THE ALTERNATE CURRENT TRANSFORMER

IN THEORY AND PRACTICE.

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THE UTILIZATION OF INDUCED CURRENTS.

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ment 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.

§ 3. **Callan's Induction Apparatus.**—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 was that the end of the secondary or thin wire was joined to the end of the thick wire, so that they formed 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* (*see* Fig. 3). Wires were soldered to the extremities of

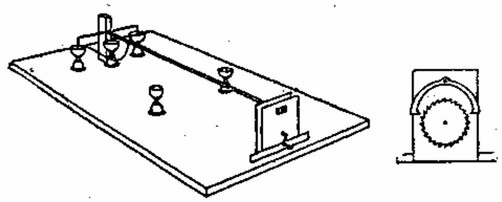

FIG. 3.—Callan's Electro-Magnetic Repeater, or Vibrating Contact Breaker.

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.

§ 4. **Sturgeon's Coil.**—In Sturgeon's *Annals of Electricity*, Vol. I., p. 418, there is a mention of the meeting of the London Electrical Society held on August 5, 1837, when Sturgeon read a paper on "Secondary Electric Currents," illustrated by a powerful double-wire horseshoe electro-magnet which had been presented to him by Prof. Callan, of the R.C. College, Maynooth. This paper or lecture stimulated

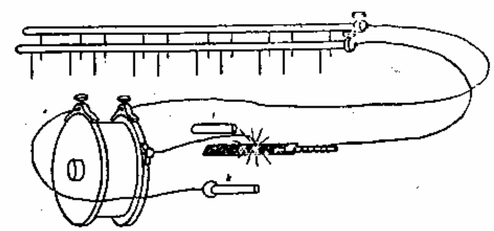

FIG. 4.—Sturgeon's Induction Coil with Wooden Core.

Contact breaker at terminal *l*, consisting of a file rubbed by the wire end. Free terminal, provided with handle *k*.

several minds, and particularly that of Sturgeon himself. On page 470 of the *Annals*, Vol. I., we have another Paper by him, on "An Experimental Investigation of the Influence of Electrical Currents on Soft Iron as regards the thickness of metal requisite for the full display of Magnetic Action, and how far these pieces of iron are available for Practical Purposes." He constructed a double-wire helix on Callan's plan. He wound on a wooden bobbin a naked copper wire insulated with sealing-wax varnish. One wire was a copper bell wire, 260 feet long, forming the inner or lower coil; and the upper or outer coil was a thinner copper wire, 1,300 feet long. The end of the fine wire was soldered to the end of the thick wire, so that it made one continuous conductor, wound all the same way on the bobbin. The reel, or bobbin, was of wood, two inches long between the cheeks. (*See* Fig. 4.) Strips of silk were interposed between the layers of wire. Hence, Sturgeon's coil was a short, wide coil, wound on a hollow wooden core, and not like Callan's magnet, which was long and thin. Sturgeon applied to his coils a break-and-make arrangement, consisting of a wire dipping in a mercury cup in one case and of a notched zinc disc in the other. (*See* Figs. 5 and 6.) The mercury cup-break was worked by a revolving cam and lever, and gave about 36 breaks per second when the cam was turned round by a winch. With the zinc disc he got 540

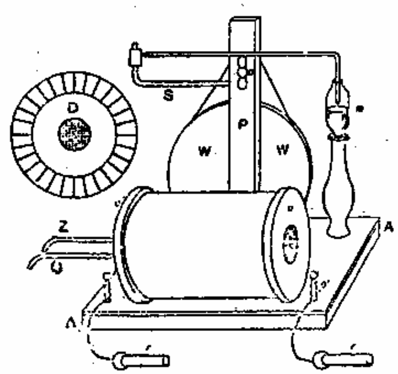

FIG 5.—Sturgeon's Induction Coil.

Z and C, wires from battery. *o o*, coil. A A, base of coil. W W, driving wheel for contact breaker. *a*, cam lifting a wire attached to arm S. *m*, a mercury contact.

breaks per second. He put a *solid* iron core in the bobbin, and he was delighted to find that he got powerful shocks from the secondary circuit when the current from one or two cells was interrupted in the primary. He then made a very curious observation. He found that with the solid iron core the shock was much diminished in amount when the revolving contact-breaker went above a certain speed. After some trials he substituted a bundle of fine iron wires for the solid core, and he got very much better results. He draws attention to the fact that (*Annals*, Vol. I., p. 481) Prof. G. H. Bachhoffner had

tried a divided iron core about a fortnight before he had with one of Sturgeon's own coils, which he had lent him. Bachhoffner observed that a bundle of fine iron wires used as a core in Sturgeon's coil gave far better shocks than when a solid iron bar was employed. We must therefore credit Bachhoffner with being the first to recognise the value of a divided iron core. W. Sturgeon noted that a rolled-up sheet of tinned iron put in as a core increased the shocking power in an extraordinary degree beyond that obtained when a solid core was used, and that with a bundle of fine iron wires as a

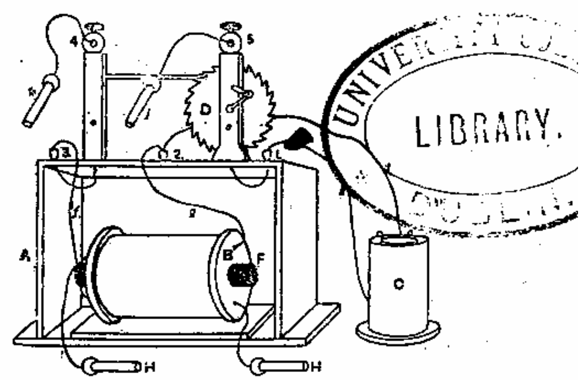

FIG. 6.—Sturgeon's First Induction Coil.

A, box containing coil. B, induction coil. C, battery. D, zinc disc contact breaker. F, iron core. H H, handles on secondary. *h* and *i*, wires from battery to contact cups 1 and 2. 4 and 5, terminals. *k* and *j*, handles.

core the shocks were still more increased. Sturgeon claimed that his coil was an advance on Callan's, and certainly when we regard the sketch of Sturgeon's first coil, we see that he gave to the appliance practically the general form which it has retained ever since. This coil of Sturgeon's was exhibited to the London Electrical Society in August, 1837.

§5. Callan's Coils with Separate Circuits.—We come next to another important Paper by Callan, dated September 11, 1837, printed in Vol. I., p. 491, of Sturgeon's *Annals of Electricity*.

"On a Method of Connecting Electro-magnets so as to Combine their Electric Powers, and on the Application of Electro-magnetism to the Working of Machines."

Callan wound on each of two iron bars a couple of wires, first a copper wire one-twelfth of an inch in diameter put on in one layer, and second, a copper wire one-ninetieth of an inch in diameter and 150ft. long, wound over the first. Each wire was carefully insulated both from itself as well as from the iron and the other wire. It is clear from the description which follows that in making these two induction coils Callan did *not join* the end of the secondary wires to the end of the primaries, but left the secondary distinct and insulated from the primary. He then *joined the primaries of these two induction coils in parallel* on a large galvanic cell, and the secondary coils he joined in series, and he obtained from the secondaries in series a shock greatly in excess of that which he obtained from either of them separately. He points out that the secondaries must be so united that the electromotive forces in each are added and not opposed to each other, and he surmises that if a hundred such induction coils could be arranged with secondaries in series and primaries in parallel on a very large quantity battery, it would be possible to have a shock equal to that of 100,000 or 200,000 single cells.

On page 493 (*Annals*, Vol. I.) he says:—"In making electro-magnets which are to be connected for the purpose of obtaining increased electric intensity, care must be taken *not to solder* the thin wire to the thick wire of the magnet, but to leave both ends of the thin wires projecting."

In a note he recommends that for lecture purposes the thick wire coil and the thin wire coil should be wound on separate bobbins, the thick wire bobbin being made to slide inside the thin wire bobbin; and he says that such a pair of separate coils was given by him to Mr. Cottam, the secretary of the Manchester Mechanics' Institute, during the lecture he gave there. Hence it is to Callan that we owe this simple piece of apparatus, now found in every physical laboratory, and it is to him that we are indebted for an induction coil having two separate wires, one thick and the other thin, used as an induction coil. Furthermore, he says that about four months before writing this Paper he coiled on a cylinder of wood (hollow)

about 10 feet of covered copper wire, one-eighth of an inch in diameter, and over this 200ft. of very thin-covered wire, and an iron bar was put into the hollow of the bobbin. With 20 pairs of plates (*i.e.*, cells) on the primary, he got severe shocks even without the iron core, and when the core was put in he got a shock even on making the contact with the battery.

§ 6. **Bachhoffner's Divided Core.**—A little later in the first volume of Sturgeon's *Annals of Electricity* we reach a Paper by a Mr. E. M. Clarke, on an induction coil (*see* Fig. 7), for giving shocks with a single pair of plates. There is nothing more in this than a description of a Callan's or Sturgeon's

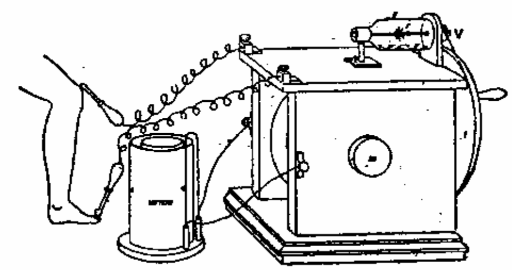

Fig. 7.—Clarke's Induction Coil.

m, core of coil. t, driving wheel of contact breaker. V, driven pulley. r, star wheel breaking contact with mercury in vessel s.

coil. The secondary wire was one ninety-second of an inch in diameter, and the contact breaker was a Barker's wheel, or copper star, revolving so that the tips of its spokes just dipped in mercury in a bottle (*see* Fig. 8).

Some time previously Mr. Barker had invented this device for interrupting a current. Mr. E. M. Clarke was a philosophical instrument maker, having a shop in the Lowther Arcade, and his memory is also handed down to us as an improver of Pixii's magneto-electric machine. Mr. Sturgeon comments on Clarke's Paper, and, for appropriating without sufficient acknowledgment Mr. Barker's wheel and his own coil, he gives Mr. Clarke, of 11, Lowther Arcade, a dignified rebuke. Various improvers having been given the clue, took up the manufacture of induction coils. On page 205 of the *Annals of Electricity*, Vol. II., a Mr. Nesbit sends a description of a coil (*see* Fig. 9); it had a revolving ratchet wheel as a contact breaker, a primary coil, consisting of 400ft. of thick wire, and a secondary of 1,700ft. of thin wire, and as a core a bundle of very fine iron wire. This

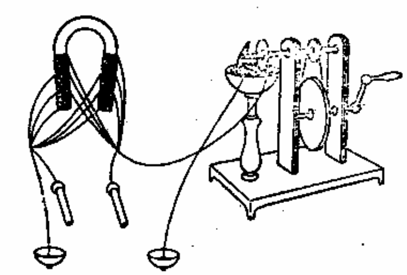

Fig. 8.—Barker's Revolving Contact Breaker, or Mercury Break.

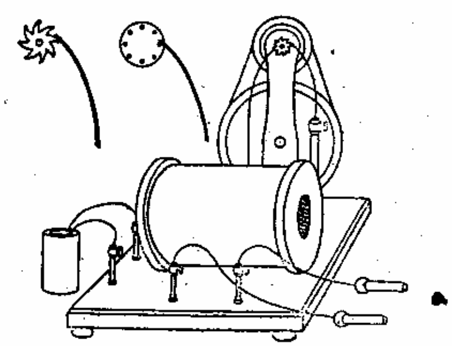

Fig. 9.—Nesbit's Induction Coil.

description is dated February 10, 1838. This coil gave very severe shocks when the primary was excited, with one cell of half a square foot of active surface. Nesbit put oil on his break to reduce the noise and check the spark. Four days later, on February 14, 1838, Prof. G. H. Bachhoffner has a description of a coil

which he made with two separate insulated copper wires and a *core of insulated iron wires*, and he notes that if the core of fine iron wires is enclosed in a tinplate tube it ceases to act as a divided core, and becomes no better than a solid core. He claims the original suggestion of using a divided iron core, and

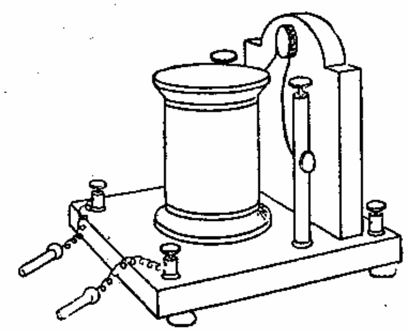

Fig. 10.—Uriah Clarke's Coil. (Side elevation.)

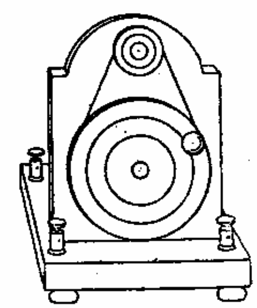

Fig. 11.—Uriah Clarke's Coil. (Back view.)

It appears from what he says that at first he used lengths of cotton-covered iron wires in a bundle as a core.

Bachhoffner refers also to a self-acting contact breaker which put on one of his coils, and which he says was made by Neeve, of 11, Great St. Andrew's-street, Seven Dials, who made for him this magnetic contact breaker greatly superior to the spur wheel of Barker or the notched disc of Sturgeon, both of which required to be actuated by hand.

Following on these researches of Sturgeon and others, numerous investigators introduced successive smaller improvements into the construction of induction coils. Uriah Clarke, of Leicester, in June, 1838, sent to Sturgeon a description of an induction coil, in which the bobbin was placed vertically (*see* Figs. 10 and 11), and which has since been a not unusual arrangement for medical coils. In Uriah Clarke's coil a primary wire of copper, $\frac{1}{13}$in. in diameter, 40 yards long, was employed, and a secondary coil of 300 yards of very fine copper wire, also a "break" consisting of a brass wheel, having on its circumference wooden pegs, and which made and broke contact with a spring of brass resting against it. Sometimes a steel wheel with a milled edge was employed for the same purpose.

§ 7. Callan's Further Researches.—In the *Philosophical Magazine* for December, 1836, Prof. N. J. Callan made further mention of his auto-induction coils, giving also a description of an improved form of galvanic battery. He wound, on an iron bar about two feet long and an inch thick, two coils of insulated wire, each about 200ft. long. These insulated wires were joined together in series, and the extremities of one wire were put in connection with a battery of 14 cells; on taking hold of the ends of the whole length of 400ft. of wire and breaking the battery circuit, a very sharp shock was felt. He concluded that if about 2,000ft. of wire were so coiled on a bar, and the first 200ft. of this wire connected to a battery, a still greater shock would be received if the ends of the whole 2,000ft. were touched, and the battery contact broken. Twenty-one years afterwards he returned again to the subject of induction apparatus, and in a long Paper, communicated to the British Association at its Dublin meeting in 1857, and reprinted in the *Philosophical Magazine* for November, 1857, Callan described many experiments he had made in his efforts to improve the induction coil and exalt its power. Referring first to the induction coil made at Maynooth College in 1836, and to one like it sent to Mr. Sturgeon in the summer of

1837, he establishes his claims to priority in the matter of the invention of an induction coil, having two *separate* wires, one thick and the other thin, by means of which a *quantity* current could be made to produce an *intensity* current. This 1857 Paper is occupied chiefly in advocating the use of an induction coil, with a secondary circuit made of insulated iron wire, and such a coil he showed to the British Association, in which the secondary circuit consisted of 21,000ft. of iron wire, about ·01in. diameter. His arrangement apparently consisted in using a secondary circuit of insulated iron wire rolled up tightly into a cylindrical form, and which formed not only the secondary circuit, but also the iron core of the primary. The primary circuit, consisting of insulated copper wire, was wound over and outside of the iron wire secondary, and the secondary circuit thus fulfilled at once the functions of core and secondary circuit. In one form of coil described the circuits were alternately overlaid. First an iron wire secondary circuit, then a copper wire primary; then over this another iron wire secondary, and a further copper wire primary. The primary circuits were to be joined in series, and the iron wire secondaries in parallel, with the object of obtaining "considerable quantity" in the secondary currents. It is suggested that in this way it would be possible to procure current enough to operate an arc light between carbon poles. One form of induction coil suggested consisted of an iron wire secondary coil wound up tightly into a helix; and on this, considered as an iron core, the copper wire primary was wound; over this copper circuit another iron wire circuit was coiled, and the two iron wire circuits were joined up in series, so that the copper wire primary acted inductively on both, and generated induced currents in each in the same direction. Reasons are given in this Paper which led the writer to consider that this insulated iron wire secondary circuit had advantages over a secondary circuit of copper wire, and an independent longitudinally divided iron core, as introduced by Bachhoffner. Callan explained with great clearness that the principle of joining together the secondary circuits of a number of coils in parallel is the right method to adopt to obtain a secondary current of sufficient strength and electromotive force to produce an arc light, and he may, therefore, be credited with the knowledge at that date of the mode of adding up either the electromotive forces or the currents in the secondary circuits of a number of distinct induction coils. It is not quite equally clear whether he ever arranged his coils with primary circuits in parallel also. The same Paper also contains suggestions as to mode of manufacture of condensers for induction coils, and certain advantages are claimed for condensers made of iron plates rather than of tin-

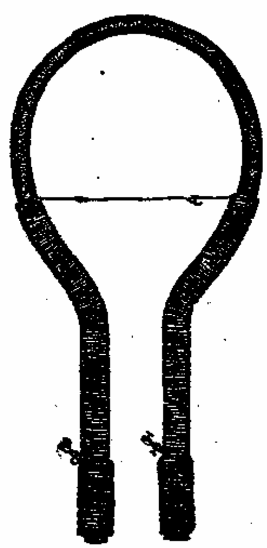

FIG. 12.—Dr. Callan's First Induction Coil (1836), with thick and thin wire Circuits.
Still preserved at Maynooth College.

foil sheets. Callan's mode of insulating the wires of his coils was ingenious. He dragged the bare iron or copper wire through a hot bath of melted resin and beeswax, and this, when set, formed a highly insulating and sufficiently flexible varnish on the wire, which appears to have rendered silk or cotton covering unnecessary. The secondary circuits were wound on the plan, previously suggested by Poggendorff, of

building up the secondary circuit of flat or vertical coils so connected that no contiguous parts of the wire were at great differences of potential when the coil was in action.

Prof. Francis Lennon has given* the following details of the remains of Prof. Callan's apparatus, which are still preserved at Maynooth College as valuable relics. The large electromagnet constructed by Callan in 1836, consisting of a horse-shoe of iron, about 13ft. in length, and weighing 210lb., is still in existence (*see* Fig. 12), but it has been deprived in course of time of one of its circuits, so that it now remains as a simple and not a compound electromagnet. A somewhat smaller horse-shoe magnet, constructed by him on the same principle, with two wire coils, one thick and one thin, was the one presented to Mr. Sturgeon. In the Physical Laboratory at Maynooth also exists one of Callan's Electromagnetic "Repeaters," which was one of the first rapid contact breakers ever made.

§ 8. **Callan's Great Induction Coil.**—The most valuable relic is, however, the large induction coil, which may be regarded as the completion of Dr. Callan's labours. Although constructed 30 years ago, it is still one of the largest coils in existence. The representation of it in Fig. 13 is from a photograph recently made. The core is a cylindrical bundle of annealed iron wires 42in. in length, and 3·5in. in diameter. The thickness of each wire is $\frac{3}{16}$in. The primary coil is a copper wire, ·25in. in diameter, covered with cotton thread, and wound in three layers. For insulation the primary coil is covered with several layers of thin sheet gutta-percha, cemented by a paste, formed by dissolving gutta-percha, resin, and wax in boiling oil. The secondary coil is of *iron* wire ·01in. diameter, and consists of three separate coils or rings. The inner diameter of each coil or ring is 6·75in., and the outer diameter is 21in. Two of the rings are 3in. in thickness, and one is 4in. The rings are so arranged on the primary coil as to divide its entire length into equal parts, the planes of the rings being perpendicular to the axis of the coil. In each ring both ends of the wire are projecting, so that the separate coils can be joined in series or parallel. The contact breaker is an automatic mercury

* See *Electrician*, March 6, 1891, Vol. XXVI., p. 554.

break, worked from one extremity of the core. Two condensers, so arranged that they can be used together or separately, serve to reduce the spark at the break. With six cells of the Maynooth or cast iron battery, sparks 15in. long in air can be still obtained, the rings or secondary coils being joined in series. Prof. Gerald Molloy states* that the construction of this coil was commenced by Dr. Callan some years before his death, which occurred in January, 1864, and that it was then left in an unfinished condition. It was probably his intention to add more secondary coils to it. It remained one of the most powerful coils down to the time of the construction of Mr. Apps' large coils for the Polytechnic and for Mr. Spottiswoode. A

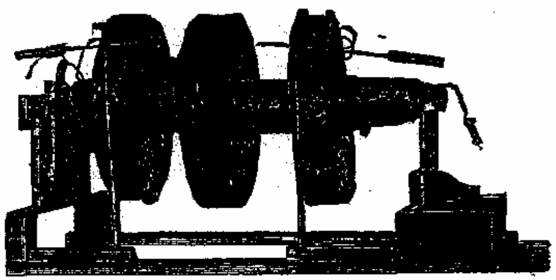

Fig. 13.—Dr. Callan's Large Induction Coil completed in 1863. Still preserved at Maynooth College.

long Paper by Dr. Callan on the induction apparatus, describing his latest researches, is printed in the *Philosophical Magazine* for 1857, Vol. XIV., 4th series, p. 323. This Paper is full of valuable suggestions and facts.

A description of the large induction coil, and experiments with it, will be found in the *Philosophical Magazine* for June, 1863 (Vol. XXV., Series 5, p. 413). Dr. Callan says that about three years and a-half before the date of writing he made an induction coil of considerable power. The secondary coil was of iron wire, No. 34 gauge, and consisted of three parts, two of which were each about two and a-half inches, and the third

* See *Electrician*, February 13, 1891, Vol. XXVI., p. 465.

three inches long. The entire length of the secondary coil was about eight inches, and it contained 150,000ft. of secondary wire. He used thin sheet gutta-percha in insulating the layers of wire. The primary coil was nearly three feet long, and the soft iron wire core three feet six inches long. This long primary coil was probably intended to be overlaid with more secondary wire, and as left at Dr. Callan's death the coil was incomplete. With three cells of the Maynooth battery this coil would give sparks 15in. in length.

Dr. Callan discovered that an increase in length in the spark is produced by connecting a large plate of any metal to the negative terminal of the coil, and that, in order to get the longest spark, the outer end of the secondary coil should be positive, and the inner end the negative. He states (see *Philosophical Magazine*, June, 1863) that when a pointed wire is connected with the positive end of the secondary a plate connected with the negative end lengthens the spark considerably, but when the point is connected to the negative end and the plate to the positive one the sparks are much shorter. Sparks 15in. long, when the first arrangement is made, are reduced to 11in. with the second. Sparks did not pass at all between positive plate and negative point until the plate was brought within eight and a-half inches from the point.

A ball, three inches in diameter, connected to the positive terminal shortens the spark as much as a 12-in. plate. He noted also that sparks from a positive point to a negative plate never went to the circumference of the plate, and scarcely ever struck the plate at a greater distance from the centre than three inches. But sparks between a negative point and positive plate always went to the circumference until the plate was brought to within two and a-half or three inches of the point; even when a rectangular plate 20in. by 28in. was used as the positive terminal the sparks flew to the edge of the plate.

§ 9. C. G. Page's Researches in Electro-Magnetism.—Very nearly at the same time that Prof. Callan, of Maynooth, was assiduously engaged in England in experimental inquiries on the induction coil, Dr. C. G. Page, at Salem and at Washington, in the United States, prosecuted with the greatest zeal and