VIII. The Bakerian Lecture.—*Experimental Determination of the Laws of Magneto-electric Induction in different masses of the same Metal, and of its Intensity in different Metals.* By S. Hunter Christie, *Esq. M.A. F.R.S. M.C.P.S. Soc. Philom. Paris. Corresp. &c.*

Read Feb. 28, 1833.

Mr. FARADAY'S highly interesting papers, entitled "Experimental Researches in Electricity," having been referred to me, to report on, by the President and Council of this Society, I necessarily entered minutely into all the experiments and conclusions of the author, and the more so that I had had the advantage of witnessing many of the most important of these experiments. It is foreign to my present purpose to descant upon the value of Mr. Faraday's discovery, or the merits of his communication; the President and Council have marked their opinion of these by the award of the Copley Medal: but I may be permitted to state, that no one can concur more cordially than I do in the propriety of that award.

Agreeing as I did generally with the author, both in the views which he took of the subject, and in the conclusions which he drew from his experiments, there was one, however, which I felt great difficulty in adopting, viz. "That when metals of different kinds are equally subject, in every circumstance, to magneto-electric induction, they exhibit exactly equal powers with respect to the currents which either are formed, or tend to form, in them:" and that "the same is probably the case in all other substances." Although the experiments might appear to indicate that this was possibly the case, I did not consider them to be conclusive. The most conclusive experiment, that of two spirals, one of copper and the other of iron, transmitting opposite currents, was quite consistent with the absolute equality of the currents excited in copper and iron; but, at the same time, the apparent equality of the currents might be due to their inequality being counteracted by a corresponding inequality in the facility of transmission.

In order to determine whether the electric currents * excited in all metals were, under the same circumstances, of equal intensity, I proposed to subject different metals directly to the same degree of magneto-electric excitation, in such a manner that the currents excited in them should be in opposite directions, and that these opposing currents should have the same facility of transmission, by which means the difference of their intensities might be measured.

With this view a helix of copper wire covered with silk, of sixty-five coils, was formed on a cylinder about an inch in diameter, so that, when vertical, the coils turned from below upwards in the direction of the sun's daily motion. Another helix of iron wire, of exactly the same gauge as the copper, covered with cotton, and likewise of sixty-five coils, was formed on the same cylinder, but with the coils turned in the contrary direction to those of the copper wire helix. The coils of the one helix were introduced between those of the other, so that they crossed each other alternately, and then a cylinder of soft iron covered with paper was introduced within the two. The wire at the ends of each helix was uncovered and brightened for about two inches, and the corresponding ends were twisted together in good metallic contact: and to these were united the wires of the galvanometer, as in Plate III. fig. 1., where M is the marked pole of the magnet with which the iron cylinder A′ B′ was brought into contact, and U its unmarked pole; A the wire leading out from the galvanometer above the needle, and B that below it.

The galvanometer consists of sixty-six nearly rectangular coils of the same copper wire, covered with silk, as that forming the helix, to which is adapted a compound needle consisting of two very light needles of fine wire, two inches and three quarters long, connected by their centres, by the quill of a small feather, so that their contrary poles are vertically over each other when suspended. This compound needle is suspended by a single fibre of silk. The lower needle traverses freely within the coils of the wire, and the other above

* I adopt the term electric current, or current of electricity, as a convenient mode of expression; and by it, I would be understood merely to imply that a conductor is in a peculiar state, manifested by certain effects produced on a magnetized needle; but I would not be considered as adopting any theoretical views on the subject:—whether this state consist in the *motion* of a peculiar fluid in the conductor, in the arrangement of one previously existing, or in the excitement of a power previously latent, I am not at present inquiring.

Fig. 1.

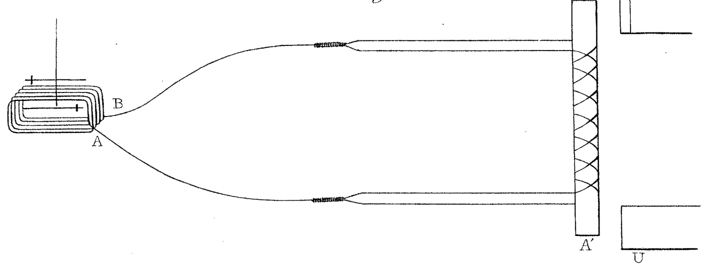


Fig. 2.

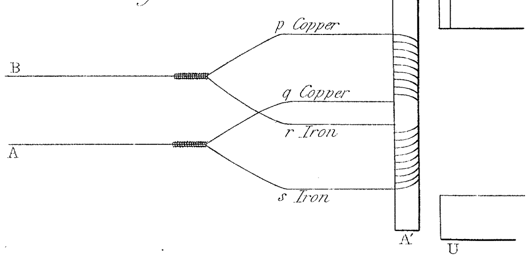


Fig. 3.

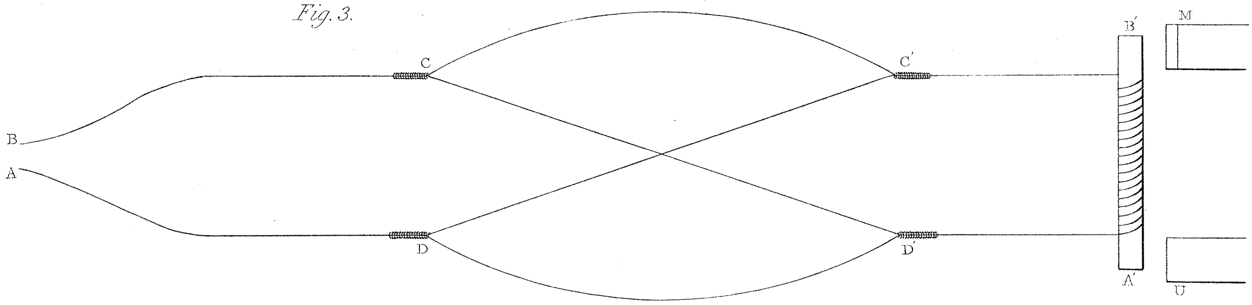


Fig. 4.

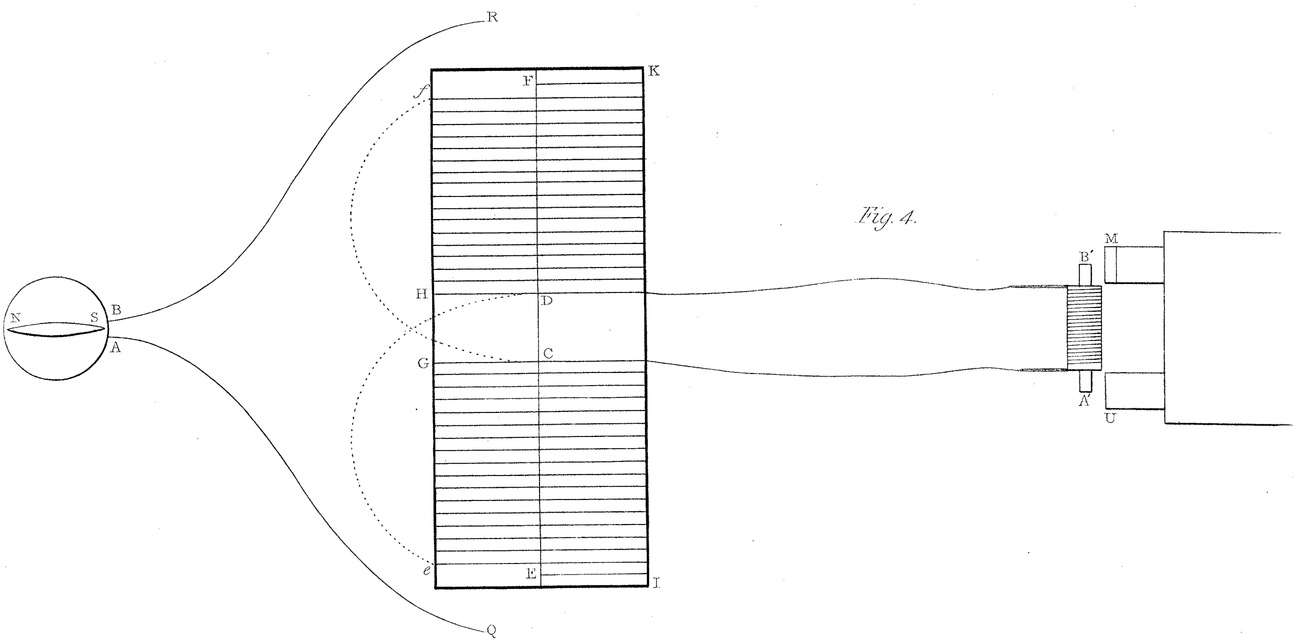
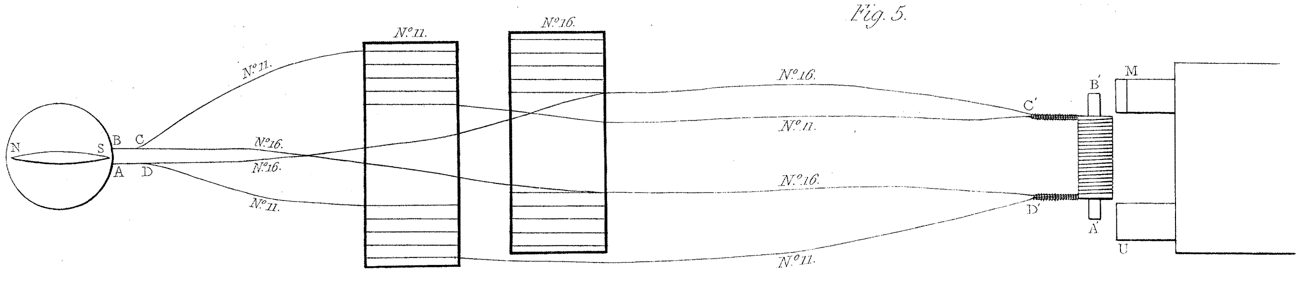


Fig. 5.



them; the intensity of the upper exceeding that of the lower just sufficiently to give it a small directive force in the meridian.

However small the difference of the currents excited in the two metals might be, I had no doubt I should detect it by means of the large magnet belonging to the Royal Society, which had been entrusted to me; but I did not expect that the difference would be of this minute character, and the results which I obtained, on making the experiment, fully justified the views with which it was undertaken. The direction of the coils of the helix of copper wire was such that, according to Mr. FARADAY's experiments, if this alone had been round the iron cylinder, on its contact with the magnet being made, so that the end B′ should be applied to M, and A′ to U, the unmarked end of the upper needle would have moved west, and on the contact being broken it would have moved east. The coils of the helix of iron wire being in the opposite direction, precisely the reverse of this would have been the case had this helix alone been round the iron cylinder. I have here referred the direction of the galvanometer needle's motion to that of the unmarked or south end of the upper needle, and the same must be understood in all the observations which follow*.

On the contact of the iron cylinder with the magnet being made, B′ with M and A′ with U, the needle moved west, and on the contact being broken, it moved east; the needle in each case spinning round several times. Turning the cylinder with the helices end for end, so that B′ was opposite to U, and A′ to M; the contact being made, the needle moved east; and being broken, it moved west, in each case, as before, several times round.

The ends of the copper helix being separated from the galvanometer wire, so that the ends of the iron helix were alone connected with that wire, on contact being made, B′ with M, and A′ with U, the needle moved east; and on its being broken, west; but in neither case was the motion so rapid as it had been in the contrary direction, when the needle was only impelled by the excess of the force of the current from the copper helix above that from the iron helix.

* In consequence of the position of my galvanometer, which was not one of choice, but almost of necessity, I could not accurately observe the motion of the marked or north end of the upper needle, and consequently always noted that of its south end; and I prefer giving the observations as they were set down, to the risk of making confusion, by omissions that might occur in altering east for west, and west for east, throughout the observations.

These experiments showed clearly that the force of the current from the copper helix exceeded considerably that from the iron one; and appeared even to indicate that the intensity of the current from the iron wire was less than half that from the copper. As however the coils of the two wires were necessarily loose round the cylinder, they could not be kept in exactly the same relative positions throughout their whole lengths, and consequently no very precise estimate could be formed of the relative intensities of the two currents. I therefore adopted a somewhat different arrangement.

Sixteen feet of the same copper wire was coiled as before on one end of an iron cylinder, about seven eighths of an inch in diameter, covered with paper; and sixteen feet of the iron wire was coiled in the contrary direction on the other end of the cylinder, there being seventy-one coils and a quarter of the copper wire, and seventy-two coils and a quarter of the iron wire. The ends of the wires being uncovered and made bright for good metallic contact, those ends of the copper and iron helices towards the same end of the bar were then united, and the galvanometer wires connected with them in good contact as in fig. 2. On contact of the iron cylinder with the magnet, B′ with M, A′ with U, being made, the needle moved west; and it moved east, on contact being broken; spinning round several times in each case.

The wires *q* and *r* were now separated from *s* and A, *p* and B, and then united together, so that the current excited in the copper must, in its transmission to the galvanometer, pass through the iron wire, and the current in the iron be transmitted through the copper wire. Contact being made, the first motion of the needle was east, then west; contact broken, the needle appeared to receive a sudden check upon its first motion, but it was difficult to say in which direction the first motion was, the motion being but just perceptible in any case, and the direction appearing to depend upon the manner in which the contact happened to be made. This form of the experiment is nearly that of Mr. Faraday's, to which I have already referred, and the results perfectly accord with those which he obtained. As the copper and iron helices were, as nearly as possible, subjected to the same inductive force, and that force was of the most powerful description, this experiment shows very clearly that however the intensity of the current excited in the copper helix might exceed that in the iron, this excess was very accurately counterbalanced by the greater difficulty of transmission offered by the iron wire to the stronger current of the copper wire, and the greater facility afforded by the copper wire to the transmission of the weaker current of the iron wire: or, in other words, that the intensities of the currents excited in the two wires were very accurately proportional to their conducting powers.

I had intended, by means of the arrangement fig. 2, to determine the relative intensities of the currents excited in different metals by reducing the number of coils of the stronger metal, until the current excited in it should be exactly equal to that in the weaker, which would be determined by no current being transmitted to the galvanometer; but a strong objection to this affording an accurate measure of the intensities was, that the several coils of the helices might not be subjected to the same intensity of magnetic action; and as at the same time that this objection occurred to me, a more accurate method of determining both the relative intensities of the currents excited in different metals under precisely the same circumstances, and their conducting power, presented itself, I prosecuted the inquiry no further in this form of the experiment, which, however, had fully answered the purposes for which it was originally intended. The arrangement which I proposed making possesses many advantages, not only for the purposes which I had in view in the first instance, but in a much more extensive field of inquiry. It affords a very accurate measure of the difference of the intensities of two electric currents, whether they arise from the same source, and are merely modified by circumstances, or have different sources; and whether the source be the magnet, the voltaic battery, or the common machine. And it affords likewise a very accurate measure of the conducting powers of different substances. The general nature of the arrangement, to which the term differential arrangement may with great propriety be applied, will be fully understood by the following experiment made with the same views as those which I have already described.

Four wires, each exactly four feet long, two being of copper and two of iron, of precisely the same diameter, having their ends brightened, were carefully twisted like the strands of a rope at their ends, two and two together, but crosswise, so that, at the corresponding ends, each of the copper wires being united with an iron wire, at the other end it was united with the other iron wire, as in fig. 3. The ends of the galvanometer wire were then brightened and laid carefully between the strands at C, D, and the ends of two copper wires being laid between the strands at C′, D′, the other ends of these were brought in contact with the ends of a compound copper wire helix wound round the iron cylinder B′ A′, and composed of eleven helices of about sixty-five coils each, united at the corresponding ends. Care was, in all cases, taken to prevent metallic contact everywhere but at the parts of the wires specified. On the contact of B′ with M, and A′ with U, the needle moved round east; and on the contact being broken, it moved round west. Reversing the iron cylinder with the helix, so that the contact now was of B′ with U, and A′ with M; on making this contact, the needle moved round west; and on breaking it, the needle moved round east. These results, it is almost unnecessary to say, agree with the preceding experiments.

On the contact of the ends of the iron cylinder with the poles of the magnet being made or broken, a current of a certain intensity being excited in the helix round the iron cylinder, became, at the points C′ D′, the source of currents in the copper and iron wires; at the points C D, equal facilities were afforded by the wires C B, D A, for the transmission of these opposing currents to the galvanometer, where, consequently, their difference might be very accurately measured. Or viewing the subject in a somewhat different light, at the points C′ D′, two routes are presented to the current excited in the wire of the helix, one through the copper wires, the other through the iron, and the effect at the galvanometer would measure the difference in the conducting powers of the two metals. According to the first view, the intensity of the current excited in the copper wire exceeded that in the iron wire; according to the second, the conducting power of the copper, in the same manner, exceeded that of the iron*.

* As in a conversation which I had previously had with Mr. Faraday on this subject, I had stated to him the difficulty I felt respecting the conclusion drawn from his experiments, "Experimental Researches," 201, when I had obtained these results, I communicated them to him, and was immediately informed in reply that he had anticipated my corrections by further experiments of his own. It was satisfactory to find that we had thus, unknown to each other, and by independent experiments, arrived at the same conclusion. In a written Report to the President and Council on Mr. Faraday's paper, I had stated the difficulty I had felt and the conclusions I had arrived at, and it was decided that this Report should be read at one of the evening meetings of the Society, together with an account of the experiments to which I referred. By some mistake, the Report on Mr. Faraday's first series of expe-

Having in this manner determined that a considerable difference existed in the intensity of the currents excited under precisely the same circumstances in two metals, iron and copper; I then determined, in the same manner, the order of the relative intensities and conducting powers of several of the metals. As, however, in this inquiry some questions arose respecting the intensities of the currents excited in different lengths of the same wire, I shall first describe the experiments made with the view of determining the law of the intensity as depending upon the length and diameter of the wire through which the current is transmitted.

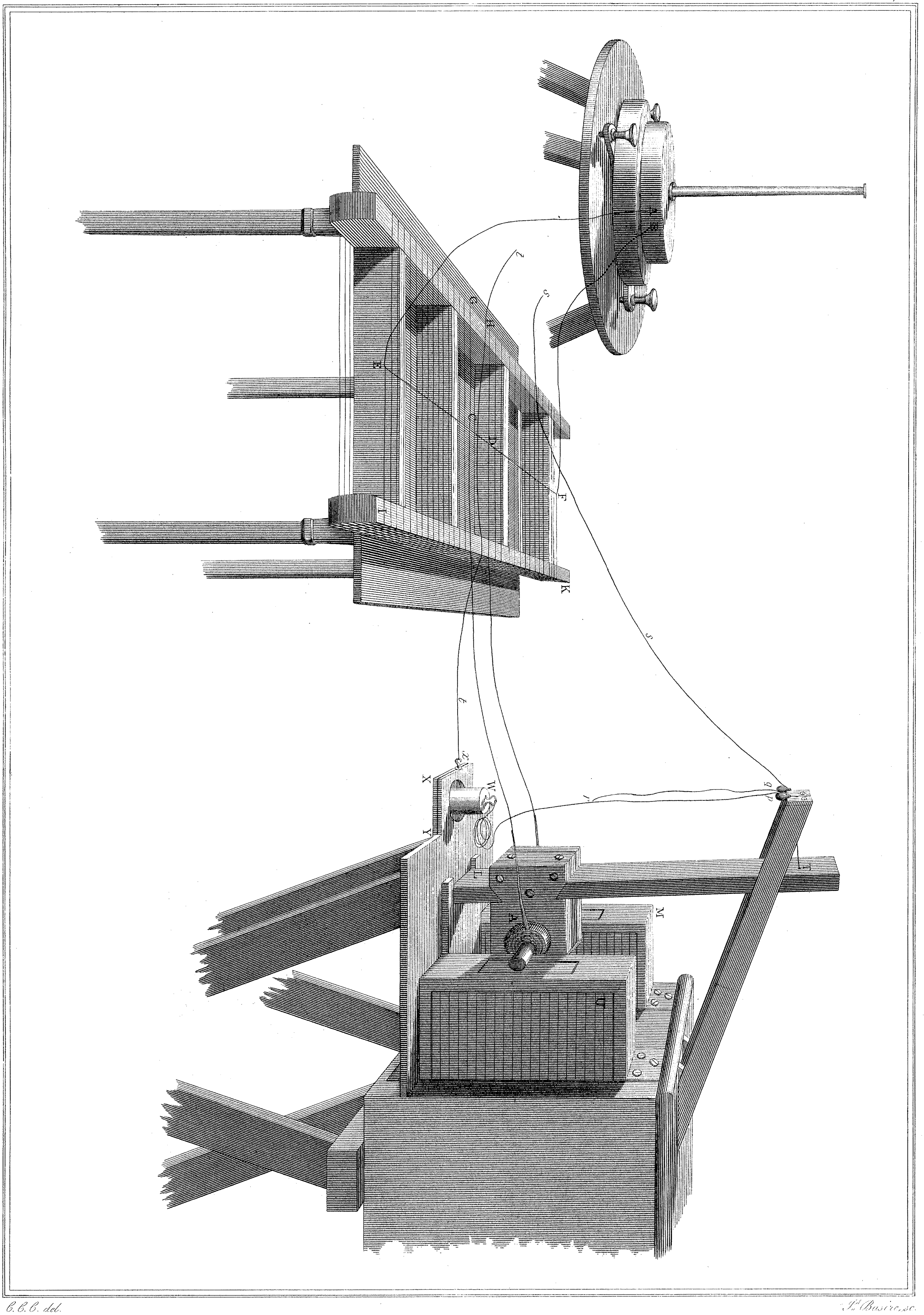
On the Law of Variation of Magneto-electric Intensity in different masses of the same metal.

I. *In different lengths of the same wire.*

According to the method of experimenting, which I have described, I could very readily obtain accurate measures of the difference in the intensities of the currents excited in or transmitted through two wires of different lengths, by crossing the wires as in fig. 3; but although it was an object to ascertain this difference, still it was necessary to have measures of the intensities themselves. I had found, in previous experiments, that considerable differences were observable in the effects at the galvanometer, according to the manner in which the contact of the iron cylinder with the magnet happened to be made or broken. This was not a matter of so much moment when only the differences of forces were to be determined, and was of none when the opposing forces counterbalanced each other; but it became of the greatest consequence when measures of the forces themselves were to be obtained. It was therefore necessary, in the present inquiry, that the contact should be made, and likewise

riments was read in its place; and therefore, when I was aware of this, I declined having the second Report either read or printed, as there had been already so much on the subject. I feel it necessary to state this, in order to account for the reading and printing of a report so long after it had been made, and at a time when it appeared quite uncalled for. I had intended completing a series of experiments on different metals previous to the paper being read to the Society, but severe indisposition, and an accident happening subsequently to a part of my apparatus, prevented me completing this at the time I proposed, and I was under the necessity of deferring the prosecution of the inquiry until I should have the leisure of the vacation. This will, I hope, account for my having so long delayed the communication of the results I obtained.

broken, in a manner as invariable as possible. The method by which this might be most readily, and, at the same time, most accurately effected, appeared to me to be, by the falling of the same weight from a constant height, to break the contact; and to renew it by suddenly relieving the cylinder of the tension caused by the same weight. The manner in which this was effected will be best understood by reference to the figure (Plate IV.). M is the marked, and U the unmarked pole of KNIGHT's magnet, belonging to the Royal Society. T L represents the lever, in the cheeks of which the helix A′ B′ containing the iron cylinder is firmly fixed; W is a leaden weight, to which a string *r p* T is attached; this string, after passing through the pulley *p*, is fixed to the lever at T. The weight W rests upon the door X Y, having hinges at Y, and supported by the pin *x*, passing through a hook on the door and into the fixed stand. On the observer at the galvanometer withdrawing the pin *x*, by means of the string *x t t*, the weight suddenly falls, and at a certain distance stretches the string *r p* T with such force, that acting upon the lever at T, the contact of the iron cylinder with the poles of the magnet is instantly broken. The weight but just touching the ground retains the lever firmly against the frame to which the pulleys *p q* are attached, and keeps the iron cylinder at a certain distance from the poles of the magnet. To the string W *r p* T, another string *r q s s*, passing through the pulley *q* to the observer at the galvanometer, is attached. On this string being suddenly pulled, the weight is raised, and the lever being relieved of its tension, the contact of the iron cylinder immediately takes place in consequence of the powerful attraction of the magnet. As the magnet has not hitherto been described, I may mention that it consists of four hundred and thirty-seven bar magnets, each fifteen inches long, one inch wide, ·5 inch thick, arranged in two parallel piles, each three bars in length, three in width, and twenty-three in height, connected within an oak box at the further end, not represented in the figure, by a pile of twenty-three bars extending from side to side. The other ends project from the box as represented at M and U, and are partly covered with sheet iron; they are nine inches asunder. The force required to separate the iron cylinder from the poles is equivalent to about sixty pounds, but I do not consider that the magnet has anything near the power which might be given to it by a different arrangement of the magnets.



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The galvanometer which I now made use of, although on the same principle, was very different from that already described; in that, the needles are light and rather short; but in this, as it was essential that in no case the needle should be driven past 180°, their weight is considerable; and their length is greater, to ensure greater accuracy of reading. The length of each needle is six inches, its weight 77·5 grains. These needles are connected by their centres, so that the poles of contrary names are vertically over each other, when suspended; the lower needle traverses within the coils of the galvanometer wire, and the upper one above them. The intensity of the upper needle exceeds that of the lower, so as to give a small directive force in the meridian. The compound needle is suspended by a few untwisted fibres of silk. The wire of the galvanometer is copper covered with silk; it is eight hundred and twenty inches in length, and consists of twenty-seven coils on each side of the needle, and one coil which unites them.

If I could possibly avoid doing so, it was not my intention to cut the wires at the several lengths, the intensities of whose action I proposed determining, since if this were once done, I should be precluded from repeating the series of experiments if doubts should arise respecting the accuracy of the results. As a preliminary step, therefore, it became necessary to ascertain how far the intensity of the currents might be influenced by the nature of the contact, when separate pieces were brought together, or by any portion of wire being a part of wires in the magneto-electric circuit, but itself not immediately in that circuit.

Two copper wires, each twelve feet long and ·045 inch in diameter, were each at one of its extremities brought into good contact with a wire one foot long, in contact with the ends of the wires of the compound helix, and at its other extremity, with a wire four feet long, proceeding from the galvanometer. I then made the observations contained in the following Table, where I have not entered the point to which the needle was impelled on making the contact of the iron cylinder with the poles of the magnet, as I found that there was still considerable want of uniformity in this respect, owing to the helix not being at this time firmly secured to the lever in the manner I have described, and in which it was in subsequent experiments.

I.

Circumstances under which the observations were made.	Point to which S. end of needle impelled on breaking contact.
The two wires of twelve feet each, having each one end in good contact with an end of the galvanometer wire, and the other end in contact with the corresponding end of the helix wire.	89° 30′ W. 91 15 90 30 90 15
Mean	90 23
Each of the two long wires cut at four feet from the junction with the helix wire; then one inch of the separated parts brightened, brought into contact, and bound round with fine wire ·027 inch in diameter, well brightened.	91 00 91 15 90 30 90 30
Mean	90 49
The ends, instead of being bound as in the last case, were fitted into a brightened sheath of thin copper an inch wide.	91 00 92 00 92 00 90 30
Mean	91 23
The sheath removed, the cut ends just touching, and fine wire bound several times round one and then round the other.	91 00 90 30
Mean	90 45
The fine wire in the last partly unwound, so that the ends of the thick wire are an inch apart, and having an inch of thin wire from the one to the other.	90 00 89 30
Mean	89 45

From these it appears that whether the wire was entire, or the contact made by any of the methods described, there was little difference in the intensity of the current transmitted to the galvanometer; and, consequently, in experiments where different portions of copper wire are successively brought into contact with each other, little error is to be apprehended in the result, from the manner in which the wires are in contact, provided that even moderate care is taken in making the contact.

My next object was to ascertain how far the intensity of the current might be influenced by a portion of wire, not itself in the circuit, but connected with the wire forming the circuit. For this purpose the two wires from the galvanometer were separated from the ends of the connecting wires, and these last wires, at the distance of 4·25 feet from the helix,—that is, just beyond where they had been previously cut and again brought into contact,—were twisted round the galvanometer wires; so that the length of the connecting wire on each side, between the galvanometer and helix, and actually forming part of the magneto-electric circuit, was now 9·25 feet; and 7·75 feet of the wire brought into contact was hanging free at one end, and forming no part of the circuit. The effect of this arrangement on the galvanometer needle having been observed on making and on breaking contact, the free ends of the wires were brought into contact with the connecting wires, very near to the place of first contact, so as to form a large loop on the connecting wire, on each side. The effect of this having been also observed, the wires were separated, where last brought into contact, and the loose part 7·75 feet on each side cut off, so that now the connecting wires were 9·25 feet on each side, and were unconnected with any other wire. The following Table contains the results of these arrangements.

II.

Arrangement of the Wires.	Point to which south end of the needle impelled on contact being Made.	Broken.
Length of connecting wire on each side 9·25 feet, and 7·75 feet of wire connected with each, but free at the other end.	112° E. 115 E.	110° W. 111 W.
Mean	112°	
Length of connecting wire on each side 9·25 feet, and 7·75 feet of wire forming a loop on each connecting wire.	113° 30′ 112 30	112° 15′ 109 00
Mean	111° 49′	
Length of connecting wire on each side 9·25 feet, and the 7·75 feet of wire cut off, so that the connecting wires have no contact with other wires.	112 30 113 30	110 00 109 00
Mean	111° 15′	

The effect of the wire not in the circuit would appear from these to have been but small. If we are not to attribute the differences in the results to errors of observation, arising from slight differences in the manner of making the contact, and also in breaking it*, but to actual differences in the intensity

* The needle traversing at some distance below the graduated circle on which its direction was read, the observation of its direction might be liable to errors arising from parallax, even with the

of the current transmitted to the galvanometer, then the part of the wire not actually in the circuit had a tendency to increase the intensity of the current; and this is an effect which might be expected from the mass of metal under induction being somewhat increased without any increase in the length of the circuit. Supposing such to have been the effect of the seven feet of wire, I do not consider that effect to have been proportional to the increase of mass, for had this portion of wire been wound round the connecting wire, so as to form a part of it, I have no doubt the effect would have been much more increased. In some subsequent experiments, made with the view of deciding roughly this point, I found that by winding the middle of each connecting wire once round a copper cylinder sixteen inches long and 0·75 inch thick, so as to be in contact the whole length, the effect at the galvanometer was increased from $135\frac{1}{2}°$ to 143°; winding part of one of the wires round a copper cylinder eight inches in diameter and 0·5 inch high, it became 151°; and on placing each of the cylinders on thick coils of copper wire, it was still further increased to 157°. The mean differences in the results in the preceding Table being, however, less than the differences in the results in the same experiment, even in those I am about to describe, and in which the helix was firmly fixed to the lever, so that the contacts were made and broken with great precision, I considered that the effect of the wire not in the circuit might be neglected.

Having satisfied myself regarding these preliminary points, in order to ascertain the law of intensity as depending on the length of the connecting wire, two soft copper wires, each ·058 inch in diameter and 986·5 inches long, were coiled on a frame, so that the coils of each were an inch apart, and the inner coils of the two wires four inches asunder. There were eleven inches less than twenty coils of each wire, so that each coil was 49·875 inches in length: I had intended that the length of each coil should have been fifty inches, and the whole length of each wire one thousand inches, and I was obliged to make up the twenty coils

needle remaining stationary, and would be peculiarly so when it was in motion, and the point at which it stopped was to be determined, if means were not adopted to prevent the occurrence of such errors. The upper needle being however always vertically over the other, and the two being exactly of the same form, by reading the direction of the upper, when, one eye being closed, its point appeared precisely over that of the lower, I considered that the observations were as free as possible from errors arising from this source.

by additional pieces, but this was not a matter of any consequence. One coil of each wire was cut off from the outer ends to make the wires of communication from the galvanometer to different parts of the wire on the frame; and half a coil of the inner end of each unwound, to make the connexion with the helix. The ends of the latter were brought into good contact with wires proceeding from the united wires of the helix at the distance 12·25 inches from the ends of these united wires: so that allowing 1·25 inch for contact on each side, when the galvanometer wires were brought into contact with the ends of the outer coils, the length of each wire of communication from the helix to the galvanometer was exactly twenty coils; and by successively bringing them into contact with the first, the third, fifth, seventh, &c. coils, reckoning from the middle of the frame, at points in a line drawn parallel to the sides of the frame and properly determined, the length of each of the wires of communication became successively two, four, six, eight, &c. coils. This will be best understood from the fig. Plate IV. and fig. 4. Plate III., where I G, K H represent the coils of the wire on the frame, which are connected with the helix at A′ B′: A Q, B R the wires from the galvanometer. When the end Q was in contact with the end E, and R with F, then the length of the wire of communication on each side was exactly twenty coils. When the end Q of the wire A Q was in contact with the wire from the helix at C, and likewise the end R with the other wire at D, the length of the wire of communication on each side was two coils. In a similar manner when the contact of the ends Q and R was made with the third coils instead of the first, in the line E F, the wire of communication, on each side, was four coils; and so on.

By this arrangement also two currents of different intensities and in opposite directions might be transmitted, at the same time, to the galvanometer. Thus the wires from the galvanometer A Q, B R being in contact with the wires from the helix at C D, on contact of the helix with the magnet being made or broken, a current in certain directions would pass through a length of two coils of wire on each side: this, without regard to its particular direction on making or breaking contact, I call a direct current, merely to distinguish it from another always in an opposite direction, which I call a reverse current. The wires being united as I have described, and a coil unwound at the part E I, and its end brought in contact with the other wire at D; likewise a coil unwound from K F and brought in contact at C; represented by the dotted lines *e* D, *f* C; then, at the same time that a current passed in one direction through the coils of the galvanometer communicated through two coils of the frame on each side, a current passed also through them in an opposite direction and communicated through twenty coils of the frame on each side: or rather the currents in the wires A′ C, B′ D, each the length of one coil, at the points C and D branched off into two currents; one communicated directly from C to A, D to B through a length of one coil, the other from C to F through eighteen coils to D, and from D to E through eighteen coils to C, and from these points one coil more to the galvanometer at B and A, in an opposite direction to the former current.—The following Table contains the results obtained with different lengths of wire in both cases.

III.

A single current, considered as the Direct Current, transmitted to the Galvanometer.			The difference of two currents transmitted to the Galvanometer, the Reverse current being always through a length of 20 coils of wire on each side.	
Length of the wire forming the connexion between the Helix and Galvanometer, on each side, for the Direct Current.	Deflection of the south end of the Needle on contact being		Deflection of the south end of the Needle on contact being	
	Made.	Broken.	Made.	Broken.
2 Coils	124° 15′ E.	121° 00′ W.	80° 50′ E.	83° 10′ W.
	121 30	121 00	81 30	82 30
	Mean . . 121° 56′.		Mean . . 82° 00′.	
4 Coils	100 30 E.	101 30 W.	51 30 E.	53 45 W.
	98 30	101 45	51 30	53 15
	Mean . . 100° 34′.		Mean . . 52° 30′.	
6 Coils	86 30 E.	87 30 W.	35 30 E.	38 00 W.
	86 00	89 00	36 00	37 30
	Mean . . 87° 15′.		Mean . . 36° 45′.	
8 Coils	78 00 E.	80 00 W.	25 30 E.	27 00 W.
	77 30	78 30	25 30	27 30
	Mean . . 78° 30′.		Mean . . 26° 22′.	
10 Coils	69 15 E.	73 00 W.	17 30 E.	20 15 W.
	70 00	73 45	18 30	20 30
	Mean . . 71° 30′.		Mean . . 19° 11′.	
12 Coils	64 30 E.	67 00 W.	12 45 E.	15 30 W.
	64 15	67 45	12 45	15 15
	Mean . . 65° 52′.		Mean . . 14° 04′.	
14 Coils	59 00 E.	62 45 W.	8 30 E.	11 00 W.
	58 45	62 45	8 30	11 00
	Mean . . 60° 49′		Mean . . 9° 45′.	
16 Coils	55 00 E.	57 15 W.	4 30 E.	7 00 W.
	53 30	58 00	5 00	7 15
	Mean . . 55° 56′.		Mean . . 5° 56′.	
18 Coils	50 30 E.	55 15 W.	1 30 E.	4 00 W.
	51 00	55 00	2 00	4 00
	Mean . . 52° 56′.		Mean . . 2° 52′.	
20 Coils	48 00 E.	50 00 W.		
	47 30	51 00		
	Mean . . 49° 08′.			
0	. . . .		51 00 W.	47 30 E.
			51 00	49 00
			Mean . . 49° 38′.	
Mean of 20 coils Direct, and 20 coils Reverse, 49° 23′.				

In order to deduce from these observations the law according to which the intensity of the current varies, some theoretical investigations are necessary:

but before entering upon these, I must point out some circumstances affecting the observations themselves. In consequence of the great power of the magnet which I employed, it was difficult to place the galvanometer at such a distance, that the needle should be beyond the sphere of its action, or rather that the mere connexion of the poles, or the breaking that connexion, should have no influence upon the needle, independent of that transmitted through the wire. The poles of the magnet being united by the iron cylinder within the helix, the wires of which were not connected with the galvanometer, I carefully adjusted that instrument so that the end of the needle pointed to zero on the graduated ring. On breaking the connexion between the poles, the south end of the needle moved to 2° 15′ E. and settled at 1° 10′ E.; and on again connecting the poles, the needle moved to 1° 10′ W. and settled at 0°. So that merely connecting the poles by the iron cylinder, independent of any effect arising from the current of electricity transmitted through the wire, was equivalent to a force that would drive the needle 1° 10′ W. beyond the zero, 0, of the closed poles; and on the other hand the effect of breaking the connexion was equivalent to a force that would drive the needle 1° 10′ E. beyond the zero (1° 10′ E.) of the open poles. However I might regret the circumstance I could not remedy it, for as the magnet was situated, I could not place the galvanometer at a greater distance than that at which it was, about eight feet; and the magnet itself weighing half a ton might almost be said to be immoveable without taking to pieces and putting up afresh, which, as it consists of nearly five hundred separate bars, would have been a work requiring much more time than I could command. The results to be deduced from the observations will not however be materially affected by this small extraneous force and shifting of the zero; for it will be seen that whether this is taken into the account in the calculation, or not, although the numerical results differ slightly from each other, the conclusions to be drawn from them are the same.

Theoretical Investigation.

From the first discovery of magneto-electricity by Mr Faraday, it appeared that the new force brought into action depended on the motion of the helix, or any conductor, in the vicinity of a magnet, and that its action ceased on the cessation of motion. The current of electricity transmitted from the helix through the galvanometer wire acts upon the needle by impulses during the motion of the helix, and it appears that the force acts at right angles to the wire *. The action upon the needle, to speak accurately, consists in successive impulses continued the whole time during which the helix moves; and in order to estimate the effect upon the needle, it would be necessary to determine the law of the intensity of the current in the helix as depending upon its distance from the magnet and the velocity of its motion. This is an inquiry into which I may enter on some future occasion, as I consider that I see the means by which the object may be accomplished; but it is quite unnecessary for the present purpose. Since in all cases the helix moved through the same space, and came in contact with the magnet with the same velocity, we may refer the action upon the needle, continued during a small but definite portion of time, to a single impulse, which will be the measure of the intensity of the electric current. The intensity of the current will therefore vary as the velocity with which the needle is impelled at the commencement of its motion; and this velocity will be the same as that which it would acquire in descending from its highest to its lowest point, by the force of terrestrial magnetism acting upon it.

Let V be the angular velocity with which the needle begins to move; A the whole arc described by the needle; v the angular velocity corresponding to any arc θ; and m the magnetic intensity acting on either pole in the direction parallel to the wires of the galvanometer, and reduced to the distance 1. Then since the force in the direction of the tangent is $m \sin \theta$, we have

$$v\,dv = -\,m \sin \theta\, d\theta.$$

Integrating from $\theta = 0$ to $\theta = \mathrm{A}$

$$\mathrm{V} = 2\sqrt{m}\,.\sin \tfrac{1}{2}\mathrm{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

Let I$'$, I$''$ be the intensities of the currents corresponding to the lengths L$'$, L$''$ of the conducting wire on each side, from the helix to the galvanometer, and to the arcs A$'$, A$''$; and suppose that the intensity varies inversely as L^n; then

$$\frac{\mathrm{L}''^n}{\mathrm{L}'^n} = \frac{\mathrm{I}'}{\mathrm{I}''} = \frac{\sin \frac{1}{2}\mathrm{A}'}{\sin \frac{1}{2}\mathrm{A}''}$$

* By placing the needle at right angles to the galvanometer wires, I found that it remained stationary both on making and on breaking contact.

From which

$$n = \frac{\log.\sin\frac{1}{2}A' - \log.\sin\frac{1}{2}A''}{\log.L'' - \log.L'}$$

On deducing the values of n from the observed values of A′, A″, &c., I found that they varied from $n = \cdot 19$, corresponding to $L' = 2$ and $L'' = 4$, to $n = \cdot 60$ corresponding to $L' = 18$ and $L'' = 20$, increasing pretty regularly, excepting in one instance. These values are far too widely different to be reconcileable with any law of the intensity, depending on a single power of L, even if I could admit that there were great inaccuracies in the observations. Although in drawing conclusions from the experiments, I had wished to abstain as much as possible from theoretical views, yet I had, even in obtaining these values of n, adopted, perhaps unconsciously, a particular hypothesis respecting the manner in which the electricity was propagated from one portion of wire to another; and I had, I now consider, very erroneously supposed, that electricity of a certain intensity, depending upon the length of wire through which it had been conducted, was transmitted to the galvanometer wire, which acted upon the needle, and that the length of the galvanometer wire being constant, would have no other influence upon the result than that of a constant coefficient. This would be a necessary consequence of supposing that, whatever might be the length of the wire uniting the two ends of the helix, the intensity of the electricity in the wire at the same distance was always the same; and would follow from the hypothesis, that the electricity is propagated like waves decreasing in magnitude as they increase in distance from the first, which is always of the same magnitude. As, however, I found that such an hypothesis was quite incompatible with the results from observation, I had no hesitation in rejecting it, and was led to consider what circumstance might influence the intensity, independent of the length of wire between the helix and galvanometer. It immediately occurred to me that the length of the galvanometer wire might influence the result in a manner very different from that which I had supposed. If instead of supposing that the intensity in any point in the wire depends alone on its distance from the helix, we suppose that it is influenced by the length of wire beyond it, then the length of the galvanometer wire will affect the results very differently. This supposition is quite compatible with the hypothesis, that the electricity is propagated like waves, decreasing in magnitude as they increase in distance from their first source, the magnitude of the first wave, however, depending on the whole distance to which the waves are propagated; and it would also follow from the hypothesis, that the intensity of the current is the same throughout the whole length of the wire connecting the ends of the helix, and dependent upon that whole length. As it is a matter to be determined by experiment, whether the intensity is the same in every part of the wire, it is not necessary to enter upon the question of which is the more probable hypothesis; but I considered that it was proper to point out the bearing of the experimental results upon different hypotheses that may be adopted*.

* Since the above was written, in order to determine the effect on the galvanometer needle when placed in different parts of the same circuit, I have made the following experiments. The wires on the frame were first connected with those of the helix and of the galvanometer, so that the length of the conducting wires on each side, from A′ to A and B′ to B, should be twenty coils or very nearly one thousand inches; the connexions were then made so that from A′ to A was two coils, and from B′ to B thirty-eight coils; and likewise so that from A′ to A was thirty-eight coils and from B′ to B two coils: and again similar connexions were made from A′ to B and B′ to A. The results, which are given in the following Table, differ so little from each other, that there can be no doubt of the perfect equality of the action in every part of the wire.

Position of the Galvanometer in the conducting wire		Deflection of the Needle on contact being		Position of the Galvanometer in the conducting wire		Deflection of the Needle on contact being	
A′ to A.	B′ to B.	Made.	Broken.	A′ to B.	B′ to A.	Made.	Broken.
2 Coils	38 Coils	49° 35′ E. 49 20 50 00	48° 10′ W. 48 20 48 20	2 Coils	38 Coils	49° 30′ W. 49 10 49 40	49° 55′ E. 49 30 49 50
		Mean . . 48° 57′.				Mean . . 49° 36′.	
20 Coils	20 Coils	49 10 E. 49 40 49 20	48 30 W. 48 40 48 00	20 Coils	20 Coils	49 25 W. 49 20 49 30	49 30 E. 49 50 49 40
		Mean . . 48° 53′.				Mean . . 49° 33′.	
38 Coils	2 Coils	49 25 E. 49 05 48 50	48 15 W. 48 20 48 15	38 Coils	2 Coils	49 20 W. 49 25 49 30	50 20 E. 49 50 50 05
		Mean . . 48° 42′.				Mean . . 49° 45′.	

This equality of the action on the galvanometer needle, in different parts of the same wire, is compatible with different hypotheses. If opposite currents be supposed to originate in the ends of the wire, from the two poles of the magnet, then the whole of the contrary electricities may be equably distributed throughout the wire; or they may be so distributed that their intensities, proceeding from the ends of the wire connected with the helix, decrease in arithmetical progression, so that, the con-

The galvanometer wire not being of the same diameter as the conducting wire, in order to introduce its length into the expression from which the value of the index n is to be determined, it is necessary that the law of intensity as depending on the diameter of the wire should be known; or this law being unknown, to eliminate n from two equations of the same form as the preceding, and by the observed values of A$'$, A$''$, &c. and known values of L$'$, L$''$, to determine, from the resulting equation, the length of wire of the same diameter as the conducting wire, which would be equal in effect to the galvanometer wire. The equation resulting from the elimination of n is of such a form, that to deduce the length in question from it, by means of the observations, would require long and extremely laborious computations. I therefore considered it better to assume a value for n, and, as a test of the correctness of this assumption, to compare the results obtained by means of the observations.

The most simple law according to which the intensity of the electricity can depend upon the length of the wire is, that it varies inversely as that length; and this is also the most probable law; since, whether the electricity is distributed on the surface of the wire or throughout the mass, this would be the law if the same measure of electricity from the same source is given to the wire, whatever may be its length. I therefore assumed this to be the law according to which the intensity varied, and the accordance of the results left no doubt on my mind of the truth of the assumption.

Let us suppose that the wires of the galvanometer are in immediate connexion with those of the helix, so that the intermediate length of wire on each side, $L = 0$; and let 2λ be the length of wire of the same diameter as that coiled round the frame, to which electricity of the same intensity would be communicated, as would, in that case, be communicated to the galvanometer wire. Let ι be the intensity that would be thus communicated to either; and α the arc

trary actions upon the needle being in opposite directions, their sum would be the same in every part of the wire. This last is an improbable hypothesis, for, independent of other considerations, it would require that the intensity of the electricity, where first communicated to the wire, should vary according to a complicated law, partly directly as the whole length of the wire, and partly inversely as that length. If a single current be supposed to originate in one pole, and to flow through the wire to the other, then the experiments show that the intensity of the current will be the same in every part of its course.

through which the needle would in consequence be impelled; then, the intensity varying inversely as the length of the wire, we shall have,

$$\frac{\iota}{I} = \frac{L+\lambda}{\lambda} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b)$$

and consequently

$$\frac{L+\lambda}{\lambda} = \frac{\sin \frac{1}{2} \alpha}{\sin \frac{1}{2} A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (c)$$

Eliminating $\sin \frac{1}{2} \alpha$ from two equations of the form (c),

$$\frac{L'+\lambda}{\lambda} = \frac{\sin \frac{1}{2} \alpha}{\sin \frac{1}{2} A'} \text{ and } \frac{L''+\lambda}{\lambda} = \frac{\sin \frac{1}{2} \alpha}{\sin \frac{1}{2} A''},$$

we have

$$\lambda = \frac{L'' \sin \frac{1}{2} A'' - L' \sin \frac{1}{2} A'}{\sin \frac{1}{2} A' - \sin \frac{1}{2} A''} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (d)$$

By combining the observations two and two, different values of λ will be obtained; and if these be substituted in the equation (c), the separate observations should give

$$(L + \lambda) \,.\, \sin \tfrac{1}{2} A = \lambda \sin \tfrac{1}{2} \alpha,$$

a constant quantity. From the mean value of $\lambda \sin \frac{1}{2} \alpha$, thus obtained, the several values of $\frac{1}{2} A$ may be computed and compared with the observations.

I have already stated, that when the poles of the magnet were closed, by the iron cylinder of the helix being applied to them, the zero of the needle was 0° 00′; and that when they were open, it was 1° 10′ E.: it is therefore necessary to inquire how far the results may be affected by this circumstance.

To determine the effect when the needle is impelled by making the contact of the helix with the magnet, let $A_{\prime}$ be the arc towards east, on the graduated ring, to which the south point of the needle is impelled; $V_{\prime}$ the initial velocity towards east due to the impulse from the electricity alone; ${}_{\prime}v$ the velocity towards west due to the magnetic impulse of closing the poles; $\varphi = 1° 10'$: Then

$$V_{\prime} - {}_{\prime}v = 2 \sqrt{m} \,.\, \sin \tfrac{1}{2} A_{\prime},$$

and

$${}_{\prime}v = 2 \sqrt{m} \,.\, \sin \tfrac{1}{2} \varphi.$$

Therefore

$$V_{\prime} = 2 \sqrt{m} \,.\, (\sin \tfrac{1}{2} A_{\prime} + \sin \tfrac{1}{2} \varphi).$$

When the contact is broken, let ${}_{\prime}A$ be the arc towards west on the graduated ring; ${}_{\prime}V$ the initial velocity towards west due to the electricity alone; $v_{\prime}$ the velocity towards east due to the magnetic impulse of opening the poles: Then the zero being 1° 10′ east,

$$ {}_{,}V - v_{,} = 2 \sqrt{m} \,.\, \sin \tfrac{1}{2} ({}_{,}A + \phi), $$

and

$$ v_{,} = 2 \sqrt{m} \,.\, \sin \tfrac{1}{2} \phi. $$

Therefore

$$ {}_{,}V = 2 \sqrt{m} \,.\, \{\sin \tfrac{1}{2} ({}_{,}A + \phi) + \sin \tfrac{1}{2} \phi\}. $$

Consequently, if ${}_{,}V = V_{,} = V$, and $A_{,} = {}_{,}A + \phi$, taking the mean of the effects due to the making and the breaking of the contact,

$$ V = 2 \sqrt{m} \,.\, \{\sin \tfrac{1}{4} (A_{,} + {}_{,}A + \phi) + \sin \tfrac{1}{2} \phi\} \quad \ldots\ldots \quad (a_{,}) $$

If $A = \frac{A_{,} + {}_{,}A + \phi}{2}$, then

$$ \frac{L + \lambda}{\lambda} = \frac{\sin \frac{1}{2} \alpha}{\sin \frac{1}{2} A + \sin \frac{1}{2} \phi} \quad \ldots\ldots\ldots\ldots \quad (c_{,}) $$

So that the equation (d) will become

$$ \lambda = \frac{L''(\sin \frac{1}{2} A'' + \sin \frac{1}{2} \phi) - L'(\sin \frac{1}{2} A' + \sin \frac{1}{2} \phi)}{\sin \frac{1}{2} A' - \sin \frac{1}{2} A''} \quad \ldots\ldots\ldots \quad (d_{,}) $$

In the following Table, which contains the results deduced from the observations in Table III., in order to obtain the mean value of λ, I have used only the combinations of the alternate observations, in order to diminish the number of computations, and because the nearer the values of L′ and L″ to each other, the greater would be the effect of any error in the observations.

IV.

	No correction made for the variation of the Zero.						Correction made for the variation of the Zero.				
L In coils on the Frame.	$\frac{1}{2}$A Observed Values.	Values of L combined in determining λ.	λ	$\lambda \sin \frac{1}{2}\alpha$ Deduced from the equation (c) when λ = 15·10.	$\frac{1}{2}$A Computed from (c) when λ = 15·10, and $\lambda \sin \frac{1}{2}\alpha$ = 14·695.	Difference between the observed and the computed values of $\frac{1}{2}$A.	$\frac{1}{2}$A Observed Values.	λ	$\lambda \sin \frac{1}{2}\alpha$ Deduced from the equation (c_1) when λ = 15·73.	$\frac{1}{2}$A Computed from (c_1) when λ = 15·73, and $\lambda \sin \frac{1}{2}\alpha$ = 15.442.	Difference between the observed and the computed values of $\frac{1}{2}$A.
2	60° 58′	L^{i} & L^{iii}	12·97	14·951	59° 15′	−1° 43′	61° 15·5′	13·37	15·726	59° 17′	−1° 58′
4	50 17	L^{i} L^{v}	14·11	14·692	50 18	+ 1	50 34·5	14·60	15·442	50 29	− 5·5
6	43 37·5	L^{i} L^{vii}	14·50	14·558	44 08·5	+ 31	43 55	15·06	15·293	44 23·5	+ 28·5
8	39 15	L^{i} L^{ix}	14·64	14·616	39 30	+ 15	39 32·5	15·27	15·348	39 46	+ 13·5
10	35 45	L^{ii} L^{iv}	14·54	14·665	35 50	− 5	36 02·5	15·05	15·401	36 06	+ 3·5
12	32 56	L^{ii} L^{vi}	15·28	14·733	32 50	− 6	33 13·5	15·88	15·477	33 05·5	− 8
14	30 24·5	L^{ii} L^{viii}	14·74	14·729	30 20	− 5	30 42	15·41	15·480	30 34	− 8
16	27 58	L^{ii} L^{x}	15·03	14·585	28 12	+ 14	28 15·5	15·57	15·346	28 25	− 9·5
18	26 28	L^{iii} L^{v}	16·11	14·752	26 21	− 7	26 45·5	16·75	15·530	26 33	− 12·5
20	24 42	L^{iii} L^{vii}	16·03	14·667	24 45	+ 3	24 51·5	16·76	15·374	24 55·5	+ 4
		L^{iii} L^{ix}	15·96					16·70			
		L^{iv} L^{vi}	16·42					17·16			
		L^{iv} L^{viii}	14·91					15·71			
		L^{iv} L^{x}	15·34					15·89			
		L^{v} L^{vii}	15·90					16·76			
		L^{v} L^{ix}	15·73					16·66			
		L^{vi} L^{viii}	13·11					13·97			
		L^{vi} L^{x}	14·57					15·01			
		L^{vii} L^{ix}	15·48					16·54			
		L^{viii} L^{x}	16·71					16·45			
		Mean..	15·10	14·695			Mean..	15·73	15·442		

Whether we look to the values of the constant $\lambda \sin \frac{1}{2}\alpha$, or to the general agreement between the computed and observed values of $\frac{1}{2}$ A, there can, I think, be no doubt that the intensity of the electricity excited, on making and on breaking contact, varies in the manner I have supposed. There are two exceptions to the very close agreement of the observed and computed values of $\frac{1}{2}$ A, those corresponding to the values of L, 2 and 6. With regard to the second, the difference is perhaps within the limits of the errors to which the observations are liable, without the interference of any particular cause of error; but the same cannot be said of the first, and I certainly consider that some circumstance connected with the manner of making and of breaking contact, of which I was not aware at the time, must have affected the results. In making these observations, the helix was not so securely fixed to the lever carrying it as is represented in the figure (Plate IV.); and, possibly, this being the first observation, the contact may have been made somewhat higher or lower on the face of the magnet than it was after the helix had been drawn into its proper position. This source of error was afterwards obviated by the method of fixing the helix represented in the figure. Had I repeated the whole series of observations, I have little doubt that I should not have found such an anomaly: but previously to being aware of its existence I had no cause for the repetition; and being aware of it, I prefer giving the observations from which I drew the theoretical conclusions, to giving others which might be in closer accordance with theory, but which must have been made after I knew pretty exactly the results required by the theory. Any doubts, however, which might, in consequence, arise respecting the accuracy of the conclusion, that the intensity varies inversely as the length of the wire, were entirely removed by the computation from similar experiments which I made with various lengths of three wires of very different diameters, with a view to determine the law of the intensity as depending on the diameter, and which I shall shortly describe. I should remark, that the results are the same in character whether the correction for the variation of the zero is made or not, there being nearly the same agreement in the several values of the constant $\lambda \sin \frac{1}{2} \alpha$ in both cases, the value however of this constant being increased by the increase in the arc. I may also remark, that the discrepancies in the values of λ, deduced from combining the observations two and two, are not to be considered as arising from the inaccuracy of the formula, but from slight errors to which such observations must be liable, and which become very sensible when they are of opposite kinds in the observations combined: indeed, it is only observations which admit of the utmost accuracy that will bear such a test.

In the following Table, the effects obtained when the difference of two currents is transmitted to the galvanometer are compared with the effects of those currents separately, taking the sine of half the angle of deflection as the measure of the intensity.

V.

The difference of two currents transmitted to the Galvanometer, the reverse current being always through a length of twenty coils of wire on each side.			The direct current alone transmitted to the Galvanometer.		$\sin \frac{1}{2} A - \sin \frac{1}{2} A^{1}$.	$\sin \frac{1}{2} A_{,} - (\sin \frac{1}{2} A - \sin \frac{1}{2} A^{1})$
Length of the wire on each side, forming the direct current.	$\frac{1}{2} A_{,}$ (° ′)	$\sin \frac{1}{2} A_{,}$	$\frac{1}{2} A$ (° ′)	$\sin \frac{1}{2} A$		
2 Coils	41 18	·66000	61 15·5	·87680	·45642	+·20358
4	26 33	·44698	50 34·5	·77246	·35208	+·09490
6	18 40	·32006	43 55	·69361	·27323	+·04683
8	13 29	·23316	39 32·5	·63664	·21626	+·01690
10	9 53	·17164	36 02·5	·58837	·16799	+·00365
12	7 19	·12735	33 13·5	·54793	·12755	—·00020
14	5 10	·09005	30 42	·51054	·09016	—·00011
16	3 16	·05698	28 15·5	·47345	·05307	+·00391
18	1 44	·03025	26 45·5	·45023	·02985	+·00040
20	0 00	·00000	24 51·5	·42038	·00000	

In drawing conclusions from these results, it is to be borne in mind, that the wires carrying the two currents, the difference of whose effects was measured at the galvanometer, did not proceed separately immediately from the wires of the helix to those of the galvanometer, but that the parts A′ C, B′ D, A Q, B R, from the helix to the contact of the wires from the galvanometer with those on the frame, and also the wires from the frame to the galvanometer, were common to both; and that it was only the parts on the frame, from that contact to the contact with the wire on the other side, which exclusively belonged to the reverse current: for example, if the wires A Q, B R were in contact with the third coils on the frame in the lines C E, D F, and the ends E and F were brought to the same points of contact, but on the opposite sides of the frame, then four coils of wire on each side would be common to the two currents, and sixteen coils, principally on the frame, would exclusively belong to the reverse current. Up to a certain point, namely where the length of wire on each side carrying the direct current is not less than ten coils,—that is, than half the length of the wire carrying the reverse current,—the effect at the galvanometer is very accurately the difference of the effects that would be produced by the currents separately; but beyond this the stronger current has an excess of influence, and this excess increases with the decrease in the length of the wire and consequent increase of the intensity of the current. It may be, that in consequence of the particular arrangement of the contacts of the wires, the full effect of the reverse current was in no case produced; but that the deficiency decreased so rapidly with the increase in the length of the wire carrying the direct current, that when this length became 10 coils, the deficiency was lost in the errors to which the observations are liable. I certainly do not consider that any such deficiency would have been observable had the wires carrying the reverse current proceeded directly from the wires of the helix across to the wires of the galvanometer. As the results from these experiments appeared somewhat anomalous, I have thought it right to give them, although I consider that before a clear explanation can be given of them, it will be necessary to ascertain how far the intensity of the electricity in different parts of the wire may be affected by the peculiar arrangement.

II. *On the Law of Variation of Magneto-electric Intensity in wires of different diameters.*

In order to determine this law, I proposed comparing the effects of three different wires whose diameters should be in the proportion of 4, 2, 1. For this purpose I had a long piece of copper wire divided into two portions, and on a gauge employed by wire-drawers I made choice of three numbers 11, 16, 22, corresponding to holes whose diameters were, as nearly as I could estimate, in the proportion 4, 2, 1. The first portion of wire was passed through the holes Nos. 10, 11; a part of it being cut off, the remainder was annealed and passed successively through the holes to 16; a part of this was also cut off, and the remainder passed through the holes from 16 to 22. The second portion was reserved to be employed as occasion might require; and finding afterwards that I had not sufficient of the wire No. 11, I gave directions that this portion should be reduced to the same diameter. On determining the diameters of all the wires, I, however, found that those of the two pieces of No. 11. were not exactly equal, the diameter of one being ·1247 inch, of the other ·1269 inch: as I employed the two in equal portions, I consider that no sensible error can arise from taking the mean ·1258 inch as the diameter of No. 11. The diameter of No. 16. I found to be ·0633 inch, and the diameter of No. 22, ·0322 inch.

Two lengths of two hundred and fifty inches each, of No. 22, were formed, in separate coils, on the ends of a small frame, and the ends of these coils nearest to the magnet were to be united with the helix wires: two other lengths of one hundred and two inches each, (an inch at each end being allowed for contacts,) were to be united with the wires of the galvanometer, and, at different points, with the wires on the frame, as in the preceding experiments, so that the length of wire conducting on each side from the helix to the galvanometer could be varied from one hundred to three hundred and fifty inches. Precisely the same arrangement was made with the wire No. 16; but in consequence of the original lengths of the two pieces of No. 11, two lengths of three hundred inches each were coiled on a frame, and the contacts between different parts of these and the galvanometer wire were made by two lengths, each of fifty-two inches.

With each of these wires I determined the effects at the galvanometer, at every fifty inches of increase in the length of the conducting wire, from one hundred to three hundred and fifty inches. Previously to commencing the series, I was under the necessity of increasing the directive force of the galvanometer needle, as I found upon the first trial that one hundred inches of No. 11. would cause the needle to pass 180°, in which case the effects could not be compared without taking into account the air's resistance, the necessity of which I considered it better to avoid. The observations which follow cannot therefore be compared with those I have described; and it is for this reason that I mention the circumstance.

The observations are contained in the following Table, where L, as before, is the length of the conducting wire between the helix and galvanometer, its unit of length being fifty inches.

VI.

The unit of length being 50 inches.	Wire No. 11. Diameter = ·1258 inch. Weight of 1 inch = 27·15 grains.		Wire No. 16. Diameter = ·0633 inch. Weight of 1 inch = 6·80 grains.		Wire No. 22. Diameter = ·0322 inch. Weight of 1 inch = 1·76 grains.	
	Deflection of the S. end of the Needle on contact being		Deflection of the S. end of the Needle on contact being		Deflection of the S. end of the Needle on contact being	
L	Made.	Broken.	Made.	Broken.	Made.	Broken.
2	127° 30′ E.	139° 00′ W.	108° 15′ E.	120° 00′ W.	76° 20′ E.	77° 15′ W.
	127 45	139 15	108 15	118 15	75 40	77 20
	127 00	138 30	108 45	118 00	76 15	77 15
	Mean .. 133° 10′.		Mean .. 113° 35′.		Mean .. 76° 41′.	
3	124 15	135 00	101 00	108 00	63 00	64 00
	124 00	135 30	99 45	108 45	63 15	63 30
	123 00	135 00	99 30	110 15	63 00	63 30
	Mean .. 129° 08′.		Mean .. 104° 33′.		Mean .. 63° 22′.	
4	120 00	128 00	93 45	98 30	54 15	54 20
	120 00	128 15	93 00	98 00	54 30	54 20
	119 30	129 00	93 15	97 30	54 30	53 45
	Mean .. 124° 08′.		Mean .. 95° 40′.		Mean .. 54° 17′.	
5	116 15	124 30	87 15	91 00	48 00	47 30
	117 15	122 30	87 30	91 00	47 45	47 15
	116 30	122 45	87 00	91 15	48 00	48 00
	Mean .. 119° 58′.		Mean .. 89° 10′.		Mean .. 47° 45′.	
6	112 00	120 00	82 00	85 30	42 30	41 30
	111 00	120 00	82 00	85 40	42 30	41 45
	112 30	120 00	82 15	86 00	42 15	42 00
	Mean .. 115° 55′.		Mean .. 83° 54′.		Mean .. 42° 05′.	
7	108 30	116 15	77 00	80 30	38 15	37 30
	110 00	115 30	76 30	80 30	38 15	37 30
	109 00	117 00	76 30	80 30	38 15	37 30
	Mean .. 112° 43′.		Mean .. 78° 35′.		Mean .. 37° 52′.	

These observations could not all be made in the same day, and to guard against any accidental change that might occur in the intensity of the galvanometer needle, I ascertained its time of vibration. I however have not this time for the day on which the observations were made with the wire No. 11, but had previously found the time of vibration to be about twelve seconds, having no record of the exact time; and two days afterwards, when the observations with No. 16. were made, the time of vibration at 10 A.M. was 12·34 seconds, and at 10 P.M. 12·48 seconds, making the mean time 12·41. Seven days afterwards, immediately before making the observations with the wire No. 22, the time of vibration was found to be 12·42 seconds. So that no very sensible change can have taken place during the time of making the observations.

In the following Table, the values of $\frac{1}{2}$ A are corrected for the variation of the zero; those of λ are computed from the equation $(d_{,})$; those of λ sin $\frac{1}{2}\alpha$ from the equation $(c_{,})$; and by means of these, the values of $\frac{1}{2}$ A.

VII.

	Wire No. 11.					Wire No. 16.					Wire No. 22.				
			Deduced from Equation $(c_{,})$, when λ=46·40.	Computed from Equation $(c_{,})$, when λ=46·40. λ sin $\frac{1}{2}\alpha$=45·131.	Difference between the observed and computed values of $\frac{1}{2}$ A.			Deduced from Equation $(c_{,})$, when λ=14·00.	Computed from Equation $(c_{,})$, when λ=14·00. λ sin $\frac{1}{2}\alpha$=13·614.	Difference between the observed and computed values of $\frac{1}{2}$ A.			Deduced from Equation $(c_{,})$, when λ=3·76.	Computed from Equation $(c_{,})$, when λ=3·76. λ sin $\frac{1}{2}\alpha$=3·6563.	Difference between the observed and computed values of $\frac{1}{2}$ A.
L.	$\frac{1}{2}$ A.	λ.	λ sin $\frac{1}{2}\alpha$.	$\frac{1}{2}$ A.		$\frac{1}{2}$ A.	λ.	λ sin $\frac{1}{2}\alpha$.	$\frac{1}{2}$ A.		$\frac{1}{2}$ A.	λ.	λ sin $\frac{1}{2}\alpha$.	$\frac{1}{2}$ A.	
2	66° 53′	61·09*	45·007	67° 16′	+23′	57° 05′	15·71	13·576	57° 13′	+ 8′	38° 38′	3·703	3·6548	38° 39′	+ 1′
3	64 51	50·84	45·220	64 37	−14	52 34	13·94	13·672	52 15	−19	31 59	3·756	3·6494	32 03	+ 4
4	62 21	49·31	45·157	62 17	− 4	48 08	14·05	13·587	48 15	+ 7	27 26	3·856	3·6542	27 27	+ 1
5	60 16	47·63	45·156	60 13	− 3	44 53	14·34	13·601	44 56	+ 3	24 10	3·741	3·6754	24 02	− 8
6	58 15	48·10	45·092	58 20	+ 5	42 15	14·00	13·651	42 06	− 9	21 20	3·757	3·6500	21 22	+ 2
7	56 39	43·18	45·150	56 37	− 2	39 35	12·29	13·595	39 39	+ 4	19 14	3·830	3·6541	19 15	+ 1
		44·67					13·20					3·977			
		44·07					13·83					3·763			
		45·40					13·51					3·784			
		46·32					14·34					4·174			
		44·54					14·87					3·717			
		46·26					14·07					3·759			
		42·83					15·50					3·201			
		46·22					13·91					3·493			
		50·29					12·41					3·881			
Means...		46·40	45·131	sin $\frac{1}{2}\alpha$=·97265			14·00	13·614	sin $\frac{1}{2}\alpha$=·97243			3·760	3·6563	sin $\frac{1}{2}\alpha$=·97242	

If, from the results obtained from the former experiments, by means of the formula

$$\frac{L+\lambda}{\lambda}=\frac{\sin\frac{1}{2}\alpha}{\sin\frac{1}{2}A+\sin\frac{1}{2}\phi},$$

any doubts could be entertained of its accuracy, they must be entirely removed by the results in the foregoing Table: the agreement of the constants among themselves and of the computed with the observed values of $\frac{1}{2}$ A are far closer than I had at all anticipated.

* This result, being so widely different from any of the others, is not included in the mean.

These experiments, however, failed in the principal object I had in view in making them,—the establishing the law according to which the intensity depends on the diameter of the wire; for although they may indicate the law, which I have no doubt, from other experiments, really exists, and satisfactory reasons may be given for the deviations of the results from that law, they certainly do not prove its truth. To apply them to the purpose in view, let $2\lambda_{\prime}$, $2\lambda_{\prime\prime}$, $2\lambda_{\prime\prime\prime}$ be the values of 2λ corresponding to three wires whose diameters are $D_{\prime}$, $D_{\prime\prime}$, $D_{\prime\prime\prime}$, that is, the lengths of those wires which, acting upon the needle like the galvanometer wire, and being in immediate connexion with the helix, shall impel the needle through the same arc α; and suppose that the intensity of the electricity varies directly as the n^{th} power of the diameter of the wire, and inversely as its length: then μ being a constant,

$$\frac{D_{\prime}^{n}}{\lambda_{\prime}} = \mu \sin \tfrac{1}{2}\alpha, \quad \frac{D_{\prime\prime}^{n}}{\lambda_{\prime\prime}} = \mu \sin \tfrac{1}{2}\alpha, \quad \frac{D_{\prime\prime\prime}^{n}}{\lambda_{\prime\prime\prime}} = \mu \sin \tfrac{1}{2}\alpha \quad . \quad . \quad . \quad . \quad . \qquad (e)$$

We have therefore,

$$\frac{\lambda_{\prime}}{\lambda_{\prime\prime}} = \frac{D_{\prime}^{n}}{D_{\prime\prime}^{n}}, \quad \frac{\lambda_{\prime}}{\lambda_{\prime\prime\prime}} = \frac{D_{\prime}^{n}}{D_{\prime\prime\prime}^{n}}, \quad \frac{\lambda_{\prime\prime}}{\lambda_{\prime\prime\prime}} = \frac{D_{\prime\prime}^{n}}{D_{\prime\prime\prime}^{n}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (f)$$

and consequently

$$n = \frac{\log.\lambda_{\prime} - \log.\lambda_{\prime\prime}}{\log.D_{\prime} - \log.D_{\prime\prime}}, \quad n = \frac{\log.\lambda_{\prime} - \log.\lambda_{\prime\prime\prime}}{\log.D_{\prime} - \log.D_{\prime\prime\prime}}, \quad n = \frac{\log.\lambda_{\prime\prime} - \log.\lambda_{\prime\prime\prime}}{\log.D_{\prime\prime} - \log.D_{\prime\prime\prime}}$$

Taking $D_{\prime} = \cdot 1258$, $D_{\prime\prime} = \cdot 0633$, $D_{\prime\prime\prime} = \cdot 0322$; $\lambda_{\prime} = 46\cdot 40$, $\lambda_{\prime\prime} = 14\cdot 00$, $\lambda_{\prime\prime\prime} = 3\cdot 76$; the values of n are 1·744, 1·844, 1·945; the mean, 1·844.

From these it would be inferred, either that the intensity did not vary as any single power of the diameter, or that, varying as the square of the diameter, there were circumstances connected with the experiments themselves which caused the aberrations from the law, and that their influence increased with the diameter of the wire. Having ascertained from experiments made immediately following these, that the intensity varies as the square of the diameter of the wire, I was led to consider what could be the cause of this discrepancy in the results. It is clear that, according to this law, the values of $\lambda_{\prime}$ and $\lambda_{\prime\prime}$ are too small as compared with that of $\lambda_{\prime\prime\prime}$, and that the deficiency of $\lambda_{\prime}$ is by much the greatest. If the arcs of deflection were increased, the values of λ would be so likewise; and the greater the increase in the one case, the greater would it be in the other. It therefore appeared not improbable, as the resistance of the air on the needle would produce a greater diminution in the arcs the larger they were, that this was the cause.

Assuming then $\lambda_{\prime}, \lambda_{\prime\prime}, \lambda_{\prime\prime\prime}$ to be as $D_{\prime}^2, D_{\prime\prime}^2, D_{\prime\prime\prime}^2$; that is, making no change in $\lambda_{\prime\prime\prime}$, and assuming $\lambda_{\prime} = 59{\cdot}608$, $\lambda_{\prime\prime} = 15{\cdot}092$; taking $\sin \frac{1}{2} \alpha = {\cdot}97250$, the mean of the values obtained, I computed the values of $\frac{1}{2}$ A corresponding to the different values of L. Comparing these with the observed values, I found, in both cases, that as the arcs decreased, the differences increased. If instead of assuming $\lambda_{\prime} \sin \frac{1}{2} \alpha = 59{\cdot}608 \times {\cdot}97250$ and $\lambda_{\prime\prime} \sin \frac{1}{2} \alpha = 15{\cdot}092 \times {\cdot}97250$, I determined their values from the observations; and then computed the values of $\frac{1}{2}$ A from the mean values so determined, the larger arcs were all in defect, and the smaller in excess. So that in either case the result was the reverse of what would arise from diminution of the arc by the air's resistance, which therefore clearly could not be the cause of the discrepancy in question. The results of these assumptions and computations are contained in the following Table.

L.	No. 11. $\lambda = 59{\cdot}608$. $\lambda \sin \frac{1}{2}\alpha = 57{\cdot}969$.			No. 11. $\lambda = 59{\cdot}608$. $\lambda \sin \frac{1}{2}\alpha = 56{\cdot}854$.			No. 16. $\lambda = 15{\cdot}092$. $\lambda \sin \frac{1}{2}\alpha = 14{\cdot}677$.			No. 16. $\lambda = 15{\cdot}092$. $\lambda \sin \frac{1}{2}\alpha = 14{\cdot}427$.		
	½ A. Computed.	½ A. Observed.	Difference.	$\lambda \sin \frac{1}{2}\alpha$.	½ A.	Difference.	½ A. Computed.	½ A. Observed.	Difference.	$\lambda \sin \frac{1}{2}\alpha$.	½ A.	Difference.
	° ′	° ′	° ′		° ′	° ′	° ′	° ′	° ′		° ′	° ′
2	68 33	66 53	+1 40	57·289	65 53	−1 00	58 03	57 05	+0 58	14·522	56 30	−0 35
3	66 19	64 51	+1 28	57·310	63 53	−0 58	53 14	52 34	+0 40	14·550	51 56	−0 38
4	64 19	62 21	+1 58	56·992	62 05	−0 16	49 20	48 08	+1 12	14·412	48 12	+0 04
5	62 30	60 16	+2 14	56·759	60 26	+0 10	46 05	44 53	+1 12	14·383	45 09	+0 16
6	60 51	58 15	+2 36	56·458	58 55	+0 40	43 17	42 15	+1 02	14·396	42 22	+0 07
7	59 20	56 39	+2 41	56·318	57 30	+0 51	40 51	39 35	+1 16	14·302	40 00	+0 25
			Mean	56·854					Mean	14·427		

Whatever may be the law according to which the intensity depends upon the diameter of the wire, if the wire in the coils of the galvanometer wire act merely as a multiplier, without any effect of accumulation or diminution arising from the action of the contiguous wires upon each other, and the degree of which action may depend on the intensity itself, then the values of $\lambda_{\prime}, \lambda_{\prime\prime}, \lambda_{\prime\prime\prime}$ should be half the length of the galvanometer wire, reduced, according to that law, to wires whose diameters are $D_{,}$, $D_{,,}$, $D_{,,,}$. The diameter of the galvanometer wire is ·0380 inch, and the whole length of it in the circuit 819 inches; so that, if λ_0 is half its length in the unit of length, 50 inches, $\lambda_0 = 8·19$. If its diameter is D_0, then

$$\lambda_{,} = \lambda_0 \cdot \frac{D_{,}^{\,n}}{D_0^{\,n}}, \qquad \lambda_{,,} = \lambda_0 \frac{D_{,,}^{\,n}}{D_0^{\,n}}, \qquad \lambda_{,,,} = \lambda_0 \cdot \frac{D_{,,,}^{\,n}}{D_0^{\,n}}.$$

Taking the value of n in the first equation to be 1·844, as that deduced from wires whose diameters are most nearly $D_{,}$ and D_0; and in the second and third, for the same reason, to be 1·945; we shall have $\lambda_{,} = 74·5$, instead of 46·4, deduced from the observations; $\lambda_{,,} = 22·1$, instead of 14; and $\lambda_{,,,} = 5·93$ instead of 3·76. Also if the values of λ_0 are deduced from those of $\lambda_{,}$, $\lambda_{,,}$, $\lambda_{,,,}$ determined from the observations, these values will be 5·222, 5·189, 5·189, instead of 8·19, the true value. It is therefore clear from all these results, that the galvanometer wire acts as a wire of less than its real length, that is, that there is an increase of intensity in it, in consequence of the action of the coils upon each other. Had the value of λ_0 been deduced from the values of $\lambda_{,}$, $\lambda_{,,}$, $\lambda_{,,,}$, on the supposition that $n = 2$ in the above equations, those values would have been 4·234 from the first equation, 5·045 from the second, 5·237 from the third, instead of 8·19: showing not only that an accumulation of electricity arising from the action of the coils of the galvanometer on each other takes place, but that the accumulation becomes greater as the intensity increases. To this accumulation I consider that the discordances in the values of n are to be attributed, and that these values do not give the number 2, nearly as their mean.

As soon as I was aware that the length of the galvanometer wire must enter into the expression for the intensity, I foresaw the difficulties that would arise in drawing theoretical conclusions from the observations with different wires; and I had proposed making use of a galvanometer having only one turn of the wire, which should be the same as the other part of the conducting wire, and which must therefore be removable in order to determine the effects of different wires: but I felt that so much must depend upon the different wires occupying precisely the same position with respect to the needle, that I feared the changing the wire of the galvanometer would be a great source of error in the observations, and therefore gave up the idea.

I have already stated that I ascertained, by other experiments, that the intensity varies as the square of the diameter of the wire. The method which I adopted in these, was that described in the beginning of this paper, and consisted in determining what length of wire of one diameter would exactly destroy the effect of a given length of another wire of a different diameter. In this manner I had proposed to compare the wire No. 11. with each of the others, and also these with each other; but the experiments which I have described showed that three hundred and fifty inches, the whole length of No 11, was not sufficient to reduce its action to that of eighty-five or eighty-six inches of No. 22, the shortest length that would reach from the helix to the galvanometer. I could therefore only compare No. 11. with No. 16, and again this with No. 22. For this purpose, both the frames on which the wires No. 11. and No. 16. were coiled, were placed between the magnet and galvanometer, as in fig. 5, care being taken that the wires should be kept well apart from each other. Two corresponding ends of the wires of each frame were united with the helix at A′, and the other two corresponding ends, in like manner, with the helix at B′. Fifty-two inches of No. 11. (an inch at each end being allowed for contact,) and likewise fifty-two inches of No. 16. were each at one end in contact with the galvanometer wire at A, and similarly fifty-two inches of each were in contact with the other galvanometer wire at B. The ends of No. 11. not in contact with the galvanometer wire, were brought into good contact with the corresponding ends of No. 11. on the frame, so that the helix and galvanometer were connected by three hundred and fifty inches of No. 11. from A′ to A, and three hundred and fifty inches from B′ to B. The ends of No. 16. proceeding from A and B, were brought into good contact with No. 16. on the frame, but on contrary ends of it; so that the helix at A′ was connected with the galvanometer at B, and likewise the helix at B′ with the galvanometer at A, by No. 16. In other words, what I have, for the sake of distinction, termed the direct current, was transmitted to the galvanometer by three hundred and fifty inches of the wire No. 11. on each side, and what I have termed the reverse current was transmitted by No. 16.

I first reduced the length of No. 16. on each side to one hundred inches, and as there was a motion of the needle of about 5° E. on making contact, and of about 4° W. on breaking it, I further reduced the length to ninety inches. There still appearing a small motion easterly on making contact, and a slight westerly motion on breaking it, I reduced the length to eighty-nine inches, when the wires appeared exactly to counteract each other's effects. I therefore considered that by this method it appeared that three hundred and fifty inches of No. 11. was exactly equivalent in effect to eighty-nine inches of No. 16. I then determined separately the effects at the galvanometer, when A′ and A, B′ and B were connected by three hundred and fifty inches of No. 11; and when A′ and B, B′ and A were so connected; and in like manner when similar connexions were made with eighty-nine inches of No. 16. Observations, precisely similar to these, were made with the wires No. 16. and No. 22, excepting that as ninety inches of No. 22. was found to be equivalent to three hundred and fifty inches of No. 16, the effects of these lengths of those wires were determined. These observations are contained in the following Table.

VIII.

The Wires No. 11. and No. 16. compared.			
350 inches of No. 11. from U to A, and 350 inches from M to B. 89 inches of No. 16. from U to B, and 89 inches from M to A.			
Motion of the S. end of the Needle on contact being			
Made.		Broken.	
From 1° 10′E. no motion E. then slowly to 1° 00′W. The same, 1° 10′E. to 1° 00′W. The same, 1° 10′E. to 1° 00′W.		From 0° 00′ no motion W. then slowly to 2° 00′ E. The same, 0° 00′ to 2° 10′ E. The same, 0° 00′ to 2° 10′ E.	
No. 11. alone.		No. 16. alone.	
350 inches from U to A, and 350 inches from M to B.		89 inches from U to A, and 89 inches from M to B.	
Contact made.	Contact broken.	Contact made.	Contact broken.
118° 00′E.	123° 15′W.	117° 30′E.	123° 20′W.
118 40	123 00	117 30	123 50
118 00	122 30	117 40	123 45
Mean 120° 34′		Mean 120° 36′	
350 inches from U to B, and 350 inches from M to A.		89 inches from U to B, and 89 inches from M to A.	
Contact made.	Contact broken.	Contact made.	Contact broken.
123° 00′W.	116° 20′E.	122° 00′W.	115° 00′E.
123 00	116 20	122 15	115 00
123 15	116 20	122 30	115 30
Mean 119° 43′		Mean 118° 43′	
Means 120° 08′		119° 39′	

The Wires No. 16. and No. 22. compared.			
350 inches of No. 16. from U to A, and 350 inches from M to B. 90 inches of No. 22. from U to B, and 90 inches from M to A.			
Motion of the S. end of the Needle on contact being			
Made.		Broken.	
From 1° 00′E. no motion E. then slowly to 0° 50′W. The same, 1° 10′E. to 1° 00′W. The same, 1° 10′E. to 1° 00′W.		From 0° 00′ no motion W. then slowly to 2° 00′E. The same, 0° 00′ to 2° 15′E. The same, 0° 00′ to 2° 00′E.	
No. 16. alone.		No. 22. alone.	
350 inches from U to A, and 350 inches from M to B.		90 inches from U to A, and 90 inches from M to B.	
Contact made.	Contact broken.	Contact made.	Contact broken.
79° 10′E.	81° 00′W.	78° 45′E.	80° 30′W.
79 20	80 30	78 40	80 45
79 35	80 00	78 45	80 25
Mean 79° 56′		Mean 79° 38′	
350 inches from U to B, and 350 inches from M to A.		90 inches from U to B, and 90 inches from M to A.	
Contact made.	Contact broken.	Contact made.	Contact broken.
81° 15′W.	78° 30′E.	81° 15′W.	78° 30′E.
81 20	78 30	81 30	78 30
81 20	79 00	81 30	78 45
Mean 79° 59′		Mean 80° 00′	
Means 79° 57′		79° 49′	

The motion of the needle, when three hundred and fifty inches of No. 11. acted, according to the differential arrangement, against eighty-nine inches of No. 16, and also when three hundred and fifty inches of No. 16. acted against ninety inches of No. 22, being precisely that which, as I have before described, was due to the closing and opening of the poles of the magnet, shows that the opposite currents of electricity were precisely equal in both cases; that is, that the intensity in three hundred and fifty inches of No. 11. was precisely equal to that in eighty-nine inches of No. 16; and the intensity in three hundred and fifty inches of No. 16. equal to that in ninety inches of No. 22. And if the results obtained by this mode of experimenting admit of confirmation, they are fully confirmed by a comparison of the results obtained with these lengths of the wires arranged singly. With regard to the latter results, I may notice that they all exceed those which I had before obtained with the same lengths of the wires, and which are given in Table VI. As my object in making these experiments was to obtain the relative results with the two wires, my attention was not at the time particularly drawn to this circumstance, and I can now assign no particular cause for this want of agreement, but find, on referring to the experiments, that the results which I obtained at this time with other lengths of the wires possess the same character, although an interval of only a few days had elapsed since the former observations had been made.

If the intensity vary directly as the n^{th} power of the diameter of the wire, and inversely as its length, then

$$\frac{I_{/}}{I_{//}} = \frac{D_{/}^{n}}{L_{/}+\lambda_{/}} \times \frac{L_{//}+\lambda_{//}}{D_{//}}$$

and if $I_{/} = I_{//}$

$$D_{/}^{n}(L_{//}+\lambda_{//}) = D_{//}^{n}(L_{/}+\lambda_{/})$$

also $$D_{/}^{n}\lambda_{//} = D_{//}^{n}\lambda_{/}$$

therefore $$D_{/}^{n}L_{//} = D_{//}^{n}L_{/}$$

whence $$n = \frac{\log. L_{/} - \log. L_{//}}{\log. D_{/} - \log. D_{//}}$$

Substituting 350 for $L_{/}$, 89 for $L_{//}$, ·1258 for $D_{/}$ and ·0633 for $D_{//}$, we have $n = 1·9937$;
and again, 350 for $L_{/}$, 90 for $L_{//}$, ·0633 for $D_{/}$ and ·0322 for $D_{//}$, we have $n = 2·0093$

Mean .... $n = 2·0015$

There can be no doubt from these results that, in wires of a given length, the intensity of magneto-electricity varies as the squares of the diameters. The law therefore which has been established, is, that in wires of different lengths and different diameters, the intensity of magneto-electricity, or, in other words, the conducting power, varies as the squares of their diameters directly, and as their lengths inversely. Or we may say, that the intensity or conducting power varies as the mass or weight directly, and the square of the length inversely.

Different laws according to which volta-electricity and thermo-electricity are conducted by wires, have resulted from the investigations of different philosophers. DAVY found that*, "when different portions of the same wire, plunged in a non-conducting fluid, were connected with different parts of the same battery equally charged, their conducting powers appeared in the inverse ratio of their lengths;" and that the conducting power of a wire for electricity was nearly as the mass,—that is, when the wire was of a given length; and also, that it was independent of surface. The same law was subsequently shown by M. BECQUEREL to be true, by a totally different method†. M. BECQUEREL thus states the law which he found to hold: "Ainsi pour obtenir la même conductibilité dans deux fils de même métal, il faut que leurs poids soient proportionnels aux carrés de leurs longueurs, au bien que leurs longueurs soient dans le rapport des sections des fils." The law as thus stated would hold whether the conducting power be, as the diameter directly and the square root of the length inversely, or as the square of the diameter directly and the length inversely. M. BECQUEREL has, however, previously shown that when the diameter is the same, the conducting power is inversely as the length; and it therefore follows that in general it is as the square of the diameter directly and length inversely.

From experiments described in a very interesting paper, "On the Development of Electro-Magnetism by Heat‡," Professor CUMMING states that "so far as these experiments (given as mere approximations,) may be depended on, the conducting power of copper wires of considerable length varies as $\frac{D}{\surd L}$§."

* Philosophical Transactions, 1821, p. 435.

† Annales de Chimie, 1826, p. 425.

‡ Cambridge Philosophical Transactions, 1823.

§ Manual of Electro-dynamics.

Although the deviations of the magnetic needle, obtained with wires 32, 16, 8, 4 feet in length*, give values of the index of L, varying from $-\cdot394$ to $-\cdot655$, yet they give a mean $-\cdot536$, which may be considered as an approximation to $-\frac{1}{2}$. Some of the experiments however with wires of different diameters, give results approximating to 2 rather than to 1 as the index of D; thus with eight feet of wire $\frac{1}{20}$th of an inch in diameter, the deviation was $15\frac{1}{2}°$; and with eight feet of wire $\frac{1}{37}$th of an inch, the deviation was $6\frac{1}{2}°$. These would give 1·68 as the index of D, which might be considered as an approximation to $\frac{3}{2}$. And again,

† "Six wires of $\frac{1}{46}$ gave the same deviations as one of $\frac{1}{23}$ each $16\frac{1}{2}$ inches long
Four wires of $\frac{1}{130}$ gave the same deviations as one of $\frac{1}{60}$ each $16\frac{1}{2}$ inches long
Three wires of $\frac{1}{46}$ gave the same deviations as one of $\frac{1}{23}$ each $1\frac{1}{2}$ inch long."

These give respectively 2·58, 1·79, 1·58 as the index of D, or 1·98 as the mean.

In a preceding paper‡, Professor CUMMING states, that "in using large wires, the surface alone does not transmit this magnetic influence." Had this remark been followed out in its consequences, it must have led to the law of the square of the diameter. The law, however, deduced by Professor CUMMING, is in accordance with the enunciation of M. BECQUEREL's which I have quoted.

From experiments with conducting wires varying in length from eight hundred and thirty-eight feet to ninety-eight feet, Mr. BARLOW infers, that the electro-magnetic effect from a battery varies very nearly inversely as the square root of the length of the conducting wire §. But the results computed on this hypothesis differ so widely from the observations, (as much in one instance as 1° 59′ in 4° 30′, in another 2° 16′ in 8° 31′, and very commonly more than 1° 30′ in 8° or 9°,) that it appears to me these observations can scarcely be adduced in support of the probability of the existence of such a law. Experiments described in the same paper, with wires of the same length, but of different weights, would lead to the conclusion, that, although the effect increases with the diameter of the wire, yet the increase is extremely small; since in copper wires of the same length, and varying in weight from seventeen grains to one thousand five hundred and ninety grains, the deflection of the needle, measuring the effect, only increased from 25° to 38°; and with brass wires varying

* Cambridge Philosophical Transactions, 1823, p. 63.

† Ibid. p. 72.

‡ Camb. Phil. Trans. 1821, p. 277.

§ Edinburgh Philosophical Journal, 1825.

in weight from thirty-eight grains to three thousand seven hundred and seventy grains the deflection only increased from 26° to about 32°.

Considering, then, that the law according to which volta-electricity is conducted is that laid down by Sir HUMPHRY DAVY and M. BECQUEREL, it appears that magneto-electricity is conducted according to the same law; or rather, I would say, that the intensity of the electricity excited in the conducting wires varies, in the two cases, according to the same law. I am disposed to think that the intensity of thermo-electricity varies likewise according to the same law, and that the reason that the experiments hitherto made have not led to the establishment of this law has been, the difficulty of separating the effects produced on the wire by the conduction of the agent from the power primarily excited in it. Without having made the trial, it is difficult to say how far the arrangement which I have made use of may be applied with success to the determination of the law according to which thermo-electricity is excited in wires of different lengths and different diameters. I foresee difficulties, arising from the circumstance that heat being applied at the junction of the crossed wires of different diameters, with the two different metals, a secondary action would ensue. These difficulties may not however be insurmountable, and would perhaps be overcome by dispensing altogether with the thermo-electric battery of two metals. Should I have leisure, I may make the attempt, but at all events it is my intention to apply the principle of the differential arrangement to volta-electricity, as I consider that, where applicable, it is capable of giving results to a degree of accuracy hitherto unattained.

From the law which has been established we may conclude, that whatever may be the length of a wire of an invariable diameter, it will in all cases receive the same measure of electricity from the first source, or that the whole amount of electricity excited in it will be the same: that where the section perpendicular to the direction in which the electricity may be said to be propagated is variable, the amount is proportional to the section, so that every portion of this section receives the same measure of electricity. Whether magneto-electricity consists in a current of imponderable matter, or is a latent power brought into action during the motion of a body in the neighbourhood of a magnet, it would appear that it is developed with the same intensity in every part; but this it cannot be at the same instant, since in one case, time must be required for its progress from one point to another, and in the other, for its development. If the power consist in any peculiar arrangement of particles, still time must be required to produce that arrangement, which must proceed from particle to particle, the action on the more remote particles only taking place through the intervention of the nearer. The velocity of the current, the rapidity with which the power is brought into action, or with which the arrangement takes place, whichever it be, may be quite beyond any means which can be devised for their determination; and this they may be, not only without surpassing velocities of which astronomical phenomena give us a conception, but even falling very short of them; but although they may surpass them as much as these do any which are obvious to our senses, still the action on the remote parts of the wire cannot be absolutely simultaneous with that on the parts in the immediate neighbourhood of the magnet. The electricity in the wire must consequently be considered as in motion, however short may be the time of its passage from the nearest to the most remote point.

III. *On the Intensity of the Electricity excited in different metals.*

I have already referred to the manner in which I proposed pursuing this inquiry. For the comparison of the intensities in copper, zinc, tin, iron and lead, I made use of wires about one twentieth of an inch in diameter, and for that of the finer metals, gold, silver, platinum, with copper, of wires of about three hundredths of an inch. The former were all drawn through the same hole, as were also the latter. The copper, zinc, tin, iron and lead, are the ordinary metals of commerce; the gold is unalloyed, and the silver is standard.

Two lengths, of fifty inches each, were accurately measured of each of the larger wires, exclusive of an inch and a half marked off at each end for contact. The wires of the two metals under comparison were arranged as in fig. 3; the wire of the metal which had the greatest intensity always connecting A′ with A, and B′ with B, or, as I have before designated it, carrying the direct current, and the wire of the metal of weaker intensity connecting A′ with B, and B′ with A, or carrying the reverse current. The length of wire from D′ to D and from C′ to C was in all cases fifty inches. The length of the wire from D′ to C and from C′ to D was also in the first instance fifty inches. The effect at the galvanometer having been observed, the distance between the contacts on these last wires was reduced five inches, and the effect again observed: and I continued reducing the lengths of these wires by five inches and observing the effects, until the deflection of the galvanometer needle was reduced to 4° or 5°. I then observed at smaller intervals, and determined the length of the wires of the metal having the weaker intensity, which was equivalent in effect to fifty inches of the other, on each side, either by no motion taking place in the galvanometer needle on the contact of the iron cylinder with the magnet taking place, or on that contact being broken; or otherwise, by finding two lengths of the shorter wire which gave opposite deflections of the needle, and dividing the interval between them in the proportion of these deflections The galvanometer made use of in this case was the extremely sensible one with light needles, already described. The effect on this, of closing the poles of the magnet with the iron cylinder, was to make the needle vibrate from $1\frac{1}{2}$ E. to $1\frac{1}{2}$ W., and the effect of opening them, to vibrate from 0° to 3° E.

In this manner each of the metals, zinc, tin, iron, lead, was compared with copper; tin, iron, lead, with zinc; iron, and lead with tin; and lead with iron.

With all the metals except lead these deflections of the needle decreased pretty regularly as the wire of the weaker was shortened; but with the lead, on some occasions, I found that when I had decreased the length of its wires, an increased effect of the same kind as before, took place; and on others, when on a first trial of making contact, and also on breaking it, the needle remained immoveable; on a second it was deflected 5° or 6° in a direction indicating that the lead wire was still too long. When this wire had been slightly diminished in length, the needle was deflected decidedly in the opposite direction; so that it was hardly possible to say what was the correct length required of the lead wire. At first I attributed this anomalous effect to some of the wires approaching each other too nearly, but at length I was satisfied that it proceeded from the metallic contact between the lead and the other metals gradually becoming imperfect by the oxidation of the surface of the lead. The effect is so singular, that I give the observations which pointed out to me the true cause. From previous observations I considered that about eleven inches of lead wire would be equivalent to fifty inches of zinc wire, but had found this anomalous effect to take place with these lengths. I therefore brightened the ends of the wires on each side at these distances, and again bound them together with bright copper wire, the lengths of the zinc wires carrying the direct current being each fifty inches, and of the lead wires carrying the reverse current each 11·2 inches.

Time.	Motion of the Needle on the contact of the Helix with the Magnet being Made.	Broken.	Time.	Observations continued. The wires nearest to the Helix unbound, brightened, and rebound. Contact Made.	Contact Broken.	Time.
h m			h m			h m
	Steady, then 2° W.	2° W. then 6° E.		Steady, then 1° W.	1° W. then E.	
	2° E.	Steady, then 3 E.		1½° E. to 2° E. then W.	3 W. then E.	8 21
	3 E.	3 W.		4 E.	1 W. then E.	
	7 E.	4 W.	4 12	2 E.	2 W. then E.	9 22
4 20	14 E.	10 W.		28 E.	29 W.	18 40
	16 E.	14 W.		The wires were accidentally shaken.		
	25 E.	14 W.				
	15 E.	7 W.		10° E.	10° W.	
	17 E.	12 W.	4 36	5 E.	5 W.	
	28 E.	14 W.	5 54	One set of wires raised six inches above the other.		
	30 E.	28 W.				
	35 E.	50 W.	7 38	Steady, then 3° W.	3° W.	19 20
	Changed the Positions of the wires, but their contacts untouched.			5° E.	3 W.	19 27
				10 E.	11 W.	20 05
	45° E.	38° W.		22 E.	21 W.	21 00
	The wires nearest to the Galvanometer unbound, brightened, and again bound.			At the places of contact, the wires were pressed so that the binding wire entered the lead, but the wires were not moved.		
	30° E.	30° W.		3° E.	2° W.	21 5
				3 E.	2 W.	21 9
				4 E.	2 W.	21 11
				6 E.	4 W.	21 17

The following are similar observations with copper and lead wires; the length of the lead wires on each side being 5·9 inches, and of the copper wires, as usual, fifty inches.

Time.	Motion of the Needle on the contact of the Cylinder with the Magnet being Made.	Broken.	Time.
h m			h m
22 10	Steady, then 1° W.	Steady, then 2° E.	
	Steady, then 1½ W.	1° W. then 3 E.	
	½° E. then 2 W.	2 W.	22 17
	Steady, then 2 W.	5 W.	22 20
	8 E.	12 W.	24 25
	12 E.	13 W.	24 29
	Pressed all the joints of the wires.		
	Steady, then ½° W.	Steady, then 2° E.	24 31
	Steady,	Steady, then 2 E.	24 32

From the former set I inferred that, when all the contacts were good, 22·4 inches of lead wire in the arrangement was equivalent to one hundred inches of zinc wire; and from the latter that 11·8 inches of lead wire was equivalent to one hundred inches of copper wire.

I had no doubt, after making these observations, that the anomalies I had previously observed, arose from the contact between the lead and the other metals becoming imperfect after a very short time; and I therefore determined the length of the lead wires to be that which, on the observation being made immediately after the wires had been bound together, produced no motion in the galvanometer needle. In consequence however of this, I do not place the same confidence in the results obtained with the lead wire which I do in the others*. Nothing of this kind was observed with any of the other metals, though, probably, it might take place if the wires were left for a considerable time in contact. With the lead I noticed the effect principally when it was compared with iron, with zinc, and with copper.

The relative lengths of the wires of different metals, as determined by the observations, are arranged in the following Table.

IX.

Metals taken as Standards, the lengths of their wires being 100 inches.	Metals compared, and the lengths of their wires corresponding to 100 inches of the wire taken as the standard.				
	Copper.	Zinc.	Tin.	Iron.	Lead.
	inches.	inches.	inches.	inches.	inches.
Copper	100	52·0	25·5	22·8	11·8
Zinc	......	100·0	49·08	42·0	22·4
Tin	......	......	100·00	89·4	52·0
Iron	......	......	......	100·0	62·0

In order to reduce the relative lengths of two wires determined by experiment, to the standard of one hundred inches of copper wire, it is necessary either to assume one of them of the length determined by comparison with the

* I might have avoided this uncertainty, by making the ends of the wires just touch the surface of mercury contained in four cups, properly placed for the purpose; and this in many cases may be the most convenient way of making the differential arrangement of the wires: but in making these experiments it was an object to avoid cutting the wires, which must have been done had mercury been used.

copper, or to assume their sum as so determined, and divide it in the ratio of the observed lengths. As the second method tends to distribute the errors of the first determination equally between the two reduced lengths, I adopt it in the reductions, made in the following Table, of the above observations.

X.

Metals with which others are compared.	Metals compared, and the lengths of their wires reduced to the Standard of 100 inches of copper wire.				
	Copper.	Zinc.	Tin.	Iron.	Lead.
	inches.	inches.	inches.	inches.	inches.
Copper	100	52·0	25·5	22·8	11·8
Zinc	100	....	25·52	22·13	11·68
Tin................	100	51·98	....	22·80	12·76
Iron	100	52·67	25·50	....	13·24
Lead	100	52·12	24·54	21·36	....
Means	100	52·19	25·26	22·27	12·37

The lengths of the several wires, as deduced from the different comparisons, agree as nearly with each other as could possibly be expected, except those of the lead, and for any want of agreement in these I have already assigned the cause.

With the finer metals, I was under the necessity of employing shorter lengths than fifty inches on each side, for the wire of the metal having the greater intensity; but in all cases I made these as long as the length of the wire would admit. The results of the comparisons which I made with wires of copper, gold, silver, and platinum, are contained in the following Table

XI.

Metals taken as Standards.	Metals compared, and the lengths of their wires corresponding to the invariable length of the wire taken as a Standard.			
	Gold.	Silver.	Copper.	Platinum.
	inches.	inches.	inches.	inches.
Gold	36	48·82	32·7	8·0
Silver..............	....	70	46	11·1
Copper	....	....	100	24·76

These reduced to the standard of one hundred inches of copper wire are contained in the following Table.

XII.

Metals with which others are compared.	Metals compared, and the lengths of their wires reduced to the Standard of 100 inches of copper wire.			
	Copper.	Silver.	Gold.	Platinum.
	inches.	inches.	inches.	inches.
Copper	100	152·2	110·1	24·76
Silver..............	100	....	111·33	24·22
Gold	100	150·97	....	24·52
Platinum	100	152·74	110·34	....
Means	100	151·97	110·59	24·50

The numbers in this and Table X. represent the lengths of the wires of the respective metals, in which electricity would be excited of the same intensity as that excited in a copper wire of the same diameter, and one hundred inches long, from the same source. Since, then, with the same metal, the intensity of the electricity excited in a wire of a given diameter varies inversely as the length of the wire, the intensities in wires of the same length, but of different metals, will be directly proportional to the lengths of the wires in which the intensities are the same. These numbers will, consequently, represent the relative intensities in wires of the same length of the different metals. If the principle, that the conducting powers of different metals are proportional to the intensities of the electricity excited in equal wires, which I have shown to be true for copper and iron, be admitted for all, then these numbers will also represent the relative conducting powers of the different metals; and it will follow, that the conducting powers of different metals will vary as the length of the wires of the same diameter which transmit electricity of the same intensity, or as the quantity of electricity transmitted through the same length of wire, from a common source, either of which may be taken as the measure of the conducting power.

The numbers which I have thus determined as representing the intensity of magneto-electricity in different metals, are not only not the same as have been previously determined for the intensities of either electricity from the ordinary machine, volta-electricity, or thermo-electricity, but the order of the metals differs from them all in some particulars. In order to form a comparison, I have placed these results and different determinations of the relative intensities of electricity in different metals, in the same Table. In Table XIII. copper is taken as the standard, and silver in Table XIV.

XIII.

Electricity from the Magnet.		Electricity from the Voltaic Battery. Davy*.		M. Becquerel†.		Thermo-Electricity. Professor Cumming‡.		Electricity from the Machine. Mr. Harris§.	
Metals.	Intensities.	Metals.	Conducting powers ‖.	Metals.	Conducting powers.	Metals.	Conducting powers.	Metals.	Conducting powers.
Silver ..	152·0	Silver ..	109	Copper	100	Silver ..	176·5	Copper	100
Gold ..	110·6	Copper	100	Gold ..	93·6	Copper	100	Silver ..	100
Copper	100	Gold ..	73	Silver ..	73·6	Zinc ..	53	Gold ..	66·7
Zinc ..	52·2	Lead ..	69	Zinc ..	28·5	Gold ..	35·2	Zinc ..	33·3
Tin	25·3	Platinum	18	Platinum	16·4	Iron ..	24·3	Platinum	20·0
Platinum	24·5	Iron ..	14·5	Iron ..	15·8	Tin	23·9	Iron ..	20·0
Iron ..	22·3			Tin	15·5	Platinum	21·6	Tin	16·7
Lead ..	12·4			Lead ..	8·3	Lead ..	16·8	Lead ..	8·3

XIV.

Electricity from the Magnet.		Davy.		M. Becquerel.		Professor Cumming.		Mr. Harris.	
Metals.	Intensities.	Metals.	Conducting powers.	Metals.	Conducting powers.	Metals.	Conducting powers.	Metals.	Conducting powers.
Silver ..	100	Silver ..	100	Copper .	135·9	Silver ..	100	Copper .	100
Gold ..	72·8	Copper .	91·7	Gold ..	127·2	Copper .	56·7	Silver ..	100
Copper .	65·8	Gold ..	66·7	Silver ..	100	Zinc ..	30·0	Gold ..	66·7
Zinc ...	34·3	Lead ..	63·3	Zinc ...	38·7	Gold ..	19·9	Zinc ...	33·3
Tin	16·6	Platinum	16·7	Platinum	22·3	Iron ...	13·7	Platinum	20·0
Platinum	16·1	Iron ...	13·3	Iron ...	21·5	Tin	13·5	Iron ...	20·0
Iron ...	14·7			Tin	21·0	Platinum	12·2	Tin	16·7
Lead ...	8·2			Lead ...	11·3	Lead ...	9·5	Lead ..	8·3

In Table XIII., in which copper is the standard, the agreement is the closest between Professor Cumming's results and those which I have obtained: the intensities of zinc, iron, tin, platinum, are nearly the same, though the order of

* Philosophical Transactions, 1821.

† Annales de Chimie, 1826.

‡ Manual of Electro-Dynamics, p. 288.

§ Philosophical Transactions, 1827.

‖ Deduced from the lengths of the wires of these metals which discharged the electricity of the same battery, p. 433. If the conducting powers are estimated by the number of pairs of plates discharged by the same length of wire of each, they appear to be

		Or taking silver as the standard
Silver . .	116	100
Copper .	100	86
Tin . .	21·4	18·5
Platinum .	19·8	17·0
Iron . .	16·1	14·0
Lead . .	82	71

the last three is different; and the intensities of silver do not very greatly differ in the two cases.

In Table XIV., where silver is taken as the standard, some striking coincidences may be noticed. The intensities of zinc, tin, lead, are very nearly the same as the conducting powers of those metals determined by Mr. Harris, and the difference with gold is not great. The intensity of platinum is nearly the same as the conducting power determined by Davy; those of iron also agree pretty nearly, and those of gold do not greatly differ. That these coincidences are not observable when copper is taken as the standard, may perhaps be partly attributable to impurities usually found in the copper of commerce, of which the wire I employed consisted. Mr. Harris states that the metals which he employed were pure; and I presume that the same was the case with those made use of by Sir Humphry Davy, though he does not state so. In neither of the Tables are similar coincidences observable between M. Becquerel's results and those which I have obtained, or indeed any of the others, excepting that his determinations for platinum and iron do not differ much from Mr. Harris's results.

It is to be expected, that, from whatever source electricity may be derived, whether from the voltaic battery or the magnet, whether it be excited by heat or by friction, all other circumstances being alike, the relative intensities with which it is excited in different metals will be the same; and if so, all the determinations in the Tables ought to have agreed. It is not for me to put my own observations, or the methods I have adopted, in competition with those of others, but I think that circumstances may have interfered in other methods of obtaining the intensity of electricity, which could have no influence on the results obtained with the magnet by the method I adopted.

Taking the intensity of the electricity discharged as a measure of the conducting power, and assuming that this intensity varies as the number of plates in the battery,—a principle, however, which must be established independently,—the method adopted by Sir Humphry Davy would determine the conducting powers of metals. But there are many circumstances that would interfere with the accuracy of the results, some of which are noticed by the author, and others are pointed out by M. Becquerel; and these or others may not have equally affected all the metals. That some circumstance must have particularly affected the results obtained with lead, and that to a considerable extent, is quite evident. Taking silver as the standard, 100, the conducting power of lead, determined by the length of the wire discharging the electricity of the same number of plates, is 63; and by the number of pairs of plates it is 71: whereas, taking the same standard, it is only 11·3 according to M. Becquerel, 9·5 according to Professor Cumming, 8·3 according to Mr. Harris, and 8·2 according to the experiments I have detailed.

In the arrangement adopted by M. Becquerel, two currents, in separate wires, and in contrary directions, influence the galvanometer needle; and these currents are rendered equal by shortening the wires of one until the needle retains its original position; two secondary circuits being then formed, it is assumed that the intensity of the electricity in these will be equal, if the needle remains uninfluenced. It is, however, not quite clear that this will be the case, if the want of symmetry in the arrangement of the wires of the galvanometer is compensated by a difference in their lengths*. The wires made use of by M. Becquerel were short, not more than four or five inches in length, so that a small error in their lengths would cause a considerable difference in their comparative conducting powers, but not sufficient to account for the differences between his results and mine.

In comparing the electric powers of different metals by means of a thermo-electric apparatus, great precaution is necessary to guard against any anomalous influence which the agent in this case employed for exciting electricity may exert upon different metals. It is possibly to such influence that we are to attribute the very low electric power of gold determined by Professor Cumming. This is indeed the only marked instance of disagreement between his results and those which I obtained.

The principle employed by Mr. Harris, and first suggested by Mr. Children,—namely, that the heat evolved by the passage of electricity through conductors is in some inverse ratio of the conducting power,—was employed by Sir

* When first I made use of the arrangement which I have described, the subject being quite new to me, I was not aware of that employed by M. Becquerel. There is some similarity in the two, but the principles on which their application depends are very different. M. Becquerel's depends upon two equal currents, in separate wires, being equally diminished by two other currents, likewise in separate wires: mine, on the effect of a current in a single wire being counteracted by an equal and opposite current in the same wire, or that the opposite electricities neutralize each other, so that no current exists in the wire of the galvanometer. It appears to me that my arrangement combines the advantages of greater simplicity and greater accuracy.

HUMPHRY DAVY*; and though he obtained no very definite numerical results, yet it appeared, in one instance, that the generation of heat was nearly inversely as the conducting power. According to this principle, the order of the metals relative to their conducting power was found to be silver, copper, lead, gold, zinc, tin, platinum, palladium, iron, which corresponds very nearly with the order previously determined by the lengths of their wires, and also, with the exception of lead and gold, with the results I have obtained. That the principle may give in some cases a close approximation to the truth, I think is probable from the agreement of the results obtained by means of its application; but I think it more likely that the conducting power is a function both of the absolute heat and of the specific heat of the conductor. I have already noticed the agreement between Mr. HARRIS's results and mine; possibly the differences observable in the two cases are to be attributed to this circumstance; and also that the heat evolved may not be a measure of the heat of the conductor.

I am very desirous of obtaining results with the voltaic battery, and also if possible with a thermo-electric apparatus, and the common machine, by means of an arrangement similar to that which I have employed with the magnet, as I consider that a comparison of results obtained by the same means in the different cases must throw some additional light upon this interesting subject; and I shall avail myself of the first opportunity of leisure which I have to prosecute the inquiry.

Royal Military Academy.
8th January 1833.

* Philosophical Transactions, 1821, p. 438. In this valuable communication the author states, that the most remarkable general result which he obtained was, that "the conducting power of metallic bodies varied with the temperature, and was lower in some inverse ratio as the temperature was higher:" and that whether the heat was occasioned by the electricity, or applied from some other source, the effect was the same. The conducting power being as the intensity, it would follow that the intensity varies in some inverse ratio of the heat of the conductor. On this point I have not had leisure to make any experiments with a view to obtain numerical results, but I have found that a diminution of intensity is the consequence of an increase of temperature. Four copper wires of precisely the same length, each thirty inches, were connected so that the currents transmitted through them to the galvanometer neutralized each other: heat was then applied to the two which crossed each other, and through which one of the currents was transmitted. On the contact of the iron cylinder with the magnet being made, the needle deviated 9° in one direction, and on its being broken, it deviated 8° in the other; and these directions indicated a diminished intensity in the heated wires.