THE HISTORICAL DEVELOPMENT OF THE INDUCTION COIL AND TRANSFORMER.*

BY DR. J. A. FLEMING, M.A.

The induction coil and the transformer are no exceptions to the general law that improvements in experimental appliances advance along definite lines by a process of evolution in which rudimentary forms are successively replaced by more and more completely developed machines. We are able by careful scrutiny of existing and pre-existing modifications to detect the ideas which have at every step impelled invention forward, and also to examine the prototypes in their relation to the final and fully developed idea. Most readers would probably consider that the proto-typical form of all modern induction coils and transformers was the iron ring with which Faraday made the initial discovery in electro-magnetic induction,† and in one sense this is of course correct, but a careful examination of the early stages of the development of the induction coil as we now possess it seems to show that it is descended in the direct line not from Faraday's ring so much as from Henry's flat spirals, and that it is these latter which are the chiefs of the clan and true ancestors of our modern coil.

Henry's claim to be an independent discoverer of the fundamental fact of electro-magnetic induction is not now disputed. In the July number of *Silliman's American Journal of Science* for 1832, Joseph Henry, then a young teacher in the Albany Academy, gave an account of the manner in which he had independently, and before receiving an account of Faraday's work performed in the previous autumn, elicited from his own great electro-magnet an induced current by wrapping round the soft iron armature certain coils of insulated wire.‡ In the same Paper in which he thus discloses his anticipated discovery he rendered an account of that in which he had in turn anticipated his illustrious rival by the discovery of the fact of the *self-induction* of a spiral conductor, and denoted the phenomenon by the name by which it has since been known. Simply confining himself to the bare statement of the new fact that if the poles of a small battery are joined by a wire a foot long no spark will be found on breaking the circuit, whereas if the wire be thirty or forty feet long, and particularly if it be coiled into a spiral, it gives a bright spark when so employed, Henry noted the discovery and correctly attributed the phenomenon to the induction of the circuit upon itself. Finding, however, that Faraday was following on the same line of discovery he published in the *Journal of the Franklin Institute*, in March, 1835 (Vol. XV., pp. 169-170), a brief epitome of the facts he had collected, and made mention, for the first time, of the use of the spirals of flat copper tape or ribbon, insulated and closely wound together, with which he subsequently conducted his brilliant train of discoveries on the mutual induction of circuits.

A few months later, in the July number of *Silliman's American Journal of Science*, 1835 (Vol. XXVIII., pp. 329-331), he followed this up with a more explicit account of his investigations on the action of a spiral conductor, especially a flat tape spiral, in increasing the spark and the shock from a single cell of a galvanic battery. Using a very large single cell of very low internal resistance known as "Dr. Hare's Calorimotor," he sent the current from this through a spiral conductor formed of copper ribbon about one inch wide and from sixty to one hundred feet long, well covered with silk, and the several spires closely wound on each other. One end of the conductor being attached to one pole of the battery and the other being brought in contact with or rubbed along the rough edge of a plate of metal attached to the other end, he obtained vivid sparks at the place of contact. Moreover he noted that if copper cylinders two inches in diameter and about five inches long, were attached as handles to the ends of the spiral by supplementary wires, and if these cylinders were grasped by moistened hands, a series of sharp shocks was experienced when the end of the spiral conductor was as before drawn along the rough edge of one plate of the calorimotor. This preliminary investigation on the production of a spark and a shock from a single cell of a battery led him to make a thorough investigation of the phenomenon, and in which he most fully explored the whole of the facts. The experiments he recounted in the *Transactions of the American Philosophical Society* for February, 1835, (Vol. V., pp. 223-231); and in *Silliman's American Journal of Science* for July, 1835, covering in these pages a recital of the independent investigations he made in going over the same ground as that occupied by Faraday in his Ninth series of "Electrical Researches" *On the Influences by Induction of an Electric Current on Itself*, sent to the Royal Society in December, 1834, and read in January, 1835. Henry's removal from Albany Academy to Princetown College created an interruption in his researches, but the news of them travelled to England, and in turn created a further wave of discovery. The subject was taken up by William Sturgeon, the inventor of the electro magnet. Sturgeon met one day a Mr. Peaboddy, lately from the United States, in the Adelaide Gallery of Practical Science*, and this gentleman informed him of Henry's experiments on the production of a shock and spark from a single pair of plates in a galvanic cell. Sturgeon was at that time just engaged in launching a new venture, in the shape of his *Annals of Electricity*, a monthly journal devoted especially to electrical science; and in the first volume of this publication, he led off with a paper "On the Electric Shock from a Single Pair of Plates," in which he gave an account of Henry's work and of his own repetition of the experiments (*Sturgeon's Annals*, Vol. I., p. 67). This was published in October, 1836. W. Sturgeon did not appear at this time to have been acquainted with Faraday's Ninth series of Electrical Researches; but after repeating most of Henry's experiments, and adding some of his own, he arrived at the conclusion that the action of the spiral conductor in creating a shock was due to the *collapse* of the magnetic lines of force

* This series of articles forms part of the second volume on "The Alternate Current Transformer in Theory and Practice."

† See "The Alternate Current Transformer," Vol I., p. 2.

‡ See "Collected Scientific Writings of Professor Joseph Henry," Vol. I., p. 73; also, *Silliman's American Journal of Science*, July, 1832, Vol. XXII., pp. 403-408; also, Prof. E. N. Dickerson's "Sketch of the Life of Joseph Henry," p. 12.

* The building, which was formerly the Adelaide Gallery of Practical Science, now survives as Gatti's restaurant in the Strand. It has many interesting electrical reminiscences connected with it. In the Adelaide Gallery Wheatstone performed his classical experiments on the "Velocity of Electricity" in 1834 (*see* "Wheatstone's Scientific Papers," p. 90). In it also Faraday performed the experiments on the Electrical Fish or Gymnotus, and established the real electrical nature of its shock in 1838 (*see* "Electrical Researches," Vol. II., p. 3).

The following extract from EDWARD WALFORD'S "Old and New London" may be of interest.

"Adjoining the Lowther Arcade, with its entrance in Adelaide-street, is the Adelaide Gallery, originally intended as a place of amusement and instruction combined. It was first opened in the year 1830, and named after Queen Adelaide, the consort of William IV. Its varied fortunes from the day when it was opened as a temple of science down to its tranformation into a casino, are thus cleverly sketched by the late Mr. Albert Smith in his little book on 'London Life and Character':—'Some time back—dates are very dry things, so we need not care about the precise year—there existed in the neighbourhood of the Lowther Arcade an establishment called the Adelaide Gallery. It was at first devoted to the diffusion of knowledge. Clever professors were there, teaching elaborate sciences in lectures of twenty minutes each; fearful engines revolved and hissed and quivered, as the fettered steam that formed their entrails grumbled sullenly in its bondage; mice led gasping sub-aqueous lives in diving bells; clock-work steamers ticked round and round a basin perpetually to prove the efficacy of invisible paddle-wheels; and on all sides were clever machines which stray visitors were puzzled to class either as coffee-mills, water wheels, roasting jacks, or musical instruments. There were artful snares laid for giving galvanic shocks to the unwary, steam guns that turned bullets into lead sixpences against the target; and dark microscopic rooms for shaking the principles of teetotallers, by showing the wriggling abominations in a drop of the water which they were supposed daily to gulp down. Then came a transition stage in the existence of the Adelaide Gallery, at first stealthily brought about. The oxy-hydrogen light was slily applied to the comic magic lantern, and laughing gas was made instead of carbonic acid. By degrees music stole in, then wizards, and lastly talented vocal foreigners from Ethiopia and the Pyrenees. Science was driven to her wit's end for a livelihood, but she still endeavoured to appear respectable. . . . And at last all the steam-engines and waterworks were cleared away, and the Adelaide Gallery was devoted entirely to the goddess of the "twinkling feet," and called a casino. It was altered into the Marionette Theatre in 1852, and is now one of the refreshment rooms of Messrs. Gatti."

when the current in the coil was interrupted, and that this gave rise to a momentary self-induced current in the coil set in motion by a greater electromotive force than that of the exciting cell. Subsequently he became acquainted with Faraday's prior work on self-induction, and in a critical paper (Sturgeon's *Annals of Electricity*, Vol. I., p. 192) he discusses Faraday's results, and with great skill experiments with a number of coils with and without iron cores, with the object of finding out how much of the "shock" was due to the iron, and how much to the wire coils. On page 283, Vol. I., of the *Annals* there is a full reprint of Henry's Paper read before the American Philosophical Society in February, 1835.

The next important fact seems to have been added by Prof. C. G. Page, of Washington, in the United States, who published an account in *Silliman's American Journal of Science* for October, 1836 (Vol. XXXI., p. 137), of his researches on the self-induction of spiral conductors. Sturgeon abstracted an account of Page's work in his *Annals* (Vol. I., p. 290), and made it available for English readers. Prof. C. G. Page constructed in 1835 a spiral copper strip coil, of which the strip was one inch wide and 220ft. long, carefully insulated, and having terminal wires

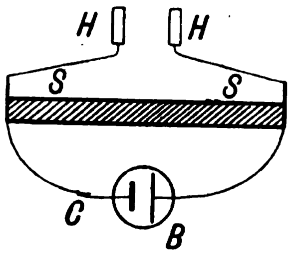

Fig. 1.—Henry's Coil.

soldered at intervals of 55ft. This strip was rolled up into a flat spiral, and mercury cups attached to the six terminal wires.

A single cell of a Hare's calorimotor, or large copper-zinc cell, was then attached to an adjacent pair of terminals, and it was found that on breaking the battery contact sparks and shocks could be procured by touching any of the other terminals in pairs.

The difference between Henry's and Page's arrangements may be indicated by a diagram, in which for clearness the copper strip is represented as unrolled.

Let S S (Fig. 1) be Henry's copper strip coil unrolled, and let B be a galvanic cell, and H H the handles for taking the inductive shock, when the battery circuit is broken at C. In Henry's experiments the arrangement of the coil was such that the self-induction of the whole of it was employed in producing the shock when a person held the handles H H.

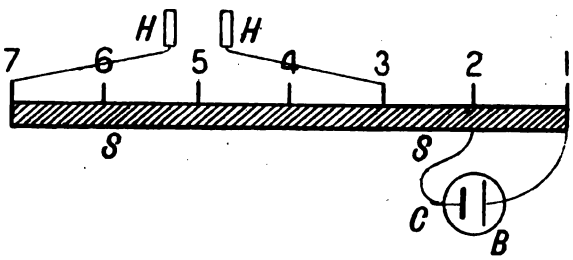

Fig. 2.—Page's Coil.

In Page's arrangement the strip with its six or seven contacts is represented by S S (Fig. 2), and the cell or battery was applied to the terminals 1 and 2. Page found that severe shocks could be obtained by taking hold of metal handles attached to the terminals 7 and 3, or 6 and 5, or 7 and 6, when the battery circuit was broken at C. By making the break and make of contact by rapidly revolving spur wheel he got a succession of sparks from a portion of the strip not included between the battery terminals. In place of a spur wheel he also made and broke contact rapidly by dragging one end of the battery wire over a file or rasp in contact with the plate of the battery.

On page 294 of Vol. I. of the *Annals* Sturgeon explained Page's experiment correctly as due to the induction of one part of the coil on the other. Page really made the first experiment in *auto-induction*, and showed that different parts of the same conductor might act as primary and secondary circuits to each other if in contiguity.

We then come to an important contribution by the Rev. N. J. Callan, of Maynooth College. This investigator followed up with great interest and success the researches of Faraday, Henry, Page, and W. Sturgeon, and on page 295 of Sturgeon's *Annals of Electricity*, Vol. I., we have a Paper by him, written in 1836, "On the best method of making an electro-magnet" "for electrical purposes, and on the vast superiority of the" "electric power of the electro-magnet over the electric power of" "the common magneto-electric machine."

In this Paper Callan describes the construction of an electro-magnet with *two separate insulated wires, one thick and the other thin*, wound on the iron core together. He first coiled on a long and thick horseshoe-shaped bar of iron a very *thick copper wire* covered with silk or cotton, and securely over this a very long *thin iron wire*, also insulated with cotton, and one end, viz., the inner end, of the iron wire was joined to the outer end of the copper circuit. In his first magnet the copper wire consisted of a wire 50ft. long and one-twelfth of an inch in diameter, and the iron wire was 1,300ft. long and one-fortieth of an inch in diameter.

He sent a current from a battery of one or two pairs of plates through the thick copper wire, and attached metallic handles to the ends of the iron wire for the purpose of taking a shock, and then on making and breaking the circuit of the battery rapidly he got severe shocks from the iron wire circuit. Here we have the first description that exists of an induction coil with a short thick and a long thin wire upon it; but the peculiarity of it is that the end of the secondary or thin wire is joined to the end of the thick wire, so that they form one circuit wound all in the same direction upon the magnet. Callan's experiment was, therefore, an extension of Page's, and this last, again, was an improvement on Henry's apparatus. Callan followed up this Paper by another dated June 14, 1836, published in Sturgeon's *Annals*, Vol. I., p. 376, being "A description of the most powerful electro-magnet yet constructed." He had forged an iron bar 2½ inches in diameter, 13 feet long, and bent into a horseshoe. It weighed 15 stone. Four hundred and ninety feet of insulated copper wire, one-sixth of an inch in diameter, were wound on it in one layer, and over this a thin insulated copper wire 10,000 feet long and one-fortieth of an inch in diameter; and one end of the thin wire was soldered to one end of the thick wire, so that the whole length of the two wires formed a single circuit, wound all in the same direction on the big horseshoe. The current from 20 large Callan cells (iron cells), or from a Wollaston battery of 280 pairs of plates, was passed through the thick copper wire circuit alone, and rapidly interrupted by an apparatus Callan called a repeater. Wires were soldered to the extremities of the fine wire circuit to receive the induced current. Provided with this formidable apparatus, the inventor proceeded to perform striking experiments with the induced currents. "When by means of an *electro-magnetic repeater* a rapid succession of secondary currents was induced in the fine wire, and passed between charcoal points attached to the ends of the secondary circuit, they were slightly ignited." The shock, as can be imagined, was exceedingly severe, and the ardent experimentalist proceeded to pass from this germinal experiment in the production of an arc light by means of a transformer to an experiment in *electrocution*. For he adds: "Although the" "igniting power of the electric current produced in the long" "coil of thin wire was very feeble, its intensity was exceedingly" "great. When it (the secondary current) was passed through" "the body of a large fowl instant death was produced." This magnet, or one like it, was sent by Callan to Mr. Sturgeon, and by him exhibited to the London Electrical Society at a meeting held on August 5, 1837, and members and visitors enjoyed powerful shocks from the secondary wire of this electro-magnetic apparatus.