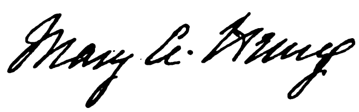
AMERICA'S PART IN THE DISCOVERY OF MAGNETO-ELECTRICITY—A STUDY OF THE WORK OF FARADAY AND HENRY.—III.

BY

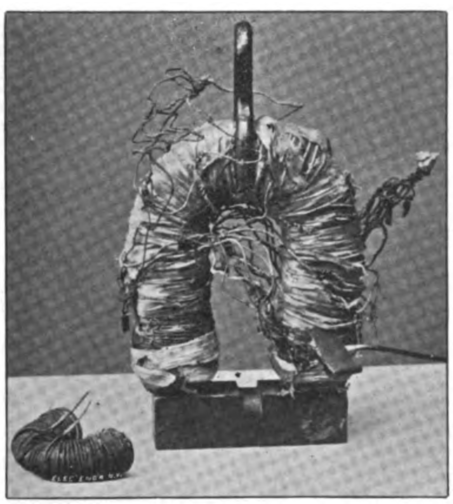


In every well-ordered library stand the volumes of Silliman's *Journal of Science*, the chief repository of the labors of the pioneers, the scientific investigators of our earlier years. If it has been pleasant to dwell in our own words upon Henry's experiment which answered the great question: Can Magnetism produce Electricity? let us now allow him to tell his own story; let us find in the *Journal* the paper we saw him hurriedly preparing for its pages in those last days of June, after reading the brief notice which told him of Faraday's success. It is dated July, 1832. We give it entire, breaking the thread of the narrative here and there for comment:

ON THE PRODUCTION OF CURRENTS AND SPARKS OF ELECTRICITY FROM MAGNETISM.[15]

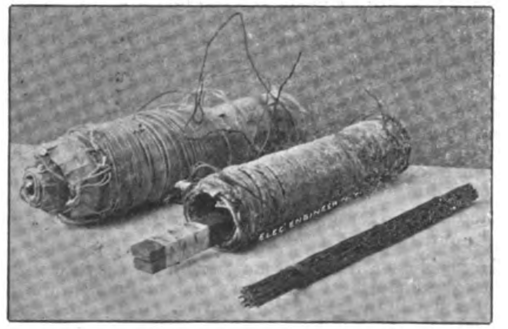
Although the discoveries of Oersted, Arago, Faraday and others, have placed the intimate connection of electricity and magnetism in a most striking point of view, and although the theory of Ampère has referred all the phenomena of both these departments of science to the same general laws, yet until lately one thing remained to be proved by experiment, in order more fully to establish their identity; namely, the possibility of producing electrical effects from magnetism. It is well known that surprising magnetic results can readily be obtained from electricity, and at first sight it might be supposed that electrical effects could with equal facility be produced from magnetism; but such has not been found to be the case, for although the experiment has often been attempted, it has nearly as often failed.

Henry's discovery was no accidental stumbling upon a fact. He believed with all his heart that electricity could produce magnetism before he put the matter to experimental test. From the very beginning of his researches he had the subject in view.



ELECTROMAGNET WITH WHICH THE DISCOVERY OF MAGNETO-ELECTRIC INDUCTION WAS MADE BY HENRY; NOW IN THE CABINET OF THE COLLEGE OF NEW JERSEY.

It early occurred to me, that if galvanic magnets on my plan were substituted for ordinary magnets, in researches of this kind, more success might be expected. Besides their great power, these magnets possess other properties, which render them important instruments in the hands of the experimenter; their polarity can be instantaneously reversed, and their magnetism suddenly destroyed or called into full action, according as the occasion may require. With this view, I commenced, last August,[16] the construction of a much larger galvanic magnet than, to my knowledge, had before been attempted, and also made preparations for a series of experiments with it on a large scale, in reference to the production of electricity from magnetism. *I was however at that time accidentally interrupted* in the prosecution of these experiments, *and have not been able since to resume them until within the last few weeks,*[17] and then on a much smaller scale than was at first intended. In the meantime, it has been announced in the 117th number of the *Library of Useful Knowledge*, that the result so much sought after has at length been found by



APPARATUS MADE BY HENRY, WITH WHICH HE REPEATED THE EXPERIMENT OF FARADAY. NOW IN THE CABINET OF THE COLLEGE OF NEW JERSEY.

Mr. Faraday of the Royal Institution. It states that he has established the general fact, that when a piece of metal is moved in any direction, in front of a magnetic pole, electrical currents are developed in the metal, which pass in a direction at right angles to its own motion, and also that the application of this principle affords a complete and satisfactory explanation of the phenomena of magnetic rotation. No detail is given of the experiments, and it is somewhat surprising that results so interesting, and which certainly form a new era in the history of electricity and magnetism, should not have been more fully described before this time in some of the English publications; the only mention I have found of them is the following short account from the *Annals of Philosophy* for April under the head of "Proceedings of the Royal Institution."

Feb. 17, Mr. Faraday gave an account of the first two parts of his researches in electricity; namely, volta-electric induction and magneto-electric induction. If two wires, A and B, be placed side by side, but not in contact, and a voltaic current be passed through A, there is instantly a current produced by induction in B, in the opposite direction. Although the principal current in A be continued, still the secondary current in B is not found to accompany it, for it ceases after the first moment, but when the principal current is stopped then there is a second current produced in B, in the opposite direction to that of the first produced by the inductive action, or in the same direction as that of the principal current.

If a wire connected at both extremities with a galvanometer, be coiled in the form of a helix around a magnet, no current of electricity takes place in it. This is an experiment which has been made by various persons hundreds of times, in the hope of evolving electricity from magnetism, and, as in other cases in which the wishes of the experimenter and the facts are opposed to each other, has given rise to very conflicting conclusions. But if the magnet be withdrawn from or introduced into such a helix, a current of electricity is produced *whilst the magnet is in motion*, and is rendered evident by the deflection of the galvanometer. If a single wire be passed by a magnetic pole, a current of electricity is induced through it which can be rendered sensible.[18]

So far, Henry's paper is introductory. It now gives two series of experiments, *the one made before*, *the other after* seeing the brief account of Faraday's result. In the first series we find the experiment we have sketched, and if made before April, 1832, the date of the notice, then, before August, 1831, when Henry's experiments stopped.

Before having any knowledge of the method given in the above account, I had succeeded in producing electrical effects in the following manner, which differs from that employed by Mr. Faraday, and which appears to me to develop some new and interesting facts. A piece of copper wire, about 30 feet long and covered with elastic varnish, was closely coiled around the middle of the soft iron armature of the galvanic magnet, described in vol. xix, of the *American Journal of Science*, and which, when excited, will readily sustain between 600 and 700 pounds. The wire was wound upon itself so as to occupy only about one inch of the armature, which is seven inches in all. The armature, thus furnished with the wire, was placed in its proper position across the ends of the galvanic magnet, and there fastened so that no

15. From Silliman's *American Journal of Science*; July, 1832; vol. xxii, pp. 403-408.

16. That is, August, 1831, since the paper was published July 1, 1832. M. A. H.

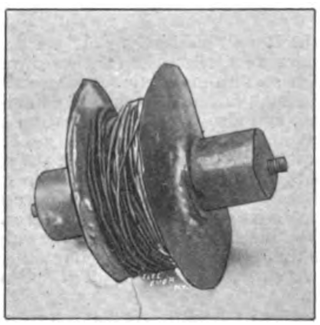
17. The last two weeks in June (see latter part of the paper) an interval of ten weeks between the cessation and resumption of the experiment. M. A. H.

18. *Phil. Mag. and Annals of Philosophy*; April 1832: vol. xi, p. 300.

motion could take place. The two projecting ends of the helix were dipped into two cups of mercury, and there connected with a distant galvanometer by means of two copper wires, each about 40 feet long. This arrangement being completed, I stationed myself near the galvanometer and directed an assistant at a given word to immerse suddenly, in a vessel of dilute acid, the galvanic battery attached to the magnet. At the instant of immersion, the north end of the needle was deflected 30 degrees to the west, indicating a current of electricity from the helix surrounding the armature. The effect, however, appeared only as a single impulse, for the needle, after a few oscillations, resumed its former undisturbed position in the magnetic meridian, although the galvanic action of the battery, and consequently the magnetic power, was still continued. I was, however, much surprised to see the needle suddenly deflected from a state of rest to about 20 degrees to the east, or in a contrary direction, when the battery was withdrawn from the acid, and again deflected to the west when it was reimmersed. This operation was repeated many times in succession, and uniformly with the same result, the armature the whole time remaining immovably attached to the poles of the magnet, no motion being required to produce the effect, as it appeared to take place only in consequence of the instantaneous development of the magnetic action in one, and the sudden cessation of it in the other.

Notice here Henry's instant recognition of the fundamental conditions of the phenomenon.

This experiment illustrates most strikingly the reciprocal action of the two principles of electricity and magnetism, if indeed it does not establish their absolute identity. In the first place, magnetism is developed in the soft iron of the galvanic magnet by the action of the currents of electricity from the battery, and secondly, the armature, rendered magnetic by contact with the



APPARATUS USED BY HENRY FOR INVESTIGATING EFFECT OF ROTATION OF IRON CORE WHILE SUBJECTED TO INDUCTION.

poles of the magnet, induces in its turn currents of electricity in the helix which surrounds it; we have thus as it were electricity converted into magnetism and this magnetism again into electricity.

Another fact was observed which is somewhat interesting inasmuch as it serves in some respects to generalize the phenomena. After the battery had been withdrawn from the acid, and the needle of the galvanometer suffered to come to a state of rest after the resulting deflection, it was again deflected in the same direction by partially detaching the armature from the poles of the magnet to which it continued to adhere from the action of the residual magnetism, and in this way, a series of deflections, all in the same direction, was produced by merely slipping off the armature by degrees until the contact was entirely broken. The following extract from the register of the experiments exhibits the relative deflections observed in one experiment of this kind:

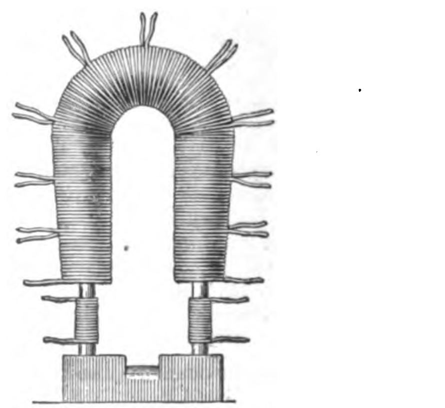
At the instant of immersion of the battery, deflection	40° west.
At the instant of emersion " " "	18° east.
Armature partially detached " " "	7° "
Armature entirely detached " " "	12° "

The effect was reversed in another experiment, in which the needle was turned to the west in a series of deflections by dipping the battery but a small distance into the acid at first and afterwards immersing it by degrees.

From the foregoing facts, it appears that a current of electricity is produced for an instant, in a helix of copper wire surrounding a piece of soft iron, whenever magnetism is induced in the iron; and a current in the opposite direction when the magnetism ceases; also that an instantaneous current in one or the other direction accompanies every change in the magnetic intensity of the iron.

The paper now proceeds to give the series of experiments, made in the last weeks of June, 1832, *after* seeing the brief notice of April of Faraday's results.

Since reading the account before given of Mr. Faraday's method of producing electrical currents, I have attempted to combine the effects of motion and induction; for this purpose a rod of soft iron ten inches long and one inch and a quarter in diameter, was attached to a common turning lathe, and surrounded with four helices of copper wire in such a manner that it could be suddenly and powerfully magnetized while in rapid motion by

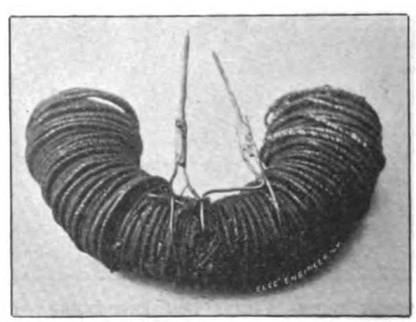


HENRY'S APPARATUS FOR INCREASING MAGNETO-ELECTRIC EFFECT.

transmitting galvanic currents through three of the helices; the fourth being connected with the distant galvanometer was intended to transmit the current of induced electricity; all the helices were stationary while the iron rod revolved on its axis within them. From a number of trials in succession, first with the rod in one direction then in the opposite, and next in a state of rest, it was concluded that no perceptible effect was produced on the intensity of the *magneto-electric* current by a rotary motion of the iron combined with its sudden magnetization.

The same apparatus, however, furnished the means of measuring separately the relative power of motion and induction in producing electrical currents. The iron rod was first magnetized by currents through the helices attached to the battery, and while in this state one of its ends was quickly introduced into the helix connected with the galvanometer; the deflection of the needle in this case was seven degrees. The end of the rod was next introduced into the same helix while in its natural state and then suddenly magnetized; the deflection in this instance amounted to thirty degrees, showing a great superiority in the method of induction.

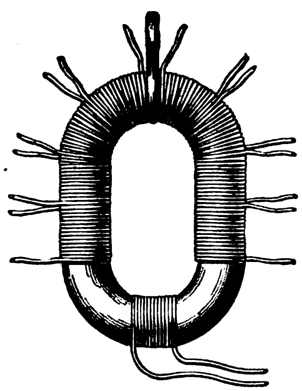
The next attempt was to increase the *magneto-electric* effect while the magnetic power remained the same, and in this I was more successful. Two iron rods six inches long and one inch in diameter, were each surrounded by two helices and then placed perpendicularly on the face of the armature, and between it and the poles of the magnet, so that each rod formed as it were a prolongation of the poles, and to these the armature adhered when the magnet was excited. With this arrangement, a current from one



ARMATURE USED BY HENRY TO PRODUCE THE ELECTRIC SPARK. NOW IN THE CABINET OF THE COLLEGE OF NEW JERSEY.

helix produced a deflection of thirty-seven degrees; from two helices both on the same rod fifty-two degrees, and from three, fifty-nine degrees; but when four helices were used the deflection was only fifty-five degrees, and when to these were added the helix of smaller wire around the armature, the deflection was no more than thirty degrees. This result may, perhaps, have been somewhat affected by the want of proper insulation in the several spires of the helices, it however establishes the fact that an increase in the electric current is produced by using at least two or three helices instead of one. The same principle was applied to another arrangement which seems to afford the maximum of electric development from a given magnetic power; in place of the two pieces of iron and the armature used in the last experiments, the poles of the magnet were connected by a single rod of iron, bent into the form of a horseshoe, and its extremities filed perfectly flat so as to come in perfect contact with the faces of the poles; around the middle of the arch of this horseshoe, two strands of copper wire were tightly coiled one over the other. A current from one of these helices deflected the needle one hundred degrees, and when both were used the needle was deflected with such force as to make a complete circuit.

When two clouds approach each other in the summer



Apparatus Employed by Henry for Producing the Magneto-Electric Spark.

sky, the electricity in them is manifested by the lightning which leaps from one to the other. Henry desired a similar manifestation of the electricity he could make his magnets produce, and in the next experiment he obtains this in *the electric spark*.

But the most surprising effect was produced when, instead of passing the currents through the long wires to the galvanometer, the opposite ends of the helices were held nearly in contact with each other and the magnet suddenly excited; [see illustration] in this case a small but vivid spark was seen to pass between the ends of the wires, and this effect was repeated as often as the state of intensity of the magnet was changed.

In these experiments the connection of the battery with the wires from the magnet was not formed by soldering, but by two cups of mercury which permitted the galvanic action on the magnet to be instantaneously suspended and the polarity to be changed and rechanged without removing the battery from the acid; a succession of vivid sparks was obtained by rapidly interrupting and forming the communication by means of one of these cups; but the greatest effect was produced when the magnetism was entirely destroyed and instantaneously reproduced by a change of polarity.

It appears from the May number of the *Annals of Philosophy* that I have been anticipated in this experiment of drawing sparks from the magnet by Mr. James D. Forbes of Edinburgh, who obtained a spark on the 30th of March; *my experiments being made during the last two weeks in June.* A simple notification of his result is given, without any account of the experiment, which is reserved for a communication to the Royal Society of Edinburgh. My result is therefore independent of his, and was undoubtedly obtained by a different process.

The paper closes with the discovery of the "extra current", which we have shown Henry making in 1829, distinctly inserted here, we ask the reader to notice, as a phenomenon of the same order. Five years later, in 1834, this fact, rediscovered by Faraday, formed another star in his crown.

ELECTRICAL SELF-INDUCTION IN A LONG HELICAL WIRE.

I have made several other experiments in relation to the same subject, but which more important duties will not permit me to verify in time for this paper. I may, however, mention one fact which I have not seen noticed in any work, and which appears to me to belong to the same class of phenomena as those before described; it is this: When a small battery is moderately excited by diluted acid, and its poles, which should be terminated by cups of mercury, are connected by a copper wire not more than a foot in length, no spark is perceived when the connection is either formed or broken; but if a wire thirty or forty feet long be used instead of the short wire, though no spark will be perceptible when the connection is made, yet when it is broken by drawing one end of the wire from its cup of mercury, a vivid spark is produced. If the action of the battery be very intense, a spark will be given by the short wire; in this case it is only necessary to wait a few moments until the action partially subsides, and until no more sparks are given from the short wire; if the long wire be now substituted a spark will again be obtained. The effect appears somewhat increased by coiling the wire into a helix; it seems also to depend in some measure on the length and thickness of the wire. I can account for these phenomena only by supposing the long wire to become charged with electricity, which by its reaction on itself, projects a spark when the connection is broken.

THE PRACTICAL MANAGEMENT OF DYNAMOS AND MOTORS.—III.

BY

Francis B. Crocker and SSWheeler.

Electrical Connections.—As already stated these should be very carefully cleaned and this may well be carried to the extent of rubbing them vigorously with clean cloth or chamois skin. Any of the metal surfaces used in making electrical contacts which are tarnished should be brightened with fine sandpaper or by scraping them, but all sand, metallic particles, etc., must be carefully removed afterwards. Particles of sand or dirt are often left accidentally between surfaces which should be in perfect contact.

Wiring.—It is very desirable to have a thoroughly competent lineman or electrician to connect a dynamo or motor to the circuit, see that everything is properly arranged and start the machine the first time.

The connections should all be made in a substantial and permanent manner. Good quality of insulated wire should be used and should be properly arranged and laid.

Temporary, loose or poorly insulated wires or connections are very objectionable. All circuits exposed to moisture should be supported on glass, porcelain or other waterproof insulators. Circuits of over 250 volts even where not exposed to moisture should also preferably be carried on porcelain or similar insulators, as shown in Fig. 4, and out of reach if possible, and the best insulated wire should be used.

Low-voltage circuits of 230 volts or under may be run in wooden moulding or cleats where entirely unexposed to moisture. Where wires pass through walls, floors, over pipes or are otherwise liable to injury they should be protected by hard-rubber tubing or other equally good covering. No wire smaller than No. 8 B. & S. gauge should be used for the arc current of 10 amperes, and other wires should be in proportion; that is, they should have from 800 to 1,200 circular mils per ampere. The former figure (800) is for small wires, in cool places; the latter figure (1,200) is for wires carrying heavy currents or high voltage and wires in hot places such as ceilings of kitchens, etc. No wire smaller than No. 16 should ever be laid to carry any current from a dynamo (smaller wires may be used for primary battery currents) no matter how small the current may be.

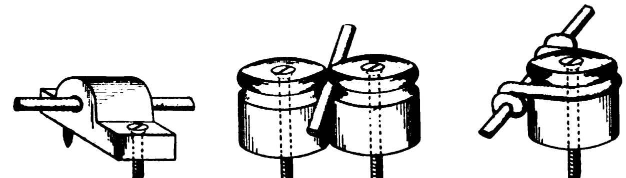


Fig. 4.—Wires Carried on Porcelain.