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MICHAEL FARADAY, EXPERIMENTAL RESEARCHES IN ELECTRICITY (1831)¹

The early nineteenth century witnessed the discovery of the connection between electricity and magnetism, a science referred to as electromagnetism. While there were many scientists who made key discoveries toward the development of electromagnetism and electrochemistry, none until then made greater contributions than Michael Faraday (1791–1867). Although he had little formal education, he revealed the unitary nature of all types of electricity and discovered electromagnetic rotation—by which electric current and a magnetic field interact to rotate a metal object—and electromagnetic induction, which is elaborated upon in the passage below. His discoveries led to the development of the technology of the electric motor and other practical uses of electricity. In recognition of his contributions, the International System of Units (SI) unit of electrical capacitance, the farad, was named after him.

The passage below is excerpted from a scientific paper presented by Faraday on November 24, 1831. For the excerpt, click <u>here</u>. For the full text of Experimental Researches in Electricity, from which the passage below was excerpted, click <u>here</u>.

- 1. The power which electricity of tension possesses of causing an opposite electrical state in its vicinity has been expressed by the general term Induction; which has been received into scientific language, may also, with propriety, be used in the same general sense to express the power which electrical currents may possess of inducing any particular state upon matter in their immediate neighborhood, otherwise indifferent. It is with this meaning that I purpose using it in the present paper.
- 2. Certain effects of the induction of electrical currents have already been recognized and described: as those of magnetization; Ampère's² experiments of bringing a copper disc near to a flat spiral; his repetition with electro-magnets of Arago's³ extraordinary experiments, and perhaps a few others. Still it appeared unlikely that these could be all the effects which induction by currents could produce; especially as, upon dispensing with iron, almost the whole of them disappear, whilst yet an infinity of bodies, exhibiting definite phenomena of induction with electricity of tension still remain to be acted upon by the induction of electricity in motion.
- 3. Further: whether Ampère's beautiful theory were adopted, or any other, or whatever reservation were mentally made, still it appeared extraordinary, that, as every electric current was accompanied by corresponding intensity of magnetic action at right angles to the current, good conductors of electricity, when placed within the sphere of this action, should not have any current induced through them, or some sensible effect produced equivalent in force to such a current.

¹ Oliver J. Thatcher (ed.), *The Library of Original Sources*, 9 vols. (New York: University Research Extension, 1907), 9:17–20.

² André-Marie Ampère (1775–1886) was famous for proving a relationship between electricity and magnetism and being a founder of classical electromagnetism.

³ François Arago (1786–1853) discovered "Arago's rotation," which showed that a disc could be rotated (or a rotating disc stopped) by a suspended magnetic needle.

- 4. These considerations, with their consequence, the hope of obtaining electricity from ordinary magnetism, have stimulated me at various times to investigate . . . ⁴ full explanation of Arago's magnetic phenomena, and also to discover a new state, which may probably have great influence in some of the most important effects of electric currents.
- 5. These results I purpose describing, not as they were obtained, but in such a manner as to give the most concise view of the whole.

Evolution of Electricity from Magnetism

- 27. A welded ring was made of soft round bar-iron, the metal being seven-eighths of an inch in thickness, and the ring six inches in external diameter. Three helices⁵ were put round one part of this ring, each containing about twenty-four feet of copper wire one-twentieth of an inch thick; they were insulated from the iron and each other, and superposed in the manner before described (6),⁶ occupying about nine inches in length upon the ring. They could be used separately or conjointly: the group may be distinguished by the letter A, Fig. 28. On the other part of the ring about sixty feet of similar copper wire in two pieces were applied in the same manner, forming a helix B, which had the same common direction with the helices of A, but being separated from it at each extremity by about half an inch of the uncovered iron.
- 28. The helix B, was connected by copper wires with a galvanometer⁷ three feet from the ring. The helices of A were connected end to end to as to form one common helix, the extremities of which were connected with a battery of ten pairs of plates four inches square. The galvanometer was immediately affected, and to a degree far beyond what has been described when with a battery of tenfold power helices *without iron* were used (10); but though the contact was continued, the effect was not permanent, for the needle soon came to rest in its natural position, as if quite indifferent to the attached electro-magnetic arrangement. Upon breaking the contact with the battery, the needle was again powerfully deflected, but in the contrary direction to that induced in the first instance.
- 29. Upon arranging the apparatus so that B should be out of use, the galvanometer be connected with one of the three wires of A (27), and the other two made into a helix through which the current from the trough (28) was passed, similar but rather more powerful effects were produced.
- 30. When the battery contact was made in one direction, the galvanometer-needle was deflected on the one side; if made in the ether direction, the defection was on the other side. The deflection on breaking the battery contact was always the reverse of that produced by completing it. The deflection on making a battery contact always indicated an induced current in the opposite direction to that from the battery; but on breaking the contact the deflection indicated an induced current in the same direction as that of the battery. No making or breaking of the contact at B side, or in any part of the galvanometer circuit, produced any effect at the galvanometer. No continuance of the battery current caused any deflection of the galvanometer-needle. As the above results are common to all

⁴ Source illegible here.

⁵ Plural of helix. A type of twisted curve important in science, particularly physics and biology (DNA).

⁶ The numbers inserted in parentheses refer to numbered passages by Faraday within this text.

⁷ A device for detecting electric current.

these experiments, and to similar ones with ordinary magnets to be hereafter detailed, they need not be again particularly described.

31. Upon using the power of 100 pairs of plates (10) with this ring, the impulse at the galvanometer, when contact was completed or broken, was so great as to make the needle spin round rapidly four or five times, before the air and terrestrial magnetism could reduce its motion to mere oscillation.

. . .

- 39. But as might be supposed that in all the preceding experiments of this section, it was by some peculiar effect taking place during the formation of the magnet, and not by its mere virtual approximation, that the momentary induced current was excited, the following experiment was made. All the similar ends of the compound hollow helix (34) were bound together by copper wire, forming two general terminations, and these were connected with the galvanometer. The soft iron cylinder (34) were removed, and a cylindrical magnet three-quarters of an inch in diameter and eight inches and a half in length, used instead. One end of this magnet was introduced into the axis of the helix, Fig. 4, and then, the galvanometer-needle being stationary, the magnet was suddenly thrust in; immediately the needle was deflected in the same direction as if the magnet had been formed by either of the two preceding processes (34, 36). Being left in, the needle resumed its first position, and then the magnet being withdrawn the needle was deflected in the opposite direction. These effects were not great; but by introducing and withdrawing the magnet, so that the impulse each time should be added to those previously communicated to the needle, the latter could be made to vibrate through an arc of 180° or more.
- 40. In this experiment the magnet must not be passed entirely the helix, for then a second action occurs. When the magnet is introduced the needle at the galvanometer is defected in a certain direction: but being in, whether it be pushed quite through or withdrawn, the needle is deflected in a direction the reverse of that previously produced. When the magnet is passed in and through at one continuous motion, the needle moves one way, is then suddenly stopped, and finally moves the other way.
- 41. If such a hollow helix as that described (34) be laid east and west (or in any other constant position), and a magnet be retained east and west, its marked pole always being one way; then whichever end of the helix the magnet goes in at, and consequently whichever pole of the magnet enters first, still the needle is deflected the same way: on the other hind, whichever direction is followed in withdrawing the magnet, the deflection is constant, but contrary to that due to its entrance.

. . .

57. The various experiments of this section prove, I think, most completely the production of electricity from ordinary magnetism. That its intensity should be very feeble and quantity small, cannot be considered wonderful, when it is remembered that like thermo-electricity it is evolved entirely within the substance of metals retaining all their conducting power. But an agent which is conducted along the metallic wires in the manner described; which, whilst so passing possesses the peculiar magnetic actions and force of a current of electricity; which can agitate and convulse the limbs of a frog: and which, finally, can produce a spark by its discharge through charcoal (32), can only be electricity. As all the effects can be produced by ferruginous⁸ electro-magnets (34), there is no doubt that

⁸ Containing iron oxides or rust.

arrangements like the magnets of Professors Moll,⁹ Henry,¹⁰ Ten Eyke,¹¹ and others, in which as many as two thousand pounds have been lifted, may be used for these experiments; in which case not only a brighter spark may be obtained, but wires also ignited, and, as the current can pass liquids (23), chemical action be produced. These effects are still more likely to be obtained when the magneto-electric arrangements to be explained in the fourth section are excited by the powers of such apparatus,

58. The similarity of action, almost amounting to identity, between common magnets and either electro-magnets or volta-electric currents, is strikingly in accordance with and confirmatory of M. Ampere's theory, and furnishes powerful reasons for believing that the action is the same in both cases: but, as a distinction in language is still necessary, I propose to call the agency thus exerted by ordinary magnets, *magneto-electric* or *magnelectric* induction (26).

59. The only difference which powerfully strikes the attention as existing between volta-electric and magneto-electric induction is the suddenness of the former, and the sensible time required by the latter: but even in this early state of investigation there are circumstances which seem to indicate, that upon further inquiry this difference will, as a philosophical distinction, disappear (68).

. . .

⁹ Dutch physicist Gerard Moll (1785–1838).

¹⁰ Joseph Henry (1797–1878) helped to develop electromagnetism into a practical science and discovered electromagnetic induction independently of Faraday in the same yea, but failed to publish his work first.

¹¹ Philip Ten Eyck (1802–93) worked alongside, and then succeeded, Prof. Henry.