On a New Action of the Magnet on Electric Currents.

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Sometime during the last University year, while I was reading Maxwell's Electricity and Magnetism in connection with Professor Rowland's lectures, my attention was particularly attracted by the following passage in Vol. II, p. 144:

"It must be carefully remembered, that the mechanical force which urges a conductor carrying a current across the lines of magnetic force, acts, not on the electric current, but on the conductor which carries it. If the conductor be a rotating disk or a fluid it will move in obedience to this force, and this motion may or may not be accompanied with a change of position of the electric current which it carries. But if the current itself be free to choose any path through a fixed solid conductor or a network of wires, then, when a constant magnetic force is made to act on the system, the path of the current through the conductors is not permanently altered, but after certain transient phenomena, called induction currents, have subsided, the distribution of the current will be found to be the same as if no magnetic force were in action. The only force which acts on electric currents is electromotive force, which must be distinguished from the mechanical force which is the subject of this chapter."

This statement seemed to me to be contrary to the most natural supposition in the case considered, taking into account the fact that a wire not bearing a current is in general not affected by a magnet and that a wire bearing a current is affected exactly in proportion to the strength of the current, while the size and, in general, the material of the wire are matters of indifference. Moreover in explaining the phenomena of statical electricity it is customary to say that charged bodies are attracted toward each other or the contrary solely by the attraction or repulsion of the charges for each other.

Soon after reading the above statement in Maxwell I read an article by Prof. Edlund, entitled "*Unipolar Induction*" (Phil. Mag., Oct., 1878, or Annales de Chemie et de Physique, Jan., 1879), in which the author evidently assumes that a magnet acts upon a current in a fixed conductor just as it acts upon the conductor itself when free to move.

Finding these two authorities at variance, I brought the question to Prof. Rowland. He told me he doubted the truth of Maxwell's statement and had sometime before made a hasty experiment for the purpose of detecting, if possible, some action of the magnet on the current itself, though without success. Being very busy with other matters however, he had no immediate intention of carrying the investigation further.

I now began to give the matter more attention and hit upon a method that seemed to promise a solution of the problem. I laid my plan before Prof. Rowland and asked whether he had any objection to my making the experiment. He approved of my method in the main, though suggesting some very important changes in the proposed form and arrangement of the apparatus. The experiment proposed was suggested by the following reflection:

If the current of electricity in a fixed conductor is itself attracted by a magnet, the current should be drawn to one side of the wire, and therefore the resistance experienced should be increased.

To test this theory, a flat spiral of German silver wire was inclosed between two thin disks of hard rubber and the whole placed between the poles of an electromagnet in such a position that the lines of magnetic force would pass through the spiral at right angles to the current of electricity.

The wire of the spiral was about ½ mm. in diameter, and the resistance of the spiral was about two ohms.

The magnet was worked by a battery of twenty Bunsen cells joined four in series and five abreast. The strength of the magnetic field in which the coil was placed was probably fifteen or twenty thousand times H, the horizontal intensity of the earth's magnetism.

Making the spiral one arm of a Wheatstone's bridge and using a low resistance Thomson galvanometer, so delicately adjusted as to betray a change of about one part in a million in the resistance of the spiral, I made, from October 7th to October 11th inclusive, thirteen series of observations, each of forty readings. A reading would first be made with the magnet active in a certain direction, then a reading with the magnet inactive, then one with the magnet active in the direction opposite to the first, then with the magnet inactive, and so on till the series of forty readings was completed.

Some of the series seemed to show a slight increase of resistance due to the action of the magnet, some a slight decrease, the greatest change indicated by any complete series being a decrease of about one part in a hundred and fifty thousand. Nearly all the other series indicated a very much smaller change, the average change shown by the thirteen series being a decrease of about one part in five millions.

Apparently, then, the magnet's action caused no change in the resistance of the coil.

But though conclusive, apparently, in respect to any change of resistance, the above experiments are not sufficient to prove that a magnet cannot affect an electric current. If electricity is assumed to be an incompressible fluid, as some suspect it to be, we may conceive that the current of electricity flowing in a wire cannot be forced into one side of the wire or made to flow in any but a symmetrical manner. The magnet may *tend* to deflect the current without being able to do so. It is evident, however, that in this case there would exist a state of stress in the conductor, the electricity pressing, as it were, toward one side of the wire. Reasoning thus, I thought it necessary, in order to make a thorough investigation of the matter, to test for a difference of potential between points on opposite sides of the conductor.

This could be done by repeating the experiment formerly made by Prof. Rowland, and which was the following:

A disk or strip of metal, forming part of an electric circuit, was placed between the poles of an electro-magnet, the disk cutting across the lines of force. The two poles of a sensitive galvanometer were then placed in connection with different parts of the disk, through which an electric current was passing, until two nearly equipotential points were found. The magnet current was then turned on and the galvanometer was observed, in order to detect any indication of a change in the relative potential of the two poles.

Owing probably to the fact that the metal disk used had considerable thickness, the experiment at that time failed to give any positive result. Prof. Rowland now advised me, in repeating this experiment, to use gold leaf mounted on a plate of glass as my metal strip. I did so, and, experimenting as indicated above, succeeded on the 28th of October in obtaining, as the effect of the magnet's action, a decided deflection of the galvanometer needle.

This deflection was much too large to be attributed to the direct action of the magnet on the galvanometer needle, or to any similar cause. It was, moreover, a permanent deflection, and therefore not to be accounted for by induction.

The effect was reversed when the magnet was reversed. It was not reversed by transferring the poles of the galvanometer from one end of the strip to the other. In short, the phenomena observed were just such as we should expect to see if the electric current were pressed, but not moved, toward one side of the conductor.

In regard to the direction of this pressure or tendency as dependent on the direction of the current in the gold leaf and the direction of the lines of magnetic force, the following statement may be made:

If we regard an electric current as a single stream flowing from the positive to the negative pole, *i. e.* from the carbon pole of the battery through the circuit to the zinc pole, in this case the phenomena observed indicate that two *currents*, parallel and in the same direction, tend to repel each other.

If, on the other hand, we regard the electric current as a stream flowing from the negtive to the positive pole, in this case the phenomena observed indicate that two *currents* parallel and in the same direction tend to attract each other.

It is of course perfectly well known that two *conductors*, bearing currents parallel and in the same direction, are drawn toward each other. Whether this fact, taken in connection with what has been said above, has any bearing upon the question of the absolute direction of the electric current, it is perhaps too early to decide.

In order to make some rough quantitative experiments, a new plate was prepared consisting of a strip of gold leaf about 2 cm. wide and 9 cm. long mounted on plate glass. Good contact was insured by pressing firmly down on each end of the strip of gold leaf a thick piece of brass polished on the under side. To these pieces of brass the wires from a single Bunsen cell were soldered. The portion of the gold leaf strip not covered by the pieces of brass was about 5½ cm. in length and had a resistance of about 2 ohms. The poles of a high resistance Thomson galvanometer were placed in connection with points opposite each other on the edges of the strip of gold leaf and midway between the pieces of brass. The glass plate bearing the gold leaf was fastened, as the first one had been, by a soft cement to the flat end of one pole of the magnet, the other pole of the magnet being brought to within about 6 mm. of the strip of gold leaf.

The apparatus being arranged as above described, on the 12th of November a series of observations was made for the purpose of determining the variations of the observed effect with known variations of the magnetic force and the strength of current through the gold leaf.

The experiments were hastily and roughly made, but are sufficiently accurate, it is thought, to determine the law of variation above mentioned as well as the order of magnitude of the current through the Thomson galvanometer compared with the current through the gold leaf and the intensity of the magnetic field.

The results obtained are as follows:

Current through Gold Leaf Strip. C.	Strength of Magnetic Field. M.	Current through Thomson Galvanometer. c.	$\frac{C \times M}{c}$
.0616	11420 H	.00000000232	303000000000.
.0249	11240 "	085	329..........
.0389	11060 "	135	319..........
.0598	7670 "	147	312..........
.0595	5700 "	104	326..........

H is the horizontal intensity of the earth's magnetism $= .19$ approximately.

Though the greatest difference in the last column above amounts to about 8 per cent. of the mean quotient, yet it seems safe to conclude that with a given form and arrangement of apparatus the action on the Thomson galvanometer is proportional to the product of the magnetic force by the current through the gold leaf. This is not the same as saying that the effect on the Thomson galvanometer is under all circumstances proportional to the current which is passing between the poles of the magnet. If a strip of copper of the same length and breadth as the gold leaf but ¼ mm. in thickness is substituted for the latter, the galvanometer fails to detect any current arising from the action of the magnet, except an induction current at the moment of making or breaking the magnet circuit.

It has been stated above that in the experiments thus far tried the current apparently tends to move, without actually moving, toward the side of the conductor. I have in mind a form of apparatus which will, I think, allow the current to follow this tendency and move across the lines of magnetic force. If this experiment succeeds, one or two others immediately suggest themselves.

To make a more complete and accurate study of the phenomenon described in the preceding pages, availing myself of the advice and assistance of Prof. Rowland, will probably occupy me for some months to come.

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It is perhaps allowable to speak of the action of the magnet as setting up in the strip of gold leaf a new electromotive force at right angles to the primary electromotive force.

This new electromotive force cannot, under ordinary conditions, manifest itself, the circuit in which it might work being incomplete. When the circuit is completed by means of the Thomson galvanometer, a current flows.

The actual current through this galvanometer depends of course upon the resistance of the galvanometer and its connections, as well as upon the distance between the two points of the gold leaf at which the ends of the wires from the galvanometer are applied. We cannot therefore take the ratio of C and c above as the ratio of the primary and the transverse electromotive forces just mentioned.

If we represent by E' the difference of potential of two points a centimeter apart on the transverse diameter of the strip of gold leaf, and by E the the difference of potential of two points a centimeter apart on the longitudinal diameter of the same, a rough and hasty calculation for the experiments already made shows the ratio $\frac{E}{E'}$ to have varied from about 3000 to about 6500.

The transverse electromotive force E' seems to be, under ordinary circumstances, proportional to Mv, where M is the intensity of the magnetic field and v is the *velocity* of the electricity in the gold leaf. Writing for v the equivalent expression $\frac{C}{s}$ where C is the primary current through a strip of the gold leaf 1 cm. wide, and s is the area of section of the same, we have $E' \propto \frac{MC}{s}$.

November 22d, 1879.