same, except that, when the tension

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diminishes, we hear, in addition to the longitudinal sound, a very peculiar metallic noise, which seems to run along the wire, as well as other peculiar noises. With transmitted currents we also hear the longitudinal sound; and it remains nearly the same in intensity whether the current traverses only a part of the bar, or traverses the whole; a proof of the analogy existing between the action of the transmitted current and that of any other mechanical force, such as friction; equally a proof that the sound is not due to vibrations of a particular kind, engendered by the current. The longitudinal sound occurs equally in bars and in wires; but when we operate with wires, if they are not well stretched, the longitudinal sound is accompanied by the divers noises of which we have spoken. In fine, whether with bars or wires, every time the current is transmitted, but only in the parts where it passes, we hear a dry noise, a crepitation similar to that of the spark, and which is transformed into a distinct sound only in the stretched portion, if it is a wire that is in the circuit. Such are the facts established by M. Wertheim's researches: they are of a nature to confirm the deduction I had drawn before him from the simple study of the sonorous phenomena, namely, that magnetization on the passage of the electric current produces a molecular derangement in magnetic bodies, and that the sounds arise from the oscillations that are experienced by the particles of bodies around their position of equilibrium, under the influence of currents, whether exterior or transmitted. But what now is the nature of this molecular derangement? and how is it able to determine both the mechanical effects and the sonorous effects that we have described? When the action of exterior currents is in question we may form a tolerably exact idea of the nature of the molecular derangement brought about by magnetization. For this purpose we have merely to refer back to the experiment in which either fragments of wire or iron filings are placed in the interior of a helix whose axis is vertical. As soon as the current is made to pass through the wire of this helix the fragments of iron wire all place themselves parallel to the axis, that is to say, vertically, and the filings arrange themselves in small elongated pyramids in the direction of the axis, which destroy themselves and rapidly form again when the current is intermittent. The action of the helix, therefore, upon filings, consists in grouping them under the forms of filaments parallel to the axis—filaments which gravity alone prevents being as long as the helix itself. This experiment succeeds equally well with impalpable powder of iron as with filings; it succeeds equally well with powder of nickel and cobalt; only if the current that traverses the helix is discontinuous, very different effects are observed with each of these three metals—effects that depend, as to their particular nature, upon the greater or less number of interruptions which the current experiences in a given time. The pyramids of filings are at their maximum of height when the disk that sustains them is in the middle of the helix. They turn under the influence of discontinuous currents, providing the succession of these currents is not too rapid, so that there are not more than 60 or 80 in a second. With 160 there is no longer any effect. These differences are indirectly due to the fact that the softest iron has still some coercitive force, and that it requires a certain time for magnetizing and demagnetizing. By comparing under this relation iron, nickel and cobalt, all reduced to an impalpable powder, and prepared by hydrogen, we find that nickel still manifests movements for a velocity of succession of currents, at which iron ceases to manifest any; and that cobalt, on the contrary, ceases to manifest them before iron, which is quite in accordance with what we know of the coercitive force of these three metals.

The following is an experiment of Mr. Grove's, which demonstrates in an elegant manner this tendency of the particles of magnetic bodies to group themselves, under the influence of magnetization, in a longitudinal or axial direction. A glass tube, closed at its two extremities by glass plates, is filled with water holding in suspension fine powder of a magnetic oxide of iron. On looking at distant objects through this tube, we perceive that a considerable proportion of the light is interrupted by the irregular dissemination of the solid particles in the water. But, as soon as an electric current traverses the wire of a helix,

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with which the tube is surrounded, the particles of oxide arrange themselves in a regular and symmetrical manner, so as to allow the larger proportion of the light to pass. The particles in this case are not small fragments of iron wire, artifically disaggregated from a more considerable mass, but iron precipitated chemically, and consequently in its natural molecular state. such as constitutes a solid body by its aggregation.

This disposition of the particles of iron and of magnetic bodies to approach each other in the transverse direction, and to extend in the longitudinal direction, under the influence of an exterior magnetization, which is probably due to the form of the elementary molecules, and to the manner in which they are polarized, is now established in an irrefragable manner by direct and purely mechanical proofs.

It is easy to see that it accounts in the clearest manner for the production of sound in a bar or a wire subjected to the influence of the intermittent current of the helix. The particles contending against cohesion arrange themselves in the longitudinal direction when the current acts, and return to their primitive position as soon as it ceases: there follows from this a series of oscillations, which are isochronous with the intermittence of the current. All these effects are much more decided in soft iron than in steel or hardened iron, because the particles of soft iron are much more mobile around their position of equilibrium.

I have also remarked that both iron and steel, when they are already magnetized in a permanent manner by the current transmitted through a second helix, or by the action of an ordinary magnet, do not experience such strong vibrations when the discontinuous current tends to magnetize them in the direction in which they are already magnetized, but stronger ones in the contrary case. It is evident that, in the former case, the particles already possess, in very nearly a permanent manner, the position that the exterior action to which they are submitted tends to impress upon them; while, in the latter case, they are farther removed from it than they are in their natural position. Much more powerful oscillations, therefore, ought to occur to

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them around their position of equilibrium in the latter case, and less powerful in the former, than when they are in their normal position, at the moment when the discontinuous current exercises its action.

The effects of the transmitted current are due to an action of the same order, but acting in a different direction. In order to analyze this action well, we must study the distribution of iron filings around a wire of iron, or of any other metal traversed by a powerful electric current. These filings always place themselves so as to form lines perpendicular to the direction of the current, and consequently parallel to each other. This is very readily perceived by fixing the conducting wire in a groove formed in a wooden plank, covered with a sheet of paper upon which the filings are placed. The latter arrange themselves transversely above the wire, whatever be the manner in which it is curved, forming small filaments of the sixth or eighth of an inch in length, which present opposite poles at their two extremities. When the conducting wire is free, these filaments, instead of remaining rectilinear, join together by their two edges, and envelop the surface of the wire, forming around it a closed curve, like a species of envelope composed of rings that cover each other and are pressed against each other. Now, the arrangement assumed by the particles of iron filings round any conducting wire, iron as well as every other metal, when it transmits a current, ought to be in like manner assumed by the molecules of the very surface of a soft iron wire itself traversed by a current, under the influence of the current transmitted by the entire mass of the wire. This, also, is equally demonstrated by the mechanical effects studied by Joule and Beatson. It follows, therefore, that when the transmitted current is intermittent the particles of the surface of the iron wire oscillate between the transverse position and their natural position, and that there is consequently, a production of vibrations. These oscillations ought to be the more easy, and consequently the vibrations more powerful, as the iron is softer; with hardened iron, and especially with steel, there is a greater resistance to be overcome;

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thus the effect is less sensible. If the wire that transmits the discontinuous current is itself traversed by a continuous current moving in the same direction as the discontinuous one, the oscillatory movement ought to be annulled, or at least notably diminished, since the transmission of the continuous current impresses upon the particles in a permanent manner the position which the passage of the discontinuous current tends to give them in a temporary manner. Thus the sound in this case would completely disappear or notably diminish. If the wire is of steel or of well hardened iron, the continuous current is, on the contrary, favorable, by its presence, to the oscillating action of the discontinuous current, because it deranges the particles from their normal position, without, however, being able completely to impress upon them the transverse direction, on account of the too great resistance they oppose to a displacement, which is easily brought about in soft iron. The two currents united produce what a single current would not be able to accomplish, or would accomplish less effectually, and the sound is then reinforced, as is proved by experiment. In support of the explanation that I have just given, I have found that a copper wire, with a thin envelope of iron which is contiguous to it, gives rise to the same effects and of nearly the same intensity, when the discontinuous current traverses it as if it were entirely of iron; the sound is merely less musical; it resembles that which M. Wertheim designated under the name of "metallic" (iron-y *feraille*). As this result might be attributed to a part of the current traversing the iron envelope itself, instead of circulating exclusively through the copper wire, I insulated the latter by means of a thin covering of silk or wax, so that the iron cylinder that surrounds it is not able to communicate metallically with the copper. The effect is exactly the same as in the preceding case, that is to say, the discontinuous current that traverses the copper wire determines a series of vibrations in the iron envelope, which proves that we may admit that the same effect is produced upon the surface of an iron wire which itself transmits the current. With regard to the envelope, we can easily prove that it experiences a transverse magneti-

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zation when the copper wire is in the voltaic circuit; for if we make in it a small longitudinal groove, we perceive that the iron filings are attracted upon its two edges, which have also an opposite polarity.

The detailed explanation that we have given of the molecular phenomena, which, in magnetic bodies, accompany the action of currents both exterior as well as interior, finds a further confirmation in the observation of several facts of different kinds. Thus I have remarked that permanent magnetization, whether impressed upon a soft iron rod by the action of an enveloping helix, or by the action of a powerful electro-magnet, increases, in a very decided manner, the intensity of the sounds that are given out by this rod, when traversed by a discontinuous current.

This reinforcement is, in fact, evidently due to the conflict that is established between the longitudinal direction that is impressed upon the particles of iron by the influence of the magnetization, and the transverse direction that the passage of the current tends to give to them. The oscillations of the particles ought necessarily to have greater amplitude, since they occur between more extreme positions. The effect is more decided with soft iron rods than with those of steel, and especially tempered steel. Mr. Beatson arrived at a similar result by quite another method. He observed, that if a continuous current traverses a wire, and if, at the same time it is subjected to the action of a helix in which a discontinuous current is passing, the wire will undergo a series of contractions and expansions which become inappreciable, if the continuous current ceases to be transmitted, even when the helix continues to act in the same manner. The author drew from this the same conclusion that I had deduced from the sonorous effects, namely, that the action of the helix impresses upon the particles of iron an opposite state to that which is produced by the transmitted current, and that one of these actions has the tendency to invert the arrangement which the other tends to establish.

A very curious fact is that magnetization tends to impress

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upon the particles of soft iron an arrangement similar to that which they possess in tempered steel, even before it is magnetized. What confirms the correctness of this remark is, that the sound which magnetized soft iron gives out under the action of the transmitted current, is not only more powerful than it is when there is no magnetization, but it also acquires a peculiar dry tone, which makes it resemble that which steel gives out without being magnetized.

The very remarkable influence of tension, which, beyond a certain limit, diminishes in soft iron wires their aptitude to give sounds, is a further consequence of our explanation. In fact, the molecules, by the effect of tension, undergo a permanent derangement in their normal position, and are consequently found crippled in their movements, and are no longer able, under the influence of exterior or interior causes, to execute the oscillatory movements, and consequently the vibrations which constitute the sound.

Two facts, of a character altogether different from the preceding, still further show that the magnetization of iron is always attended by a molecular change in its mass.

The first of these facts was discovered by Mr. Grove. It is, that an armature of soft iron experiences an elevation of temperature of several degrees when it is magnetized and demagnetized several times successively by means of an electro-magnet, or even of an ordinary magnet set in rotation in front of it. Cobalt and nickel present the same phenomenon, but in a somewhat slighter degree; whilst non-magnetic metals, placed under exactly the same circumstances, do not present the slightest traces of calorific effects. This experiment can only be explained by admitting that the development of heat arises from the molecular changes which accompany magnetization and demagnetization. The second fact, which is no less important, is due to Dr. Maggi, of Verona, who proved that a circular plate of very homogeneous soft iron conducts heat with more facility in one direction than in the other when it is magnetized by a powerful electro-magnet; whilst, when it is in the natural state, its conduct-

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ibility is the same in all directions, and, consequently, perfectly uniform. The plate is covered with a thin coating of wax melted with oil, and the heat arrives at its centre by a tube that traverses it, and in the interior of which the vapor of boiling water is passing. The plate is placed horizontally on the two poles of a powerful electro-magnet, several insulating cards preventing contact between it and the iron of the electro-magnet. So long as it remains in its natural state, the curves that bound the melted wax assume the circular form which indicates a uniform conductibility for heat in all directions. But, as soon as the electro-magnet is magnetized, the curves are deformed; and they are always elongated in a direction perpendicular to the line that joins the magnetic poles; which proves that the conductibility is better in the direction perpendicular to the magnetic axis than in the direction of the axis; a result in accordance with the fact that we have established, that the particles of iron approach each other, by the effect of magnetization, in the direction perpendicular to the length of the magnet, and recede in the direction of that length, which is always the magnetic axis.

INFLUENCE OF MOLECULAR ACTIONS UPON MAGNETISM PRODUCED BY DYNAMIC ELECTRICITY.

We have seen that heat, tension, and mechanical actions generally facilitate magnetization.[1] M. Matteucci has found that torsion and percussive and mechanical actions, not only facilitate the magnetization produced upon soft iron by a helix that is traversed by a powerful current, but they also contribute, when the current has ceased to pass, to the destruction of magnetism in a very rapid manner. The same philosopher has likewise observed, that torsion, when it does not pass beyond certain limits, augmented the magnetization produced upon steel needles by discharges of the Leyden jar.

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[1] M. Lagerhjelm observed that iron becomes strongly magnetic by rupture.

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M. Marianini, who has made numerous and interesting researches upon magnetization, arrived at curious results upon the aptitude that iron bars may acquire of becoming more easily magnetized in one direction than in another, and even in being little or much magnetized by the influence of the same cause. When an iron bar has been magnetized by the influence of an instantaneous current that circulates around it, and when it has lost this magnetization by the action of a contrary current, it is more apt to be magnetized afresh in the former case than in the latter. We are able, by contrary currents, to give it even more aptitude to be magnetized in the latter direction than in the former. The augmentation of aptitude that it acquires of being magnetized in one direction is equal to the loss of aptitude that it experiences for being magnetized in the other direction. But, by reiterating the action of the currents upon the same bar, the increase of aptitude in one direction, and the corresponding diminution in the other, become always more and more feeble. The modifications of aptitude for acquiring magnetization are accompanied by modifications in the aptitude for losing this magnetization; but in such direction that the latter is the reverse of the former.

Willing to enter more deeply into the study of the effects that we have been relating, M. Marianini subjected iron to different physical and mechanical actions. First of all, he satisfied himself that neither elevation of temperature, nor especially the cooling by which it is followed, neither percussion nor torsion, nor a violent shock, nor any mechanical action, even the most energetic, are able of themselves to determine magnetization; nor, indeed, does the discharge of a Leyden jar through an iron bar magnetize it. But these various operators, incapable of magnetizing, may all serve to destroy the polarity of magnetized bodies; the quantity of magnetic force that they thus lose, when their aptitude has not been altered, is the greater, as the magnetization has been more feeble. But if, after having undergone one of these actions, the bar has still preserved a little magnetism, it can no longer lose it by this or by any similar action.

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What is very remarkable is, that when the magnetism of a bar has been destroyed, on remagnetizing it in a contrary direction by a succession of instantaneous currents, so that its magnetization is null, we may restore to it its former magnetism by means of a violent shock, by letting it fall, for instance, on the pavement from the height of a couple of yards. The greater the height of the fall, the more powerful is the magnetism it recovers. Thus, a bar, that made a needle deviate 60°, having been brought by a succession of discharges to exercise no deviation beyond 0°, gave 14° on falling from a height of 12.8 feet, 15° 30′ on falling from a height of 15.0 feet, and 21′ on falling from a height of 6.4 feet. This new polarity was in the same direction as the primitive one.

Even when, by destroying the primitive magnetization of the bar, we have actually imparted to it a new one in a contrary direction, we find on letting it fall upon the pavement that we restore to it the first that is possessed. M. Marianini would be disposed to believe from this experiment and other similar ones, that the bar had retained its former magnetization while still acquiring the contrary one, which neutralized the effect of the first and even surpassed it; and the shock merely destroyed the second, either in whole or in part, which permitted the former to reappear. Flexion, friction, heat, or an electric discharge traversing the iron directly, may take the place of the shock, particularly when very fine wires are in question.

The action that is exercised by an instantaneous discharge through the wire of a helix upon a body already magnetized, increases or diminishes the magnetism of this body according to the direction in which it is sent; but this increase or diminution is the less sensible as the iron is more magnetized. In any case, a given instantaneous current produces proportionately more effect when it is made to act with a view of diminishing the polarity in the magnetized bodies than when it is made to act with a view of increasing it.

M. Marianini, in order to explain the results of these experiments, admits a difference between what he calls polarity and

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magnetism. Thus, the same magnet, although deprived of polarity, may very readily retain magnetism, when magnetized at one time in two contrary directions with an equal force. We must then suppose that contrary magnetic systems producing equilibrium are able to exist in iron, and that exterior forces, such as a current or a mechanical action, do not act with the same energy upon the opposite systems. This opinion, which does not as yet appear to us to rest upon facts sufficiently numerous, has, however, nothing in it that is inadmissible; nothing, in fact, opposes there being in the same bar a certain number of particles arranged so as to produce a magnetization in a certain direction, and others so as to produce magnetization in the opposite direction; as, for example, the interior particles may be found to have in this respect an arrangement the opposite of those on the surface; and that such exterior action operates proportionately with greater force upon the one than upon the other. This point would need to be made clear by further observations, and especially by comparative experiments made upon bars of different forms and different dimensions—upon hollow and solid cylinders, for example. But if some doubts still remain upon the conclusions that M. Marianini has drawn from his experiments, there are not any upon the new proof which they bring in favor of the connection that exists between magnetic and molecular phenomena. The different degrees of aptitude acquired by iron under the influence of certain actions, of becoming more easily magnetized in one direction than in the other, are all quite in harmony with the disposition with which the particles of bodies are endowed to arrange themselves more easily in one direction than in another. This loss of aptitude, after the multiplied repetition of the contrary actions, corresponds with the indifference to arrange themselves in one manner or the other, which is finally presented by the particles of bodies, after having experienced numerous derangements in different directions.[1] Finally the remarkable

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[1] We have a remarkable example of this in the fragility presented by iron when it has been for a long time subjected to rapid and frequent vibrations, as are the axles of locomotives.

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effects of shock, flexion, heat, in fact, of all those actions that change the relative position of the particles, come in support of the relation that we have endeavored to establish.

The whole of the magneto-molecular phenomena that we have been studying, lead us to believe that the magnetization of a body is due to a particular arrangement of its molecules, originally endowed with magnetic virtue; but which, in the natural state, are so arranged, that the magnetism of the body that they constitute is not apparent. Magnetization would therefore consist in disturbing this state of equilibrium, or in giving to the particles an arrangement that makes manifest the property with which they are endowed, and not in developing it in them. The coercitive force would be the resistance of the molecules to change their relative positions. Heat, by facilitating the movement of the particles in respect to each other, diminishes, as indeed does every mechanical action, this resistance, that is to say, the coercitive force.

There remains an important question to be resolved. Are mechanical or other actions—disturbers, as they are, of the electrical state—able of themselves to give rise to magnetism? or do they only facilitate the action of an exterior magnetizing cause; for example, terrestrial magnetism, which, in the absence of all others, is ever present? M. Marianini's researches would seem to be favorable to the latter opinion; however, the facts that are known do not appear to us sufficient as yet to establish it in an incontestable manner. Let us remark that, even although it should be established, yet the non-existence of a previous and proper polarity of magnetic bodies, or of electric currents, circulating around them in a determinate direction, would not necessarily follow. We should merely conclude from it that, in the absence of an exterior acting cause, the particles when left to themselves, constantly arrange themselves so as to determine an equilibrium between their opposed polarities; whence results the nullity of all exterior action.

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A NEW METHOD OF PRODUCING TONES BY THE ELECTRIC CURRENT.

[1] In 1837 Dr. Page, of Salem, Mass., made the important discovery that a horseshoe magnet, before or between whose poles a flat spiral of copper wire was suspended, began to emit tones whenever he passed through the spiral the discontinuous current of a galvanic battery.

Other physicists, and especially Delezenne, Beatson, Marrian, Matteucci, De la Rive, and Wertheim, in following up the discovery, have shown us that it is the interrupted current only which generates this new formation of tones, and that for this purpose it can be applied in two ways, either direct, as when it is passed through the bodies themselves, or again, when conducted through a helical wire placed around these bodies.

In this manner tones have been produced in iron and steel, and in these metals only it would seem, as Wertheim has found from actual experiment, that bars and wires of other metals cannot be made to emit tones by either method; and although De la Rive says in his first treatise that he has obtained tones by both methods from platinum, silver, copper, brass, lead, tin, and zinc, it will be observed that he modifies this assertion in a subsequent work by saying that this took place only when a powerful electro-magnet was acting at the same time on the wire.

The method which we are now about to describe, and which the writer happened to discover accidentally in the fall of 1854, possesses the advantage of generalizing matters, as it shows that all metals can, under certain conditions, be made to emit tones; there are also other considerations which render it interesting as regards its connection with the theory of electricity. This method is based upon the interruptions of a battery current, although in reality it is not the latter, but rather the induced currents produced by the interruptions that must be considered as the generator of the tones. In place also of bars or wires as

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[1] J. C. Poggendorf. Poggendorf's Annalen, xcviii., p. 193. Monatsberichten der Acad. März, 1856.

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heretofore used for producing the tones, tubes formed of sheet metal are substituted, and surround the coils through which the current is passed.

The writer used in his experiments coils five inches in length and about one and one eighth inches in diameter. Both wires of the coils were connected, so that their united length was about 100 feet; the diameter of the wire was 1.4 millimetres. The coils were maintained in a vertical position by means of a stand provided for the purpose, and so placed that the lower ends could be connected to the battery, which, as a rule, consisted simply of a single Grove cell. The tubes to be examined, which were about five inches long and from two to four inches in diameter, were then placed over the coils. Some of them were left entirely open, some closed by soldering, and others bent together so that the edges just touched each other. The material of the tubes consisted of platinum, copper, silver, tin, brass, zinc, lead and iron.

A Wagener hammer of peculiar construction, so as to deaden the noise of its own vibrations, and thus prevent it from interfering with the investigations, was used for interrupting the current.

From the experiments made with this apparatus it has been found that none of the metals, except iron, can be made to emit tones when formed into either open or completely closed tubes and placed over the coils. If, however, the edges of the tubes just touch each other, then all metals can be made to emit a very audible tone, which will vary in loudness and quality of sound with the dimensions of the tubes, the elasticity and quality of the material employed, the strength of the current, and certain other minor considerations that will readily suggest themselves.

Iron is distinguished from the other metals by the fact, due no doubt to its magnetic properties, that it gives a crackling tone both when made into an open tube which surrounds the coil, and also when placed alongside of it. The tone in this case is similar to that heretofore noticed in sheet iron when laid in the coil, but it is much weaker than that heard when the edges of

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the tube come in contact. In the latter case it seems as though a second tone appears with the former one.

The sounds obtained in this manner from metallic tubes whose edges just come in contact with each other, are evidently produced by the induced current generated in the mass of the tubes by the action of the intermittent current in the coil. They must evidently, therefore, become stronger or weaker as the conditions which give rise to them render the induced current stronger or weaker. For example, they are increased when iron wires are placed in the coils, as was done in the experiments made by the writer. They are also increased, but in a smaller degree, when the coil is connected with a condenser, which was also done in all of these experiments.

The weakening of the tones, however, may be still more strikingly shown. For this purpose it is only necessary to place between the tube producing the tone and the induction coil another metallic tube, completely closed and of somewhat smaller diameter. As soon as this is done, the tone of the wider tube ceases instantly, and when the smaller tube is withdrawn again the tone recommences at once.

Even two tubes of different diameters capable alone of giving out tones will show this weakening, but if placed simultaneously one within the other around the coil, they do not interfere with each other.

In place of the smaller closed tube, which, for example, may consist of zinc or any other non-magnetic metal, an open iron tube may be substituted. In this case also the action depends upon the length and thickness of the metal, and weakens or destroys the tones accordingly; not, however, because an induced current is formed in it, as in the case of the closed zinc tube, but because it becomes magnetized by the action of the coil, just as the core does, and the effects of the coil and core consequently oppose each other.

The proof of the connection of the tones with the induced current, if additional proof is necessary, is still further shown by the fact that they are quite independent of the diameter of the

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tubes. The writer has obtained tones from tubes of two, four, and eight inches diameter without noticing any difference in the strength of the sound, other than what might be attributed to a change of proportion between the length and diameter of the tubes.

With proportionate length, a hollow cylinder of any diameter whatever would obviously be forced by the action of a single cell of battery to emit tones just as well as a tube of only an inch in diameter.

Now, while it may be considered sufficiently evident that the tones in question owe their origin to the induced currents which are produced in the tubes parallelly with the convolutions of the coil, and in this respect therefore correspond to the tones generated in steel or iron wires when an intermittent current is passed directly through the latter, we must by no means conclude that they are the result of a molecular action extending throughout the entire mass of the metal, as is certainly the case when iron wires or open iron tubes are used. On the contrary, as the writer is fully convinced, the development of tones first noticed by him, has its origin at the points where the edges of the tubes touch each other, and that, in consequence of this, slight concussions occur which set the tubes to vibrating and thus give out tones.

The tones, moreover, are only a secondary phenomenon, and may entirely fail when the material of which the tubes are made possesses but little elasticity, as, for instance, when lead is used. The real part of the acoustical phenomenon lies in the dull sound or kind of ticking, somewhat similar to that of a watch, which is heard at the points where the edges come in contact simultaneously with the strokes of the vibrating hammer.

It is consequently this ticking alone, and not the tone production, whose investigation properly comes within the province of electrical science, and which I consequently made the especial subject of study, but up to the present time I am obliged to say I have not yet succeeded in bringing about a complete solution of the problem.

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The ticking tone is not audible in a tube whose edges have been soldered, and thus probably made to resemble more nearly a hollow cast-iron cylinder. Even a soldered tube, which has been so nearly cut in two that only a portion of metal of about a line in width remains, is found to give no ticking sound under the conditions I employed.

This shows that a certain separation of the edges is required for the production of the sound; it is furthermore perfectly clear that the adjacent edges of the tube do not come in so close contact as the particles within the mass, and is also proven by phenomena in other provinces of physical science. With apparently the very best contact, also, we must admit the existence of a thin air stratum between the edges of the tube, the same as exists even in the dark centre of Newton's rings.

The influence which distance between the edges of the tubes has on the ticking is shown by the fact that, the more the edges are pressed together the greater is the decrease in the sound, and it is not improbable therefore that if the compression were increased with force sufficient to press the particles of metal firmly against each other, the sound could be entirely destroyed. On the other hand, again, if a loud sound is wanted it is necessary to make the edges just touch each other loosely.

It might be thought an increase of pressure would increase the number of contact points also, and in this manner cause the decrease in the strength of the sound. This could only have been the case when I caused greater portions of the edges of the tubes that were not quite parallel to approach each other, so that in general such a conclusion will hardly be found to hold good. It has furthermore been found that when a short piece of wire or a sewing needle is placed between the edges of the tube, the ticking then becomes very loud, but decreases in like manner with increased pressure, although the needle is never made to touch at all points.

Portions of the tube edges may also be in close metallic contact without the entire disappearance of the ticking if only other portions make but slight contact with each other. Hence tubes

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which have been partially cut in two, like those previously mentioned, will commence to give out sounds if a needle or wedge-shape piece of metal is inserted in the slit. This explains a phenomenon which is observed with tin. When a sheet of this metal is bent around the induction coil and its edges are brought close to each other, they immediately become fastened together as if soldered, and yet the ticking continues to be heard exceedingly well. If, however, the neighboring edges are melted together with a spirit flame or soldering iron, the sound ceases.

The principal question in this examination is of course this: What causes the ticking sound at the divided edges? On first consideration it might be attributed to the passage of sparks, but this certainly is not the origin of the sound. Sparks may generally be seen by separating the edges of the tubes from each other at the moment the hammer interrupts the battery current. They are also noticed, but in a lesser degree, with tubes which have been partially cut in two, when the wedge is allowed to drop into the opening. But so long as the edges remain quietly near each other no spark is observed, even in perfect darkness, and yet the ticking continues all the time without the slightest interruption. I further placed the induction coil with the metallic tube under the exhausted receiver of an air pump, but even there the ticking was heard without the least spark being visible between the edges of the tube.

The sparks, moreover, possess an exceedingly low potential, but this is not to be wondered at when we consider that they are produced in a metallic conductor of only a few inches in length.

With easily fusible metals, such as tin for example, sparks are often seen to be projected for a distance of several lines, but these cannot be considered as genuine electrical sparks; they are caused rather by the projection of particles of melted and glowing metal, and their direction also is generally contrary to that of the electrical current, being sometimes towards one side and sometimes towards another. In any case, however, they can never be real electrical sparks, since the electrical potential of the current, as already stated, is too low for their production. It

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made no difference how near I brought the edges together without causing absolute contact, I could never preceive the passage of sparks between them. The slight space might also be closed by the moistened fingers, or the tip of the tongue even might be placed between the edges of the tubes without feeling the slightest sensation.

If sparks were the cause of the sound one would naturally suppose it would disappear in a fluid conductor, but while maintaining the tube in a horizontal position, I have dipped its edges in spring water, and even in diluted sulphuric acid, without being able to perceive any decrease in the sound. When, however, a thin piece of blotting paper, which has been saturated with diluted sulphuric acid, is placed between the edges, and consequently the metallic contact is broken, the sound disappears. It also disappears with zinc tubes when the edges are so thoroughly amalgamated that drops of mercury remain adhering thereto, obviously, however, because perfect metallic contact is thus established.

On the other hand, again, the sound did not cease when the edges were highly heated by the flame of a spirit lamp, but a decrease in its loudness was certainly noticeable.

The question therefore presents itself still more forcibly. If sparks do not produce the sound, what then is the cause that does?

We might attribute it to a kind of repulsion such as that which, as has been shown by Ampère, exists between different elements of a current for each other. It is possible that during the time the current is being generated this repulsion causes the edges of the tubes to separate a little, and on its disappearance allows them to approach each other again. This alone, however, is not sufficient; it seems hardly possible that these weak currents could produce such disproportionate mechanical results. I have noticed the sound in zinc tubes of two inches diameter and over two and a half lines thickness, which required considerable effort to bring the edges together. Besides, however much we may incline to the idea that the sound results from a me-

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chanical knocking of the edges together, observation so far has given no proof that such is the case.

To the unassisted eye the edges seem to remain absolutely at rest, and even when viewed in the microscope, magnifying at least a hundred times, which would seem powerful enough to show any such motion if it existed, we are unable to perceive any change. In addition to this also, the liquids in which the ticking tubes were dipped showed no signs whatever of the slightest tremor or undulating motion, so that the ticking and toning vibrations, if such they *really* are, must be extremely small.

The most natural view of the phenomena is, that notwithstanding the apparent metallic contact of the edges of the tubes, no uniform flow of electricity actually follows, but that as the current is interrupted, a sudden discharge does take place, without, however, the appearance of sparks.

This assumption may seem to be a very extraordinary one, but at the same time it cannot be said to contradict the experience heretofore obtained; there seems to be no real ground for asserting that the passage of electricity through an exceedingly thin stratum of air should necessarily be accompanied by sparks, while, on the contrary, arguments may be adduced to show that the appearance of sparks under similar circumstances is somewhat doubtful. It still remains an open question whether, in the sparks as they appear, we really see the substantial transfer of electricity; these sparks may just as well be only accompanying phenomena of a dark invisible discharge of electricity, and their comparatively slow motion in certain cases would seem to render this view not altogether improbable.

I do not, however, purpose forming an hypothesis here, and additional light on the phenomena in question must be derived from future observations.

ELECTRICAL TRANSMISSION OF SPEECH.[1]

I have not thought it desirable to give prominence in this chapter on the Electric Telegraph to a fantastic idea of a cer-

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[1] **Exposé des applications de l'électricité. Paris, 1857, par Le Cte. Th. Du Moncel.**

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tain M. Ch. Bourseilles, who believes that we shall be able to transmit speech by electricity, for it might be asked why I class amongst so many remarkable inventions an idea which is at present only a dream of its author. Nevertheless, as I am bound to be faithful to the duty I have undertaken of mentioning every electrical application which has come to my knowledge, I will give you some details which the author has already published on this subject. He says: I ask myself, for example, if words themselves cannot be transmitted by electricity; in other words, if one could not speak at Vienna and make oneself heard in Paris—the thing is practicable, and I will show you how.

Imagine that you speak against a sensitive plate, so flexible as to lose none of the vibrations produced by the voice, and that this plate makes and breaks successively the communication with an electric pile; you may have at any distance another plate, which will undergo in the same time the same vibration.

It is obvious that numberless applications of high importance would immediately arise out of the transmission of speech by electricity; any one who was not deaf and dumb could make use of this mode of transmission, which would not require any kind of apparatus,—an electric pile, two vibratory plates, and a metallic wire are all that would be necessary.

In any case, it is certain that in a future, more or less distant, speech will be transmitted to a distance by electricity. I have commenced experiments with this object; they are delicate and require time and patience for their development, but the approximations already obtained give promise of a favorable result.

PROPAGATION OF TONES TO ANY DISTANCE BY MEANS OF ELECTRICITY.[1]

Previous to 1840, the attempts to transmit signals to great distances by means of electricity were not very successful. Since that time, however, great advancement has been made, and tele-

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[1] Bottger's Polytechnical Notezblatt, 1863.

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graph wires are now so generally erected throughout the country that it leaves little to be desired.

Experiments have been made to transmit tones to any desired distance by means of electricity. The first experiment which was in any degree successful was made by Philip Reiss, professor in natural philosophy at Friedrichsdorf, near Frankfort on the Main, and repeated in the meeting room of the Physical Society, in Frankfort, on the 26th of October, 1861, before a large number of members. One part of his apparatus was set up in the Civic Hospital, a building about three hundred feet distant from the meeting room, the doors and windows of the building being closed. Into this apparatus he caused melodies to be sung, and the same were rendered audible to the members in the meeting room by means of the second part of his apparatus. The apparatus used to obtain this wonderful result is shown in fig. 68, a small light wooden box in the form of a hollow cube, having a large and a small aperture at each end. Over the small opening was stretched a very fine membrane, *s*, against the centre of which rested a small platinum spring *e*, which was fastened to the wood. Another strip of platinum *f*, likewise fastened at one end to the wood, had a fine horizontal peg inserted in the other end, which peg rested on the platinum spring at the point of contact with the membrane. As is well known, tones are generated by the condensation and rarefaction of the air taking place in rapid

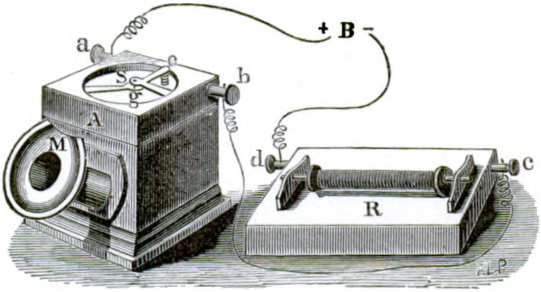

Fig. 68.

succession. If these motions of the air, called waves, strike the thin membrane they cause it to vibrate, which forces the platinum spring resting upon it against the horizontal peg inserted in the second platinum strip, which hops up and down with it. Now, if the latter be connected by a wire with one of the poles of a galvanic battery, and the electricity conducted by a wire attached to the other pole of the battery, to any desired distance, then through a helix, R, six inches long, formed of very fine spun copper wire, and thence back to the platinum spring on the transmitting apparatus—then at every vibration of the membrane an interruption of the electric current will take place. Through the opening in the helix above described, an iron bar ten inches long is run, the ends of which project about two inches and rest upon two sticks of a sounding board.

It is well known that when an electric current passes through a helix enclosing an iron rod in the manner described, at each interruption of the current a tone, produced by the elongation of the rod; is audible. When the interruptions follow each other at a moderate rate, a tone is generated (owing to the change in position of the molecules of the rod) which is known as the longitudinal tone of the bar, and which depends upon its length and the strength of the current. If, however, the interruptions of the electric current in the helix take place more rapidly than the movements of the molecules of the iron bar, which are limited by its elasticity, then they are not able to complete their course, and the movements consequently become smaller and quicker in proportion to the rapidity of the interruptions. The iron bar then does not emit its longitudinal tone, but a tone whose pitch is dependent upon the number of interruptions of the current in a given time. It is a well known fact that higher and deeper tones depend upon the number of air waves which succeed each other in a second's time. We have seen heretofore that on these air waves depend the number of interruptions of the electric current of our apparatus, through the agency of the membrane and the platinum strips, and the iron bar consequently should emit tones of the same pitch as

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those acting upon the membrane. Tones may thus be reproduced, with a good apparatus, at almost any distance.

It is evident, therefore, that it is by the electric impulses alone, and not by the transmission of the sound waves themselves through the wire, that the tones become audible at the distant end, for the tones are no longer apparent when the terminal wires of the helices are joined by a metallic conductor, and thus the instrument shunted out of circuit.

The reproduced tones are generally somewhat weaker than the original ones, but the number of vibrations is always the same. Consequently, while we may easily reproduce precisely the same pitch of the tone, it is difficult for the ear to determine the difference in the amplitude of the vibrations, on account of the gradually decreasing vibrations, which limit even the weaker tones. The nature of the tone, however, depends upon the number of the vibrations—that is to say—tones of the same pitch are produced by the same number of waves per second—at the same time each wave, as, for instance, the 4th, 6th, etc., may be stronger than any succeeding wave.

Scientists have shown that when an elastic spring is made to vibrate by being struck by the teeth of a cog-wheel, the first vibration is the strongest, and each succeeding one, less. If, before the spring stops, it is again struck, then the next vibration becomes equal to the first vibration of the first stroke—without the spring, however, making more vibrations on that account.

It may be that the time is still distant when it will be possible for us to hold a conversation with a friend at a distance, and to distinguish his voice as if he were in the same room with us. Still the probability of success in this has become as great as it was during the important experiments of Niepce for the reproduction of the natural colors by photography.

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