IEEE MILESTONE PROPOSAL

Rev. Nicholas Callan's pioneering contributions to electrical science and technology

NOMINATION FORM AND SUPPORTING MATERIAL

Submitted by:

Dr. Seán McLoone,
Secretary IEEE UKRI Section,
Dept. of Electronic Engineering, National University of Ireland Maynooth,
Maynooth, Co. Kildare, Ireland

Dr. Niall McKeith,
Curator of the National Science Museum at Maynooth,
Dept. of Experimental Physics, National University of Ireland Maynooth,
Maynooth, Co. Kildare, Ireland

Contents

NOMINATION FORM

IEEE MILESTONE IN ELECTRICAL ENGINEERING AND COMPUTING

Date: 16th October 2004

To: Director
IEEE History Center
Rutgers University
39 Union Street
New Brunswick, NJ 08901-8538
ph. 732-932-1066,
fax 732-932-1193
history@ieee.org

From: Seán McLoone
Secretary IEEE UKRI Section
Dept. of Electronic Engineering
National University of Ireland Maynooth
Maynooth, Co. Kildare, Ireland
ph. 00353 1708 6313
ph. 00353 1708 6027
s.mcloone@ieee.org

NOTE: This two-page form is intended as a cover sheet for submitting nominations. Fill in items (a) through (e) and present items (g) and (h) on additional pages. Items (d), (g), and (h) should reference supporting material. Attach the supporting material for them and list in item (i).

(a) Name of proposed Milestone:

Rev. Nicholas Callan's pioneering contributions to electrical science and technology**.**

(b) Location(s) of proposed Milestone (be specific):

Foyer of the Electronic Engineering and Biosciences Building, North Campus, NUI Maynooth.

(c) Present owner(s) of site(s):

NUI Maynooth

(d) Disposition of owner(s) toward Milestone (attach supporting material):

The Milestone has the full support of NUI Maynooth and St. Patrick's College. A letter of support from the President of NUI Maynooth is attached [1].

(e) Significant date(s):

1826-1864

(f) Proposed citation (optional; absolutely limited to 75 words; 50-60 is preferable. NOTE: Whether or not the nominator suggests a citation, The IEEE History Committee shall have final determination of the wording of the citation):

Proposal A (preferred): Rev. Nicholas Callan (1799-1864), a priest and professor of Natural Philosophy at St. Patrick's College Maynooth, was a pioneer in electrical science and technology. In addition to building the first induction coil and step-up transformer in 1836 he made important contributions in the development of electromagnets, galvanization, batteries and equipment to generate high voltage electricity.

Proposal B: Rev. Nicholas Callan (1799-1864), a priest and professor of Natural Philosophy at St. Patrick's College Maynooth, was a pioneer in electrical science and technology. He made key contributions in the invention of induction coils and transformers, including building the first successful mechanical rapid current breaker and the first induction coil with separate primary and secondary circuits. He also made important advances in the development of batteries, electromagnets, galvanization and equipment to generate high voltage electricity

(g) Historic significance of this work: its importance to the evolution of electrical and computer engineering and science and its importance to regional/ national/international development. Answer on a separate sheet, and reference and include supporting material. Be sure to be clear about the scope of the importance.

As a pioneer in the study of electromagnetism and the development of electrical technology for the production of large currents and high voltages, Nicholas Callan made several internationally relevant contributions:

- Invented the induction coil and step-up transformer (1836)
- Built the first successful mechanical current breaker (1836) (which he called a 'repeater')
- First to establish the link between rate-of-change of current and electromagnetic induction (1836)
- First to discover the principle of the self exciting dynamo (1838)
- Made significant advancements in battery technology (1854-1855)
- Patented a method for protecting iron from rust – an early form of galvanization (1853)
- Built the most powerful batteries and electromagnets of his time (Encyclopedia Britannica, 1860)

A focus of Callan's research was to develop equipment to convert low voltage electricity (as obtained from batteries) to high voltage electricity. Influenced by the work of Faraday and Henry, he worked on the idea of the induction coil from 1834 onwards and developed his first induction coil in 1836. He also developed a mechanism to generate an interrupting supply (changing current) and built the first step-up transformer in 1836.

The historical significance of the work lies in the fact that without the induction coil, radio waves, x-rays, and the electron would not have been discovered and exploited as they have. In addition his discoveries in relation to the generation of high voltage electricity are equally significant, given the importance of transformers in the transmission of electricity worldwide.

The significance of his work was also recognized by many of his contemporaries with his experiments and apparatus being copied and extended by many scientists in Europe and America. (e.g. Sturgeon, Nesbit, Joule, Page, Clark, and Bacchoffner, [2], page 53).

The evidence for Callan's inventions can be found in the papers that he published on his research. A full list of Callan's publications and details of how they relate to his contributions can be found in [2, pp.88-91] and [4]. Those specifically relating to the invention of the induction coil and step-up transformer are:

- Sturgeon's Annals of Electricity (1,493: 11 Sept 1837)
- Philosophical Magazine (Dec 1836).

Callan also presented his case for the invention of the induction coil in 1857 at a meeting of the British Association for Advancement of Science held in Dublin. According to Casey [4], the report of this meeting (*Report of the British Association for the Advancement of Science*, 1857 (pt.2) 11-13) quotes Callan as saying:

> 'It is now more than twenty years since I discovered the method of making the induction coil, or a coil by which an electric current of enormous intensity may be produced with the aid of a single galvanic cell-a coil which is now to be used for working the Atlantic Telegraph. Mr Faraday was the first who developed the laws of electrical induction; but he did not discover the method of making a coil by which a current of very great intensity may be obtained by means of a very small battery. This was first discovered in Maynooth College in 1836. In the summer of 1837, I sent the late Mr Sturgeon a small coil which he exhibited at a meeting of the Electrical Society in London and from which he gave shocks several of the members . . , This was the first induction coil of great power ever seen outside the College of Maynooth. The first notice of the discovery of the coil is found in a paper of mine published in the London Philosophical Magazine for December 1836. … In April 1837 I published in Sturgeon's Annuls of Electricity a description of an instrument which I devised for producing a rapid succession of electrical currents in the coil by rapidly making and breaking communication with the battery . . . Thus before April 1837 I had completed the coil as a machine for producing a regular supply of electricity'.

It is clear from Callan's own words that he was aware of the significance of his invention with respect to the working the Atlantic Telegraph. Callan published a revised version of this paper in the Philosophical Magazine for Nov. 1857. A copy of this version is attached [8].

Other notable acknowledgements of Callan as the inventor of the induction coil can be found in

- Noad's Treatise on Electricity: Noad H., *Lectures on Electricity and the State of Electrical Knowledge in 1844*, Vol. 2, No.8: 138-146 and Noad H.M., *A Manual of Electricity* (Lockwood and Co., London, 1859),
- *Encyclopaedia Britannica 1910*, (11th edition), 'The induction coil' Vol. 14, pp. 502-503. (attached [9])
- Fleming J.A., *The Alternative Current Transformer in Theory and Practice*, Vol.2, London: The Electrician Printing and Publishing Co. Ltd., 1903, p7ff. (attached [10])
- Shiers G., *The Induction Coil*, Scientific American 224, 80-87 (1971)
- Rowbottom, M. and Susskind C., *Electricity and Medicine, History of their Interaction*. San Francisco Press Inc, 1984.

Fleming, for example, in his account of the historical development of the induction coil and transformer in [10] states on page 12:

> 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 think and one thin, used as an induction coil.

Further evidence is provided by some of his contemporaries who explicitly acknowledge his contribution in their own publications. ([2, pp. 98-99])

Two other Callan papers worth mentioning are

- Sturgeon's *Annals of Electricity 1* (Feb. 1836), 229-30
- Sturgeon's *Annals of Electricity 2* (Feb. 1838), 317-8

In the first Callan describes his 'repeater', the first successful mechanical rapid contact breaker, while in the second, in addition to pointing out the priority of the his induction coil, Callan also documents his discovery of the principle of the self-exciting dynamo. (See [2, pp. 55] for further details.)

(h) What features or characteristics set this work apart from similar milestones? Answer on a separate sheet, and reference and include supporting materials.

Since Callan's contributions represent pioneering work when the field of electrical technology was in its infancy it is difficult to identify similar milestones. Certainly his contributions together with those of his contemporaries lay the foundation for modern society.

One characteristic, which sets Callan's contributions apart from those of others, was the scale of his efforts. Driven by a desire to obtain large currents and high voltages he built the largest batteries, electromagnets and induction coils of his time. His electromagnets could lift 20 tons (Encyclopedia Britannica, 1860) and he succeeded in generating voltages of the order of 600 kV that could produce 15-inch long sparks. See [2], [8] and [10] for further details. When describing Callan's Great Induction Coil Fleming [10] noted 'Although constructed 30 years ago, it is still one of the largest coils in existence'.

(i) List of supporting materials included:

[1] Letter of support from NUI Maynooth.

[2] P.J. McLaughlin, *Nicholas Callan, Priest-Scientist (1799-1864)*. Dublin: Clonmore & Reynolds, 1965. Pages 41-56, 88-91 and 98-99 are attached with this document for convenient reference. The full text is also included as a separate item.
- Pages 41-56: An account of Callan's research
- Page 88-91: A list of his research publications and how they relate to his research contributions
- Page 98-99: An extract from Nature, vol. 180, pp. 730-2, 12 October 1957.

[3] C. Mollan and J. Upton, *The Scientific Apparatus of Nicholas Callan and other Historic Instruments*, Sr. Patrick's College Maynooth and Samton Ltd, 1994.
- Page 49-69: Examples of Callan's batteries, electromagnets and induction coils
- Page 84-85: Example of Callan's repeater

[4] M.T. Casey, *Nicholas Callan, Priest Professor and Scientist*, Physics Education, Vol.17, 1982, pp.224-234

[5] C. Mollan, W. Davis and B. Finucane, (editors), *Irish Innovators in Science and Technology*, Publ. Royal Irish Academy, 2002, pp.79-80

[6] E. Katz, *Nicholas Joseph Callan*, The history of electrochemistry, electricity and electronics website: http://chem.ch.huji.ac.il/~eugeniik/history/callan.html

[7] D.P. Currier, *A Biographical History of induction coils*, Essay by Dean P. Currier (dpcurr@aol.com) posted on www.radiantslab.com/quackmed/Deanbio.html

[8] Rev N. Callan, *On the Induction Apparatus*, Philosophical Magazine, Nov 1857.

[9] *Encyclopaedia Britannica 1910* (11^{th} edition), 'The induction coil' Vol. 14, pp. 502-503.

[10] J.A. Fleming., *The Alternative Current Transformer in Theory and Practice*, Vol.2, London: The Electrician Printing and Publishing Co. Ltd., 1903, p7ff.

Seán McLoone

Signature of Chairman, Section History Committee or Other Nominator.

R.J. Dodds

Signature of Section Chairman. Print name and address below.

NATIONAL UNIVERSITY OF IRELAND, MAYNOOTH
MAYNOOTH, CO. KILDARE, IRELAND

PRESIDENT'S OFFICE
President: W.J. Smyth, B.A., Ph.D., LL.D.

NUI MAYNOOTH
Ollscoil na hÉireann Má Nuad

Our Ref: P/BB

12 December 2003.

Director
IEEE History Center
Rutgers University
39 Union Street
New Brunswick,
NJ 08901-8538

Dear Director,

National University of Ireland, Maynooth is pleased to support the application submitted by Dr Seán McLoone in respect of Professor Nicholas Callan's pioneering work in applied electricity.

Nicholas Callan was an exceptional man, by Irish and international standards. His work was exhibited at home and abroad and as such he operated with effect within an informed transnational community of scientists. His achievement, properly assessed, deserves the fullest recognition in the annals of modern professional associations. I am delighted to support this application and were it to be deemed appropriate, the University will be pleased to display the commemorative plaque in the foyer of the Engineering and Biosciences building.

Yours sincerely,

Dr W.J. Smyth
President.

Tel: +353 1 708 3895 Fax: +353 1 628 6583 Email: president.nuim@may.ie
OLLSCOIL NA hÉIREANN, MÁ NUAD

II

Extracts from

P.J. McLaughlin,

Nicholas Callan, Priest-Scientist (1799-1864),

Clonmore & Reynolds, Dublin, 1965.

Pages 41-56:	An account of Callan's research
Page 88-91:	A list of his research publications and how they relate to his research contributions
Page 98-99:	An extract from Nature, vol. 180, pp. 730-2, 12 October 1957.

Chapter V

ARDENT EXPERIMENTER

WHEN IN 1928 I was appointed professor of experimental physics in Maynooth, I found myself the inheritor of a massive load of junk. It was a sad lot of obsolete apparatus. The big hall off the lecture theatre, passages that were remnants of old Long Corridor, store rooms high up in the dim and labyrinthine recesses of Front House, and cellars in the marvellously fan-vaulted basement of Stoyte House I found crammed with the forlorn and dusty relics of ancient science, the bits and pieces lying around in a bewildering disarray.

"Yes", said Kelly, the college engineer, "nice mess. But very handy. Any time we want to do a repair job in the power house or around the college, we come down to the science hall and help ourselves. It's mostly Dr. Callan's old stuff. There's his great induction coil that Dr. Lennon took such care of-had it mounted on a new support. There are cells from the giant batteries, some of them giants themselves. Look at those wires and electros from his engines, but the big stuff belonging to his electro motors has disappeared. Some of it lay outside the plumber's place till lately, big iron wheels and all that. There is plenty of stuff left yet, as you can see for yourself. A few of his old tools are around and bits of his old lathe. He used them for winding his great coils. Lots of them around somewhere too. I've adapted pieces of the stuff to wind coils for wireless sets".

The contents of the lumber rooms belonging to the old science hall were mute evidence of Callan's tremendous activity as an experimenter. My problem was: how to make these inanimate witnesses speak and tell a coherent tale?-how to see the interconnections, and catch a glimpse of the thoughts and of the man that created them?

In this matter, the textbooks of my student days (as most of the textbooks of today), the work of hacks, copying at fifth-hand, were not only useless but utterly misleading in the views or flashes they usually presented about historical developments in science. Theirs is a grievous responsibility since they make the first impressions on the young student, impressions that for most of us are the lasting ones, and hard to alter or correct afterwards. The general shortcoming of the textbook is to substitute what pretends to be logic in the place of history. This might be allowed as fair enough if the textbook made-it clear that a methodological short circuit was being employed in order to impart rapidly to the reader information that took the best minds ages to acquire, and not leave the student with the notion that such was the way things actually happened. But the textbook writer is guilty of a greater fault still when he ignores the original papers and attributes the invention of one man to another. He is guilty of injustice for he robs a man of whatever fame he may be entitled to. Callan had been robbed in this way.

Gradually I was driven back to the sources. There were many difficulties to overcome before I discovered what the sources were, where they could be found, and how I' could gain access to them. There was plenty of sheer spade-work. The more one consulted contemporary documents, the more one saw how false and wrong-headed is the picture presented by most modem textbooks of how science developed. This is particularly true of electricity which in its modem aspects is little more than a century old.

The prime source for a study of Callan's contribution to the development of electrical science lay in the apparatus he left behind him in his laboratory and workshop, or rather in what remained of that apparatus. When sorted out, these bits and pieces fell naturally into four large groups, showing that Callan had worked extensively on

1. Batteries to produce great currents of low-tension electricity.
2. Induction coils to produce big amounts of high-tension electricity.
3. Electro motors to harness electricity as a prime mover.
4. Apparatus for electric light.

There were of course derivatives of these Main groups. For example, .his famous cast-iron cell led him to invent and patent a form of "galvanized' iron. He devised effective switch gear for his batteries and high-tension cut-offs for his shock machines. He invented an ingenious paste to insulate his high-tension generators. He found safe ways for exploding the mixed gases in his lighthouse apparatus. He hit on an electric valve to suppress the reverse current from the induction coil. He constructed a special galvanometer to measure the prodigious currents he generated.

When we look at the scale and variety of these instruments (many of them now preserved in the Maynooth science museum) we naturally ask: whence the funds for all this equipment? Even in Callan's day, scientific research was costly, facilities were meagre and a great deal could not be done on the much vaunted if proverbial shoe string. Entries in the Journal show that the trustees of the college were not deaf to Callan's requests for equipment for the physics department, but this was chiefly for teaching purposes. Callan's researches were financed from his private means, family legacies. A document in the bursar's office consists in administration papers which Callan took out for his father's will in January 1839, and states that by that time the residuary legatees had yielded their interest to Nicholas. Callan's own will shows he was a beneficiary under the will of his sister Catherine who had property in Dundalk. In the "Famine Forties", Callan's private means were such as to allow him to devote - the whole of his salary as a professor to relief projects.

For his researches, he purchased vast amounts of mercury, great sheets of copper and zinc, literally miles of copper and iron wire, porous pots and glass containers by the gross, platinum foil, brass and iron and coke in rod and sheet and plate, insulating materials in bulk. At times the science hall must have looked like a factory. He was generous to fellow scientists in various parts of the world, in Ireland, England and as far away as India, sending them induction coils and electro motors he had personally constructed. All this would need a pretty long shoe string.

Much if not most of Callan's research apparatus was made by himself, assisted by local "handy-men" or tradesmen. The laboratory technician had not yet arrived. It is traditionary that in his heavier jobs, as, for instance in the shaping of his 210-lb. Magnet, Callan had the co-operation of a Maynooth blacksmith, James Briody of Coffey's lane. Dublin was but fifteen miles away and could supply many skills that might be beyond the powers of neighbours. It was still the period of the craftsman and the small manufacturer. The Muspratts and the Gambles had not yet all migrated to England to found Britain's heavy chemical industries. From such Dublin firms Callan obtained a good deal of the raw materials he needed. But jobs, such as drawing thirty miles of fine iron wire through an insulating varnish to make one of his flat bobbins for a transformer, he trusted to nobody but himself, since a single break in the winding could vitiate an entire series of experiments.

As in the case of most scientists, two periods stand out in the life of Callan the experimentalist, a period as a young professor full o(go and originality, and the period of consolidation and development in his later days. The two periods sandwiched the decade of the Irish famines when Callan devoted most of his spare time to turning out devotional books. The first of these periods is the important one from the point of view of science and technology, particularly the "hot" years 1836 to 1838. To see the motives and sense the urge, to discern the remote aims and appreciate the immediate purposes within Callan, we must look at all his work, and try to envisage it in its context. The ultimate clues are to be found in his writings and in those of his contemporaries.

Callan's scientific writings[1] are few and those few are brief. They give the impression of a man of action, a man of the "laboratory" impatient to be back to the instruments with which he hopes to prise open the secrets of nature. This is especially true of the earlier papers which state an important observation in as little as a single sentence, and suppose that the reader is at home in the experimenter's universe of discourse. It was only towards the end of his life, when friends urged him that Callan wrote his longer papers, largely to vindicate the claims of his earliest discoveries.

For Callan, as for most scientists of his time, the problem of communication was acute. The day of the scientific pamphlet (like Berkeley's on the therapeutic effects of tar water), the day of the prolific and assiduous letter-writer (like Richard Kirwan) had gone, and the day of the scientific periodical was fitfully coming in. The *Transactions* or *Proceedings* of learned bodies, such as the Royal Society or the Royal Irish Academy, or of semi-scientific groups, such as the Royal Dublin Society, were issued irregularly and for the benefit of members. Membership of such bodies was restricted to polite society, pundits and persons who had already acquired a ' quantum of status symbols. In Ireland, where general causes operate more sharply and intensely than in 1he world at large, because racial and religious rancours are superimposed on social divergences, Callan and his work were initially ignored by associations dominated by the Ascendancy.

Ireland's attempt at a scientific quarterly in the Dublin Philosophical Journal and Scientific Review, brilliant while it lasted, lasted only a little over a year. The Philosophical Magazine had a Dublin editor, Robert Kane, a forward-looking young medical man with a keen interest in chemistry, afterwards author of Industrial Resources of Ireland and first president of the Queen's University in Cork; and later on Kane was to read papers of Callan's to the Royal Irish Academy. It may have been Kane who opened the pages of the Philosophical Magazine to Callan. This valuable journal covered a very wide area of science, while Callan was interested in a section of that field, a section of great promise then attracting bold enquirers. To cope with their needs, Sturgeon, inventor of the electromagnet, founded his Annals of Electricity which for a few years was the chief forum for news and discussions and reports relating to the new branch of science, electromagnetism. Here, among a mass of good, bad and indifferent articles, we find nearly all of Callan's brief but important communications in the first period of his life as an experimentalist. Looking back, we would say that the two most important contributors to Sturgeon's Annals during its meteoric existence were Callan in Maynooth and Joule in Manchester, each of them by succinct letters sparking off significant developments. A periodical catering for inventors, the Mechanics' Magazine, published papers by other Irish workers in the field of electromagnetism, but Callan does not appear to have made use of its pages for his communications to the scientific world. Finally, we have to note that none of Callan's private letters to other men of science has so far come to light, though we are told that he wrote many.

In seeking to penetrate to the urge that drove Callan to experiment in his particular field of research, we have to keep in mind some general points too commonly overlooked today. First of all, science is primarily a human activity and not the mere product of computers or robots, or of any other kind of machine. The story of electricity in the first half of the nineteenth century is a very human story. In it we find ambition, rivalries, social and intellectual snobs, personal and national antagonisms, generosity and meanness, disinterested endeavour and calculating commercialism. Callan's own character as a man of science was open and liberal: he communicated his results freely, he was fair and just to the work of others, but he could be firm in asserting and restrained in claiming his rights. The human element was refreshingly evident in most scientific writings of the period, the style of writing was less depersonalized than now, but fame, that "last infirmity of noble mind", was a universal spur, and Callan like others was sensitive to its prod.

From his scientific publications along with the remains of his instruments we get a clear idea of the goal Callan set before him. His general aim was to try to exalt the powers of electricity so as to harness its mysterious force for the benefit of people at large. He had visions of electricity in the service of man. He dreamt of it as a prime mover; as a common source of lighting to replace oil, rushes and candles, and compete with the new arrival, coal gas. He aimed to discover how to produce electricity both in abundance and cheaply. Despite the chaffing of the doubting Thomases among his colleagues, he held on to his vision and it sustained him throughout the greater part of his life. To his enthusiasm as a visionary he joined extensive practical gifts. He focused on two aspects of electricity which in the beginning appeared to be two different sorts of electricity, what he called quantity electricity and what he called intensity electricity. He aimed to produce at low cost large amounts of both sorts. He aimed also to find out how to convert one into the other. In doing so, he discovered the principle of the step-up transformer, the first rung on the ladder to high-tension electricity, and to electricity as a public utility among large communities.

To understand what Callan meant by quantity and intensity electricity, we must flash back for a while.

In his little book, Electricity and Galvanism, which appeared in 1832, Callan used the word "electricity", like his contemporaries, to denote what we now call static or frictional electricity. The term came from the ancient Greeks who, 2,500 years before, found that their highly prized amber (got from the Baltic and called "electra") acquired a fascinating power when rubbed: it could attract light objects. We repeat their discovery by rubbing a fountain pen on our sleeve or running a comb through our hair, and finding that the ebonite or plastic material can lift pepper grains, little bits of paper or hair or thread, and what have you. Further investigation shows that both the rubbed material and the rubber itself can, after friction together, lift light bodies, that is, both rubbed and rubber are "electrified". They are however electrified "oppositely", and the opposite sorts of electricity attract each other. This is the fundamental law. We use it to "explain" how a piece of, say, unrubbed paper is attracted by our rubbed fountain pen. We say opposite electricity is induced on the paper by the presence of the pen "charged" with its electricity. We then speak of "electric induction" (or, to spell it out fully, "electrostatic induction" as the process by which this occurs). The electricity is called static because it stays put on insulators such as amber, ebonite and the common plastic materials. If you try to hold this electricity on a piece of metal in your hand, it seems to run away to the earth like water in a river running to the ocean, "because" the metal like your body is a "conductor".

The amount of electricity that can be generated in the above way is trifling. Larger but still trifling amounts can be got by continuing the rubbing process in a machine. In Callan's day, the plate machine was much used for this purpose and gave "machine electricity". It was a large disc of glass rotated between silk rubbers and provided with devices for collecting the charges of electricity. If you touched these you got a shock, an "electric shock" similar to what you got from touching an electric fish. Such a shock in moderation was thought to have a beneficial effect on health. For this reason, electric machines were in demand and the firm of Samuel Healy in Dublin manufactured them expensively on great mahogany bases for medical men in Callan's time. It was seen too that sparks, "electric sparks" could be got from these machines, but the sparks had little power. Such machines provided electricity, but it was high-pressure electricity in feeble amount.

The other term in Callan's book "galvanism" serves to introduce us to what Callan understood by quantity electricity. The name derives from the professor of anatomy in Bologna University, Luigi Galvani.

Galvani found that a trickle of machine electricity sent through the nerves of a dead frog 'produced a violent agitation of the muscles, as if the frog had come alive again. He inferred that muscles and nerves are tensed in opposite electrical states, but a metal restores equilibrium by affecting a sort of discharge. If so, then one metal should do. Volta, however, showed that two metals are usually required, and further there is no need to connect a muscle and a nerve-these merely act as conductors between the metals. He demonstrated that contact between the metals produces electrical excitement. His discovery was communicated to the Royal Society and the ensuing investigation went on to assign the galvanic effect, not to contact between metals, but to chemical action on one or both of the metals, producing in the metals opposed electric states.

The controversy engendered by the difference of opinion between Galvani and Volta led to much experimenting. Some of it was gruesome, as when efforts were h1ade to resuscitate corpses by passing electricity into them. Some of it was fruitful and gave us the Voltaic cell (or "circle") and the galvanic battery, a grouping of Voltaic cells. A simple Voltaic cell can be made by putting two dissimilar metals, say copper and zinc, into a jam jar of salt water or a mild acid that attacks chemically one of the metal plates. The space in the jar between the metals is the internal circuit. If the metals are connected by a wire, we have the external circuit. When a battery of cells is set up and the external circuit is completed, heat is developed in the external circuit; in other words, the wire in that part of the circuit gets hot.

This generation of heat in the external circuit was to Callan the chief test of quantity electricity. Under suitable conditions the heat could produce light. A second test of quantity electricity employed by Callan was the amount of chemical action obtainable as, for instance, the amounts of hydrogen and oxygen he could get when he passed the quantity electricity through water. The third test he employed was the magnetic effect he could obtain. We shall see a good deal about the magnetic effect later. Callan was to study it under two very different aspects.

We may sum up Callan's truly operational views on quantity and intensity electricity as follows. He judged intensity from goodly shocks and goodly sparks. He had quantity electricity when there was notable heat or chemical action or significant magnetic effect.

In these abstract notions of electricity Callan had in mind analogies from other branches of science such as hydrostatics and heat. He saw quantity electricity like, say, a supply of water in a wide, shallow tank, and intensity electricity as water under pressure or with a notable head. Or again, he saw quantity electricity as the heat in a kettle full of boiling water. The water holds more heat than a red hot needle, but if the needle is dropped in the kettle, heat flows from it to the water; it flows from the hotter to the cooler body and not necessarily from the body with most heat in it.

In forming these abstract notions of quantity and intensity electricity, Callan was mathematizing. He was replacing an array of facts by a general idea, an idea susceptible of mathematical treatment. He here exemplifies the important process by which science has so rapidly advanced in our own day. He exemplifies another feature in the development of science, the marriage of the empiric with the rational. From the seventeenth century onwards, rationalists and pure mathematicians, fed on and enamoured with Euclid and the ancient Greek tradition, believed that the universe was mathematical in structure, so that the forms of natural science could be anticipated with certainty: given certain items, the whole future of the material world could be accurately and precisely foretold. On the other side were those who argued that our knowledge of nature depends on chance discoveries, so that natural science must always be accidental and without coherent shape. For Callan, and other experimenters, the truth lay in between these extremes. Discoveries cannot be anticipated by pure reason, because natural knowledge is always incomplete. At the same time, every verification or falsification of a reasoned forecast marks an advance in systematic knowledge. With Edison, the scientist has gained when he has found out something that does not work the way he thought it should.

A final point we note here about Callan as an experimentalist. His period marks the beginning of a significant change-over. Before his time, most technical developments were the result of empirical discoveries by practical men, and technology contributed more to science than science did to practical pursuits. After Callan, electrical industry was to show a new pattern in that its birth and growth were to be direct consequences of scientific research. We see traces of these beginnings in the Callan story, tentative beginnings.

Callan's Batteries.-A steady objective in Callan's scientific life was bigger and better batteries in order to have electricity in abundance and cheaply. He wanted electricity to be an element in everyday living and not let it remain as he found it, a philosopher's toy, a plaything for the curious. At an early stage he made up his mind that the only practical way to achieve plentiful supplies of electric power was through the Voltaic cell. This line of thought led him in the end to his famous cast-iron cell with its derivatives, the Maynooth battery and the single fluid cell. We can trace the sequence of his ideas by means of a list giving the chief contemporary cells he experimented with.

1836	Wollaston's double copper
	Poggendorf's chromic acid
	Daniell's two fluid
1839	Grove's platinum
1843	Bunsen's carbon
1848	Callan's cast iron
1854	The Maynooth battery
1855	Callan's single fluid

In all these cells the second metal was zinc, and the size of the zinc plate was a key to the power of the cell for producing quantity electricity. The standard size was a square of zinc four inches each side, for short called a "four inch". Callan was at once struck by the way Wollaston doubled the efficiency of the ordinary copper-zinc cell by enclosing the zinc between two plates of copper, thus bringing both faces of the zinc into use. Callan had high admiration for Wollaston and to some extent modelled his own research on the example of the renowned English scientist. He saw him as a man who 'combined the genius of the philosopher with the skill of the artist and did not fear, as a gentleman in a snobbish age, to make practical applications of some of his important discoveries.

Three of Callan's batteries merit mention. Two of them consisted in groupings of Wollaston units.

The first was a twenty-cell battery with remarkable features. Even today we rub our eyes when we look at the size of the cells. The zinc plate was measured not in inches but in feet, two feet by two. Each cell carried a charge of a gallon and a half of sulphuric acid. A windlass served to lift the zinc plates out of the acid when he wished to interrupt the chemical action and stop the production of electricity. A drain cock in each cell let him run off the acid and flush out the dregs and detritus of - chemical action when desired. He has already dispensed with glass containers and uses the copper as a water-tight container as well as one of the two poles of the cell. Finally he has a switchboard of mercury cups (a "voltamerist") so that he can employ at will any number from one to twenty of the cells in his battery. With this apparatus and his tests for quantity and intensity electricity, he discovers for himself, like Cavendish before him, Ohm's law.

The story of Ohm's law, now a cornerstone in electrical science, is one of those curiosities that illustrate even in the domain of science the power and the stupid rigidity of the pundit. When Callan was appointed professor in' Maynooth, ideas about the flow or conduction of electricity were vague, except that it travelled very fast in a metal, perhaps as fast as lightning. Analogy was therefore sought from the speedy propagation of light, but with the limited powers of experiment in those days this analogy led nowhere. In 1827, Georg Ohm, a teacher of mathematics from Munich, believed he had found a good analogy between electricity in motion and the flow of heat in a metal bar. Basing himself on the great study of heat conduction by the French mathematician, Fourier, by abstract reasoning he arrived at the electrical law that now bears his name. The German physicists in the department of education would have none of it. They hounded Ohm for daring to teach such a law and drove him from his post in a Jesuit college. It was only ten years later when Pouillet in France enunciated a similar law as a result of experiment, that the victimization of Ohm eased off. But up to 1860, Continental physicists as a body refused to accept Ohm's assimilation of electric current to heat flow. As late as eight years after Callan's death, there was no accord on the units in Ohm's law, and each physicist had to manage the best he could with his own standards of electric pressure and electric resistance.

It is quite clear from his papers and from the relics of his apparatus that Callan had puzzled out Ohm's law in all its essentials for himself. He saw the cell as an electric pump that by chemical action brought the metal plates to unequal electric pressures. He knew that the current of electricity he could obtain from a cell was limited by the cell's internal resistance, and he knew how to diminish that resistance by using large plates close together in good conducting fluid. He knew the importance of balancing the internal resistance of a generator against the resistance of the external circuit. He knew how to group cells so as to get maximum power. He knew how to combine primary circuits in parallel and secondary circuits in series so as to yield a maximum of either quantity or intensity electricity from a given battery. We find his exact specifications being repeated by other experimenters, for instance, by Sturgeon.

Callan tested the power of his batteries chiefly through the heat and magnetism that electric currents from the batteries could generate. He measured quantity electricity by the fusing of wires of all kinds and sizes. He also measured it by the direct magnetic effect obtained when the current energized an electromagnet. He did this simply by seeing what was the maximum weight the magnet could lift as the current flowed. But the magnetic effect could also be used indirectly, by producing secondary currents, if he had a secondary coil wound round his magnet (turning it into a "compound magnet"). The strength of these induced currents he tested by the physiological effect or shock they gave, since they consisted in intensity electricity. Employing units of his twenty cell Wollaston battery, and one of his smaller compound magnets, he persuaded some of his students to act as human voltmeters. He tells us: "With fourteen cells the shock was so strong that the person who took it felt the effect for several days". Then he prettily complains: "I could not induce anyone to take the shock from the electromagnet when a greater number than sixteen of our large cells was used".

Callan's second Wollaston battery was a high-pressure affair. It consisted in f 280 cells, but the units were of the conventional type with standard four-inch zincs. In the presence of 300 students he carried out some striking experiments with this battery. To test the magnetic effect he had a novel tug-of-war between a team of students and one of his electromagnets. When the current was sent through the set of primary coils, all the efforts of robust students failed to dislodge the keeper from the magnet. With another of his compound-wound electromagnets, for the first time ever, he got induced currents powerful enough to

a) ignite coke points and produce a brilliant light;
b) electrocute a large fowl.

The demonstrations were in a sense exhibitionist, but they showed that Callan had found out how to exalt the powers of electricity, and that he was on the track of how to turn quantity electricity into intensity electricity effectively. The grip of this idea on his mind from an early date is evident from the very tide of his first scientific communication to the *Philosophical Magazine* (1836)-he had already sent several papers to Sturgeon's *Annals*. In modem terms the title would read: "How to Transform 20 into 1,000 Volts".

Callan experimented with many types of Voltaic cell before arriving at his own iron cell and giant battery.

Poggendorf in Germany had followed Callan's work closely and had described it in his *Annalen*. Callan in turn took an interest in Poggendorf s chromic acid cell, which incorporated ideas of Callan and Wollaston, but substituted carbon for copper plates, and added chromic acid to reduce chemical fug and keep the cell clean.

Callan found he could get more reliable action from Professor Daniell's cell which applied Poggendorf's two-liquid idea in a fresh way: it kept the two fluids separate by enclosing one in a porous pot, with the zinc and the other in a glass vessel with the second metal. This arrangement kept the zincs clean for long periods. Like Wollaston, Daniell used copper for his second plate. Callan does not seem to have experimented with the Irish counterpart of Daniell's cell, Mullins's cell, which employed a membrane of gut or silk in place of Daniell's porous pot to keep the two fluids separate. "

The next cell that Callan experimented with was the Grove cell. At this stage of cell evolution, it was naturally a two-liquid cell on the Daniell principle. One of the liquids was nitric acid, a good conductor, but few metals can resist its bite. Gold and platinum can, and Grove employed platinum, then not so dear as gold but still very expensive. The cell was costly, and its great advantage -big currents over a long period -was dearly bought.

Soon after 1843, Bunsen's cell, in which carbon or gas coke was substituted for the expensive platinum foil of Grove, came into prominence. We have a derivative of this cell in the ordinary dry portable battery used for flashlamps. Callan found it hard to make good contact between his thick copper leads and the carbon plate, and the smelly brown fumes given off by the cell when in action were very disagreeable. His Bunsen cells, some of which are still to be seen in the Maynooth museum, are of great size with plates measured in feet and not in the customary inches.

Impressed by writings of Sturgeon, Callan now turned his attention to the virtues of cast-iron, and in 1848 he published accounts of his cast-iron cell. He substituted cast-iron for Bunsen's carbon' and he effected a notable economy by casting the iron to serve as a water-tight container (thus dispensing with a glass container) and double round a porous pot holding the zinc and attacking acid fluid. He put nitric acid into the cast-iron container. The cell then had good pressure, low resistance, and a remarkably good life, and gave very intense currents over a long period.

With 577 of these units (300 four-inch zincs, 100 six by four, and 177 six-inch) he constructed what a contemporary physicist called "probably the world's largest battery". It was at least twice as powerful as the Wollaston one constructed at Napoleon's orders for the École Polytechnique in Paris. To charge his battery he required fourteen gallons of nitric and sixteen gallons of sulphuric acid. Before a gaping audience he demonstrated the powers of his battery. A very large turkey was instantly electrocuted when placed in the electric circuit. A five-inch arc of blinding light was obtained between copper and brass terminals. Carbon arcs burned away too rapidly for the length of arc to be determined. At this' stage, several porous pots burst, and some copper leads fell off their zincs through combustion of the solder. Notwithstanding this interruption, considerable heat effects continued to be got from the remaining cells. According to these experiments of Callan, the cast-iron cell was fifteen times more powerful than a Wollaston of the same size, and twice that of a Grove. Grove's large battery used twenty square feet of platinum, and Callan's great battery was estimated to be seven times as powerful. .

Callan found that cast-iron stood up to nitric acid almost as well as gold or platinum, and was of course much cheaper. The surprising behaviour of iron gave rise to a lot of talk especially amongst German physicists.[2] Callan found that iron from his cells also stood up to the weather, and he patented[3] the process. He got an enhanced effect when he coated the iron with an alloy of lead and tin, or platinized lead. This led him to his Maynooth battery in which the cast-iron has been so treated. A derivative of Callan's iron cell was that of Roberts who employed the cell for blasting purposes.

An Act of Parliament in 1836 gave the Elder Brethren of Trinity House the monopoly of making the coasts safe for seamen collecting fees from all ships that used the ports. There was consequently a demand for suitable lights for lighthouses. The contentious Dubliner, Michael Donovan, experimented a lot with oil lighting for Trinity House, to the point of being characteristically involved in a law suit with the Brethren. Callan had the idea of developing electricity for the Purpose. In 1855 he designed his single-fluid battery for the lighting of light houses. It was a low resistance cell, simple in shape, consisting in a very large plate of zinc suspended in a narrow iron tank so constructed as to hold a goodly supply of acid.

Neither the Maynooth battery nor any of its variations is any longer of practical importance, but the steps that led to them illustrate in simple fashion how science and technology advance. Progress is towards compact efficiency through an endless series of successive improvements. Callan's aim was to get electrical power at the lowest cost. He was not the only one with such an idea: a hundred others had a similar objective in mind. We cannot say their efforts were wasted because their apparatus is now obsolete. As mentioned earlier, we have a derivative of one of these cells in the modem dry portable battery in universal use for such varied apparatus as flash-lamps, transistor radios and recorders.

Callan's Magnets. -If we judge by the results which he achieved, we infer that Callan knew as much about electromagnets as any man of his time. His magnets constitute a key phase in the evolution of the electrical age: they had what to most of us will appear to have been a strange influence on the course of events.

Callan's friend, Sturgeon,[4] had discovered how to make an electromagnet in 1825 but his original apparatus was a pretty crude affair. It consisted simply in eighteen turns of bare wire twisted round a core of soft, that is to say, untoughened or unannealed, iron. Sturgeon spent much of his life experimenting with unhardened iron and Callan used to think of him as "soft-iron" Sturgeon. Professor Henry in America improved on Sturgeon's invention by employing insulated wire, and by 1831 had produced the most powerful magnet known up to then. Callan is the next person of importance in the story of how this kind of magnet evolved. He was the first to make an intense and systematic study of all the factors accessible to test in his day. In 1834 he persuaded the Maynooth trustees to have a large electromagnet constructed for the college-at nearly the cost of a professor's salary-and he purchased a great quantity of material in order to make and study electromagnets.

As he succinctly tells us, he tried a great variety of experiments employing iron cores of all shapes and sizes, some straight and some u-shaped, one a square. He experimented with bars and rods, thick and thin, long and short. He had an exciting result with thin rods, finding them in some ways more effective than thicker cores. He tried different ways of winding great cods of thick, carefully insulated, copper wire on the iron cores, obtaining, as he points out, the best results by winding the spires at right angles to the core. In our mind's eye we can see him at work. From his knowledge of Ohm's law, he knows how to combine many coils in parallel so as to get the greatest magnetizing currents from his batteries. He achieves an astonishing density of ampere-turns, to use a modem term.

He supplies us with detailed specification of three of his electros. One is a small straight-bar electro that is to be historic and go to Downside College in England as the world's first induction coil and step-up transformer. He gives particulars relating to two large electromagnets that are also to play important roles in the story of electromagnetics. One of these is to achieve fame and be recorded as the most powerful of its time: the *Encyclopaedia Britannica* of 1860 estimates that with the prodigious currents from Callan's large battery, it had a lifting capacity of nineteen tons. Even the keepers of these large magnets Callan turns into experimental electros.

One way he has of testing his magnets is to find the greatest weight they can lift when energized by the current from a voltaic battery. He carried out enthusiastic demonstrations before an audience of students and visiting scientists. He challenges a team of robust young men to come and try to separate the keeper from the magnet when the current is on. The team loses this new game of tug-of-war. Then the professor plays a little trick. He cuts the current as the team makes a mighty heave: the magnet is no longer active and the members all fall in a heap on the floor, much to the amusement and applause of the onlookers.

By 1836 Callan had got from his magnets fields so strong as to astonish his contemporaries -and even evoke a cry of incredulity from Faraday's self-appointed spokesman, Professor William Ritchie of London University.

The great force Callan drew from his electromagnetic apparatus led him to two other lines of research. He studied how to turn his magnets into motors, into prime movers for traction; and he employed his magnets so as to revolutionize the shock machine. This last development was to lead to the induction coil and the modern transformer.

The Induction Coil.-The modern reader, looking at a picture of Faraday's historic iron ring (with which an early hint of how electricity can be got from magnetism was obtained), hastily concludes that here we have the transformer in embryo. Such a conclusion would be quite misleading.

The induction coil and transformer were derived by Callan from the primitive shock machine of Professor Henry of Princeton.

Joseph Henry, an independent discoverer of electromagnetic induction under the form of self-induction-a varying current inducing back electricity on itself-constructed a shock machine by interrupting the current from a voltaic cell through a long ribbon of copper rolled up into a spiral. An assistant-you may call him victim, patient or accomplice according to your mood:'--held two metal handles in his hands, the handles being in contact with the ends of the copper tape. When Henry broke the battery circuit by simply rubbing one of the terminals on a file, the collaborator got a shock. A follower of Henry's, Dr. C. G Page[5] of Salem, inspired by the trembler-interrupter of Professor McGauley[6] of Dublin, improved the method of breaking the circuit. Callan's so-called "repeater" was a further advance: it substituted a more reliable action for the delicate and uncertain action of McGauley's automatic hammer-break (employed in the ordinary electric bell). Moreover, Callan's repeater allowed him to vary the rate of interrupting the battery current, and made it possible-for him to measure the rate. The device consisted essentially in the escapement of an old grandfather clock activating a rapid make-and-break of amalgamated copper wires dipping into cups of mercury. It is the first instrument devised for studying the influence of the time element in electromagnetic induction. With this apparatus Callan showed that the shock effect is augmented through rapid change in the battery current.

Callan's next step was equally important and fundamental. Instead of tape or ribbon, he took wire and wound it in coils round a soft iron core. In his earliest shock machine, he had two equal coils, each two hundred feet in length, wound on a straight bar of iron two feet long. One of the coils was connected via his repeater to a battery, while shock handles were fixed to the ends of the total length of wire in the two coils.

When the repeater was operated, there was a shock of great intensity. In Callan's phrase, he had generated an intensity current of electricity. This was the world's first induction coil, and it was later presented to Downside College in England (May 1837).

Callan was not yet satisfied; he was all afire to exalt still further his high-pressure electricity. He must have seen fairly deeply into the heart of the phenomenon, for he now cut his battery coil to a mere fifty feet, but fifty feet of very thick copper wire. For his second coil he took a great length of fine wire (thirteen hundred feet). Now when he activated the repeater, the intensity shock was unbearable. He next turned to one of his great magnets and furnished it with a secondary coil of fine wire two miles long. When he operated his repeater in the battery or primary circuit, the induced intensity current was prodigious. Before a gathering of three hundred persons, as we have previously seen, he displayed its powers. He demonstrated that the induced electricity was strong enough (a) to ignite the carbons in an arc lamp, and (b) to electrocute a large fowl. No one else had come near this at the time.

Finally, he discovered that if he separated completely the primary and secondary circuits, so that the wires did not make electrical contact with each other, he got enhanced effects. At this stage, which he reached by 1836, he had discovered all the essential features of the induction coil except the condenser. He was to investigate the condenser later.

Callan sent a replica of his apparatus to Sturgeon in London who exhibited it to members of the Electrical Society in August 1837. Although the model was on a reduced scale, the exhibition of its powers initiated a wave of imitation and experimentation in Europe and America. Almost immediately there followed a spate of induction coils of all kinds. some for medical purposes, Sturgeon's, Nesbit's, Joule's, Page's, the two instruments of Uriah Clarke and E. M. Clarke, Bacchoffner's and others. It is clear from the pages of Sturgeon's Annals of Electricity where the stimulus came from. Bacchoffner explicitly acknowledged the debt to Callan. Sturgeon adopted Callan's exact specifications for the lengths of his coils. Page in Massachusetts changed over from his tape machine to Callan's "compound magnet", as some called it. The year 1837 thus marked the peak point in the first and chief phase in the evolution of the induction coil.

The interest of men of science in the induction coil then declined. It was revived after 1851 when Ruhmkorff's well-made instruments (Callan Coils incorporating a condenser, designed by Fizeau) became extensively employed to produce beautiful effects with the new scientific toy, the vacuum tube. As the induction coil gained fresh fame, Callan's early work was remembered and Callan himself resumed his researches on the production of intensity electricity. He improved both the contact-breaker and the insulation. He studied and explained the action of the condenser, constructing condensers of different kinds some of enormous size. He had been from an early stage interested in the electrical condenser, the so- called Leyden jar invented by Bishop Musschenbroek, a device capable of holding large amounts of the old form of electricity, "machine" electricity. He investigated - the best size of condenser to use with his coils.

He now built huge coils as well as medium-sized ones, and with great liberality he presented them to men of science and institutions in different parts of the world. Recipients I have been able to trace include (besides Sturgeon and Downside College, Bath) St. Edmund's College, Ware (the Westminster seminary); St. Malachy's College, Belfast (on account of its connection with Dr. Denvir, probably); M. de la Rive; and the Earl of Rosse, president of the Royal Society. At the time of his death he was engaged in the construction of a huge coil for the vice-president of the Royal Society, J. P. Gassiott. The power of his machines, at this period may be gauged from the fact that with a small battery of three voltaic cells activating the primary coil, he obtained sixteen-inch sparks from his secondary winding-that is, hundreds of thousands of volts from a mere five or six! At the Dublin meeting of the British Association for the" Advancement of Science in 1857, he vindicated his claim to priority of invention of the induction coil. No one challenged the claim in his lifetime.

Callan's Electromagnetic Engines.-After the rapid development of the induction coil in 1837, Callan's interest passed to a new growing point, the electromagnetic motor. It was another aspect of his study of Sturgeon's electromagnet. The great force he was able to produce from his, electromagnets suggested to him that they might suit as prime movers. Mechanical transport had appealed to him from boyhood when some of his people were in the coach and posting business. The steam engine was being perfected and Ireland was witnessing the installation of its first steam railway. In view of the enormous expense involved in using locomotive engines, other contrivances were being discussed and tried, among them the exciting "atmospheric" railway from Dun Laoghaire (then Kingstown) to Dalkey. Callan considered that magnetic traction could be superior to any of these forms of transport, more practical, more economic, and better suited to Irish conditions. He was grossly misled by statements of Sturgeon and by extravagant claims of American and other inventors of the time.

On three different principles he constructed a variety of magnetic motors. In 1836 we find him imparting rapid motion to a massive flywheel. The following year he estimates from his experiments that a magnetic engine as powerful as the steam engine on the Kingstown line can be built for £250, weigh less than two tons, and be maintained at an annual cost of under £300, say a quarter the cost of steam power. He designs an engine to propel a carriage and load at eight miles per hour. As late as the end of 1839 he is still optimistic. He is engaged in building a machine with ten times the power of Professor Jacobi's; he is fully convinced that electromagnetism will ere long be substituted for steam as a prime source. Then we hear he is having trouble with his engines-the practical difficulties he meets with are very great, whether he tries out engines equipped with a few big magnets or many small ones. Magnetic action is powerful only at short distances, and large magnets interfere with each other. Batteries of small electros are complicated and harder to manage than a steam engine giving the same power. He notes too that the galvanic battery needed to produce notable power is both expensive and troublesome. After trials on a large scale, Callan has to admit defeat. But not before he makes an important discovery, like Joule in Manchester, who from similar efforts on magnetic engines at this time lays the foundation of the all important concept of energy, mechanical energy, and provides a way of measuring it.

The Self-induced Dynamo.-Callan's discovery of the principle of the self-induced dynan1o arose out of his researches on electro-magnetism as a prime mover. While working with one of his engines, he was astonished to find, as he tells us, that "by moving with the hand some of the electromagnets, sparks are obtained from the wires coded around them, even when the engine is no way connected to the voltaic battery".

This is an observation of the first importance, as we now know. We can see that Callan had an insight into the phenomenon when we find him adding: "I know not how to account for the sparks except by supposing that the motion of the iron bars excites in them a certain magnetic power by which an electric current is produced in the wire coiled around them. When the bars are at rest, they do not exhibit any magnetic power whatever". It speaks highly of his electromagnets that merely moving them in the earth's weak magnetic field was sufficient to generate noticeable an1ounts of electricity.

Callan's communication of this historic observation is dated "Maynooth, February 20, 1838". To see the statement in perspective, we note that it has been usual to attribute the discovery of the principle of the self-induced dynamo to Werner Siemens in 1866. Siemens communicated his observation to the Berlin Academy of Science on 17 January 1867. Thus Callan anticipated Siemens by twenty-nine years. Had Callan or another followed up the discovery of 1838, the development of electricity as a public utility could have been accelerated by nearly a generation. Callan noted that the electric current which produced the sparks was feeble: it was "incapable of producing sensible heat, of giving shocks, or of affecting the tongue in the slightest degree" as he revealingly remarks. For this reason Callan made no attempt to develop the dynan1o, but in his further researches was content to obtain vast an1eunts of electric power, at high pressure and low, from huge voltaic batteries and prodigious induction coils.[7]

Further Researches.-Callan resumed his scientific investigations in 1846 with the construction of a new type of voltaic battery. Clearly he had made up his mind that this was the practical way to achieve large an1orlnts of electric power, both at low pressure and high, in conjunction with his transformer. In addition to the production of huge currents, he was interested in the economics of his processes, and they led him in the end, as we have seen earlier, to his cast-iron cells in a variety of forms, including the Maynooth battery and a single-fluid cell. To measure the large currents he obtained, he devised a special galvanometer, afterwards much used by Stewart and Gee in Britain and sometimes called by their name. One of his aims was to apply electricity to illumination. He experimented with various forms of electric lighting, from arcs to an ingenious but highly dangerous and explosive type of lime-light. The principle utilized in his lime-light was simple enough. With an electric current he got hydrogen and oxygen from water and then combined the gases on a hot lime. The explosive force of the combination was not easy to control, but eventually he had some measure of success: The intensity of the light thus produced was so great that he hoped his device would serve for lighthouses, but practical difficulties militated against this consummation.

Callan does not seem to have had much better fortune with his "galvanized iron", another by-product of his new battery studies. We have seen that he patented the process which consisted in inducing chemical passivity or inertness in an iron alloy employed as one of the plates in a voltaic cell. Cells treated in this fashion over a century ago are to be seen in the Maynooth museum fresh and rust-free, although they had lain neglected for a hundred years or more in damp cellars.

Excessive work led to a breakdown in health entailing an interruption of Callan's scientific studies for the greater part of the period 1849-51, but on his return from Continental spas he resumed his investigations. By this time there was a revival of interest in the induction coil through the introduction of a condenser into Callan's original apparatus. In spite of defective health, Callan drew on some latent source of energy and plunged into fresh studies of how to improve his first great scientific brainchild. So we find him at work on condensers, contact breakers, high-tension insulation, and connected problems. He turns the science halls and precincts almost into a factory as he constructs a large number of coils on new plans, and generously presents them to other experimenters. With one of his huge machines he investigates sparking potentials, and studies the nature of the spark as he varies the shape of the terminals attached to the ends of his secondary windings. Some of his findings have application in the design of lightning conductors and in the shaping of sparking plugs for motor car engines. Of particular interest is his discovery of the peculiar properties of the point-plate valve (later to be utilized to suppress the reverse current in X-ray tubes). This is an early instance of the semi-conductor (commonly exemplified today in the transistor). In mathematical hands Callan's valve could have led to a helpful theory of these still-puzzling entities.

physical sciences, and coupled with them in a distinguished manner, too. But I apprehend that Dr. Callan was the wrong man in the wrong place, and that with his peculiar capacity, he would have found a wider and more fitting field for it elsewhere than in an institution specially established to educate theological teachers for the , peasantry of Ireland. He was a thoroughly accomplished scientific scholar, and withIn the grand circle of the physical sciences lay the full sphere of his legitimate labours. In the Irish Ecclesiastical College of Maynooth they have a professorship of natural philosophy. This was Dr. Callan's chair, and he filled it well, the only pity being that he had not a larger circle to address his teachings to than a few young students, future curates in a few wild rural Irish parishes, whose interest in chemistry was of the smallest.

I met Dr. Callan only twice, but he impressed me favourably. He was spare and angular, with a hard square, high forehead, and a large deep set eye. His manner was serious and absent; but when he smiled his expression of face was singularly droll; and when he did attempt a joke or two his hits were exceedingly sly and effective. As I said, I am no student of the physical sciences; but it has been my lot to have been present at many a scientific'lecture delivered by the ablest "experts" of the day. It was at one of these I first encountered the name of Dr. Callan. The lecturer was preparing his electric battery, and 1 was struck by the neatness, and the small space it occupied. "That's a pretty thing", I said. "Yes", he answered, "and makes a vast saving of power. It is a circular battery, and we call it the Callan Battery, because it was invented by one Dr. Callan, a professor (of all places in the world) of Maynooth." Afterwards, of course, I found that Dr. Callan's name was one of distinction in the world of science, and that in France; especially, he was better known than in his own country. He was a splendid mathematician -rapid and accurate in his calculations, like all his countrymen who have manifested a proclivity for the exact sciences-and it is a question if there was an abler electrician in the empire. Of course he had his weaknesses; and one was that he thought himself bound to translate for the benefit of the laity of Ireland the works of a well-known Italian ascetic theologian, which works the said laity paid little heed to; plain people cannot help regretting that he did not stick to his useful researches in electricity, and let Liguori's speculations rest in the original.

In character, Callan was an amiable man, modest and retiring, grave and absent-yet not without genuine humour and the power, when needful, of self-assertion. He was always a worker, and when he died, he left some important acquisitions behind him to add to the scientific wealth of the world.

CHAPTER V ARDENT EXPERIMENTER

1. CALLAN'S SCIENTIFIC PAPERS.-The modem reader has to approach Callan's scientific papers with caution on account of the difference of vocabulary (the same word can mean such different things) and the difference in emphasis (the key words in titles often being concerned with what we regard as trifles, while today's really important matters lie buried in the body of the memoir). Thus the Royal Society's catalogue of Callan's scientific papers is not only incomplete, but it is also quite defective because it is th his based on misleading terms in old-style tides.

As a translator and writer of devotional works, Callan's style is that of his contemporaries, unrestrained and uncurbed. By contrast to his prolific output of popular volumes, his scientific papers--especially in the early phase-are relatively few, and those few tend to be brief, at times exasperatingly so. They illustrate admirably the characteristic which Newman assigned to scientific publications, where the results of years of research may be adequately set down on a single page. In his scientific communications, Callan's style of expressing himself is typical of the scientist-he is at once clear and plain but devoid of sparkle and variety.

It is a point of some significance that Callan's earliest papers appear in the very first ~ and volume of Sturgeon's historic venture, *The Annals of Electricity*. His third paper in that r was periodical is dated "14 June 1836" and it describes experiments that have been carried out with "an electromagnet of great power"-the one constructed in 1834. It introduces us to central thoughts underlying Callan's first researches, and it establishes beyond been question his priority in a wide and important field of electromagnetic investigation. The paper before that, dealing with "electromagnets for magnetic and electric purposes", brings into relief in a masterly if succinct fashion the two themes he studied so fruitfully, namely, the production of strong magnetic fields and the generation of high-tension electricity, basing himself on the electromagnet. Callan's first paper in the *Annals* describes his "repeater" and has the barest mention of its application while suggesting its pregnant quality. A fairly connected account of the matter in these three papers, along with mention of fresh experiments, was sent to the Philosophical Magazine in December own 1836. Part of the title of this paper would read in modern terms: "how to transform 20-volt electricity into 1,000-volt electricity", and it pin-points one of Callan's major preoccupations in his first researches. It indicates that his discovery or invention of the induction coil was no accident but the result of a sustained effort and of a pretty clearly envisaged aim. A notable paper on the right way to connect electromagnets appeared in the *Annals of Electricity* on 11 September 1837.

Two other important communications of Callan in this period were likewise made to Sturgeon's *Annals*, one in February 1838, and the other in November of the following year. The first pointed out the priority of the Callan Coil, and described the discovery of the principle of the self-induced dynamo. The second was chiefly concerned with establishing Callan's priority in designing certain kinds of electromagnetic engine. When Callan resumed his scientific investigations after the interruption of the "Hungry - Forties", Sturgeon's *Annals of Electricity* had ceased publication, and we find most of Callan's memoirs from this time on in the *Philosophical Magazine*. A few appear in the *Proceedings of the Royal Irish Academy* (in fact the first of his new series of papers appears there in 1847, significantly enough) and one long paper was published in the , *Report of the British Association for the Advancement of Science* after its Dublin meeting in 1857. During this period, Callan delivered a number of extra-mural lectures on the subject researches, chiefly to bodies interested in the new applications of electricity, such as the Mechanics' Institute at Ardee, as already noted.

LIST OF CALLAN'S SCENTIFIC PAPERS:

Annals of Electricity 1, Sturgeon (1836), 229-30: The Callan repeater. Plate.
Ibid. 1 (1836), 295-302: Electromagnets for magnetic and .electric purposes.
Ibid. 1 (1836), 376-8: Electromagnet of great power.
Philosophical Magazine 9 (1836),272-8: Results of several years.~ experiments with electromagnets and transformers.
Annals of Electricity 1 (1836), 491-4: On connecting electromagnet-5.
Philosophical Magazine 10 (1837), 459: Reply to Ritchie's criticism.
Annals of Electricity 2 (1838), 317-8: Priority of the Callan Coil; the self-induced dynamo.
Ibid. 4(1840) 333-4: Priority of Callan's electromagnetic engines.
Proceedings of the Royal Irish Academy 3 (1847), 471-6: New battery and experiments.
Philosophical Magazine 33 (1848), 49-53: A new prodigious battery.
Proceedings of the Royal Irish Academy 4 (1850), 152-7: Improved battery experiments.
ibid. 6 (1853),37: Illumination by the iron battery (title only).
Philosophical Magazine 7 (1854), 73-97: Illumination by the Maynooth battery; galvanometer for large currents.
ibid. 9 (1855),260-72: Single-fluid cell for illumination.
Report of the British Association for the Advancement of Science, 1857 (pt. 2), 11-13: Improved induction coil.
Philosophical Magazine 14 (1857), 323-40: The induction apparatus; high-tension insulation.
ibid. 15 (1858), 255-9: Contact breakers and condensers.
Ibid. 17 (1859),332-4: Electrodynamic induction.
ibid. 25 (1863), 413-7: Callan's great coil; sparking potentials; the Callan point-plate valve.

2. Cpo Poggen. Annal. 1 (1836),255.

3. CALLAN'S PATENT PAPERS 1853 No. 2340

STAMP

VICTORIA BY THE GRACE OF GOD Of the United Kingdom of Great Britain and Ireland, Queen, Defender of the Faith, To all whom these presents shall come Greeting. WHEREAS Nicholas Callan of the R.C. College of Maynooth in the County of Kilare Ireland-':"--hath by his petition humbly represented unto us that he is in possession of an Invention for "a means of protecting iron of every kind against the action of the weather and of various corroding substances so that iron thus protected will answer for roofing, cisterns, baths, gutters, pipes, window frames, telegraphic wires, for marine and various other purposes" which the petitioner believes will be of great public utility that he is the first and true Inventor thereof and that the same is not in use by any other person or persons to the best of his knowledge and belief The Petitioner therefore most humbly prayed that We would be Graciously Pleased to grant unto him his executors administrators and assigns Our Royal Letters Patent for the sole use benefit and advantage of his said Invention within Our United Kingdom of Great Britain and Ireland, The Channel Islands and Isle of Man, for the term of fourteen years pursuant to the Statute in that case made and provided AND WHEREAS the said Nicholas Callan hath purported particularly to describe and ascertain the nature of the said Invention and in what manner the same is to be performed by an instrument in writing under his hand and seal and has caused the same to be duly filed in the Office of Our Commissioners of Patents for Inventions. And We being willing to give encouragement to all Arts and inventions which may be for the public good are Graciously Pleased to condescend to the Petitioner's request Know Ye therefore that we of Our especial trace certain knowledge and mere motion HAVE given and granted and by these Presents for Us Our heirs and successors Do give and grant under the said Nicholas Callan his executors administrators and assigns Our especial licence full power solo privilege and authority that he the said Nicholas Callan his executors administrators and assigns and every of them by himself and themselves or by his and their Deputy or Deputies Servants or Agents such others as he the said Nicholas Callan and his executors and administrators or any of them shall in his or their discretion seem meet And that he the said Nicholas Callan his executors administrators and assigns shall have and enjoy the whole profit benefit commodity and advantage from time to time coming growing accruing and arising by reason of the said Invention for and during the term of years herein mentioned To HAVE HOLD exercise and enjoy the said licences powers privileges and advantages hereinbefore granted or mentioned to be granted unto the said Nicholas Callan his executors administrators and assigns for and during and unto the full end and term of Fourteen years from the day of the date of these Presents next and immediately ensuing according to the Statute in such case made and provided. And to the end that he the said Nicholas Callan his executors administrators and assigns and every of them may have .and enjoy the full benefit and the sole use and exercise of the said Invention according to Our gracious intention hereinbefore declared We do by these Presents, for Us Our heirs and successors require and strictly Command all and every person and persons bodies politic and corporate and all other Our Subjects whatsoever of what estate quality degree name or condition soever they be within Our United Kingdom of great Britain and Ireland the Channel Islands and Isle of Man that neither they nor any of them at any time during the continuance of the said term of Fourteen years hereby granted either directly or indirectly do make use or put in practice the said Invention or any part of the same so attained unto by the said Nicholas Callan as aforesaid nor in anywise counterfeit, imitate or resemble the same nor shall make or cause to be made any addition thereunto or subtraction from the same whereby to pretend himself or themselves the Inventor or Inventors Devisor or Devisors thereof without the consent licence or agreement of the said Nicholas Callan his executors administrators or assigns in writing under his or their hands and seals first had and obtained in that behalf upon such pains and penalties as can or maybe justly inflicted on such Offenders for their contempt of this Our Royal command. And further to be answerable to the said Nicholas Callan his executors administrators and assigns according to Law for his and their damages thereby occasioned AND MOREOVER WE do by these Presents for Us our heirs and successors Will and Command all and singular the justices of the Peace Mayors Sheriffs Bailiffs Constables Headboroughs and all Officers and Ministers whatsoever of Us Our heirs and successors ……

influence as a pioneer in electromagnetic science and testified to his priority in achieving a breakthrough in high-tension. electricity: (For a fuller account of the Irish school of electromagnetics see McLauglm, P. J., "Some Insh Contemporaries of Faraday and Henry", Proceedings of the Royal Irish Academy, 1964.)

MODERN TRIBUTES

Extract (with permission) from Nature, vol. 180, pp. 730-2, 12 October, 1957.

A session of the British Association for the Advancement of Science was held on 10 September in the Great Lecture Theatre of the Science Buildings of University College, Dublin. The audience, which was large, included Prof. P. M. S. Blackett, president of the Association; Dr. Henry St. John Atkins, president of University College, Cork; the Rev. Prof. J. McConnell, of Maynooth; Dr. A. C. Williams, senior chief inspector of the Ministry of Education of Northern Ireland; Mr. P. McGown, inspector of the Department of Education in Eire; Prof. J. Doyle, Prof. T. Murphy and Prof. F. Hackett, of University College, Dublin. Prof. D. A. Webb, of Trinity College, i Dublin, president of Section X, was in the chair.

The Rev. Dr. M. T. Casey, O.P., lecturer in general science at Maynooth College and senior science master at Newbridge, opened the session with and address on "Science in Our Irish Schools". ,

The first of the juvenile lectures was given by Mr. John D. Gallivan, of the sixth form at Newbridge College. He read a very interesting paper, illustrated by lantern slides, on "The Reverend Dr. Callan of Maynooth, pioneer of electrical research". Callan, born in Co. Louth in 1799, spent the greater part of his life in St. Patrick's College, Maynooth, where he held the chair of natural philosophy from 1826 until his death early in 1864. Attracted by the researches of Faraday and Sturgeon, he built a giant horse-shoe magnet, some 7ft. high and weighing 2101b. When supplied with current from his battery, this magnet could lift two hundred times its own weight. Before 1836, Callan had investigated the principle of the electric motor and had built three types. In the earlier forms, he employed a wheel having horizontal soft-iron bars attached to its rim. This was made to rotate by an intermittently energized electromagnet, the interruptions of current being effected by the rotating wheel. A later model using forty electromagnets was able "to propel at eight miles an hour a thirteenhundredweight carriage". Callan also experimented with various types of primary cell and eventually arrived at one which was manufactured commercially by E. M. Clarke, of the Strand, London, and called the "Maynooth Battery". The positive plate was a cast-iron container, holding a porous pot with the zinc plate enclosed.

Callan's most important invention was the induction coil. When repeating experiments on electromagnetic induction, Callan found that the shorter the interval at break, the higher the voltage of the induced current. From the escapement mechanism' of an old clock, he constructed an interrupter which gave several thousand interruptions a minute. Using this apparatus coupled to an electromagnet on which he wound a secondary coil over the primary, he found that the machine would give prodigious shocks. He sent a replica of the whole apparatus to Sturgeon who demonstrated it at an electrical exhibition in London in 1837, where it attracted much attention. Callan now constructed his "medium-sized" coil. This had a bundle of soft iron rods as core on which he wound the primary coil. Over this he wound a secondary coil of very fine wire very carefully insulated. The interrupter was of the trembler type devised by his contemporary, Prof. McGauley of Dublin. This apparatus gave considerable sparks. Callan still continued and made his giant induction coil, which was built on the same principle as the medium one. The core is 42in. long and I the primary coil is made from copper wire, 1/4in. in diameter, insulated with thread and wound in three layers. The whole is enclosed in an insulating paste made from wax and gutta percha. The secondary consists of three coils each containing about ten miles of very fine wire all carefully insulated with his paste. Callan had a large condenser across the interrupter, and using three cells of his Maynooth battery to feed the primary coil, he got sparks 16 in. long from the secondary terminals.

For some time Callan's claim to the invention of the induction coil was in dispute, but it has long since been vindicated beyond all controversy. The principal evidence to be found In Callan's own papers published in *Sturgeon's Annals of Electricity* (1, 493: 11 September 1837), and also In the *Philosophical Magazine* (December 1836), where we have the induction coil. Noad's *Treatise on Electricity* and Prof. J.A. Fleming's *The Alternate Current Transformer* also pay tribute to Callan as the inventor of the induction coil. Furthermore, French writers no longer claim Ruhmkorff (who constructed his first coil in 1851, fifteen years after Callan's) as its inventor. Mr. Gallivan concluded his paper by paying a tribute to Prof. McLaughlin, vice-president of Maynooth, whose researches had rescued Callan from oblivion.

Among further tributes to Callan, with particulars about his induction coils, may be mentioned those of Gerald Molloy in the *Electrician* (26, 1891, 465); Francis Lennon, (ibid., p. 554), O. Mahr in his *Die Enstehung der Dynamomaschine* (Berlin 1941); and R. C. Cuffe in his chairman's address to the Institution of Electrical Engineers, Irish Branch; October 1954: "Some Irish Contemporaries of Faraday".

TRIBUTES TO DR. CALLAN BY CONTEMPORARY SCIENTISTS

In the Irish Monthly (19, 1891, 304-6) appears a number of letters from distinguished scholars to Dr. Charles Russell on the occasion in January 1866 of a proposed memorial to Dr. Callan. The Earl of Rosse assigns him priority in inventing the induction coil and refers to the Callan cast-iron cell and goes on: "The largest batteries I ever saw were those of the Light & Colour Company, and they were Callan's I never met a scientific man with more zeal and singleness of purpose, or who was more ready with a true philosophic spirit to encounter difficulties." Thomas Romney Robinson, inventor of the cup anemometer that bears his name, also speaks of Callan's coil and batteries, and refers to Callan as his valued friend whose scientific attainments had not received their full due. , Provost MacDonnell of Trinity College, Dublin, in endorsing the scheme for a memorial, mentions that Callan was "particularly attractive by his modesty and affability". Sir Robert Kane thinks the proposal would be a "very just tribute to the scientific devotion of Dr. Callan. On hearing of Callan's death, Dr. Robinson also wrote to Bishop Denvir of Down and Connor, Callan's predecessor in the Maynooth's physics chair, still alive, and mentions his experiences with Callan's cells, including with reference to Callan's " high inventive power and knowledge, sterling worth and kindly heart.

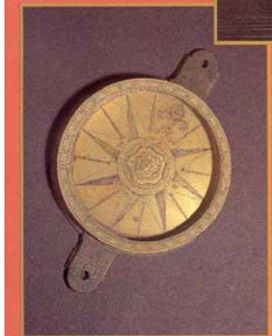
III

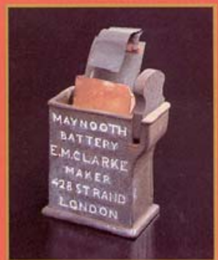
Extracts from

C. Mollan and J. Upton,

The Scientific Apparatus of Nicholas Callan and other Historic Instruments,

Sr. Patrick’s College Maynooth and Samton Ltd, 1994.





ISBN 1-898706-01-8

The Scientific Apparatus of Nicholas Callan *& other Historic Instruments*

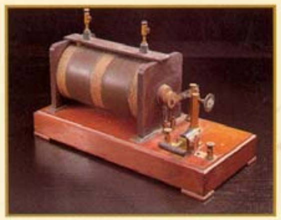
Charles Mollan
John Upton

MAYNOOTH
SAMTON

MAYNOOTH COLLEGE

The Scientific Apparatus of Nicholas Callan

and other Historic Instruments



Charles Mollan
John Upton

CATALOGUES OF HISTORIC SCIENTIFIC INSTRUMENTS

IN IRISH COLLECTIONS

NUMBER ONE

ST PATRICK'S COLLEGE, MAYNOOTH

THE SCIENTIFIC APPARATUS OF

NICHOLAS CALLAN

AND OTHER HISTORIC INSTRUMENTS

by

CHARLES MOLLAN AND JOHN UPTON

ST PATRICK'S COLLEGE MAYNOOTH
and SAMTON LIMITED

1994

base, and a semi-circular silvered scale (90-0-90°). The base has a circular groove for a missing glass dome.

*This is a compact version of **035**.*

BATTERIES AND CELLS

*Under the section of the Catalogue "Electrostatic Generators and Static Electricity" (pages 107-117), the instruments listed deal with electricity which is produced by machines giving "intensity" electricity of high voltage but little power. However, for his researches, Callan required "quantity" electricity (McLaughlin 1965,61). This was supplied by batteries or cells. It was Alessandro Volta (1745-1827), the Italian scientist, who invented the electric battery, or "voltaic cell", in 1799. He found that a pile of discs, alternately silver and zinc (or copper and zinc), with absorbent materials soaked in water between each disc, produced an electric current. Entry **056** is a later version of the voltaic "pile". Previously, another Italian, Luigi Galvani (1737-1798) had thought that this electricity was released by animals (for example frogs' legs) when they came in contact with metals. Volta showed that the animal component was unnecessary. From this beginning much research was carried out to improve the reliability and power of batteries, and this work continues to-day. Indeed a current priority in this area is the development of batteries which are not too heavy, last a long time, and can be recharged quickly, to power road transport of the future in an environmentally-friendly way.*

Callan experimented with voltaic cells and made substantial improvements in them. McLaughlin (1965,64) lists contemporary and new cells investigated by Callan:

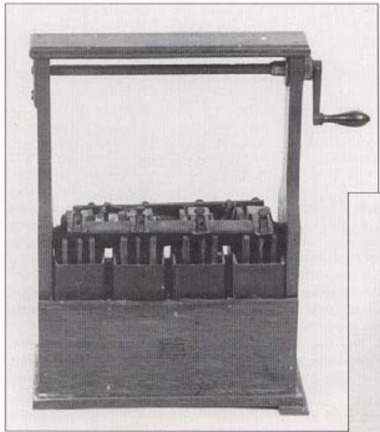
		Catalogue entry	
1836	Wollaston's double copper	057	
	Poggendorf's chromic acid	046	047
	Daniell's two fluid	052	
1839	Grove's platinum	053	
1843	Bunsen's carbon	048	049
1848	Callan's cast iron	050	
1854	The Maynooth battery	055	
1855	Callan's single fluid	051	

All these battery types are preserved in the collection, although not all would have been used by Callan. Other types of battery have been added since. Maynooth has the best collection of nineteenth century batteries in the country.

046 BICHROMATE BATTERY c1877 R.
1794 Signed: Yeates & Son, Dublin

Base diameter 119; maximum diameter 149; height 313.
A bulbous glass flask, with a cylindrical neck, has a brass sleeve on top. On this is an ebonite disc, from which is suspended one (of two) carbon plates (the second is missing), and a smaller zinc plate. The height of the plates is varied using a brass rod through a sleeve in the centre of the disc. On top of the disc are also two brass screw terminals.

This battery was invented by the German scientist Johanne Christian Poggendorf (1796-1877) (Lyall 1991,372, Williams 1982,422). The exciting liquid used was a mixture of one part of potassium bichromate, two of sulphuric acid, and ten of water (Ganot 1890,786). Such a "Bi-Chromate Bottle Battery" was offered in Yeates (1877,195-197). Although Callan experimented with this type of cell, this example and the next entry are unlikely to have been those actually used by him in his early experiments. While Yeates instruments can be difficult to date (see page 15), these were probably made after Callan's researches ceased.



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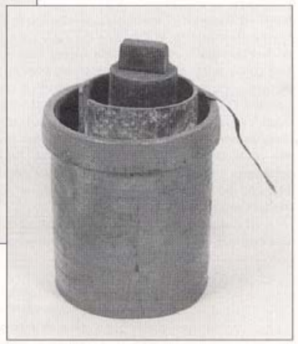

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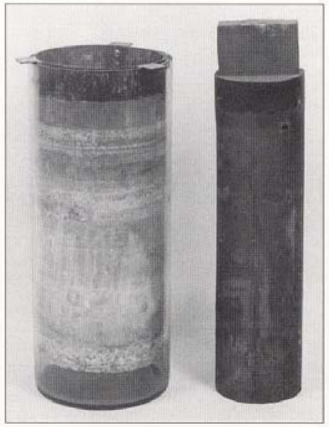

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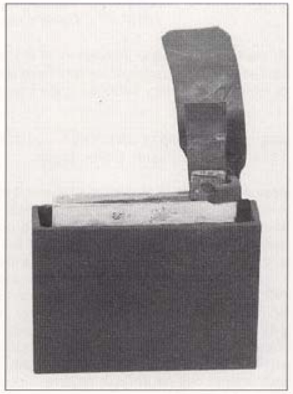

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047 BICHROMATE BATTERY c1877 R.
1771 Signed: YEATES & SON Opticians TO THE UNIVERSITY DUBLIN

Tray 274x142x15; height 375.
Four ebonite cells rest in compartments in a mahogany tray, which has extended vertical sides with a horizontal bridge joining them on top. Through the sides is an iron bar and handle, in a ratchet arrangement, for raising and lowering the plates out of the cells. Each couple consists of two graphite plates with a zinc plate between. The plates are joined together by mahogany strips. The pairs of graphite plates, and the central zinc plates, are connected by brass ribbons to brass screw terminals. Two of the graphite plates on one couple have broken off, and one of the two mahogany strip feet is missing from the tray.

*This is a four-cell version of **046**. The lifting arrangement was necessary since the zinc is attacked by the exciting liquid when the cell is on open circuit. In the single-cell version, the central zinc plate can be raised instead. A similar apparatus is offered in Yeates (1877,215&216), for use with either six Smee cells or with six Bichromate cells. The Smee cell had a sheet of platinum, or of platinised silver, between two zinc plates with dilute sulphuric acid as the exciting liquid (Ganot 1890,783).*

048 BUNSEN CELL (SMALL) c1843 R. 682-9
1774 Unsigned

Earthenware pot maximum diameter 160; height 190.
An earthenware pot contains a hollow cylinder of amalgamated zinc, a porous pot (now missing), and a cylinder of carbon. A copper strip on the zinc cylinder was attached to the carbon of the preceding cell by means of a clamp, but this also is now missing.

*The porous pot, with its carbon cylinder, contained concentrated nitric acid. The outer vessel contained dilute sulphuric acid (Ganot 1890,782). Invented in 1843, the battery of Robert Bunsen (1811-1899) is in effect a Grove battery (**053**) in which the platinum foil is replaced by a carbon rod. Because of the good conducting properties of the carbon, the cell had a low internal resistance and was less costly than the Grove cell.*

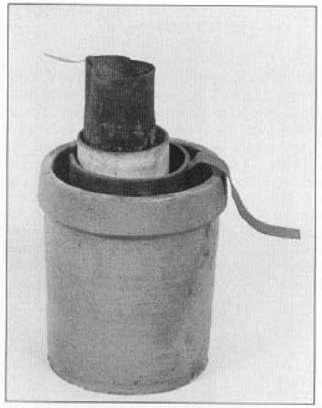
049 BUNSEN CELL (LARGE) c1843 R. 682-9
1774 Unsigned

Outer vessel diameter 265; height 630.
This larger version of entry **048** has a glass outer cylinder, an open zinc cylinder, a porous pot, and a central carbon cylinder. Once again, the porous pots are missing. There are five glass outer vessels (two damaged) and seven large central carbon cylinders.

050 CALLAN CAST IRON BATTERY c1848 R. 690-2
1663 Unisgned - attributed to Nicholas Callan

Outer cell 131x106x29, 141x128x35, or 161x135x43.
A cast iron cell contains a porous pot and a zinc plate. Copper strips are soldered to the cell, and to the zinc plate, to join cells in series. There are ten of these cells, seven of the smallest size, and one each of the larger sizes.

The porous pot contained dilute sulphuric acid, while the outer cell contained concentrated nitric acid. Callan found he had trouble making good contact between his thick copper leads and the carbon plate of the Bunsen battery, and that the latter gave off disagreeable fumes. He therefore substituted cast-iron for the carbon, and this also had the advantage that the cast-iron could serve as the container of the battery, dispensing with the need for another outer container. He constructed a battery with 577 of these units, probably the world's largest battery, at least twice as powerful as that constructed on Napoleon's orders for the École Polytechnique in Paris. He proved its effectiveness by electrocuting a very large turkey! According to his experiments, his cast-iron cell was fifteen times more



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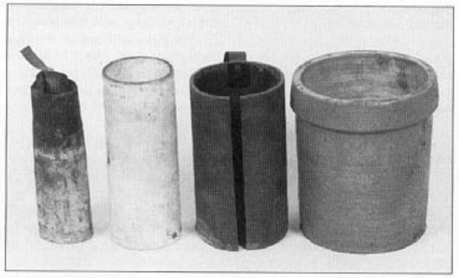

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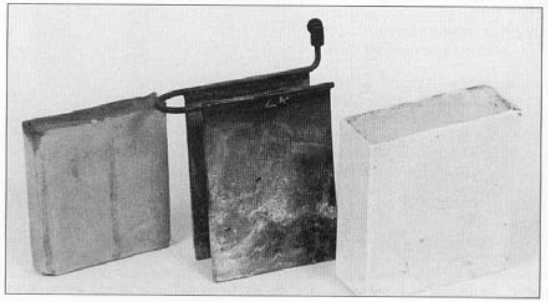

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*powerful than a Wollaston **(057)** of the same size, and twice that of a Grove cell **(053)**, which used expensive platinum for its anode. In the course of this work he found that cast-iron from his cells stood up to the weather, and he patented the process (see entry **380**) (McLaughlin 1965,68).*

051 CALLAN SINGLE FLUID CELL c1855 R. 697-8
4056 Unsigned - attributed to Nicholas Callan

Dimensions as for previous entry
This is identical to Callan's Cast Iron Cell **(050)**, with the omission of the porous vessel. The zinc plate was separated from the cast-iron cell by pieces of wood.

*Callan invented this cell in June 1854 because he needed to produce a more economical and convenient alternative to his cast-iron battery, for the purpose of exhibiting optical experiments which required a very strong light. He experimented with different fluids and found that best results were obtained with one part of concentrated sulphuric acid to two of water. During a public demonstration in the College in September 1854, he showed that 182 of these single fluid cells, excited by one part of sulphuric acid and three of a strong solution of common salt, appeared to be superior in power to 275 of the cells using nitric acid **(050)**. He also outlined a design for the replenishment of the exciting fluid using siphon tubes and a clockwork activated stop-cock. A graphic account of his experiments in given in Callan 1855.*

Yeates (1877,202-205) offered both "Callan's Cast-iron double Fluid Battery" and "Callan's Cast-iron Single Fluid Battery", the latter charged with: "a saturated solution of common salt in water, to which is added one-fifth of sulphuric acid".

052 DANIELL CELLS c1836 R. 674-80
1772 Unsigned - attributed to Nicholas Callan

Earthenware pot maximum diameter 160; height 190.
A glazed earthenware pot contains an open copper cylinder and a cylinder of amalgamated zinc, separated by a porous pot, the zinc being innermost. A strip of copper and a zinc tongue serve for connecting the cells in series. There are 41 outer pots, all of similar size, two of them being without a lip on top. These were also used for the small Bunsen cells **(048)**.

*The liquids used included a saturated solution of copper sulphate in the earthenware pot, and a dilute solution of sulphuric acid in the porous pot. This was the first form of the "constant" battery, invented by English scientist John Daniell (1790-1845) in 1836 (Williams 1982,129). It was an improvement on the Wollaston Battery **(057)**, which used only one fluid, and this led to "the rapid enfeeblement of the current produced". By using two fluids, as in the Daniell cell, the "action continues without material alteration for a considerable period of time" (Ganot 1890,780).*

053 GROVE BATTERY c1839 681
1793 Signed: WEDGWOOD

Outer housing 141x50x48.
A white ceramic housing contains two zinc plates on the outside of a red porous pot vessel. The zinc plates are connected by a copper U which has a brass terminal at one end.

The outer vessel was partially filled with dilute sulphuric acid (1:8) while the porous pot contained strong nitric acid and a thin platinum foil (Ganot 1906,486). The platinum foil is missing in this example.

Invented around 1839 by English scientist William Grove (1811-1896) (Gillispie 1981,V,559) this was considered to be one of the most powerful of the "two fluid" batteries, but became expensive owing to the high price of platinum (Ganot 1906,848). Platinum became really expensive only after 1902, when the Russian-born chemist Friedrich

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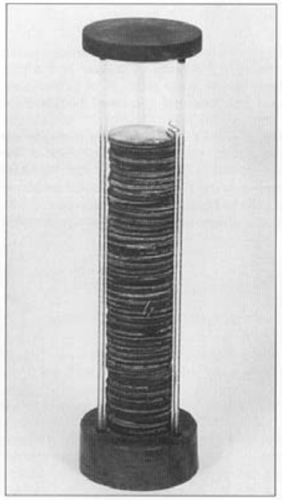

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Ostwald (1853-1932) discovered that it was an excellent catalyst for the oxidation of ammonia to nitric acid. This meant that it became essential to the manufacture of explosives, so much so that its use in photography (where it was very popular in the late nineteenth century) became prohibitive (McDonald 1982,386-393). The authors are grateful to Alison Morrison-Low for this information and reference.

054 LECLANCHÉ CELLS Late 19 C. G.
1775 Signed: LECLANCHÉ BARBIER PATENT R A L & CO LONDON

Base of vessel 112x112, height 188; total height 240.
A glass square-section vessel has a circular opening on top. Into this fits a carbon cylinder with a zinc rod in the centre. There are twenty seven of the larger vessels, most with their carbon cylinders, but only three with their central zinc rod. There are two smaller vessels (80x80x141), similarly signed, and one smaller still (76x76x134) signed: "PILE LECLANCHE BARBIER PARIS".

Invented by the French scientist Georges Leclanché (1839-1882) in 1866, this battery, in its usual form, uses a central carbon electrode, surrounded by manganese dioxide, in a porous pot, with a zinc rod for the positive terminal in a glass bottle outside the central electrode. The exciting fluid is a solution of sal-ammoniac (ammonium chloride) (Williams 1982,318, Turner 1983,199). In the Leclanché-Barbier version, as here, the zinc rod is carried in the centre, and the carbon electrode is composed of manganese peroxide and plumbago (a form of carbon) with a cast metal collar (Harris 1908,156). This was a relatively inexpensive battery, widely used, especially in door-bell circuits.

055 MAYNOOTH BATTERY c1850 R. 693-5
1664 Signed: MAYNOOTH BATTERY E.M. CLARKE MAKER 428 STRAND LONDON

Housing base 116x68, height 123; height with electrode 270.
Two. A treated cast-iron housing contains a porous pot and a zinc plate with a copper strip. A mahogany shaped piece fits a groove at the top right side.

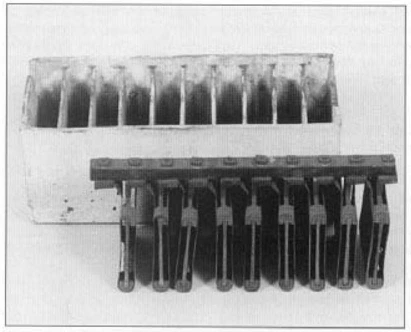
*The fluids were those of the cast-iron battery (**050**). Callan found that sheet-iron coated with an alloy of lead and tin resisted the action of acids and weathered more effectively than iron treated in other ways (Callan 1854,83). In the Maynooth Battery, the iron of the outer vessel is treated in this way. In 1859, Callan obtained sparks of about ten inches with his Great Induction Coil (**072**) using three cells of this Battery (Callan 1863,413).*

*Edward Marmaduke Clarke traded at 428 Strand from 1840-1851 (Downing 1988, 23). It is probable that this was the same Edward Clarke who traded in Dublin from 1810-1832, as Edward Marmaduke emerged in London, working for the firm of Watkins and Hill, in 1833, before setting up on his own (Morrison-Low 1989,49). For more details of E.M. Clarke, see entry **124**.*

056 VOLTAIC PILE c1836 G. 719
1725 Unsigned

Base diameter 133, height 54; overall height 522; disc diameter 78.
A red-painted oak base has three glass pillars supporting a wood disc on top. On the base stands a column of copper and zinc discs, each pair separated by circular pieces of cloth. The top and bottom discs each have a copper wire attached. The glass pillars and wood disc are modern replacements.

For information about the origin of the voltaic pile, see the introduction to this section (page 49). To actuate the pile, the cloth is moistened with acidulated water (Ganot 1890,777). McLaughlin (1955,719) records that "If the top and bottom discs - or wires connected to them - be touched simultaneously with moist fingers, there is a perceptible shock". This example of the Voltaic pile was probably used by Callan.



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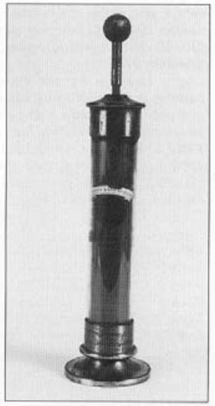

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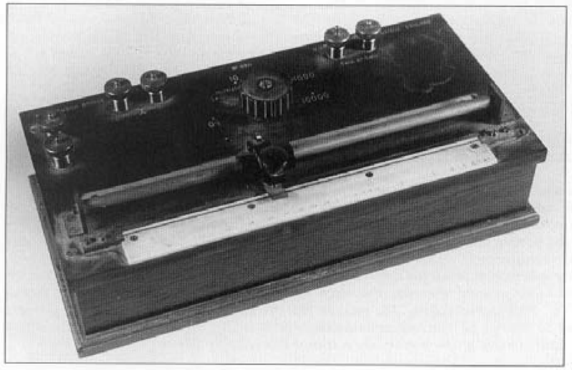

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057 WOLLASTON BATTERY c1836 R. 623-72
1770 Unsigned

Housing 360x142x141.
A ceramic vessel (there are four of these - two of them chipped) is divided into ten cells. Nine plates of thick rolled zinc and thin sheet copper are fixed to a cross frame of mahogany, and these dip into the ceramic vessel. The copper sheets are bent to surround the zinc plates without touching them. Contact is prevented by small pieces of cork.

The water in the cells was usually acidulated with 1/16 sulphuric and 1/20 nitric acid. This battery was invented by English scientist William Hyde Wollaston (1766-1828). It was an improved form of the "couronne des tasses" or "crown of cups", invented by Volta as a modification to his voltaic pile (056). An important feature was that several cells were connected together, and these could be removed from the exciting fluid when not in use (Ganot 1890,779). Callan was particularly struck by the fact that the copper was bent around the zinc, thus bringing both faces of the zinc into use. He made a twenty-cell battery with zinc plates measuring two feet by two, and a 280 cell battery with more-usual four inch plates. Using the latter he carried out a tug-of-war between a team of students and one of his electromagnets, and the electromagnet won! (McLaughlin 1965,64-66).

058 ZAMBONI DRY PILE BATTERY c1877 R. 834
1587 Signed: YEATES & SON, DUBLIN.

Base diameter 62; height 255; cylinder housing diameter 33.
A brass base supports a lower brass sleeve, holding a vertical glass cylinder, which has another brass sleeve on top (marked "+"). The upper sleeve is closed, and has a rod ending in a sphere above it. Inside the glass cylinder are the discs of the pile.

"Dry piles are remarkable for the permanence of their action, which may continue for several years...A Zamboni's pile of 2,000 couples gives neither shock nor spark, but can charge a Leyden jar and other condensers" (Ganot 1890,789).

Yeates (1877,230-231) offered: "Zamboni's Battery or Dry Pile, composed of alternate discs of tin-foil and paper coated with black oxide of manganese", either in a single tube of 1000 discs (as here) or in two tubes with 2000 discs.

BRIDGES AND RESISTANCES

A Bridge is an instrument for comparing two electrical resistances. A rheostat is a variable resistance.

059 KOHLRAUSCH POTENTIOMETER BRIDGE c1914 R.
4134 Signed: KOHLRAUSCH BRIDGE W.G. PYE & Co. CAMBRIDGE ENGLAND
No.4911

Housing 340x172x75.
A mahogany housing has an ebonite top, with three sets of two brass contacts, labelled "Batt or Sec. Coil", ")(", and "Tele or Galv". There is a central ebonite knob, with a pointer to "Multiply Scale Reading" from 0.1 to 10000. On front of the ebonite plate is a brass mounted horizontal bar with a sliding sleeve, incorporating an ebonite knob to touch a wire running along a bone log scale (0-9). The slide can be clamped using a pivoted brass bar behind.

Pye (1914,52) illustrates a similar Bridge, with the description: "Kohlrausch Universal Bridge arranged for the measurement of electrolytic or solid resistance through a range of from 0.01 to 50,000 ohms. The design of this instrument is especially adapted for rapid measurement of resistance, having switches on the dial principle. The rubbing contacts of

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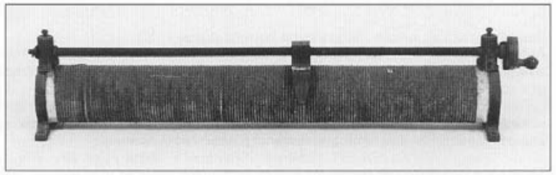

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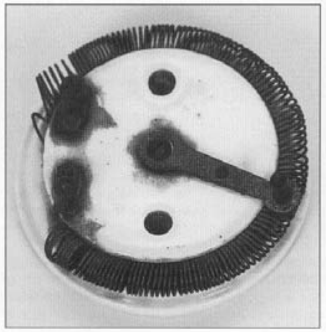

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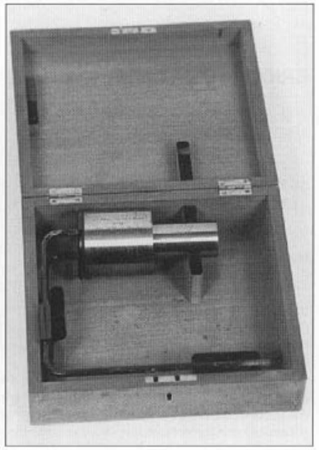

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the switches are of ample cross-section and enclosed in the case of the instrument. The slide wire is carefully selected for uniformity of cross-section and contact is made to it by an improved form of 'jockey' which enables either continuous or tapping contact to be made".

060 RHEOSTAT c1883 S.
1799 Signed: G.P.O. 502 ("8 10\83" handwritten on the base)

Base diameter 101; height 66.
A mahogany base holds a brass cylinder with a (cracked) glass top, enclosing a silver metal disc scale (0-275), which can rotate, its position being recorded by a pointer secured to the cylinder. Mounted on an ebonite arc on the base is a curved brass resistance bar, with three sections labelled "300", "G.P.O. 502", and "600". There are four holes in the bar, with two keys of brass and ebonite.

061 RHEOSTAT Late 19 early 20 C. G.
1710 Unsigned

Length 627; maximum height 148; cylinder diameter 66.
A cast-iron cylinder, on two feet, has a coil wound on an asbestos insulator. A screw-thread above the coil moves a brass contact. A wooden handle turns the screw thread.

062 RHEOSTAT Late 19 early 20 C. G.
1741 Unsigned - numbered "1241".

Diameter 86; height 38.
A white ceramic base holds two brass contacts and a wire coil in the shape of an almost complete circle. An arm, contacting the coil, is pivoted from the centre top of the base.

063 STANDARD RESISTANCE Late 19 early 20 C. G.
4335 Signed: = 1 Ohm at 15.2 Cent No.11. Elliott Bros London

Height 215; diameters of cylinders 66 & 36; diameter of wires 7; case 288x255x187.
A standard resistance coil is housed in a water-tight brass double cylinder, with a hollow centre. On top of the upper cylinder is an ebonite disc, and two stout copper wires rise in parallel out of the cylinder, bending in two right-angles. They are held by a plate and two screws, and the free ends show the remains of the mercury from the contacts in which they would have been placed.

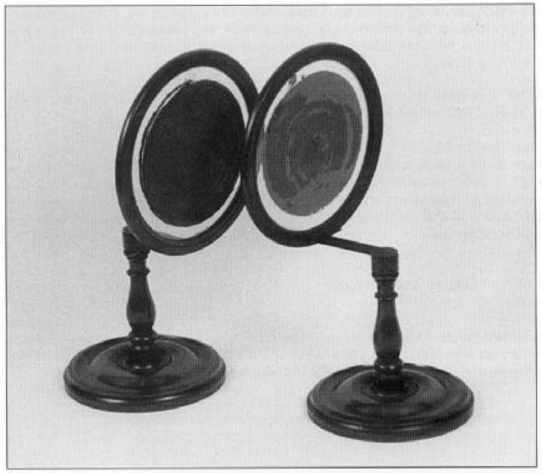
An unknown resistance is determined by comparison with such a standard resistance via a bridge.

The Elliott Brothers 1895 Catalogue (p.30) advertised standard resistances, from 0.1 to 10,000 ohms, made from platinum silver wire in nickel silver housings.

ELECTROMAGNETS AND INDUCTION COILS

"We have a priest here from Co. Louth, Dr,. Callan, the Professor of Science, and many are afraid he will blow up the College."...."But he is a very holy priest."

These are quotes, recorded in McLaughlin (1965,37), from a student at Maynooth, Lawerence Johnson, when he wrote to his folks at home on February 21 and April 9, 1855, and they seem to sum up the character of Callan very pithily. It was his coils which enabled him to produce dramatic results, like killing turkeys, and rendering unconscious a later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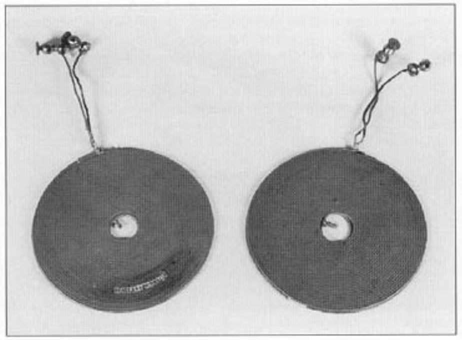
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Archbishop of Dublin, William Walsh. Callan's lasting claim to fame is as the inventor of the induction coil in 1836, and Maynooth retains original coils and other apparatus made and used by Callan in his researches. This section of the Catalogue includes Callan's primaries, secondaries and complete induction coils, and also related instruments acquired later by the Museum.

*When a soft-iron bar - the "core" - is surrounded by a coil of wire carrying a current, the core becomes magnetised, and the system is called an electromagnet. Callan, with the help of the local blacksmith, James Briody (McLaughlin 1965,58), constructed a large "horse-shoe" electromagnet (**068**), the coils being wound in different directions on each end of the bent bar, so that they had opposite polarity. When current was passed through the coils, this magnet had an impressive lifting capacity. McLaughlin (1965,70) records that Callan demonstrated the strength of his magnet by challenging a team of "robust young men" to try to separate the keeper [i.e. an iron bar held by magnetism to the poles of the magnet] when the current was on. The team lost. "Then the professor plays a little trick. He cuts the current as the team makes a mighty heave: the magnet is no longer active and the members fall in a heap on the floor, much to the amusement and applause of the on-lookers".*

*These effects were not new, although the power of his electromagnet was unsurpassed at the time. Callan's original contribution had two parts. To the coil consisting of a small number of turns of thick wire around the core - called the "primary" - he added an unconnected coil consisting of many turns of fine wire - the "secondary". He also constructed a means of interrupting the current to the primary, his "repeater" (**102**), using the escapement of an old grandfather clock. He found that, when the current was interrupted rapidly in the primary circuit using his repeater, a prodigious charge was produced in the secondary, although it was not connected to the primary. This was the world's first induction coil, completed by 1836 (McLaughlin 1965,72).*

064 APPARATUS FOR SHOWING INDUCED ELECTRIC CURRENTS 1859-1864
1589 Signed: Horatio Yeates Dublin **838-9**

Base diameter 231; height 558; coil housing diameter 308.
Each of two flat coils is supported vertically on a glass plate in a circular mahogany frame. The frame is fixed to a turned mahogany base and pillar by an oxidised brass bracket. The wires are covered with silk and insulated with a thick layer of shellac varnish. The ends of the coil are exposed at the centre and at the edge.

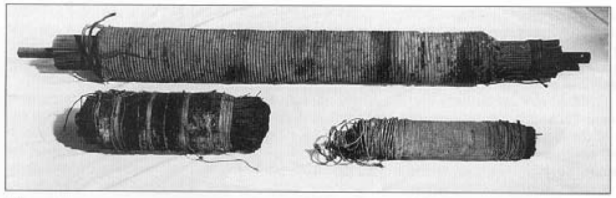
Ganot (1906,989) records that this apparatus was devised by the Italian scientist Carlo Matteucci (1811-1868), for showing the development of induced currents by the discharge of a Leyden jar (see page 85). Matteucci is best known for his work, carried out between 1836 and 1844 on animal electricity (Gillispie 1981,IX,176). However, McLaughlin (1955,838-9) reports that the apparatus was first found described in a letter of Callan's in Sturgeon's Annals of Electricity *in 1836. The coils are placed face to face, and a Leyden jar is discharged into one of them. A person holding two brass handles, connected to the other coil, receives a shock, which increases in intensity as the two coils are placed closer to each other.*

Horatio Yeates (1834-1906) traded at several Dublin addresses in the years 1859-1864, before emigrating to London, and then to South Australia (Morrison-Low 1989,42&139).

065 APPARATUS FOR SHOWING INDUCED ELECTRIC CURRENTS c1877 R.
1590 Signed: YEATES & SON, DUBLIN **838-9**

Diameters 115 & 116.
Each of two flat coils, coloured red on one side and green on the other, consists of a double strand of wire wound concentrically and joined at the centre. The wires have brass contacts at the outside ends.

This is a simpler arrangement of the previous apparatus for showing induced electric currents. Yeates (1877,318) offered "Large flat coils, to use with powerful batteries, for



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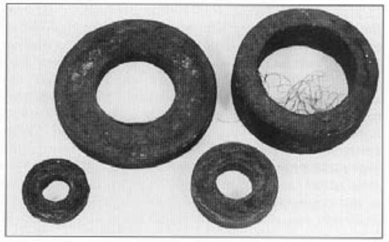

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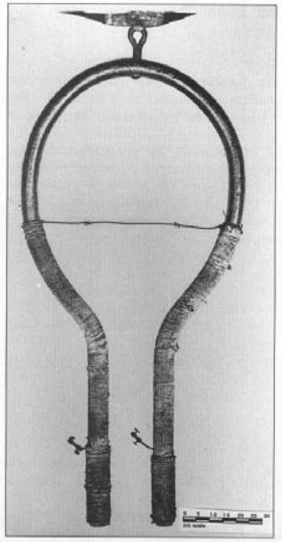

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showing attraction and repulsion of parallel currents".

066 PRIMARY COILS c1857 R.
1796 Unsigned - attributed to Nicholas Callan

Lengths 1360, 1115 & 400; maximum diameters 121, 22 & 80.
Three. The largest has a solid cylindrical iron core (with one squared end) surrounded by a bundle of wires. An insulated coil of heavy copper wire is wound around this system. The thinnest coil has a core consisting of a hollow iron tube, with a single insulated wire wound around it. The smallest has a bundle of wires as a core, with ten heavier wires in the centre. The insulated copper wire is wound around this core.

In 1838, George Henry Bachhoffner (1810-1879), the founder of the Polytechnic Institution in London, described a coil which he made with a core of insulated iron wires, and this gave better results than a coil with a solid core (Fleming 1893,11&15, Hackmann 1989,238). Callan suspended his investigations into electromagnetism in 1837 until the beginning of 1855 when, he states, "I made a long series of experiments on the various parts of the induction coil and apparatus" (Callan 1857,324). He described a coil in which a secondary circuit of insulated iron wire, rolled up tightly into a cylinder, formed not only the secondary circuit but also the core of the primary. Callan went on to describe the advantages of this arrangement over the divided core. However most of Callan's surviving coils have the Bachhoffner-type core [but using uninsulated rods], including those coils dated after 1857.

067 SECONDARY COILS c1857 R.
1796 Unsigned - attributed to Nicholas Callan

Diameters 125, 165, 290 & 330; wire diameter 0.03.
Four secondary coils consisting of insulated fine iron wire.

In 1857 Callan reported that iron wire was superior to copper wire for his secondary coils: "When the secondary coil is made of iron wire, the magnetic power it will receive from the primary current, and from the magnetic inductive force of the core, will be far greater than if it be made of copper wire" (Callan 1857,327). He discovered the advantage of using iron wire while experimenting with a coil in which the secondary coil also formed the core. In the same paper, Callan goes on to describe "an improved method of insulating the secondary coil" (pp.334-6), by drawing it through melted rosin and bees-wax. The varnish had hardened if the coil was wound at a distance of about 25 feet from the stove in which it was heated, and the wire could be insulated at a rate of 8000 feet an hour. The layers were separated by paper used in copper-plate engravings saturated with a solution of gutta-percha [a latex exuded from certain trees] in oil. These secondary coils are insulated in this way.

068 CALLAN LARGE ELECTROMAGNET 1836 R. 611
1660 Unsigned - attributed to Nicholas Callan and James Briody.

Height 1705; width 775; iron core diameter 60.
An iron bar is bent into a horse-shoe shape, with long parallel ends. Part of the curved bar, and all of the long ends, are wound with thick insulated copper wire, and the poles are double wound.

McLaughlin (1955,611) records that: "The iron core weighs 15 stone; the primary originally consisted of seven coils of copper wire, each coil containing 70 feet of wire, 1/6 inch in diameter. These coils could be connected in series or in parallel. The secondary coil contained 10,000 feet of copper wire 1/40 inch in diameter. This machine was capable of giving quite high voltages. A small model of it was exhibited in London in 1837, where it achieved great notoriety. Clarke's first medical coil, and the machines of Backhoffner, Sturgeon and others, were inspired by this model. Used as an electro magnet, the large instrument had a lifting power of several tons". Some of the primary windings and

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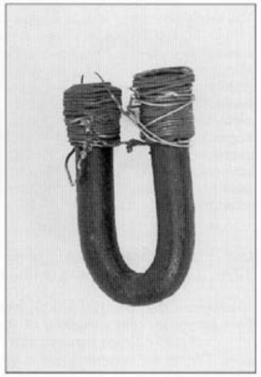

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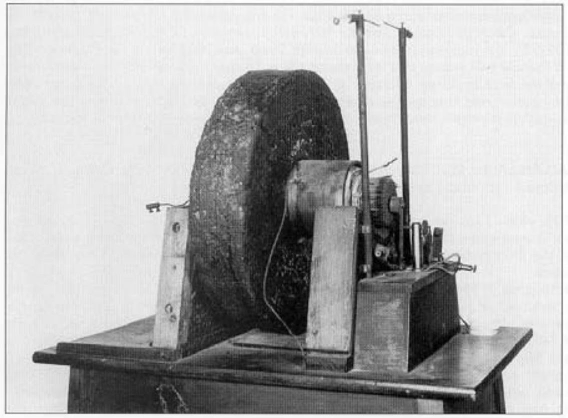

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the secondary coil are missing. The iron core was made by the Maynooth village blacksmith, James Briody.

This important instrument is the earliest preserved induction coil. The World's first induction coil, which was wound on a straight iron bar, was presented to Downside Abbey in England in May 1837 (McLaughlin 1965,72). See also entry ***096.***

069 ELECTROMAGNET c1877 R. 845.1
1722 Signed: YEATES & SON DUBLIN

Base 215x140x22; height 190; coil housing diameter 57; core & wire diameter 25&3.
A mahogany base, on four feet, has a rectangular mahogany support for a U-shaped iron bar. On each arm of the bar is a brass-bound coil of thick, insulated copper wire. The electromagnet has an iron roof-shaped keeper with a hook on top.

Yeates (1877,335) advertised a "Small Electro Magnet, horse shoe form, with stand, &c."

070 ELECTROMAGNET Mid 19 C. G.
1797 Unsigned - attributed to Nicholas Callan

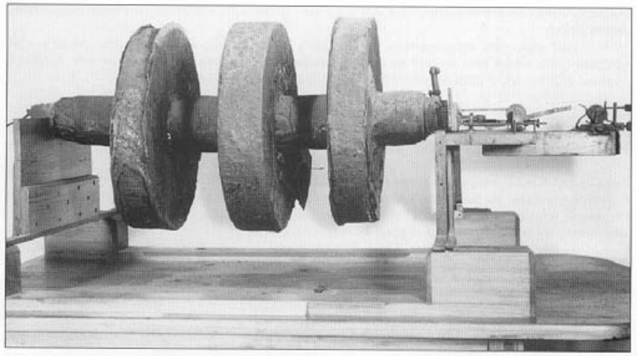
Height 225; bar diameter 36; wire diameter 2.
A rough-cast iron bar, bent in the shape of a U, has copper wire coils around each pole, the wire insulated with red windings. A hole at the base of the U-turn suggests that the electromagnet was once mounted on a base. There is an iron keeper, in the shape of a T, with a cylindrical handle.

071 CALLAN MEDIUM SIZED INDUCTION COIL c1857 R. 612
1659 Unsigned - attributed to Nicholas Callan.

Secondary coil diameter 530, width 108; ebonite cylinder diameter 155; primary coil length 380.
The primary coil of heavy copper wire, insulated with cotton thread, is wound on a bundle of annealed iron wires. The primary is insulated from the secondary by an ebonite cylinder. The secondary coil is of light iron wire insulated with melted rubber and bees-wax. The coil is fitted with a McGauley type interruptor (see below): a vertical iron bar is secured at the bottom, and has a small iron cylinder attached to the upper end, which makes or breaks contact with the core of the electromagnet. A turned brass pillar holds a screw, which makes or breaks contact with the bar. The coil is also fitted with a Rühmkorff-type commutator (**096**), consisting of a mounted ebonite cylinder which can be turned by an ebonite handle: the cylinder is fitted with two brass plates, which make alternating contact with two brass springs. There are two pillars, which hold point electrodes with glass handles. The apparatus sits on boxwood supports on a mahogany table.

Callan (1857,327-8) described his newly-made coil with a secondary of iron wire of 21,000 feet (later increased to 50,000 feet), which he demonstrated to the Dublin Meeting of the British Association for the Advancement of Science in 1857. McLaughlin (1965,73) records that Callan built "huge coils as well as medium-sized ones, and with great liberality he presented them to men of science and institutions in different parts of the world".

James William McGauley (c1806-1867), who was Professor of natural philosophy to the Board of Education in Ireland from 1836-1856, was an "independent inventor" of the "automatic hammer contact breaker", a "first-rate and now multifariously and universally employed device" (McLaughlin 1965,118). Several other people introduced similar devices at around the same time, but McGauley's description to the Liverpool Meeting of the British Association for the Advancement of Science in 1837 seems to have anticipated the others (Hackmann 1989,241). McGauley used a mercury contact-cup, but this was soon replaced and the interruptor became the well known "trembler" of the electric bell, still used today.



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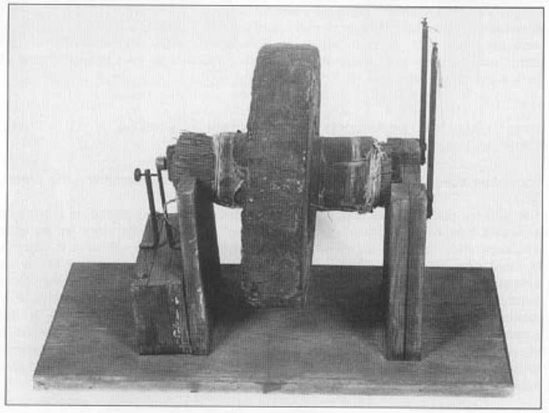

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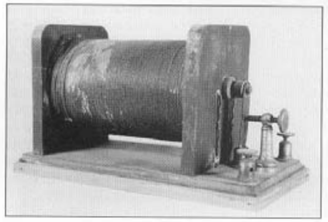

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072 CALLAN GREAT INDUCTION COIL c1859-1863 R. 613
1070 Unsigned - attributed to Nicholas Callan

Primary coil length 1090, maximum diameter 150; secondary coil diameters 530, 550 & 530, widths 90, 107 & 90.
A cylindrical bundle of annealed iron wires forms the core, about which a primary of heavy copper wire, insulated with tape, is wound in three layers. The primary coil is insulated with several layers of thin sheet gutta-percha, cemented with a paste of gutta-percha, resin and bees-wax dissolved in boiling oil. The secondary consists of three separate coils of fine iron wire, each similar to the secondary on the Medium Coil (**071**). The secondary coils are so arranged as to divide the primary into four equal parts, the planes of the coils being perpendicular to the axis. In each coil, the ends of the windings are left projecting so that they can be joined in series or in parallel. Callan used about 150,000 feet of wire in the secondary (Callan 1863,413). The contact breaker is an automatic mercury break of the type developed by Callan in 1858 (Callan 1858,255-259 - **102**), but it is now incomplete. The coil is also fitted with a Rühmkorff-type commutator (**096**), whose drum has an elliptical section. The coil is now mounted on a specially-constructed boxwood table.

*Callan (1863,413) reports that he made an induction coil "of considerable power" in 1859-60, with the secondary in three parts. In early 1863 he improved it with a new primary coil and core, and with better insulation between the primary and secondary. With these modifications, he produced sparks 15 inches in length across a point and plate arrangement (**181**) using three cells of the Maynooth battery (**055**). (To produce a 15-inch spark, a voltage of 600,000 volts is required - M. Casey, personal communication). With this coil, Callan carried out many experiments on sparking potentials and on the influence of the shape of the electrodes on the character of the spark produced. As a result of these experiments, he discovered a method of rectifying high tension alternating current, which was employed in suppressing the reverse current in early X-ray tubes (McLaughlin 1955,613). He also constructed two large condensers (**105**), which he used with the coil to reduce the spark at the break in the primary.*

Fleming (1893,20) reports Rev. Gerald Molloy as stating that the construction of this coil was started by Callan some years before his death, and that it was then left in an unfinished condition.

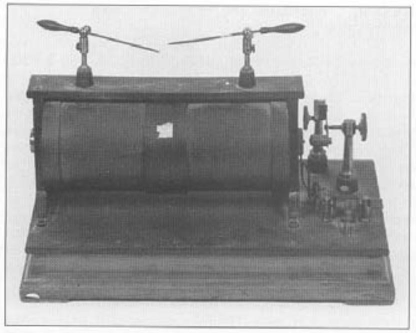
073 CALLAN SMALL-SIZED INDUCTION COIL c1857 R.
1658 Unsigned - attributed to Nicholas Callan

Secondary coil diameter 48, width 102; primary coil diameter 130, width 390.
This is similar to the medium-sized coil (see entry **071**), except that it has a core of iron wires of different diameters: thick in the centre, then very thin, then intermediate. In this case, the primary coil is covered in cloth, rather than an ebonite cylinder.

074 INDUCTION COIL 1865-1877 G.
1803 Signed: Made by Yeates & Son Dublin.

Base 288x111; height 123.
A mahogany base holds two vertical ebonite supports for a horizontal coil. The interruptor is of the McGauley type (see **071**). On the base, which is mounted on a later boxwood frame, there are two brass screw contacts.

Yeates & Son (1877,p.36) advertised a variety of induction coils, which could produce sparks of length one-eighth of an inch to five inches, all of which had built-in condensers, and all but the smallest equipped with a commutator also. They are described as having "Improved and Permanent Insulation". However, the manner of construction and the quality of the finish of this example do not seem to be of the same standard as those illustrated, so this coil may be of an earlier date.



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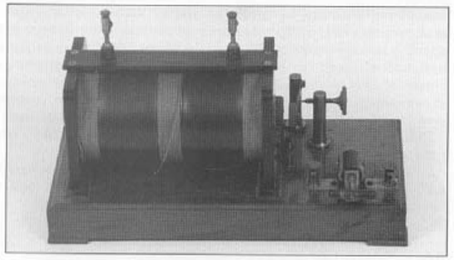

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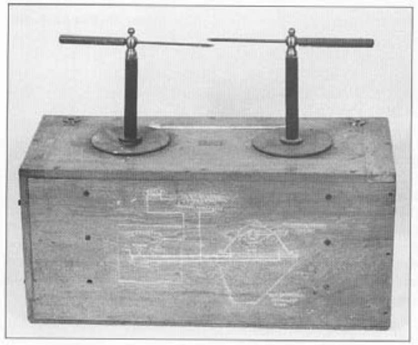

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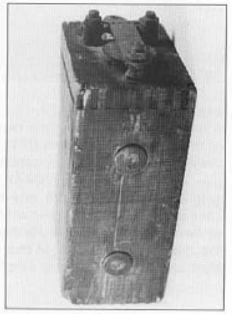


075 INDUCTION COIL c1877 R.
1811 Signed: Yeates & Son, Dublin.

Base 573x302x97; height 405; coil diameter 170.
A mahogany base, with an ebonite top, holds two tapering vertical supports, and a horizontal bridge, with the ebonite-covered horizontal coil inside this frame. At one end is a McGauley type interruptor mechanism (see **071**). Also at this end is a Rühmkorff commutator (**096**) of ebonite and brass. On the bridge above the coil are two ebonite mounts for short turned brass pillars with screw contacts. Clamped to these contacts are two pointed electrodes with turned ebonite handles.

This is probably one of the coils having "Improved and Permanent Insulation" - see previous entry.

076 INDUCTION COIL c1896 R. **751**
1593 Signed: Yeates & Son Dublin

Base 444x205x58; height 280; coil housing diameter 127.
A mahogany base, with four feet, holds two vertical ebonite supports with an ebonite bridge on top. Within this frame sits the ebonite-covered horizontal coil, with string bindings at its ends and in the centre. At one end of the base is a McGauley type interruptor (see **071**) of brass and iron, and a Rühmkorff commutator (**096**) of ebonite, copper and brass, with an ebonite turning handle (broken). Two ebonite bosses on the ebonite bar at the top of the coil support brass screw contacts.

This coil, which forms part of the gift of apparatus given to the Museum by the family of Professor A.W. Conway, was used by Marconi in his pioneering experiment at Dun Laoghaire in 1898, when he transmitted messages from a boat out in the harbour back to land (McLaughlin 1955,751) - see page 14. As a result, the Dublin Daily Express *became the first newspaper in the world to publish news received by radio - the results of the Dun Laoghaire Regatta of that year.*

077 INDUCTION COIL Post 1917 R.
Signed: SUPPLIED BY T.H. MASON 5 & 6 DAME STREET, DUBLIN.

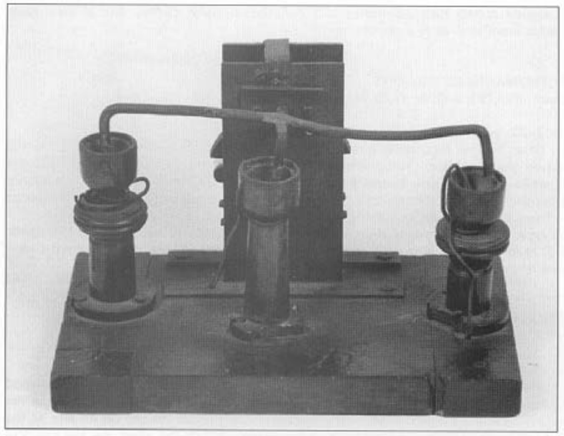
Housing 762x359x318; height 622.
A large boxwood housing conceals the coil. On top, two ebonite discs and pillars lead to brass conductors, with electrical contacts and screw clamps for ebonite-handled point electrodes. There are five brass terminals at one end, labelled "1", "2", "3", and "CONDENSER". A circuit diagram etched on front includes "DC MAIN", "PRIMARY. RESISTANCE", "END. OF. COIL 100V 200V", "200V FOR DRIVING MOTOR", and "6. LBS. MERCURY NEEDED. FOR BOWL".

Thomas H. Mason traded at this address from 1917 (Morrison-Low 1989,131).

078 INDUCTION COIL (FORD MODEL T) Patented 1914
Signed: "PATENTED APR 7, 1914 TRADE MARK K-W MADE IN U.S.A.

Housing 130x85x53.
A rough boxwood housing conceals the coil. On one end is an interuptor mechanism, with a disc connecting either to a contact on an upper brass plate, or the core of the coil. The core consists of a bundle of wires.

A card with the exhibit reads: "Callan Induction Coil: Used for producing sparks in the cylinders of the engine of a Ford Model T car, c.1920. Presented by Rev. Dr. Michael Casey, O.P., Maynooth College, 24 July 1966".



102

103

*was used as a dielectric. Ganot (1906,1062) illustrates the use of this type of interruptor with the Marconi spark gap transmitter (**164**). Very rapid interruptions were required to produce up to 30kV across the coil. AC motors of the type shown were also sold separately by Griffin.*

102 CALLAN REPEATER 1837 R. 610
1723 Unsigned - attributed to Nicholas Callan

Base 264x157x22; height 165.
A mahogany base holds three mahogany wooden mercury cups, on turned pillars, and also the modified escapement mechanism of a large clock. A metal and ivory handle turns a cogged wheel, and the axle of a double ratchet, which engages the cogs, is connected to a horizontal copper bar. The axle, and the ends of the horizontal bar, are bent to dip into the mercury cups. On rotating the crank handle, the pinion wheel causes the bar to execute a rapid see-saw movement. This causes the end pieces to make and break contact rapidly with the mercury in the two side cups. These, and the centre cup, were connected in series in the primary circuit of the induction coil.

Using this instrument, Callan was able to achieve more than fifty interruptions per second (Casey 1982,225), and his experiments lead him to the discovery that the severity of the shock produced by an induction coil is directly related to the rate of interruption of the primary current. Callan (1857,324) records: "In April 1837 I published, in Sturgeon's 'Annals of Electricity', a description of an instrument which I devised for producing a rapid succession of electrical currents in the coil by rapidly making and breaking communications with the battery. This, as Mr. Bachhoffner says in one of his papers published in Sturgeon's 'Annals', was the first contact-breaker ever made".

103 STARTING SWITCH Early 20 C. G.
1788 Unsigned

Foot span 208; housing 171x171x95; height 219.
A black metal cage houses two horizontal coils wound on ceramic cores. A sprung switching handle on top of the cage has seven contact points. The housing has a small copper coil on top and three terminals at the side.

CONDENSERS (OR CAPACITORS) AND LEYDEN JARS

"The process called condensation of electricity *consists in increasing the capacity of a conductor by bringing near it another conductor connected with earth. The two conductors are usually thin plates or sheets of metal, placed parallel to one another, with a larger plate of non-conducting material between them" (Deschanel 1891,606). "A condenser is an apparatus for condensing a large quantity of electricity on a comparatively small surface. The form may vary considerably, but in all cases consists essentially of two insulated conductors, separated by a non-conductor, and the working depends on the action of induction" (Ganot 1890,737). Condensers are now called capacitors, and the insulating materials are called dielectrics.*

*The original condenser was the Leyden Jar (**108-111**). It consists of a glass bottle with metal foil inside and out, the foil layers being the conductors, and the glass the insulating material. The jar is charged by connecting one of the coatings (as the foil layers are called) with the ground, and the other with the source of electricity. Turner (1983,189) records that the true inventor of the jar was probably the German experimenter, Ewald Georg von Kleist (c1700-1748) in 1745. But the jar is called after the Dutch town where Pieter van Musschenbroek (1692-1761) found, in early 1746, that an enormous shock was received when a glass jar containing water was electrified. Gillispie (1981,VII,403) records that von*

IV

M.T. Casey,

Nicholas Callan, Priest Professor and Scientist,

Physics Education, Vol.17, 1982, pp.224-234.

Nicholas Callan—priest, professor and scientist

Michael T Casey

Nicholas Joseph Callan (1799–1864) was an Irish priest and professor of natural philosphy at Maynooth Seminary in Southern Ireland. He was a pioneer in the study of electricity, and among the devices that he constructed were batteries, electromagnets and electric motors. The device that he seemed most proud of, however, was the induction coil which he claimed to have invented. This claim was endorsed by Lord Rosse, President of the Royal Society, in 1864 in a letter to Dr Russell, President of Maynooth.

In 1857, at a meeting of the British Association for the Advancement of Science held in Dublin, Callan made his claim in the following words.

'It is now more than twenty years since I discovered the method of making the induction coil, or a coil by which an electric current of enormous intensity may be produced with the aid of a single galvanic cell—a coil which is now to be used for working the Atlantic Telegraph. Mr Faraday was the first who developed the laws of electrical induction; but he did not discover the method of making a coil by which a current of very great intensity may be obtained by means of a very small battery. This was first discovered in Maynooth College in 1836. In the summer of 1837, I sent the late Mr Sturgeon a small coil which he exhibited at a meeting of the Electrical Society in London and from which he gave shocks to several of the members ... This was the first induction coil of great power ever seen outside the College of Maynooth. The first notice of the discovery of the coil is found in a paper of mine published in the *London Philosophical Magazine* for December 1836 . . . In April 1837, I published in Sturgeon's *Annals of Electricity* a description of an instrument which I devised for producing a rapid succession of electrical currents in the coil by rapidly making and breaking communication with the battery ... Thus before April 1837 I had completed the coil as a machine for producing a regular supply of electricity'.

In order to appraise Callan's researches in the field of electricity we shall consider them under various headings, all closely interrelated but not in chronological order since many of them were carried out simultaneously.

Electromagnetism and the induction coils

Magnetism had intrigued man for centuries. With the advent of batteries it was soon discovered that a coil of wire carrying an electric current has an associated magnetic field and that when a current-carrying coil is wound round an iron bar, the bar becomes magnetic. Sturgeon and Faraday constructed powerful electromagnets and so did Callan, who used them to test the power of his batteries. The College Museum at Maynooth houses several of his electromagnets. The great horseshoe magnet stands more than 1.8 m high, weights more than 95 kg and has poles of diameter 63.5 mm. The ironwork was made by the village blacksmith, James Briody, and Callan wound around the poles heavy copper wire of 7 mm diameter insulated by wrapping tape around it. (This was in the late 1820s, long before insulated wire became a commercial commodity.) This huge electromagnet could lift more than 1000 kg when supplied with current from Callan's battery.

Callan's experiments were influenced by those of Henry and Page in America who independently discovered the phenomenon of self-induction. (Charles Grafton Page himself is sometimes credited with the invention of the induction coil around this time.) When the current flowing through a spiral of copper ribbon was interrupted, a shock was felt if the ends of the ribbon were held in the hands. Callan replaced the ribbon used by Henry and Page in their experiments by copper wire and, very importantly, wound the insulated wire on an iron core and obtained shocks of much greater intensity. In his early investigations he tried cores of various shapes and sizes—thick, thin, straight, horseshoe-shaped and square, but not ring-shaped. Thus, while he was in fact working along the same lines as Faraday, he was not imitating him.

In one of his first coils he wound two 61 m lengths of copper wire insulated with tape around a straight

Rev. Michael Casey *is Curator of The Museum, St Patrick's College, Maynooth, Ireland. After obtaining an M Sc he became assistant to the State Chemist from 1924–28. A PhD followed, before taking priestly orders in 1934. After eighteen years as Senior Science Master at Newbridge College, Co. Kildare, he became professor of chemistry at Maynooth College in 1957 until his retirement in 1977. His chief research interests are the chemistry of natural pigments and triphenylmethane dyes.*

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Rev. Nicholas J Callan 1799–1864

iron bar 2.54 cm in diameter. The wires were joined in series and the current sent through only one coil but the shock was from the full 122 m. Using one of his cells this apparatus gave shocks of great intensity and Callan used it to assess the power of his batteries. He persuaded his students to take shocks and from their reactions he judged the battery power—a rather original procedure, one must admit! He tells us that with 14 Wollaston cells the shock was so strong that the recipient felt the effect for some days. He adds that with 16 cells nobody could be persuaded to take the shock. There is a story that one student named William Walsh—later Archbishop of Dublin—became unconscious from a shock.

Callan was the first to recognise that the intensity of the shock depended on the rapidity of the break in the primary current. He constructed an ingenious device for interrupting the primary current extremely rapidly. It consisted of the escapement mechanism of a grandfather clock. He attached a crank handle to the escapement cogwheel and a thick copper bar to the rocker. This carried three projecting pieces of copper which dipped into mercury cups. On rotating the crank handle he got more than fifty interruptions per second. He called this device a 'repeater' and published an account of it in Sturgeon's *Annals of Electricity* in April 1837. The repeater is still preserved in the College Museum. It is important in the history of the nature of electromagnetic induction because it focused the attention on the significance of rapid change in the magnetic flux.

In his next experiment Callan used a primary coil of 15.24 m of thick copper wire and a secondary coil of 396.24 m of fine iron wire. This allowed him to increase the density of ampere-turns. In preliminary trials he sent the battery current through the primary coil and took the shock from both primary and secondary coils. His next step was to separate the coils. He found that the shock from the secondary was augmented and thus discovered the principle of the step-up transformer of modern high-voltage electricity. Callan now had all the elements of the modern induction coil except the capacitor. This was suggested 17 years later by Fizeau (1853). Callan used amalgamated copper contacts which dipped in and out of mercury covered with a layer of oil to prevent oxidation.

Callan sent a replica of his apparatus to Sturgeon who demonstrated it to members of the Electrical Society in London in August 1837. It certainly appears that Callan's example gave rise to a spate of induction coils from Sturgeon, Nesbit, Joule, Page, Bacchoffner and others. Bacchoffner explicitly acknowledged his debt to Callan in Sturgeon's *Annals* of 1838 and Sturgeon himself adopted Callan's exact specifications for the lengths of his windings.

In another coil the primary consisted of seven parallel sections each 21 m long and a secondary coil of 3050 m of very fine iron wire, all hand-insulated with a mixture of beeswax and guttapercha (rubber). With this formidable apparatus he obtained secondary currents strong enough to ignite the carbons in an arc lamp. No other experimenter at the time got results in any way comparable. Callan investigated various insulating materials and found that a mixture of beeswax and guttapercha gave the best insulation. The proof of its excellence as an insulator is given by the enormous sparks, 0.38 m long, obtained with his giant induction coil in 1837.

Callan now built his 'medium sized' coil—still kept in the College Museum. It has as core a bundle of thin iron wire, a primary coil of thick copper wire of 3.25 mm diameter and insulated with tape. The secondary coil consists of a few kilometres (thought to be about 10 km) of fine iron wire of 0.26 mm diameter insulated with his beeswax–guttapercha mixture. This coil has a diameter of 0.526 m and a thickness of 0.1 m. The diameter of the central opening which holds the primary coil is 0.15 m. The make and break mechanism is that invented by MacGauley of Dublin, a contemporary of Callan. This mechanism is still used in electric bells and induction coils.

The 'giant coil' which followed in 1837 is also kept in the College Museum (figure 1). The core consists of a bundle of iron rods about 1 m long. It carries the primary coil of thick copper wire, insulated with tape. There are three secondary coils similar to that of the medium coil and these coils are said to contain some 46000 m of fine iron wire, all hand insulated with the beeswax–guttapercha mixture. Fleming (1891) states 'When supplied with current from six cells of the

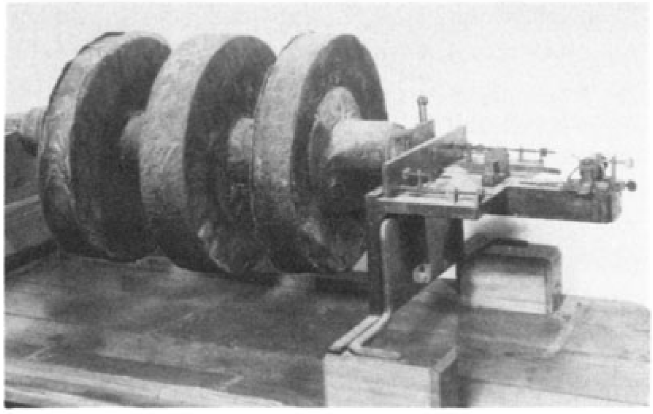

Figure 1 Callan's giant induction coil

Maynooth battery, sparks fifteen inches long can still be obtained'. Prior to 1890 a 15 inch (38 cm) spark was never exceeded. The same Fleming (1893) in volume II of his book *The Alternate Current Transformer in Theory and Practice* devotes several pages to the descriptions and illustrations of various Callan induction coils. In his article on 'The induction coil' in the *Encyclopaedia Britannica* (Fleming 1910) he gives Callan full credit for its invention. Callan sent induction coils to several people besides Sturgeon; he sent them to Lord Rosse, to Downside Abbey, to Dr Fennelly the Bishop of Madras, and to his former professor, Dr Denvir (see inset).

Electric motors

Callan's researches were inspired, one might say, by the motto 'Electricity in the service of man'. He sought to use electricity as a prime mover and to this end he constructed a motor driven by electricity from his batteries. His early motor was very simple in construction and the stator consisted of four pairs of electromagnets attached symmetrically within a metal frame. The rotor was an axle carrying eight arms or spokes with iron plates attached to their ends. The end of the axle carried a small wheel with eight teeth projecting from its rim. As the axle revolved these teeth made and broke contact with a piece of spring metal. Thus a series of pulses of current periodically energised the electromagnets, causing in turn a periodic attraction of the plates which made the axle revolve.

Callan experimented with a number of motors of this type with a view to using an electric engine to pull a train. He hoped to electrify the railway from Dublin to Dunlaoghaire (Kingstown as it was then called). He estimated from the results of his experiments that a magnetic engine as powerful as the steam engine on the Dunlaoghaire line could be built for £250. It would weigh less than two tonnes and could be maintained at an annual cost of under £300—about one-quarter of the cost of steam power. He designed an engine to propel a carriage and load at 8 mph (3.6 $m\,s^{-1}$). He met a number of snags: the batteries were unwieldy and spillable—and hence unsuitable for a moving train. Electromagnetic action is powerful only over short distances: large magnets interfere with one another. He learned that laboratory-scale results do not always apply to large-scale work and in the end he was forced to abandon the idea.

However, his experiments with electric motors were not futile. They led him to the discovery of the principle of the self-induced dynamo. One day while spinning the rotor by hand he was astonished to find that he obtained sparks from the wires leading to the terminals even though the motor was not connected to any battery. This observation is of first importance, and had he followed it up Callan would have added to his laurels the invention of the self-induced dynamo. Such recognition of his discovery would have anticipated that of Werner Siemens by 29 years. Callan noted that the current which produced the sparks was very feeble. This fact probably prevented him from following up his discovery, for at the time he was interested in big currents. Callan's communication of this event is dated 'Maynooth, 20 February 1838'.

Callan relied on his batteries to produce heavy currents at low voltages and on his induction coil to give currents at very high voltages. To measure the large currents from his batteries he used, as we have already seen, the lifting power of electromagnets and also the heating effects produced. He also devised a special type of tangent galvanometer which was afterwards much used by Stewart and Gee and, indeed, sometimes called by their names.

Voltaic cells

W H Wollaston invented the cell which bears his name in 1811. Callan improved this cell by using copper containers which not only acted as positive plates but also eliminated the use of glass or porcelain vessels. In his paper 'On a new galvanic battery' (Callan 1836) he described a very large battery consisting of 20 square zinc plates each 0.6 m × 0.6 m and covered with woven hemp nets to prevent contact with the copper. These plates had to be lowered and raised by means of a windlass and nearly 140 l of acid were required to charge the battery. He devised a system of thick wooden boards with recessed mercury troughs by which he could combine the 20 cells to form one or more cells. To us this appears a cumbersome apparatus but in Callan's day switches were not yet made. He states (Callan 1836) that 'So enormous is the quantity of electricity circulated by the battery (when all cells are in

Nicholas Joseph Callan (1799–1864)

Nicholas Joseph Callan was born on 22 December 1799 at Darver, between Drogheda and Dundalk, Co. Louth. The Callans were a well to do family of considerable local reputation who, in addition to farming extensively, were bakers, maltsters, brewers and distillers.

The fifth son of a family of seven, Callan's early education took place at the Dundalk Academy and from there he was sent to the Navan Seminary in initial preparation for the priesthood. In 1816 he entered the National Seminary at Maynooth, matriculating into the class of rhetoric where he read advanced courses in Latin, Greek and English. In his third year he read natural and experimental philosophy under Dr Cornelius Denvir, later to become Bishop of Down and Connor. Denvir was the first to introduce experimental method into his teaching. He was also interested in electricity and magnetism and his influence largely determined Callan's future researches.

After three years of literary and scientific studies, Callan entered the divinity school and spent a further three years reading dogmatic and moral theology, sacred scripture, Hebrew and canon law. In 1822 he was elected to a studentship on the Dunboyne Establishment which had been set up to enable the more distinguished students to engage in higher studies. He was ordained priest in 1823 and the following year was sent to Rome where he studied at Sapienza University and on 13 April 1826 obtained a doctorate in divinity. During his stay in Rome he became well acquainted with the work of Galvani and Volta.

On the resignation of his former professor Dr Denvir, Callan was appointed in 1826 to the chair of natural philosophy. With characteristic ardour the new professor embarked on his task of teaching mathematics, astronomy and physics. For texts he used Darré's *Treatises on Geometry and Trigonometry* which he completely revised and amplified. He incorporated these into his own *Praelectiones*. Part one deals with conic sections, mechanics, the laws of motion, various mechanical devices such as the lever, the inclined plane and pulley systems. His treatment of optics deals chiefly with mirrors, lenses and telescopes. The second part is a clear introduction to astronomy. Like Newton himself in his *Principia*, Callan employs a good deal of the Euclidean style of definition and demonstration. He provides his student with problems, such as to find the sun's altitude at a stated hour and season; given latitude and the sun's declination, to find when twilight begins; to find the time of the shortest twilight; to find latitude and longitude at sea, and so forth.

He sets down the principles of sun dial construction very clearly and shows how to fix up a dial, vertically or horizontally, so that it indicates correctly the solar time. He devotes considerable attention to the equation of time, the length of the year, the precession of the equinoxes, parallax and refraction. He makes use of the orrery to illustrate features relating to the moon and sun. He employs a 3.5 inch (8.9 cm) refractor telescope by Yeates of Dublin, so that students may see Jupiter's moons 'more clearly than ever Galileo saw them'. A special section of his *Praelectiones* is devoted to the 'Systems of the World' from the Ptolemaic to the Copernican, the merits and demerits of each being argued out; Kepler's laws and the work of Tycho Brahe come in for particular study to enable the student to find the synodic time of a planet and calculate its mean motion.

This 'gentleman's course' inaugurated and developed by Callan remained an integral part of the Maynooth curriculum until 1910 when the college came under the National University of Ireland.

From his *Praelectiones* we also gather that Callan was highly sensitive to the words of the psalmist: '*Caeli ennarant gloriam Dei, et opus manuum ejus annuntiat firmamentum*'—'The skies declare the glory of God and the vault of heaven proclaims his craftsmanship'. As a priest–scientist, Callan would be sympathetic to the view that, of all disciplines, science brings us nearest to the contemplation of the infinite, and so awakens in us a cosmic consciousness that somehow borders on religious experience.

Callan's scientific publications

1836 Sturgeon's *Annals of Electricity* **1** The Callan repeater (interruptor) 229–30; 'Electromagnets for magnetic and electric purposes' 295–302; 'Electromagnet of great power' 376–9; on connecting electromagnets 491–4

1836 *Phil. Mag.* **9** 272–8 Results of several years' experiments with electromagnets and transformers

1837 *Phil. Mag.* **10** 459 Reply to Ritchie's criticism

1838 Sturgeon's *Annals of Electricity* **2** 317–8 Priority of the Callan coil; the self-induced dynamo

1840 Sturgeon's *Annals of Electricity* **4** 333–4 Priority of Callan's electromagnetic engines

1847 *Proc. R. Irish. Acad.* **3** 471–6 New battery and experiments

1848 *Phil. Mag.* **33** 49–53 A new prodigious battery

1850 *Proc. R. Irish Acad.* **4** 152–7 Improved battery and experiments

1854 *Phil. Mag.* **7** 73–97 Illumination by Maynooth battery; galvanometers for large currents

1855 *Proc. R. Irish Acad.* **6** Illumination by the iron battery (title only)

1855 *Phil. Mag.* **9** 260–72 Single-fluid cell for illumination

1857 *Rept Brit. Assoc. Adv. Sci.* part 2 11–3 Improved induction coil

1857 *Phil. Mag.* **14** 323–40 The induction apparatus; high tension insulation

1858 *Phil. Mag.* **15** 255–9 Contact breakers and condensers

1859 *Phil. Mag.* **17** 332–4 Electrodynamic induction

1863 *Phil. Mag.* **25** 413–7 Callan's great coil: sparking potentials; the Callan point-plate valve

series–parallel combination), that on one occasion after having been active for more than an hour it rendered powerfully magnetic an electromagnet; platinum wire 1/30th inch (0.85 mm) thick was rapidly melted; and that copper and iron wires 1/12th inch (2.1 mm) thick were deflagrated in a most brilliant manner'.

Callan now experimented with the Poggendorff

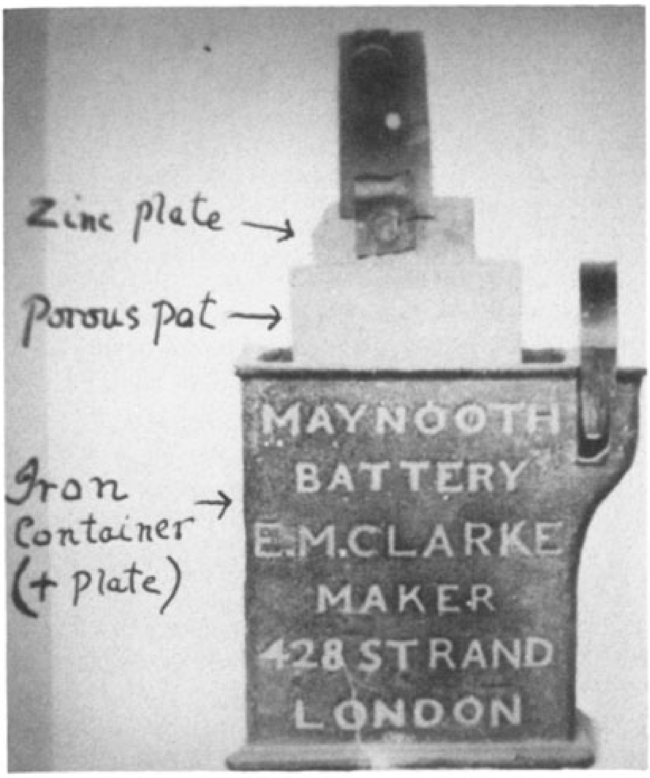

Figure 2 Callan's iron–zinc cell

dichromate cell and the Daniell cell. The former was rather wasteful of zinc and the latter had too high an internal resistance to give heavy currents. He next tried Grove's cell but platinum was far too expensive, even in those days. He next worked with the Bunsen cell in which carbon plates were used instead of platinum, but found it gave off very disagreeable fumes of nitrogen peroxide. Difficulties also arose in making good contact between the copper wires and the carbon.

In the College Museum there are some large carbon–zinc cells in glass containers. The zinc plates are cylindrical in shape, being about 0.63 m high and 0.24 m in diameter. The carbon poles are slightly taller and have a diameter of about 0.14 m. On analysing the incrustation on a zinc plate, I found it to contain ammonium chloride. This indicates that Callan used sal ammoniac as an electrolyte—the cell was in fact an original version of the Leclanché cell.

Callan now tried lead plates, lead plates coated with platinum black, and gilt lead plates—always of course in combination with zinc plates—and found them to give satisfactory results. He went on to try various other metals, all of which were inferior to platinum or platinised lead, with the exception of iron.

In 1846 he published a paper entitled 'On a new voltaic battery, cheap in its construction and use and more powerful than any battery yet made; and a cheap substitute for the nitric acid of Grove's platinum battery' (Callan 1847). In it he describes his cast iron cell. It was a cast iron container in which stood a thin-walled porous pot with the zinc plate standing in dilute sulphuric acid. The iron container held a mixture of sulphuric acid and nitre—a mixture which he found to be just as effective as nitric acid and much cheaper.

Callan now applied to the Trustees of the College for permission to convert the big Wollaston battery into a cast iron one. Using the zinc plates of the former he constructed 577 cells. This was reckoned to be the world's largest battery. It was at least twice as powerful as the Wollaston battery constructed on Napoleon's orders for the Ecole Polytechnique in Paris. On 7 March 1848 Callan demonstrated the power of his new battery before a large audience in the College. A large turkey placed in circuit was instantly electrocuted. An arc of blinding light of some 13 cm length was obtained between brass and copper terminals; carbon rods burned away too quickly for the length of the arc to be accurately determined. At this stage some of the copper leads fell off the zinc plates as the solder melted.

From these experiments and others Callan concluded that the cast iron cell was several times as powerful as the Wollaston cell of the same size and twice as powerful as the Grove's cell. Subsequently the cast iron cell was manufactured commercially by E M Clarke at the Adelaide Gallery of Practical Science, 428 The Strand, London (figure 2).

Callan had already found that cast iron withstood the action of nitric acid almost as well as platinum or gold. He made the further discovery that cast iron treated with nitric acid became 'passive' and resistant to weathering and patented the process. The College Museum still has the elaborately worded document conferring the patent rights. Attached to this is the Seal of Queen Victoria, a large cylindrical block of yellow sealing wax embossed with the Royal Seal and enclosed in a tin box.

Callan also experimented with electric lighting, that is to say arc lighting and limelight. By electrolysing acidulated water he got hydrogen and oxygen which game him some kind of oxy-hydrogen torch which heated up a lump of lime so that it gave out a brilliant light. This, he hoped, would serve for lighthouse beacons. Practical difficulties, however, militated against its use: hydrogen and oxygen form a highly explosive gas when mixed. Excessive work led to a breakdown in health entailing an interruption of his scientific studies and forcing him to take a long rest for the greater part of 1849 to 1851.

Callan died on 10 January 1864. His obituary in the *Dundalk Democrat* (17 January) stated:

'His extraordinary piety, his perfect simplicity and unaffected candour endeared him to everyone who knew him. For many years he was regarded by both professors and students of Maynooth with a

continued on p234

judged by university results. I would have expected girls who are capable of performing well in school physics to be more likely to continue in physics than their peers. It may be that the university has a socialising effect on the students such that students pace themselves with their peers and achieve only what is necessary to keep pace and retain their place in the peer group, thus producing lower mean marks than expected for exceptionally good subgroups. On the other hand, one might assume that the university system ranks and grades students correctly and one can then ask where the other potentially good women physics students go, or whether they even exist.

It is commonplace to say that we are throwing away half our potential physicists (Swarbrick 1981) through 'discrimination' (Deeson 1981). This is a serious and worrying problem but perhaps we should ask ourselves whether or not we are being realistic in assuming that the other half indeed exists in the form of available adequate physics students. If the women we find in universities are *not* more highly selected than the men, as studies of the women's scores suggest, then perhaps already we are attracting roughly the same proportion of the potentially good women physicists as of the men. Physics has a male image (Kelly 1981b) and nature, developed by males over the centuries. Perhaps it is unreasonable to expect all women to perform well in 'physics-male' and we should rather be asking our women to develop a related subject of 'physics-female' whose development techniques and bias reflect the abilities and interests of women.

It is possible that only 10% of women may wish to take physics after the obstacles of the secondary school system. The selection of these girls must however be rather random in terms of their ability to cope with university physics; otherwise the mean results presented above would not so closely match women and men. The suggestion here is that we should give serious consideration to the possibility that only 10% of our women can compete successfully with the men in our present subject, 'physics-male', and that in a similar way there may be a different but equally interesting, valid and useful subject, 'physics-female', which is better suited to all women and useful for only a small fraction of the men.

The bias of schools may be right; the physics discipline as we now know it may not be suitable for the majority of women. It may not be our attitudes to teaching that need revision, but that new developments need to be made in the discipline itself, led by women, which will lead to the subject becoming more balanced. The pointers may be there already. Look at astronomy compared to physics. Why is this subject less sexist? What properties in our physics courses show less sexual imbalance? Perhaps we can aim to produce a sexually balanced subject rather than trying to convert our potential students away from their existing gender.

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continued from p228

reverence and affection that could hardly be understood by those who did not witness his daily life; and they all deplore his death as an irreparable loss to the College which he at once edified by his virtues and adorned by his learning'.

However, were it not for the painstaking researches of the late Right Reverend Monsignor McLaughlin—himself a successor to Callan in the chair of natural philosophy and experimental physics and vice-president of Maynooth College—Callan's researches and discoveries could have disappeared entirely into oblivion. Maynooth College, and indeed the world of science, is indebted to Monsignor McLaughlin for putting Callan into true perspective and for preserving his name and fame for future historians of science.

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V

Extract from

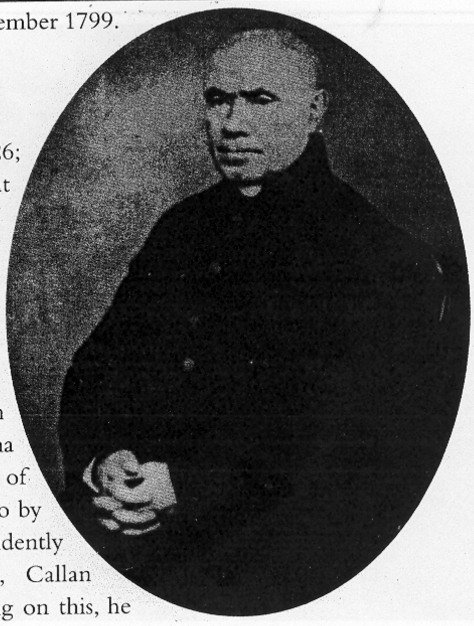
C. Mollan, W. Davis and B. Finucane, (editors)

Irish Innovators in Science and Technology,

Publ. Royal Irish Academy, 2002.

NICHOLAS CALLAN Physicist

Born: Dromiskin, near Ardee, Co. Louth, 20 December 1799.
Died: Maynooth, Co. Kildare, 10 January 1864.



Distinctions:
Awarded the Degree of STD, University of Rome 1826; Appointed Professor of Natural Philosophy at Maynooth 1826.

Callan's most notable contribution to electrical science was the Induction Coil, the forerunner of the modern step-up Voltage Transformer.

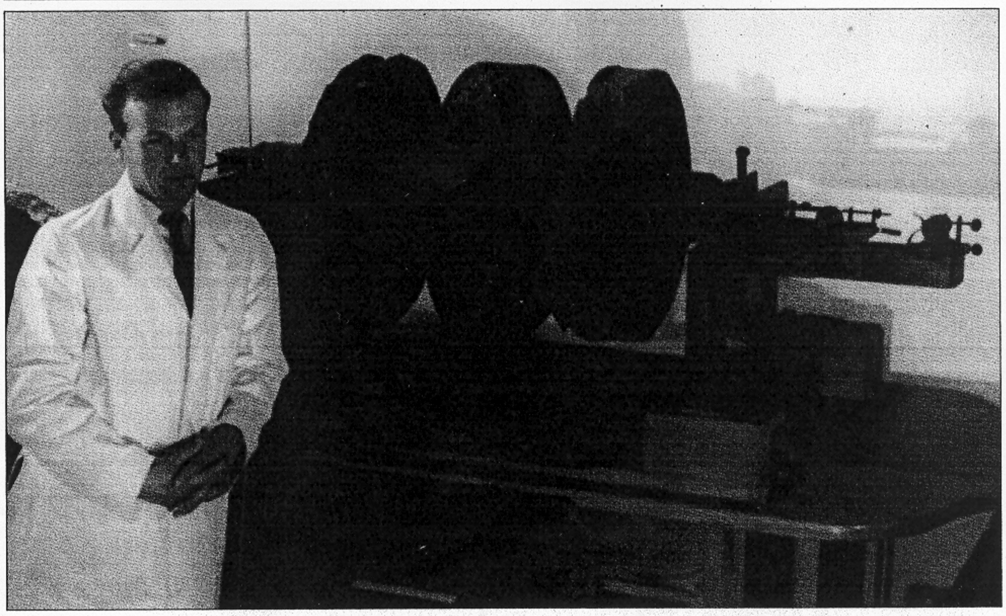
Influenced by his former professor, Dr Denvir, Callan early acquired a great interest in electrical phenomena in general. He constructed several electromagnets one of which had a lifting power of two tons. Influenced also by the work of Joseph Henry of Princeton, who independently discovered the phenomenon of self-induction, Callan constructed a coil for giving electric shocks. Working on this, he first separated the primary coil from the secondary and, more importantly, wound it round an iron core. This apparatus gave shocks of great intensity. Later he increased the number of turns of wire in the secondary coil and obtain sparks from the free ends. In his 'Giant' induction Coil there are three secondary coils connected in series. Each coil contains about ten miles of very fine wire insulated with a mixture of beeswax and gutta-percha. In 1837 this apparatus gave sparks fifteen inches long. Callan devised a 'point and plate' type of 'valve' which rectified the secondary current. This was used later in X-ray apparatus. Also, he was the first to note that the 'intensity' (voltage) of the secondary current depended, among other things, on the rapidity of interruption of the primary current.

Callan sent a smaller replica of this induction coil to his friend Sturgeon in London who demonstrated it to members of the Electrical Society of London. It evoked great interest amongst the scientific coterie at the time. It was copied by many of them.

The invention of the induction coil made it possible to produce X-rays. It also provided the means of studying electric discharges in rarefied gases. This later contributed to the elucidation of atomic structure.

Callan constructed electric motors and even drew up plans for a battery-driven train to ply between Dublin and Kingstown (now Dun Laoghaire). The plan fell through owing to practical snags.

To supply electric current for his researches Callan experimented with various types of battery. Eventually he arrived at a cast iron/zinc cell. A cast-iron trough acted as positive plate; it contained nitric acid. The negative plate was of zinc standing in a porous pot containing a mixture of sulphuric and nitric acids. This cell gave quite heavy current for a considerable period. It was subsequently manufactured commercially by the firm of E.M. Clarke at the Adelaide Galleries, 428 The Strand,

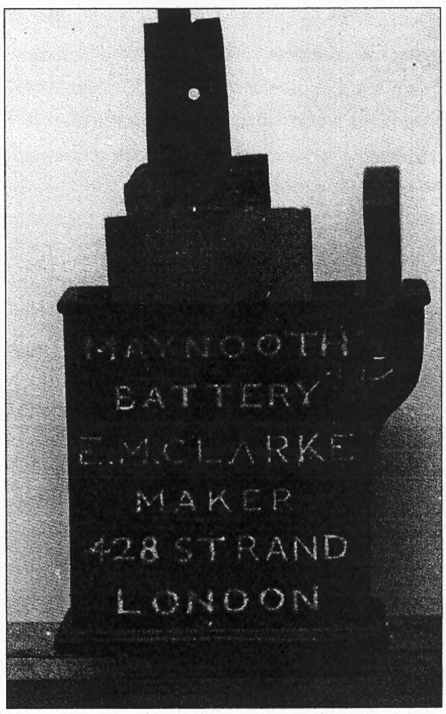


Callan's giant induction coil gave 15 inch sparks in 1837

London, who named it the 'Maynooth Battery'.

Callan found that the nitric acid rendered the cast-iron highly resistant to corrosion and obtained a patent for this process of protecting exposed iron-work from rusting.

The Museum at Maynooth houses Callan's induction coils, electric motors, his 'Maynooth Battery' and other interesting 'Callaniana'.



Callan's 'Maynooth Battery'

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Michael T. Casey: Nichoas Callan, Priest, Professor and Scientist, *Physics Education*, **17**,1982.

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Reverend Michael T. Casey, OP, 1902–1997.

VI

Extract from

E. Katz,

The history of electrochemistry, electricity and electronics

website: http://chem.ch.huji.ac.il/~eugeniik/history/callan.

Nicholas Joseph Callan

b. December 22, 1799, Darver, Ireland
d. January 10, 1864, Maynooth (near Dublin), Ireland

Nicholas Joseph Callan, Irish priest, scientist, and inventor, was a pioneer in the development of electrical science; inventor of the induction coil, which led to the modern transformer. He constructed a giant battery of 577 cells, producing enormous currents of electricity, to the delight, astonishment and danger of his students. Like Cavendish before him, he made an independent discovery of Ohm's Law. In applied science he devised several types of galvanic battery and influenced the study of high-voltage electricity. He also constructed one of the first DC electro-motors and wrote a patent on the protection of iron from rusting. Unfortunately, his name was forgotten and his inventions were attributed to other scientists.

Nicholas Joseph Callan was born on December 22, 1799, the fifth child in a family of six or seven, at Darver, between Drogheda and Dundalk, Ireland. His initial education was at an academy in Dundalk, run by a Presbyterian clergyman, William Nelson. His local parish priest, Father Andrew Levins, took him in hand as an altar boy and Mass server, and saw him start the priesthood at Navan seminary. He entered St Patrick's College Maynooth (near Dublin, Ireland) in 1816. In his third year at Maynooth, Callan studied natural and experimental philosophy under Dr. Cornelius Denvir, who was later to become Bishop of Down and Connor. Denvir introduced the experimental method into his teaching, and had an interest in electricity and magnetism. After ordination as priest in 1823, Callan went to Rome, where he studied at the Sapienza University, obtaining a doctorate in divinity in 1826. While in Rome he became acquainted with the work which had been carried out by Luigi Galvani (1737-1798), and by Alessandro Volta (1745-1827), pioneers in the study of electricity. On the resignation of Dr. Denvir, Callan was appointed to the chair of natural philosophy in Maynooth in 1826, and he remained in that post until his death in 1864.

Callan's Laboratory

During his life in Maynooth, with funding from friends and family, Callan began working with electricity. Electricity was still something of a toy, but he realised that with powerful batteries it could be put to practical and commercial use. The small priest must have seemed like an Irish Frankenstein - experimenting with electricity in his basement laboratory at Maynooth college, dishing out almighty electric shocks to unsuspecting volunteers, and electrocuting turkeys. Yet Reverend Nicholas Callan was one of Ireland's great inventors. He invented the induction coil, built the most powerful batteries and electromagnets of his time.

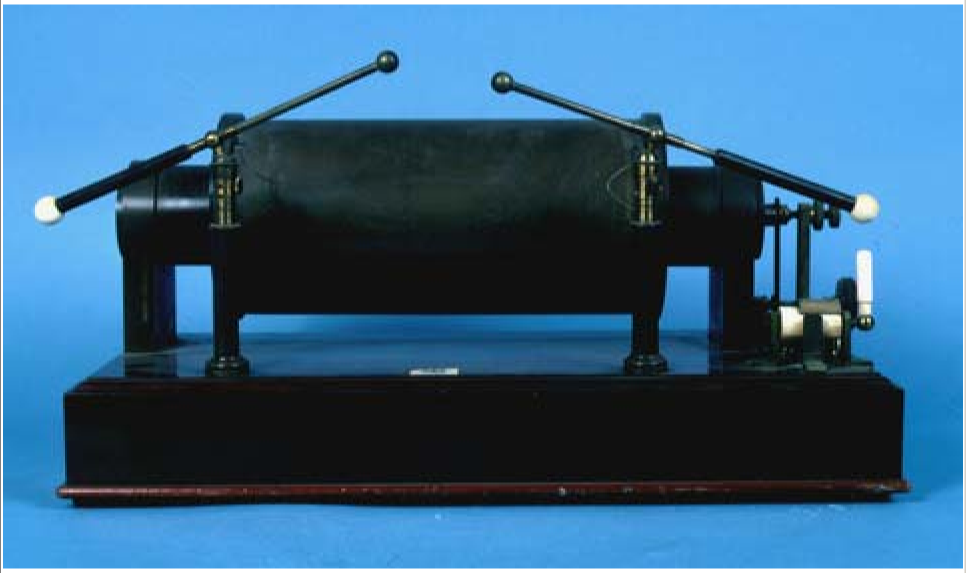
The "Great Coil" of Nicholas Callan, 1837

Callan's major claim to fame is as the inventor of the induction coil. Callan was influenced by the work of his friend William Sturgeon (1783-1850) who in 1825 invented the first electromagnet, and by the work of Michael Faraday and Joseph Henry with the induction coil. Working since 1834 on the idea of the induction coil, Callan developed his first induction coil in 1836. He took a horseshoe shaped iron bar and wound it with thin insulated wire and then wound thick insulated wire over the windings of the thinner wire. He discovered that, when a current sent by battery through a "primary" coil (a small number of turns of thick copper wire around a soft-iron core) was interrupted, a high voltage current was produced in an unconnected "secondary" coil (a large number of turns of fine wire). Callan's autotransformer was similar to that of Page's except that he used wires of different sizes in the windings.

Callan's induction coil also used an interrupter that consisted of a rocking wire that repeatedly dipped into a small cup of mercury (similar to Page). Because of the action of the interrupter, which could make and break the current going into the coil, he called his device the "repeater." Actually, this device was the world's first transformer. Callan had induced a high voltage in the second wire, starting with a low voltage in the adjacent first wire. And the faster he interrupted the current, the bigger the spark. In 1837 he produced his giant induction machine: using a mechanism from a clock to interrupt the current 20 times a second, it generated 15-inch sparks, an estimated 600,000 volts and the largest artificial bolt of electricity then seen.

At the left is the device which Callan built to make and break the primary circuit of the coil. He called it a Repeater, a usage not followed later in the century.

Callan redesigned his induction coil in 1837 by separating the coils and making only the secondary coil deliver electrical shocks. Callan sent one of his induction coils to Sturgeon in 1837 who then exhibited it at the meeting of the Electrical Society of London in August 1837. Sturgeon then built his own autotransformer but wound thick copper wire as a primary coil. He next wound thin wire as a secondary coil over a wooden core (bobbin), and then connected the two coils by wire. In building his coil Sturgeon in 1837 introduced a manual interrupter to control the current.



The induction coil added a sense of theatre to a great many nineteenth century scientific laboratories, not as a prop but as a principal performer. For example, without the induction coil neither radio waves, x-rays, nor the electron would have been discovered and exploited as they were. The first induction coils were developed by a now forgotten Natural Philosopher, Nicholas Callan of St. Patrick's College in Maynooth, Eire. Some impressive remains of his ventures can still be seen in Maynooth. Ruhmkorff received the pioneering credit for later work.

Nicholas Joseph Callan, Professor of Natural Philosophy

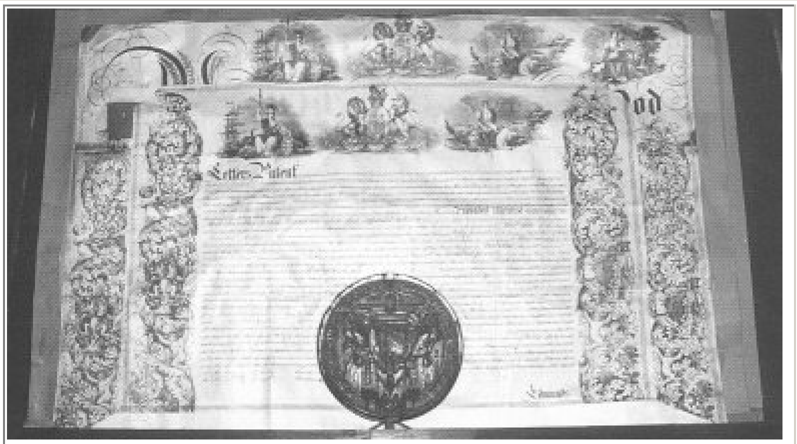
In view of the great importance of Callan's invention of the induction coil, one might wonder why he was forgotten, and his invention attributed to a German-born Parisian instrument maker, Heinrich Ruhmkorff (1803-1877). The answer is simple. Maynooth was a theological university where science was the Cinderella of the Curricula. Callan's colleagues often told him that he was wasting his time. In such an atmosphere Callan's pioneering work was simply forgotten after his death. Like all instrument makers, Ruhmkorff put his name on every instrument he made. "Ruhmkorff Coil" got into the textbooks. It was never challenged until Professor McLaughlin published his researches on Callan's publications in 1936, which incontrovertibly proved that the inventor of the induction coil was Nicholas Callan of Maynooth. The first acknowledgement of Callan as its inventor was in the 1953 edition of Gregory and Hadley's Textbook of Physics, revised by George Lodge, Senior Science Master at St. Columba's College, Rathfarnham.

In 1838 this intrepid priest stumbled on the principle of the self-exciting dynamo. Simply by moving his electromagnet in Earth's magnetic field, he found he could produce electricity without a battery. In his words, he found that "by moving with the hand some of the electromagnets, sparks are obtained from the wires coiled around them, even when the engine is no way connected to the voltaic battery". The effect was feeble so he never pursued it, and the discovery is generally credited to Werner Siemens in 1866.


Callan Cast Iron Battery


Callan Single Fluid Cell

With the need to produce reliable batteries for his researches in electromagnetism, Callan carried out important work in this area, inventing the "Maynooth" battery in 1854, and a single fluid cell in 1855. Previous batteries had used expensive platinum, or unsatisfactory carbon, for one of their plates, and zinc for the other. Callan found that he could use inexpensive cast-iron instead of platinum or carbon. In the Maynooth battery, the outer casing was of suitably treated cast iron, and the zinc plate was immersed in a porous pot in the centre. This required two different fluids, on the inside and outside of the porous pot. But he found also that he could make a simple and useful battery by dispensing with the porous pot and the two fluids, using a single solution. Callan would connect large numbers of these battery cells, and once joined 577 together, using 30 gallons of acid, to make what was then the world's largest battery. Since there were no instruments yet to measure current or voltage, Callan assessed his batteries by the weight they could lift when connected to an electromagnet. His best effort lifted two tons. When Callan reported it in the *Annals of Electricity*, a London professor came over to witness the spectacle, and was said to be incredulous.



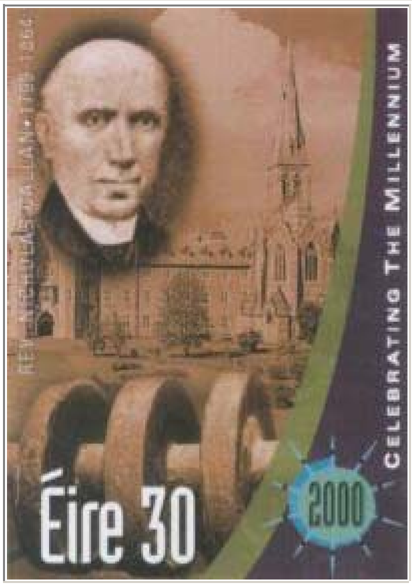
Callan's patent on the protection of iron from rusting

Callan's ingenuity knew no bounds and in 1853 he patented an early form of galvanisation using a lead-tin mix to protect iron from rusting, something he discovered when he was experimenting with various battery designs. His 1853 patent document, complete with an enormous royal seal from Queen Victoria, is displayed at Maynooth's new museum.

He also constructed electric motors. Callan probably also had one of the world's first electric vehicles, because in 1837 he was using a primitive electric motor to drive a small trolley around his lab. He even proposed using batteries instead of steam locomotives on the new-fangled railways. Callan later realised his batteries were not powerful enough, and indeed, it took another hundred years before battery-powered trains invented by another Irishman, James Drumm, were used on Dublin railways. With great foresight he also predicted electric lighting, at a time when oil was still widely used and gas was the next new thing.

He was a contemporary of Charles Parsons' father, the Third Earl of Rosse, who had a position on the Board of Visitors to Maynooth College. A student yarn relates how Callan called to Birr to see the telescopes, but for some reason was not admitted. When the Third Earl later visited Maynooth to see the induction coil, Callan sent his respects, but suggested that the noble lord should return to Birr to view the coil through his giant telescope! He was an eccentric character who was said to have used his students in his experiments to test the strength of electric voltage. Fortunately, there were no fatalities but he did manage to render a future Archbishop of Dublin unconscious. After this mishap he experimented with chickens. Maynooth College has a museum dedicated to the work and life of this priest scientist.

Nicholas Callan was a notable writer and translator of theological and ascetical works, he wrote about twenty religious books, one of which influenced the conversion of Newman. Nicholas Callan, holy priest and scientist died from natural causes at Maynooth on January 10th 1864.



As part of the Millenium celebrations An Post launched the 'Discovery' series of stamps to celebrate major scientific achievements in the second millenium. Included in the series is a stamp commemorating Reverend Nicholas Callan. Others featured in the series include Gallileo, Einstein, Marie Curie, and Thomas Edison.

This text has been compiled from the biographies of Callan available in the Internet:
(1, 2, 3, 4, 5, 6, 7).

HOME

(updated & corrected on May 17, 2003)

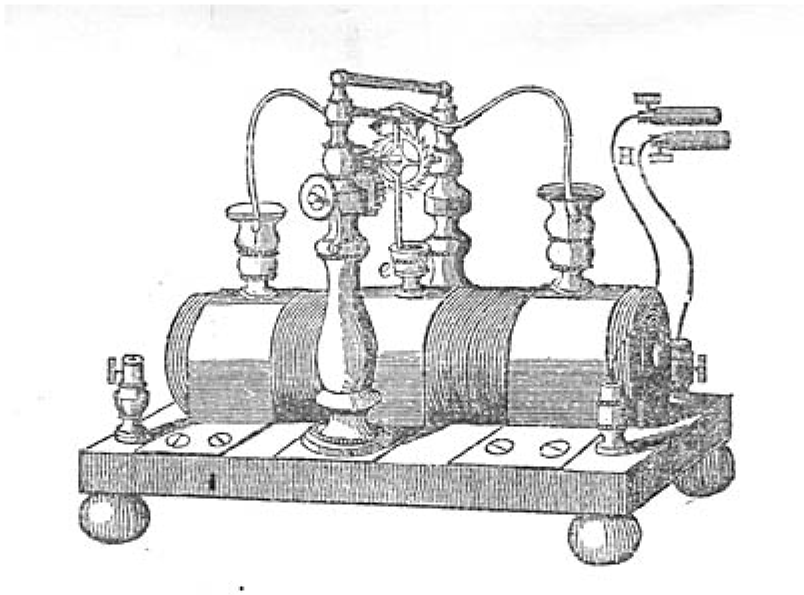
<u>VII</u>

Essay by

Dean .P. Currier (dpcurr@aol.com),

A Biographical History of induction coils,

posted on www.radiantslab.com/quackmed/Deanbio.html.



The Double Helix and Electrotome of Daniel Davis, Jr.

A BIOGRAPHICAL HISTORY OF INDUCTION COILS

By Dean P Currier

Michael Faraday's contributions in electricity changed the direction of electrotherapeutics. Almost immediately after the discovery of magnetoelectric induction by Faraday of England, and independently by Joseph Henry of the United States in 1831, inductive electricity was adopted by medicine for use in electrotherapeutics. Magnetoelectric induction is the process in which the magnetic field of a current carrying wire or device produces an electical or an electromotive force (EMF) in another wire or device located nearby without touching it. Magnetoelectric machines were soon constructed and marketed for electrotherapeutics because they were more reliable and convenient to use than the voltaic pile (battery) and static machines, and of course they were a new entity. The invention and development of the electromagnetic devices and their theory contributed greatly to the advancement of electrical science in the nineteenth century. The advances in electromagnetic technology led to the generation of electricity as an energy source, to the invention and development of the electrical light bulb, and to the development of the telegraph to advance rapid communication.(1)

Prior to 1831 Michael Faraday had anguished over a way to distinguish differences between electricity from a voltaic source and that from a magnet. Using the principles of his induction ring, he eventually built a device to generate electricity using a disc that revolved through a magnet and called it a "magnetoelectric machine." While building his magnetoelectric machine, he observed a spark with his soft iron ring and disc machine. He immediately wrote to his friend JP Hachette in France who called attention to Faraday's observation at the 26 December 1831 meeting of the French Academy of Science.(2)

Up to the 1830s only two ways of producing high voltages were possible. The oldest approach was the friction electrical machine that used a glass cylinder that when rotated rubbed against pads of various materials. Leyden jars (the first capacitors) were often used with the friction electrical machine to increase and store briefly electrical charges produced by the machine. Batteries were also used to produce voltages by varying the number of cells for a particular function. Many batteries had to be used to produce higher voltages, but until the end of the nineteenth century (after 1880) batteries were inconvenient to operate and very expensive. The induction coil offered hope for producing voltages inexpensively and conveniently.(3)

By 1832, experiments in electromagnetism were being conducted throughout England, Europe, and the United States. In the summer of 1832, the Paris instrument maker Hippolyte Pixii had devised two ways of producing sparks magnetically. Pixii had known about electromagnetism before learning about Faraday's spark produced by magnetism. During the 1820s in France, Pixii built the electromagnetic instruments used by Andre Ampere at the Ecole Polytechnique, and those used in the demonstrations of Claude Pouilett at the Sorbonne. He built the first real magnetoelectrical machine. (3)

HIPPOLYTE PIXII

Hippolyte Pixii (1808-1835) was born in France, and followed his father's occupation of instrument making. He built a hand-operated generator that delivered alternating current. His hand operated generator consisted of a steel compound permanent horseshoe shaped magnet (U shaped core) with poles that rotated vertically on its axis in front of two bobbins wound with spiral wire to serve as coils. The poles of the core or inductor spirals were fixed in the opposite direction of the revolving magnet. When current entered the wire on the bobbins the magnet rotated to change the direction of the current,(4) producing alternating current. While the induction spirals remained fixed on his first magnetoelectrical machine, he subsequently built the magnet to remain fixed while the horseshoe shaped soft iron, with or without induction spirals, moved. The machine along with an external electromagnet was capable of supporting 6.8 pounds (15 kg) and displaying vivid sparks, delivering painful shocks, diverging gold leaves of an electroscope, and decomposing acidulated water. The French Academy of Science awarded Pixii the Montyon gold medal and money for his experiments in mechanics.(5)

In 1832, alternating electrical current was not understood(6) nor had it any commercial use other than medicine so with the suggestion from Andre Ampere he added a commutator, and converted his alternating current generator to a direct current design.(7) (A commutator is a rotating switch that reverses the connection between magnet windings and the outside circuit each time the current changes direction in the windings to alter current direction.).(4)

Pixii apparently did not understand the relation between magnets and induction, since induction was a new concept. By using a hand crank (like the Davis/Kidder devices) current was dependent on the operator's ability to produce magnetic fields that were inconsistently strong and weak. Also, because he wound the conductor on a bobbin only a small portion of the conductor length was perpendicular to the magnetic field, but the commutator added to its effectiveness by having the heavy magnet as the rotating part of the device.(4) Despite these problems, Pixii's design endured the longest life of service in electrotherapeutics among available early electromagnetic instruments. Magnetoelectrical devices furnished larger current amplitudes than that by direct current batteries and accumulators, and were cheaper to operate.

JOSEPH SAXTON

Joseph Saxton (1799-1873) was a notable American inventor of the first half of the nineteenth century. He was born in Huntington, PA, and attended elementary school until he was 12 years of age at which time he began working in his father's nail factory. Saxton did not like factory work so apprenticed locally for two years in clockmaking and silversmithing.(8)

At age 18 years Saxton went to Philadelphia where he briefly worked for two different shops before establishing his own engraving and watch making business. He also studied engineering during these years. After 11 years of instrument making with distinction in Philadelphia where he received awards for his skill in clockmaking (e.g.,. the clock for the belfry of Independence Hall in 1824),(9) he went to London (1828-1837) to design, build, and market innovative instruments there.

In December 1832, he conceived the idea and committed his design to paper for a magnetoelectrical device. In June of 1833, he had built his first magnetoelectrical machine capable of producing painful sparks and shocks to his tongue. Later in 1833 he exhibited his magnetoelectrical machine at the Cambridge meeting of the British Association for the Advancement of Science where he demonstrated brilliant sparks, displayed intense light between points on pieces of charcoal, and discharged large pulse charges and shocks.(8)

He then improved on this version of his magnetoelectrical machine by using a strong horseshoe magnet mounted horizontally with three fixed coils to a shaft rotating around a horizontal axis. Like Pixii, Saxton turned the shaft of his machine by a handle attached to a wheel.(4) His machine was the first rotating coil machine to generate electricity of alternating current. By 1835, he had redesigned and built a magnetoelectrical machine that produced unidirectional (galvanic) pulsed current, strong shocks, and decomposed water.(2)

In 1837, Saxton returned home to Philadelphia, PA, to become the curator and maker of standard weighing devices for the United States Mint. From 1843 to 1873 he was in charge of the Office of Weight and Measures for the United States Coast Survey (now the National Bureau of Standards), Washington, DC. Saxton made and patented many inventions during his life, and was among the first members of the National Academy of Sciences, and a member of the American Philosophical Society.(8)

EDWARD CLARKE

Edward M Clarke (1804-1846) was born in Ireland and trained in instrument making in Dublin before working for the famous Watkins & Hill company of London in 1833. Because of his quality work he was soon asked to repair a Pixii electrical machine and get it ready for examination by a group of distinguished scientists.(2)

Earlier that year a report in the Mechanics Magazine raised the question whether Pixii or Saxton was the first to develop a magnetoelectrical machine that could produce sparks. Saxton's only response was that his device was superior to that of Pixii, but this statement led to a session of scientists wanting to test Saxton's claim on 15 November 1833 at the National Gallery of Practical Science in London. Michael Faraday was one of the examiners at the event for which Clarke had prepared a Pixii machine. During the examination, the brilliant and powerful sparks, the decomposition of water, and the heating of platinum wire by Saxton's machine was judged superior by the group.(2)

Clarke had studied both magnetoelectrical machines and soon had developed one of his own design. He soon resigned his job with Watkins & Hill, and by 1835 he was marketing his electrical machine from his own shop. His study of the Pixii and Saxton machines enabled him to build a unit of improved intensity and quantity of electrical output. Clarke's magnetoelectrical machine had two armatures so that one coil was for strong shocks while the other could produce brilliant sparks.(2)

In the October 1835 issue of the Philosophical Magazine Clarke stated that Saxton's machine was a modification of the one built by Professor Ritchie of London University. The November 1836 issue of the magazine contained an accusation of piracy by Saxton of Clarke. Saxton claimed that Clarke's machine was a version of his and differed only with a change of some parts. Since both individuals were members of the

London Electrical Society their differences developed into a heated controversy within the group. Although the controversy carried over into 1837 issues of the magazine, it was never resolved as both inventors lost their cutting edge of technology in the market of magnetoelectrical machines. Their magnetoelectrical machines were not sufficiently controlled and were too powerful for use in medicine where such devices were being used most. History has, however, assigned 1833 and 1836 for the invention of the Saxton and Clarke magnetoelectrical machines, respectively.(2)

The earliest magnetoelectrical machines were generally too powerful for use in treatment of patients by physicians, but by the 1840s serviceable and practical magnetoelectrical machines became available for medicine in England. In the United States Dr Charles Page with the instrument maker Daniel Davis (1813-1887) of Boston began to produce magnetoelectrical machines. By 1854, numerous patents and machines were using the principles of electromagnetism for machines in medicine. One of the best quality and most known was that of the Davis/Kidders design and manufacture.

Magnetoelectrical machines were built commonly using a straight bar or a horseshoe shaped magnet which really set up a major problem with its design. The design made it difficult to obtain uniform current amplitudes, voltages, and interpulse intervals from any two magnets or from the same hand cranked unit. The temper or degree of hardness of the magnets was never the same between each other, and their capability to produce magnetism was unstable due to the deterioration of the metals used in their construction. Also, the operator could not crank the gears consistently to generate currents of uniformity.

In 1861, GW Beardslee of New York City made a magnetoelectrical unit that used several V-shaped pieces of iron mounted on a revolving axis to form a radiating magnet. As the axis or wheel was rotated the pieces of iron alternately magnetized to generate current. This current could be regulated as to quantity and direction. The machine produced galvanic current easily and more economically than batteries of that period of time.(10)

CHARLES PAGE

Many new developments in electricity and magnetism took place during the 1820s when great scientists like Ampere, Faraday, and Ohm dominated that area of science. Men like Clarke, Henry, Pixii, and Saxton became well known in the 1830s for their contributions to magnetoelectrical devices. Dr Charles Page of the United States also became well known in this country for his work in electrical science. He has been, however, somewhat of a riddle to historians who have been undecided whether he was an inventor, scientist, or technician. Page was all three of these, and was an individual who achieved acclaim more when living then after death. Maurer has called him an electrical experimenter,(11) while Rowbottom and Susskin stated that he was a designer of electrical experiments and instruments.(4) Page was for sure a physician and a scientist by education, and he functioned in these fields from the 1820s into the 1850s.

Charles G Page (1812-1868) was born in Salem, MA, and became interested in botany, electricity, and floriculture early in his life. As a young man he had access to one of the best libraries and museums in the country with the Salem Athenaeum. By age of 10 years he had constructed (without a Heath kit) an electrostatic device that he used to shock his friends. While in college he built a device for increasing voltage that turned out to be the prototype for an induction coil. He also wired separate insulated supporting structures whose exposed surfaces were in contact with two semicircular troughs of mercury. He had built a commutator into the device to reverse the direction of the direct current.(12) Page submitted the description of his invention for publication in 1836, and it was printed as a letter in a 1837 issue of Silliman's American Journal of Science and Art. He received a degree in science from Harvard University in 1832, and then went to medical school in Boston.

Page had read works by Faraday and Henry on electrical induction, and as a result was able to construct a crude autotransformer (a device having only one coil but acting as both a primary and secondary coil) that he called a dynamic multiplier. His multiplier was the first closed core transformer and was used by Cromwell F Varley in his coil design for which he received credit for the invention in 1856. Page was a product of Jacksonian science, which subscribed to haphazard methodology without predetermined goals.

After graduating from medical school in 1836, Dr Page practiced medicine in Salem, but he wanted more of a challenge so continued experimentation with electricity. He rearranged the components of his multiplier in 1838 to build a new device. In the published 1839 description he used the term "compound" to say that his magnetoelectrical machine used a common single magnet, and claimed that his machine's output equaled a galvanic battery having 1,000 pairs of plates. His machine produced alternating current that was then converted into direct current by using a pole changer that he termed a "unitrep."

His machine was then unique because of its control or regulation of pulse frequencies by an attached device that he called an "electrotome." His electrotome, however, was primitive and unlike the interrupters of the 1870s-1920s. His machine was too powerful to be used in electrotherapeutics but it did have an effect on the future design of induction coils that were used in medicine. In 1837, Page built a rocking magnetic interrupter or circuit breaker that was automatic for current altering. This was the first magnetic operating interrupter for an induction coil.(13)

Dr Page apparently connected with Daniel Davis Jr of Boston who then became the leading manufacturer of magnetoelectrical machines. Page designed devices and Davis built them and marketed them. Davis assigned Page credit in his catalog of 1838 for the listed revolving electromagnet.(12) The version of the induction coil used in Page's magnetoelectrical machine of 1838-1839 was a unit similar to that by Ruhmkorff in 1851 (who was credited with its invention). The induction coil by Page had separate primary and secondary windings, and an integral self-acting circuit breaker that produced extreme alterations characteristic of coils.(11)

Researchers usually do not work in isolation, but work with colleagues and read every publication in their field. Such was probably the case of Ruhmkorff who may of known about earlier discoveries of George Bachhoffner, Charles Page, and William Sturgeon.(11) In 1838, Page moved to northern Virginia to practice medicine and continue his experiments in electricity. In 1839, he used the idea of Sturgeon's bundles of iron wires in one of his new induction coils.

Dr Page was aware of Sturgeon's improved effects produced by induction coils when bundles of iron wires were substituted for solid iron bars as cores. Sturgeon had been working with bundles of iron tubes, iron wires, gun barrels, iron bars, and rolled iron foils when he discovered the effect of the bundle of iron wires.(14)

In 1841, Dr Page left medicine to take a job in the United States Patent Office in Washington, DC. He continued building and experimenting with electricity while he worked off and on over the next 26 years as a patent examiner, examiner's adversary, and as a private agent.(15 p48-59) He taught night school in the medical department of Columbian College (now George Washingon University) from 1844 to 1849. He built equipment for Morse's telegraph, and like Joseph Henry's experience with Samuel Morse the association became a controversy over who built the equipment.(15 p60-83)

About 1850, Dr Page received $20,000.00 in congressional support to build two special electromagnetic engines for a locomotive. On 29 April 1851, the engines were ready for testing over 5 miles of track. After 1 mile and 39 minutes the batteries supplying the engines of the train loaded with dignitaries failed near Blandensburg, MD. After repairs the train took 2 hours to return to Washington. Page was convinced that with additional money the problem could be solved and the electrical train could become a reality. Because of political delays, and President Johnson's impending impeachment proceedings Page was never given the needed money. Page went into debt for the remainder of his life. Upon his death his wife sued Western Union over her husband's patents that were never paid to him by the company. Dr Page's survivors lived more comfortably after his death than during his last several years of life.(15 p162-183) The money received by Page from Congress was really one of the first grants for science, and it caused Page to become an outcast among scientists in the United States because taking government money for research was considered unethical in 1850. Today, researchers could not function if it was not for financial support from the government.(15 p84-107)

Dr Page invented a reciprocating electromagnetic engine and many other notable devices. In 1863, a mob of Union soldiers broke into his laboratory and destroyed most of his equipment. Page never returned to science after that event. Before his death he asked Congress to save his honor for the invention of the induction coil over the recognition given Ruhmkorff. Just before death in 1868, Congress passed a petition and gave Page his patents for recognition. This petition also gave the Page family the right to sue companies using his devices without authority.

From the late 1830s through the 1850s the induction coil grew into a marketable device with numerous improvements in design and construction. Several notable individuals of science played a prominent role in its development during this period of time such as: William Sturgeon (1783-1850), George H Bachhoffner (1810-1879), Alexander Kemp, Christian Neef (1782-1849), James W McGauley (1806-1867), Dr Golding Bird (1814-1854), and Dr Guillaume Duchenne.(16) Of course others also made minor changes in the development of the induction coil, and these were mostly instrument makers such as: Edward Palmer, Watkins & Hill, and EM Clarke. Englishmen dominated the development of the induction coil.

DANIEL DAVIS, JR

Daniel Davis, Jr. (1813-1887) was born in Princeton, MA, and moved to Boston at the age of 20 years (1833). He worked for William King of Boston who specialized in making lightning rods and static electrical machines.(12) Davis apparently made the static electrical machines because he acquired a credible reputation as a skilled instrument maker by 1837.

In 1837, Davis set up business for himself and specialized in making only electrical machines. He was among or was the first American to specialize only in making electrical devices. Davis began making his instruments for local scientists, one of which was Dr Charles Page, the physician in Salem, MA.(15 p84-107) He also became the first American maker of mechanical machines that generated constant electrical current for electrochemical experiments.(12)

Page designed his induction coil in 1836 and had Davis build his electrical induction devices. The two established a very good business relation. Davis published a catalog entitled Descriptive Catalogue of Apparatus and Experiments, Electro-Dynamics, Magnetism, Electro-Magnetism, Magneto-Electricity, Thermo-Electricity of his electrical instruments for sale in 1838. Davis listed and described 68 instruments within the 72-paged catalog, and also described electrostatic machines although they were not part of the title. The catalog of 1838 had improvements on 41 of the previously listed instruments.(15 p37-47) Six instruments in the catalog were accredited to Page by Davis and were: 1) the reciprocating armature engine, 2) an induction coil, 3) a galvanometer, 4) a double helix for inducting magnetism, 5) a revolving armature for displaying motion by magnetism, and 6) a vibrating armature.(12) Davis marketed Page's rocking beam motor for $12.00, and his magnetos from $35.00 to $75.00.(15 p37-47)

Dr Page invented a battery in 1837 that used released hydrogen to depress the electrolyte. Davis built the battery for Page, although it was never reproduced because of its ineffectiveness. Davis did not list or mention the battery in any of his catalogs.

Davis, like the Englishman Francis (d 1713)Hauksbee early in the eighteenth century, conducted his own experiments in electricity. He was acknowledged in an 1838 scientific article by Dr Page for discovering the improved effect of fine steel wire over iron wire in electrical machines.(12)

At the 1839 exposition of the Massachusetts Charitable Mechanics Association he won a gold metal for his workmanship and display of a variety of magnetoelectrical devices and engines. Davis was given a commendation for understanding the rationale of the instruments that he displayed and constructed.(15 p142-161)

In 1842, Davis published a manual entitled Magneto-Electricity, and Thermo-Electricity which was authored for students of various institutions. He illustrated and described a small magnetoelectrical machine designed in 1837 by Dr Page that included a device for making and breaking the circuit. Davis had a section that stressed galvanic electricity and its magnetic effects. He also described the electrotype process, electroplating, and some electrolytic experiments in the catalog. One of his machines was described as being useful for electroplating, but it was adopted by educational institutions for scientific demonstrations rather than for commercial use. Electroplating was a new process at the time, and not yet perfected or well understood.(12)

Professor Silliman of Yale College and editor of the American Journal of Science praised the manual written by Davis. The manual was used by the United States Military Academy and other institutions as a textbook, and was successful enough to have 13 editions between 1842 and 1872.(12)

Davis, in 1846, published a manual The Medical Application of Electricity, Boston, and a pamphlet The Medical Application of Electricity with Descriptions of Apparatus and Instructions for its Use in Boston. In the pamphlet he discussed galvanic belts and rings that were made using two different metals that contacted the skin when used. He indicated that the belts produced small amounts of current, but conjectured that they could not pass current through the organs of the body. He even concluded that the galvanic belt (very popular 1880s-1890s) was a device of quackery.(4)

Davis and Page continued their business relation after Page moved in 1838 to Washington, DC. Page even made several trips to Boston after moving to consult with Davis on the construction of electrical devices, but after 1849 began to look for a local instrument maker.(15 p142-161)

Davis published his second manual in 1852 which was entitled Manual of Magnetism,(17) but used the same year to retire from instrument making and dissolve his relation with Page. In Page's book History of Induction of 1867 he cited Davis several times for his catalog listings and descriptions.(15 p142-161)

ARI DAVIS

When Dr Page was searching for a skilled instrument maker with whom he could do business in the Washington, DC, area he found Ari Davis, brother of Daniel. Ari was probably recommended to Page by Daniel. Page soon afterwards had Ari Davis build a thermogalvanometer, and assist him with his public lectures on electricity. From this point Page and Ari Davis established a successful business relation that lasted for several years.(15 p142-161)

Ari Davis patented the earliest (1854) compact magnetoelectrical machine for use in medicine. He went into business with Dr Jerome Kidder of New York City to build one of the most popular units in the United States that has become known as the Davis/Kidder magnetoelectrical machine for the treatment of nervous diseases. The labels of the earliest units carried endorsements by Page and Silliman. This particular unit had a bone handled crank to operate brass gears with a pulley drive that rotated two small coils. The electrical system was housed in a small attractive mahogany box. A great number of these magnetoelectrical machines were sold in the United States to attest to its popularity.

Ari Davis was, like his brother Daniel, an outstanding instrument maker, and as a result of his skills and business relations he made a comfortable living. He also invented a wood working machine.(15 p142-161)

JEROME KIDDER

Jerome Kidder, MD, of New York had dealings with Dr Page and the United States Patent Office between 1861 and 1867. Page denied Kidder patents until his inventions met specific requirements of the Patent Office. History shows that Kidder was annoyed over these circumstances. In 1876, Kidder published a disclaimer about Page.(15 p162-183) Dr Kidder was a leading manufacturer of electrotherapeutic equipment between 1872 and 1898 and by then held several patents on components of his electrical machines. Kidder received negative publicity over his patent difficulties with Dr Page which also probably cost him business losses. In 1876, Kidder attacked the dead Dr Page (d 1868) by denying that Page ever invented an electrical coil or any other device used in electrical instruments. Kidder posted such information in some of his equipment advertisements.(15 p162-183)

The Jerome Kidder Manufacturing Company was located at 820 Broadway, New York City. His company made several types of electromedical machines such as the Davis-Kidder magnetoelectrical machine, and at the turn of the century was making X-ray machines.(18)

NICHOLAS CALLAN

Nicholas Callan (1799-1864) was a priest and professor of natural philosophy at St Patrick's College Maynooth (near Dublin), Ireland. He was an inventor, researcher, and teacher. Callan was one of the pioneers of electrical batteries, electromagnetism, electromagnets, and the induction coil. Like Page, he never received credit for his outstanding contributions to science.(19) Callan did not publish often, and since his college was a theological rather than a school of science his colleagues often tried to dissuade him in science pursuits.(20)

Callan was credited for inventing the induction coil in the 1910 edition of The Encylopaedia Britannica however by the 1973 edition his name was mentioned with the subject "induction coil." In 1953, a physics textbook cited Callan for the invention of the induction coil. He along with Page in 1836 built the first induction coils for practical use in medicine, although Michael Faraday and Joseph Henry independently invented the coil.

In an issue of the 1836 Annals of Electricity Callan described his transformer as a bar of soft iron shaped like a horseshoe that was wound first with thick copper wire, and then wound with thin copper wire over the first winding. The thick wire winding acted as the primary circuit while the two windings in series was the secondary circuit. Callan was able to break and make the circuit between 500 and 610 times per second, and because of this repetition he called the current breaking part the "repeater." By 1837, he did not connect the two different sized wires.(4)

His repeater was the first successful mechanical current breaker. He used a hand crank that turned a cogged wheel that was connected to a horizontal copper rod attached to an escapement engaging the wheel (axle of a double ratchet).(20) In 1853, Fizeau, a French physicist, added a capacitor to the induction coil to resonate the secondary coil so as to obtain even more voltage than previously.(14) Up to the time of Callan's interrupter the clockworks and manual methods of breaking and making the circuit had been unsatisfactory. Other versions of the interrupter by Bachhoffner, Neef, Page, Sturgeon, and Wagner followed Callan's type. Sturgeon's interrupter was a cam that raised a lever from a mercury cup 36 times per second, and Page developed a rocking magnet interrupter that worked only with currents of large amplitude.(4)

Callan was successful in identifying the elements required to produce the most forceful electrical shocks. His elements included: 1) a specific diameter and length of wires, 2) voltage of the primary coil, 3) space between coils and the core, 4) placement of the axis of the core, 5) wire that was insulated, and 6) a specific diameter of the core. Callan used the force needed to retract the keeper bar across the horseshoe magnet as a measure of the force of the magnetic field.(14)

Nicholas Callan was born in Dervir, Ireland, and went to the academy in nearby Dundalk. Callan was encouraged to enter the priesthood by his local parish priest, but he first went to Maynooth College in 1816. He studied electricity and magnetism under professor Cornelius Denvir. After Maynooth he became an ordained Priest in 1823 and soon went to Rome to study the works of science of Galvani and Volta. In 1826, Dr Denvir resigned and Callan became chairman of natural philosophy at Maynooth for the next 38 years (until death in 1864). Callan invented a two fluids battery in 1854, and a single fluid battery in 1855. He successfully reduced the cost of existing batteries by using a cast iron casing. While experimenting and developing his batteries he invented a method of protecting iron from rusting.(20)

JAMES MCGAULEY

James McGauley (1806-1867) was a student of Callan's at St Patrick's College Maynooth in 1826, and from 1836 to 1856 he was professor of natural philosophy to the Board of Education in Ireland. In 1837, at the meeting of the British Association for the Advancement of Science in Liverpool, McGauley described a device similar to that by Dr Page in 1838. McGauley had suspended a soft iron knob that was attached to a rocking lever from a copper wire above the solid iron core of his coil. The soft iron knob moved downward when the core was magnetized, and this movement broke the circuit of the induction coil by bringing the lever out of the mercury contact cup. The weight of the lever brought the soft iron knob upwards to make contact with the mercury, and the process was repeated as desired.(16)

In 1856, McGauley went to Canada for awhile, and upon his return to England some time later became one of the editors of the Scientific Review, a member of the Council of the Inventor's Institute in London, and managing director of the Inventor's Patent Right Association. Hackmann suggested that McGauley may have been the inventor of the trembler interrupter or of its principle about 1837,(16) although the invention of this device is usually assigned to Neef.(5)

CHRISTIAN NEEF

Christian Neef (1782-1849) of Frankfurt am Main, Germany, was the first physician to apply his type of interrupter or rheotome on induction coils of electromagnetic machines for use in medicine.(21) His interrupter of 1839 was an important advancement for the induction coil, and was still in use in 1902.(22)

Neef as a physician using electrical machines was dissatisfied with existing interrupters so worked on their improvement by modifying them. He developed a simple spring hammer that vibrated to control the frequency of current. His hammer break consisted of a spring contact that operated automatically to break the electrical circuit when displaced by the action of the electromagnet. This action was powered by a battery and eliminated the use of an assistant to manually operate the break and make contacts. Neef first presented his device to members of the Freiburg Scientific Society and then published its description in an 1839 issue of Annalen (then edited by Poggendorff). William Sturgeon of London published the first English version of Neef's device in his Annals of Electricity in the 1839-1840 issue.(4)

The common wooden box was developed about this time to enclose the electrical machines in an effort to make them small and portable (which was successful). By the 1850s natural philosophers were using induction coils in their experimental work. Their requirements were high voltage for work in X-rays (after 1895), and men like Hertz (1886-1888) and Marconi (1896) paved the way for new uses of the technology of the induction coil. By the 1920s the induction coil was used in radio, doorbells, and with applications of high powered electron tubes.

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Comments and corrections to build on the history and improve accuracy are invited.

VIII

Copy of Callan's 1857 paper

Rev N. Callan,

On the Induction Apparatus,

Philosophical Magazine, Nov 1857.

From the PHILOSOPHICAL MAGAZINE for November 1857.

ON THE INDUCTION APPARATUS.

BY

THE REV. N. J. CALLAN, D.D.,

PROFESSOR OF NATURAL PHILOSOPHY IN THE ROMAN CATHOLIC COLLEGE, MAYNOOTH.

IT is now more than twenty years since I discovered the method of making the induction coil, or a coil by which an electric current of enormous intensity may be produced with the aid of a single galvanic cell,—a coil which is now to be used for working the Atlantic Telegraph. Mr. Faraday was the first who developed the laws of electrical induction; but he did not discover the method of making a coil by which a current of very great intensity may be obtained by means of a very small battery. This was first discovered in Maynooth College in 1836. In the summer of 1837, I sent the late Mr. Sturgeon a small coil which he exhibited at a meeting of the Electrical Society in London, and from which he gave shocks to several of the members. After the meeting, I received a letter of thanks from him, in which he described the astonishment of those who experienced the extraordinary power of the coil. This was the first induction coil of great power ever seen outside the College of Maynooth. The first notice of the discovery of the coil is found in a paper of mine published in the London Philosophical Magazine for December 1836. In 1836 and 1837 I also discovered that the intensity of the current induced in the coil increased with the number of cells employed, and that a shock may be got from the coil at the moment of making as well as of breaking connexion with the battery. In April 1837 I published, in Sturgeon's 'Annals of Electricity,' a description of an instrument which I devised for producing a rapid succession of electrical currents in the coil by rapidly making and breaking communication with the battery. This, as Mr. Bachhoffner says in one of his papers published in Sturgeon's 'Annals,' was the first contact-breaker ever made. Thus, before April 1837 I had completed the coil as a machine for producing a regular supply of electricity. From 1837 till the end of 1854 my attention was directed to other matters. Since the beginning of 1855, I made a long series of experiments on the various parts of the induction coil and apparatus. Although my experiments are not yet finished, I thought it better to lay the results already obtained before the British Association*.

The following are the results of my experiments:—First, a method of getting a shock directly from the armature of a magnet at the moment of its demagnetization; secondly, the discovery of what I believe to be a new fact or law connected with the action of iron on a battery by which it is magnetized, viz. that if iron be put into a coil of covered wire, the ends of which are connected with a battery, the quantity of electricity flowing from the same battery through another coil connected with it will be considerably greater when the first coil is nearly filled with iron than when there is little or no iron in it; thirdly, a form of core which has five advantages over the cores in common use, which will enable us to get intensity and quantity currents, and may therefore answer for the Atlantic Telegraph and for the electric light; fourthly, an improved method of insulating the secondary coil; fifthly, a contact-breaker in which the striking parts are copper, and which acts as well as if they were platina; sixthly, an explanation of the action of the condenser, which appears to me more satisfactory than any other I have seen; lastly, some new facts regarding the condenser, and an improved method of making it.

The first result is a means of obtaining, not from a coil surrounding the armature of a magnet, but from the armature itself, a voltaic current capable of giving a shock. This result is obtained by making a coil of fine insulated iron wire, and an electro-magnet of such a form that the coil will fit between its poles. The iron coil is then the armature of the magnet. If the helix of the electro-magnet be connected with a battery, the iron becomes magnetized; and on account of its proximity to the magnetized iron, the coil of iron wire, or the armature of the electro-magnet, will be also magnetized, and will lose its magnetism when the connexion between the battery and electro-magnet is broken, or

* This paper was read in Section A. (on Mathematics and Physics) at the late meeting of the British Association in Dublin. The paper being hastily written, some things were omitted which are here supplied.

when the electro-magnet is demagnetized. If, at the moment the iron coil loses its magnetism, the ends of it be held in the hands, a shock will be felt. If the ends of the iron coil be connected with a delicate galvanometer, the needle will be deflected at the moment the coil is magnetized by the electro-magnet. Hence at the moment of magnetization or demagnetization, an electric current is produced in each section of the iron at right angles to its magnetic axis. From this, two inferences may be drawn,—first, that if for the copper coils used in magnetic telegraphs, coils of iron wire were substituted, electrical currents of greater intensity might be obtained; secondly, that if iron wire were used in the secondary coil of induction coils, the intensity of the secondary currents would be increased.

Here I shall take occasion to explain the causes which produce the secondary current in the induction coil. I believe that this current is the result of the combined action of three inductive forces; one arising from the sudden cessation or destruction of the magnetism of the core, the second from the cessation of the magnetism of the primary coil, and the third from the destruction of the magnetism of the secondary coil at the moment the connexion between the battery and primary coil is broken. This supposes, first, that as long as the primary coil is connected with the battery, magnetic power is given, not only to the iron core, but also to the primary and secondary coils; and secondly, that in each of them, at the moment of losing its magnetism, an electric current is produced in each of them as well as in all contiguous conductors. Both, I think, may be satisfactorily proved. First, every one knows that the iron core is magnetized by the primary current. Secondly, the primary coil itself is a magnet as long as it is connected with the battery; for every wire or conductor through which a voltaic current flows has magnetic properties: one of its sides will attract the north pole of a magnetic needle, and the opposite will attract the south pole; so that if the wire be placed over the needle at rest, the latter will be deflected from the magnetic meridian. The wire, or conductor of a galvanic current has its magnetic poles, not at its extremities, but at its opposite sides; so that were the wire divided into two halves along its length, one half would be a north and the other a south magnetic pole. The magnetic axis of such a wire is one of its diameters, or a line joining its opposite sides. Thirdly, the secondary coil is a magnet when the primary coil is connected with the battery. This is evident when the secondary coil is made of iron wire; for the primary current magnetizes iron by which it is surrounded as well as iron enclosed within it: it induces in each section of the surrounding as well as of the enclosed iron, an electrical current which magnetizes the iron. I have found by experiment that iron outside the primary coil is not so strongly magnetized as iron enclosed within it. When, as is commonly the case, the secondary coil is made of copper wire, it is also a magnet; for the primary current induces an electrical current in each spiral of the secondary coil of copper, as well as in each section of the iron core. This current magnetizes each spiral of the copper coil, and makes the whole coil a magnet at the moment the primary coil is connected with the battery. Now we must suppose, that as the primary current, whilst it continues to flow, maintains in the iron core the magnetic power produced by the currents induced in each section of the iron at the moment the primary coil is connected with the battery, although these currents last but an instant, so also the same primary current will maintain in each of the spirals of the copper coil the magnetism given to them by the currents induced in them at the moment the battery connexion is made. There is no reason why the continuance of the primary current should not maintain its first effect in the copper spirals as well as in the iron, since the first effect is the same in both, viz. the magnetization of both. Hence, when the primary wire of an induction coil is connected with a battery, the secondary coil is always a magnet, as well as the core and primary coil; and therefore in every induction coil we have three magnets so long as its primary coil is connected with a voltaic battery; and the three lose their magnetism the moment the battery communication is broken. Now in every magnet, at the moment of the cessation of its magnetism, an electric current is produced in a direction at right angles to the magnetic axis, in the magnet itself and in all contiguous bodies. First, it has been already shown that at the moment iron loses its magnetic power, an electric current is produced in each section of it in a direction perpendicular to its magnetic axis. By the laws of induction, these currents induce parallel ones in every contiguous conductor. Secondly, when a current flowing from a battery through a copper wire ceases, the wire loses its magnetism; and it is found by experiment, that at the moment of losing its magnetism, an opposite electrical current is produced in the whole length of the wire, or in a direction at right angles to its magnetic axis. Hence, because in every induction coil excited by a battery there are three magnets, viz. the core, the primary and secondary coils, having a common axis, and because at the moment the connexion with the battery is broken the three lose their magnetic power, an electrical current is produced in each section of each of the magnets in a direction perpendicular to their common axis; and these currents in each magnet induce electrical currents in the other two. Therefore, when the connexion with the battery is broken, a current is produced in the secondary coil, which is the result of the combined action of three inductive forces arising from the suspension of the magnetism of the core, of the primary and of the secondary coil. When the secondary coil is made of iron wire, the magnetic power it will receive from the primary current, and from the magnetic inductive force of the core, will be far greater than if it be made of copper wire; and therefore the intensity of the secondary current in a coil of iron wire must be much greater than that of the secondary current in a coil of copper wire. I showed, at the late meeting of the British Association in Dublin, an induction coil in which the secondary wire was of iron: its length was about 21,000 feet, and its thickness about the $\frac{1}{100}$dth of an inch. With a single cell, 6 inches by 4, and without a condenser, this coil gave sparks half an inch long. Should a condenser of the proper size increase the length of the sparks, as it does in Mr. Gassiot's great coil, in a thirtyfold ratio, my coil ought to give sparks 15 inches long with a single cell. I have not yet tried it with a condenser: I made two large condensers, in which, when both were united, the acting surface of each plate exceeded 600 square feet. After being used for some time, the insulation of the plates gave way, and the action of the condenser became feeble, and once ceased altogether. I intend to reconstruct both condensers as soon as possible, and to try their effect on the coil, on which I have, since the meeting of the Association, coiled about 28,000 feet more of fine iron wire, so that at present the length of the secondary coil is nearly 50,000 feet. Since the increased length of wire was put on the coil, I have got from it, with a single cell, 6 inches by 4, and without a condenser, sparks $\frac{1}{1}\frac{5}{6}$ths of an inch in length. I expect that with the same battery it will give sparks at least an inch long without a condenser. This is, I believe, the most powerful coil ever made.

The second result is, that if a bundle of iron wire be put into a coil of insulated thick copper wire connected with a battery, the quantity of electricity which will flow through another coil in contact with the same battery, will be considerably greater when the iron wires are in the first coil than when they are altogether or partly removed. This I found by using a contact-breaker worked by an electro-magnet, the helix of which was connected with the same battery by which an induction coil was excited. In trying the effect of the induction coil without an iron core in its primary coil, I found that the action of the electro-magnet of the contact-breaker was slow and feeble. When a few wires were put into the primary coil, the action of the contact-breaker was sensibly increased; and when the primary coil was filled or nearly filled with wire, the attraction of the electro-magnet became considerably stronger, and consequently the voltaic current flowing round it must have been considerably increased. Since the core of the induction coil increases the quantity of electricity flowing from the battery through the helix of the electro-magnet, we must suppose that the iron of the magnet reciprocally increases the quantity of electricity transmitted through the primary coil, and that therefore little or no battery power is lost by using an electro-magnet for making and breaking contact, instead of the magnetized core of the coil. Hence it appears also to follow, that a secondary current of greater intensity may be got with a battery of given power from a great number of small coils than from one large one, in which the conducting power of the primary coil is equal to the sum of the conducting powers of the primary wires of all the small coils; for the magnetic power of the core of each of the small coils will be increased by the magnetism of the cores of the others.

The third result is a form of core which has five advantages over all the cores in common use, and which may enable us to get electrical currents having at the same time great intensity and considerable quantity, and may therefore be very useful for working the Atlantic Telegraph, and for producing the electric light. In my experiments on the core, I have used cores of six different forms, and varying in weight from one pound to two hundred and a half of iron wire. I have used, first, a core of uninsulated iron wire coiled on an iron bar; secondly, the ordinary bundle of iron wires; thirdly, an elliptical or flat bundle of wires; fourthly, a coil of covered iron wire; fifthly, a core consisting of a coil of insulated iron wire and of a bundle of iron wire; lastly, a core consisting of two concentric coils of insulated iron wire, one made of fine, the other of thick wire.

When the uninsulated iron wire coiled on a bar of iron was employed as a core, the spark produced by the secondary coil was less in length and brightness than when the iron bar alone was used; because a complete circuit was formed between some of the spirals and those above them, whilst the other spirals were insulated from each other by the oxide of iron on the surface of the wire.

The elliptical or flat bundle of wire receives from a given voltaic current flowing through a primary coil made of wire of given length and thickness, greater magnetic intensity than a cylindrical bundle does; because when the length of the circumference of the two bundles is the same, a section of the former is smaller, and contains less iron than a section of the latter. Therefore, if the two coils be connected with the same battery, the same quantity of electricity will flow through both; and the quantity of iron in the flat or elliptical one being less than in the cylindrical one, it will be more intensely magnetized.

I find that all cores consisting of bundles of parallel wires have five defects. First, in each section of every wire in such cores an electrical current is induced by the primary current, and all those currents may return to the points where they originated; or there is a complete circuit for them, which is found to diminish the intensity of the secondary current. Some have imagined that by insulating the wires of the core from each other, they have prevented all complete circuits. But these persons seem to have forgotten, or not to have adverted to the fact, that when the wires of the coil are insulated from each other, the primary current induces an electrical current in each section of every wire.

The second defect consists in this, that the currents induced in each section of every wire are opposed by those in the corresponding sections of all the adjoining wires; and thus the magnetic power which the primary current is capable of producing in the core is greatly diminished, and is less than it would be if all the wires were in close contact with each other; and consequently the intensity of the secondary current is diminished

The third defect is, that the immense quantity of electricity set in motion by the primary current in all the sections of each wire in the core is lost: it remains within the core, and cannot be used for producing any electrical effect.

The fourth defect is, that we cannot ascertain the effect which a condenser applied to the primary coil has on these currents.

The fifth defect is, that we cannot apply a Leyden jar or any condenser to the currents themselves.

I have found that a core consisting of a coil of insulated or covered iron wire is free from all these defects. In such a core there is no complete circuit for any current in any section of the iron: for the electrical currents produced by the primary current in the sections of an enclosed iron coil move in the directions of the spirals of the coil; and since no spiral returns to itself, no current can return to the point where it originated. Neither does the current in any spiral of the coil oppose those in the adjoining spirals; for the currents in all the spirals flow in the same direction, or in the direction of the primary current. Thirdly, since all the currents in the spirals of the iron coil flow in the same direction from the beginning to the end of the coil, they must unite and form one current, having an intensity equal to the sum of their intensities. This I have proved by using a coil of very fine insulated iron wire, about 10,000 feet in length, as the core of a copper coil. When the connexion between the ends of the copper coil and a single cell was broken, sparks about one-twelfth of an inch passed between the ends of the thin iron wire without using a condenser. Fourthly, by connecting the primary coil with a condenser, I have found that the intensity of the current in the core is increased as it is in the current of the secondary coil. Fifthly, by connecting the ends of the core or iron coil with a Leyden jar, the length of the spark is diminished and its brightness increased. The effect of the condenser on the currents in the core may assist us in understanding the action of the condenser, which has not yet been satisfactorily explained.

A core consisting of a coil of insulated iron wire, has not only the advantages of being free from the five defects to which all the cores in common use are subject, but it will also enable us to get electrical currents having at the same time great intensity and considerable quantity, and may therefore be very advantageous for working the Atlantic Telegraph, and for producing the electric light. If we make a core of thirty covered iron wires, each one-eighth of an inch thick and 100 feet long, and wind over the iron coil a covered copper wire one-fourth of an inch thick, we can, with the aid of two cells and a suitable condenser, obtain thirty electrical currents, each having a considerable quantity of electricity, because the wires are short and thick, and an intensity greater than that which is required for the electric light. Sixty covered iron wires, of the same length and thickness as those in the core, may be rolled on the copper coil. Another coil of copper wire, one-fourth of an inch thick, may be put over the second iron one, and over this copper coil we may wind sixty or eighty covered iron wires, each 100 feet long and one-eighth of an inch thick. Then the innermost iron coil will be the core of the first copper one; the second iron coil will be the secondary coil of the first copper coil, and the core of the second; the third iron coil will be the secondary coil of the second copper coil. If the copper wires be connected with a battery of six cells, each about 5 inches square, and a condenser of sufficient size, an enormous magnetic power will be given to the 150 or 170 wires of the iron coils; and consequently 150 or 170 electric currents of considerable quantity and intensity will be produced as often as the connexion between the copper wires and the battery is broken. If necessary, the number of iron coils, and therefore the number of electric currents, may be increased. Mr. Shephard has got a brilliant electric light from eighty electric currents produced in coils of copper wire on the armatures of permanent magnets. I think that 150 currents produced by the coil I have described would far exceed in quantity and intensity the eighty currents obtained from Mr. Shephard's machine.

The electric light may perhaps be produced by several coils, like the one I showed at the meeting of the Association, and which has given sparks the $\frac{15}{16}$th of an inch, with one cell and without a condenser. The secondary coil is divided into four parts, each of which will give sparks about a quarter of an inch. I intend to make four or five other coils of equal power, and to divide the secondary coil of each into six or eight parts. The ends of the wire of each part will be left projecting from the coil. Thus in the five or six coils there will be between thirty and forty small secondary coils, each containing about 8000 or 10,000 feet of fine iron wire. Each of these secondary coils will give sparks at least one-eighth of an inch, with a battery of five or six cells and without a condenser. With a good condenser we may fairly expect that each will give sparks nearly 2 inches in length. Thus with a battery of five or six cells I think I shall have between thirty and forty currents, each capable of passing through about 2 inches of air. If the opposite ends of the thirty or forty small coils be connected with the opposite coatings of several large Leyden jars, and the sparks be passed between two coke-points, a brilliant light may be produced. Besides the coil which I have described, and which was divided into four parts, I made another which was 40 inches long, was divided into nine parts, and in which there were at least 70,000 feet of fine iron wire. Unfortunately, the secondary coil was seriously injured before I was able to make a single trial of its power. In dividing the two coils into several parts, I had three objects in view. First, to secure better insulation. The division of the secondary coil for the purpose of preventing the passage of sparks from one layer of the coil to the layer above or below it, was first recommended by Professor Poggendorff. Although this mode of preventing sparks within the coil occurred to myself before I saw his excellent paper on the induction apparatus, I was doubtful whether it would be of use, until I tried it in the last coil I made. My second object in dividing the secondary coil into parts, was to try the combined effect of the currents produced in each part by connecting the beginnings of all the parts with one coke-point, and all the ends with another. My third object was to try the effect of a Leyden jar connected with each part of the secondary wire, as well on the sparks produced by the part itself, as on the sparks produced by the whole secondary coil.

In order to get currents of considerable quantity, and at the same time of very great intensity, the core and secondary coil should be one continuous wire, about one-eighth of an inch thick, and the end of the core should be connected with the beginning of the secondary coil. I made a flat coil of covered iron wire one-eighth of an inch thick. The length of the coil was about 18 inches, its breadth 14, and its thickness between 4 and 5 inches.

The length of the wire was about 2000 feet. On this iron coil I wound 150 feet of copper wire nearly one-fourth of an inch thick. By connecting the ends of the copper wire with a battery of two or three 4-inch cells, and a condenser in which the surface of each plate was 400 square feet, sparks about the twentieth of an inch would be made to pass between the terminals of the iron core. I have reason to think that had the condenser been only one-third or one-fourth of the size, the sparks would have been longer. When the ends of the iron core were connected with a condenser in which the acting surface of each plate was about fifty square feet, and in which the plates were insulated from each other by waterproof gutta-percha cloth, the current passed from one plate of the condenser to the other as freely as if they were connected by a good conductor. When the terminals were connected with three large Leyden jars, the brightness of the spark was increased, whilst its length scarcely suffered any diminution. I intended, but had not time, to coil over the copper wire another iron one of great length, and the same thickness as the one in the core, and to unite both together. Had I been able to do so, the combined currents of the core and secondary coil would form one of enormous intensity and considerable quantity. Two coils of this kind, each having a bar of iron in the inner iron coil, and having the ends of the iron bars connected by iron armatures, in the same way as in Mr. Whitehouse's coils, would, I think, answer better than his for the Atlantic Telegraph.

It appears to me that Mr. Whitehouse's coils admit of three important improvements. First, they may be greatly improved in the core by substituting for his secondary coil of copper wire a coil of covered iron wire of the same length and thickness. The iron wire would be intensely magnetized by the primary current, and by the inductive magnetic power of the enclosed iron bar; and in losing its magnetism at the moment the battery connexion is broken, a current will be induced in it of far greater intensity than that of the secondary current in Mr. Whitehouse's coil. Mr. Whitehouse's object in connecting the ends of one core with the ends of another by iron armatures, is to prevent the rapid suspension of the magnetic power of the cores at the moment the connexion between the battery and primary coil is broken. By causing the cores to lose their magnetism gradually, a series of currents corresponding to the successive diminutions of magnetic power is induced in the secondary coil: this series of currents has the effect of a continuous current, which is found to be of use in working the telegraph. The same object may be attained by using a core consisting of an iron bar and a coil of insulated iron wire. The iron bars may be connected by iron armatures extending over the ends of the iron coils, but separated from them by a piece of gutta-percha about the one-fortieth of an inch in thickness. Mr. Whitehouse's object might perhaps be attained still better by connecting the cores of every two coils, by six or seven, or a greater number of armatures. This may be done by brazing or otherwise fastening to the iron bar in each coil, plates of iron about a quarter or three-eighths of an inch thick, and sufficiently large to project an inch or two beyond the iron coil of the core. A small piece should be cut out of each plate, that the primary wire may pass from one side of the plate to the other. The corresponding plates fastened to the two iron bars may be connected by a plate of iron. Thus the two iron bars will have as many armatures as iron plates, and the magnetic power of the core will be retained longer than if there be only two armatures, and consequently the series of induced currents will continue for a longer time. Secondly, a great improvement may be made in the primary coil. Mr. Whitehouse's primary coil consists of twenty-four copper wires, No. 14, or about the $\frac{1}{11}$th of an inch thick, and 100 feet long. Now if the primary coil were made of copper wire of the same length, and nearly half an inch thick, it would conduct as much electricity as the twenty-four wires used by Mr. Whitehouse, and would produce greater magnetic power in the core, because the electricity flowing in the thick wire would be nearer to the core than the electricity flowing through the twenty-four thin wires. A third improvement may be made by winding over the primary coil an insulated iron or copper wire of the same length and thickness as the wire in the core, or of greater length, and uniting the end of the coil in the core with the beginning of the coil outside the primary coil. Such a coil would produce with a given battery a current of far greater intensity than that which would be produced by one of Mr. Whitehouse's coils, or a current of equal intensity with a much smaller battery. It appears to me, then, that the use of coils such as I have described would be greatly to the advantage of the Atlantic Company, or any company having a very long telegraphic line.

The fifth form of core which I used consisted partly of a coil of insulated iron wire, and partly of a bundle of iron wire. In one core of this form the iron wire of the coil was about the $\frac{1}{100}$dth of an inch, in another it was one-eighth of an inch thick. From the part of the core which consisted of iron wire $\frac{1}{100}$dth of an inch thick, I got sparks a quarter of an inch with a single cell and without a condenser. The length of wire in this coil was about 15,000 feet.

The sixth form of core which I used consisted of two concentric coils of insulated iron wire: one of very fine, the other of thick wire. The coil of thick wire should be enclosed within the coil of fine wire, and should be nearly 2 or 3 inches in diameter, especially when the primary coil is made of thick wire. In making coils of thick iron wire, great care is necessary, for in such wire there are cracks or flaws. At these cracks there are sometimes sharp points, which cut the covering of a spiral in an adjoining layer, and thus make a complete circuit, which is most injurious to the intensity of all the currents induced in the various parts of the coil. It is necessary to know that the complete circuit which diminishes the intensity of the secondary current in the greatest degree, is that which is made by connecting the ends of a coil of thick wire. I have not had time to determine which of the forms of core I have used induces the most intense current in the secondary coil, or which of them makes the condenser act with the greatest effect. I once used for the core a bundle of wires, 9 inches in diameter and 26 inches long. The weight of the core exceeded two hundred and a half pounds. This core acted so badly, as to convince me that anyone who wishes to obtain currents of very great intensity, or very long sparks, should never employ cores of very large diameter.

The fourth result is an improved method of insulation for the secondary coil. In this mode the insulation is imperfect where imperfect insulation is sufficient, and perfect where such insulation is required, and consequently each spiral is brought nearer to the core, to the primary coil, and to the other spirals of the secondary coil, than in the ordinary manner of insulation, in which the parts of each layer for which very little insulation is required are as well insulated from the layer above and below it as the parts which require the best insulation. My mode of insulation differs from the ordinary one in two respects:—First, in the insulation of each spiral from the adjoining ones in the same layer; secondly, in the insulation of the spirals of every layer from the contiguous spirals of the layer above it. I do not cover the fine wire with thread of any kind; but I coat it with a very thin film of varnish by drawing it through melted rosin and bees-wax. I draw it through the hot varnish by winding it on the coil at the distance of about 25 feet from the stove by which the varnish is heated; I have found that at this distance the varnish is cool and hard, even when the wire is drawn through it at the rate of 8000 feet in the hour. Thus in this mode of insulating the fine wire, a coil may be made in a comparatively short time. The insulation is sufficient, because the difference between the intensity of any spiral and the adjoining ones of the same layer is indefinitely small. On every inch of each layer I can put eighty or eighty-two spirals of wire $\frac{1}{100}$dth of an inch thick. My mode of insulating the spirals of each layer from those of the layer above or below it, differs also from the way in which they are insulated by others. In the common mode of insulation, if, as in Mr. Gassiot's great coil, five thicknesses of gutta-percha, or of any other insulating substance, be thought necessary in order to insulate the extreme spirals of any layer from those of the layer below it, five thicknesses of the insulating substance are put between the whole length of every two adjoining layers; so that if there be twenty layers along with the first, there will be 100 thicknesses of the insulating substance. But, in my mode of insulation, there would, in such a case, be only sixty. In order to render my mode of insulation intelligible, I shall explain how the first layer of spirals is insulated from the second, and the second from the third. Every other layer, such as the third, fifth, seventh, &c. represented by an odd number, will be insulated from the one above it, in the same way as the first is insulated from the second; and every layer, such as the fourth, sixth, eighth, &c. represented by an even number, will be insulated from the one above it, in the same way as the second is from the third. In insulating the first layer from the second, when five thicknesses of the insulating substance to be used are deemed necessary for the insulation of the last spirals of the second layer from the first spirals of the first (there the difference of intensity is greatest), I divide the length of the layer into five equal parts. I then put one thickness of the insulating substance (let us suppose it to be what I use, viz. the paper employed for copper-plate engravings saturated with a solution of gutta-percha in oil) on the entire length of the first layer, and then roll the fine wire on one fifth of the layer. I next cover the whole length of the coil with another thickness of prepared paper, and coil the fine wire on the second fifth of the layer. I then put on a third thickness of paper, and wind the wire on the third fifth of the coil. I then put on another thickness of paper, and coil the wire on the fourth fifth, and so on. Then between the first fifth of the second layer and the spirals below it in the first, there is one thickness of paper; and one will insulate them as well as five will insulate the whole length of the two layers from each other. Between the second fifth of the second layer and the part of the first layer below it, there are two thicknesses of paper, and they will sufficiently insulate these two parts from each other. In the same way the third is insulated by three thicknesses, the fourth by four, and the last by five thicknesses of paper: thus the five parts of the coil are as well insulated from each other as if there were five thicknesses between the entire length of the two layers. To insulate the second layer from the third, as well as the first is insulated from the second, only one thickness of paper is necessary; for by putting a single thickness of paper on the second layer, the first fifth is covered by one, the second by two, the third by three, the fourth by four, and the last by five thicknesses of paper. Hence to insulate any two layers, only six thicknesses of the insulating substance are necessary, or three for the insulation of each layer; and therefore to insulate twenty layers, only sixty thicknesses of the insulating substance to be used are required. Thus in my mode of insulation, every spiral in the secondary coil is brought nearer to all the contiguous spirals and to the primary coil and core, than in the ordinary method of insulation; and consequently the inductive power of the core and of the primary coil on the secondary one, as well as the inductive power of the spirals of the secondary coil on each other, must produce a secondary current of far greater intensity in mine than in the common mode of insulation. The coil which was shown at the meeting of the British Association was insulated in the manner just explained. This coil and the contact-breaker, which will be presently described, were seen at work by Mr. Gassiot, Dr. Robinson, M. Foucault, Professor Rogers, and other members of the Association. Mr. Gassiot was so much pleased with their action and construction, that he ordered from Mr. Yeates, an optician in Dublin, a contact-breaker and two secondary coils like mine. In each of these secondary coils there will be nearly 60,000 feet of iron wire about the $\frac{1}{100}$dth of an inch thick.

The fifth result is a contact-breaker in which the striking parts are copper, and which act as well as if they were platina. The contact-breaker consists, first, of a small electro-magnet; secondly, of its armature screwed to a board moveable on a hinge, and having attached to it a spring connected with the vibrating piece of copper; thirdly, of a spring for pressing the striking pieces together; and of a trough containing oil, in which these pieces are always immersed." By means of the spring attached to the board to which the armature is fastened, the armature is brought within the most convenient distance from the small electro-magnet. The spring presses the striking pieces together with the greatest force the electro-magnet is capable of overcoming, and the pressure is exerted immediately over the points of contact. The oil prevents in some measure the oxidation of the copper, and serves to stop the battery current more quickly; for as soon as the pieces of copper are separated, the oil rushes in between them, and being a non-conductor, instantly stops the galvanic current from the battery. In the first contact-breaker which I made of this kind, there were two vibrating pieces, one of platina, the other of copper; the former struck against another piece of platina, the latter against a piece of copper: the copper was immersed in oil. By means of two screws, both might be made to make and break contact together, or I could cause either to make and break contact. By first causing the platina, and afterwards the copper, to make and break contact, I found that the copper acted as well as the platina. In the contact-breaker which I showed at the meeting in Dublin, there were three vibrating pieces of copper, each about three-eighths of an inch thick. M. Foucault thinks that the contact will be made and broken as well by one as by several vibrating pieces. Though that should be the case, the addition of two other pieces will not be useless; for the three may be immersed in different fluids, and thus we can discover the fluid in which contact may be made and broken with the greatest advantage.

The sixth result is a more satisfactory explanation of the condenser. In order to understand the action of the condenser, we must examine the electrical state of the primary coil at the moment its connexion with the battery is broken, and the effect which this state has on the core and secondary current. At the moment the connexion between the battery and primary coil is broken, the electricity which it received from the battery continues to flow to the end of the coil to which it was moving; but being no longer urged forward by the battery, its velocity is constantly diminished by the resistance of the wire. This electricity moving more slowly than when the coil and battery were connected, and in the same direction as the battery current, is not able to maintain in the core, or in the primary or secondary coil, the magnetic power produced in them by the battery; but it maintains a part of it, and prevents the core, the primary and secondary coil, from losing their magnetism in an instant, and consequently diminishes the intensity of the secondary current. The condenser prevents the gradual diminution of the velocity of the electricity flowing in the primary coil at the moment its connexion with the battery is broken, and probably accelerates it; for in an instant after the battery connexion is broken, the end of the coil towards which the electricity is moving, and the plate of the condenser connected with it, become positive. This positive plate instantly renders the other plate negative: the latter then attracts electricity to the former with an enormous force, on account of their very close proximity; and if the plates of the condenser be of sufficient size, the electricity moving in the primary coil will be drawn with such force to the positive plate, that its velocity, instead of being diminished, will probably be increased. Thus the condenser removes the obstacle arising from the electrical state of the primary coil, to the condenser should be made in such a way that the entire of it will produce the full effect of a condenser on the coil for which it is intended when the largest battery we wish to use is employed, and that a small or a large part of the condenser may be used when we wish to excite the coil by a weak or strong battery. I learned from Mr. Gassiot and M. Foucault during the late meeting of the Association, that they were aware of the necessity of making the condenser in this way.

Maynooth College,
Sept. 29, 1857.

P.S. I have abstained from saying anything about the primary coil, because my experiments on it have not led me to a satisfactory conclusion, and not because I think the primary coils in common use incapable of improvement. I believe that they are very badly calculated to attain their object, and that they have been made on a false principle.

IX

Induction coil entry in the

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HUSBAND to ITALIC

Dr. Niell McKeith

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and in 1857 the army, breaking away from the chief's control, besieged the British residency, and took advantage of the mutiny of the Bengal sepoys to spread disorder over that part of central India. The country was pacified after some fighting. In 1899 a British resident was appointed to Indore, which had formerly been directly under the agent to the governor-general in central India. At the same time a change was made in the system of administration, which was from that date carried on by a council. In 1903 the Maharaja, Shivaji Rao Holkar, G.C.S.I., abdicated in favour of his son Tukoji Rao, a boy of twelve, and died in 1908.

The CITY OF INDORE is situated 1738 ft. above the sea, on the river Saraswati, near its junction with the Khan. Pop. (1901) 86,686. These figures do not include the tract assigned to the resident, known as "the camp" (pop. 11,118), which is under British administration. The city is one of the most important trading centres in central India.

INDORE RESIDENCY, a political charge in central India, is not co-extensive with the state, though it includes all of it except some outlying tracts. Area, 8960 sq. m.; pop. (1901) 833,410. (J. S. Co.)

INDORSEMENT, or ENDORSEMENT (from Med. Lat. *indorsare,* to write upon the *dorsum,* or back), anything written or printed upon the back of a document. In its technical sense, it is the writing upon a bill of exchange, cheque or other negotiable instrument, by one who has a right to the instrument and who thereby transmits the right and incurs certain liabilities. See BILL OF EXCHANGE.

INDO-SCYTHIANS, a name commonly given to various tribes from central Asia, who invaded northern India and founded kingdoms there. They comprise the Sakas, the Yue-Chi or Kushans and the Ephthalites or Hūnas.

INDRA, in early Hindu mythology, god of the clear sky and greatest of the Vedic deities. The origin of the name is doubtful, but is by some connected with *indu,* drop. His importance is shown by the fact that about 250 hymns celebrate his greatness, nearly one-fourth of the total number in the Rig Veda. He is represented as specially lord of the elements, the thunder-god. But Indra was more than a great god in the ancient Vedic pantheon. He is the patron-deity of the invading Aryan race in India, the god of battle to whose help they look in their struggles with the dark aborigines. Indra is the child of Dyaus, the Heaven. In Indian art he is represented as a man with four arms and hands; in two he holds a lance and in the third a thunderbolt. He is often painted with eyes all over his body and then he is called Sahasraksha, "the thousand eyed." He lost much of his supremacy when the triad Brahma, Siva and Vishnu became predominant. He gradually became identified merely with the headship of Swarga, a local vice-regent of the abode of the gods.

See A. A. Macdonell, *Vedic Mythology* (Strassburg, 1897).

INDRE, a department of central France, formed in 1790 from parts of the old provinces of Berry, Orléanais, Marche and Touraine. Pop. (1906) 290,216. Area 2666 sq. m. It is bounded N. by the department of Loir-et-Cher, E. by Cher, S. by Creuse and Haute-Vienne, S.W. by Vienne and N.W. by Indre-et-Loire. It takes its name from the river Indre, which flows through it. The surface forms a vast plateau divided into three districts, the Boischaut, Champagne and Brenne. The Boischaut is a large well-wooded plain comprising seven-tenths of the entire area and covering the south, east and centre of the department. The Champagne, a monotonous but fertile district in the north, produces abundant cereal crops, and affords excellent pasturage for large numbers of sheep, celebrated for the fineness of their wool. The Brenne, which occupies the west of the department, was formerly marshy and unhealthy, but draining and afforestation have brought about considerable improvement.

The department is divided into the arrondissements of Châteauroux, Le Blanc, La Châtre and Issoudun, with 23 cantons and 245 communes. At Neuvy-St-Sépulchre there is a circular church of the 11th century, to which a nave was added in the 12th century, and at Mézières-en-Brenne there i interesting church of the 14th century. At Levroux there fine church of the 13th century and the remains of a f(fortress, and there is a magnificent château in the Renaiss style at Valençay.

INDRE-ET-LOIRE, a department of central France, consi of nearly the whole of the old province of Touraine and of s portions of Orléanais, Anjou and Poitou. Pop. (1906) 337 Area 2377 sq. m. It is bounded N. by the department Sarthe and Loir-et-Cher, E. by Loir-et-Cher and Indre, S. S.W. by Vienne and W. by Maine-et-Loire. It takes its n from the Loire and its tributary the Indre, which enter i its eastern border and unite not far from its western bo The other chief affluents of the Loire in the department the Cher, which joins it below Tours, and the Vienne, w waters the department's southern region. Indre-et-Loir generally level and comprises the following districts: Gâtine, a pebbly and sterile region to the north of the L largely consisting of forests and heaths with numerous sı lakes; the fertile Varenne or valley of the Loire; the Ch. peigne, a chain of vine-clad slopes, separating the valleys of Cher and Indre; the Véron, a region of vines and orcha in the angle formed by the Loire and Vienne; the plat of Sainte-Maure, a hilly and unproductive district in the ce of which are found extensive deposits of shell-marl; and in south the Brenne, traversed by the Claise and the Creuse a forming part of the marshy territory which extends under same name into Indre.

Indre-et-Loire is divided into the arrondissements of To Loches and Chinon, with 24 cantons and 282 communes. T chief town is Tours, which is the seat of an archbishopric; a Chinon, Loches, Amboise, Chenonceaux, Langeais and Az le-Rideau are also important places with châteaus. T Renaissance château of Ussé, and those of Luynes (15th a 16th centuries) and Pressigny-le-Grand (17th century) are a of note. Montbazon possesses the imposing ruins of a squ donjon of the 11th and 12th centuries. Preuilly has the m beautiful Romanesque church in Touraine. The Sainte Chape (16th century) at Champigny is a survival of a château of t dukes of Bourbon-Montpensier. The church of Montrés (1532) with its mausoleum of the family of Montrésor; that St Denis-Hors (12th and 16th century) close to Amboise, wi the curious mausoleum of Philibert Babou, minister of finan under Francis I. and Henry II.; and that of Ste Catherine Fierbois, of the 15th century, are of architectural interes The town of Richelieu, founded in 1631 by the famous minist of Louis XIII., preserves the enceinte and many of the buildin of the 17th century. Megalithic monuments are numero in the department.

INDRI, a Malagasy word believed to mean "there it goes, but now accepted as the designation of the largest of the existin Malagasy (and indeed of all) lemurs. Belonging to the famil *Lemuridae* (see PRIMATES) it typifies the subfamily *Indrisina* which includes the avahi and the sifakas (*q.v.*). From both th latter it is distinguished by its rudimentary tail, measuring onl a couple of inches in length, whence its name of *Indris brevi caudatus.* Measuring about 24 in. in length, exclusive of th tail, the indri varies considerably in colour, but is usually black with a variable number of whitish patches, chiefly about th loins and on the fore-limbs. The forests of a comparativel small tract on the east coast of Madagascar form its home Shoots, flowers and berries form the food of the indri, whicl was first discovered by the French traveller and naturalis Pierre Sonnerat in 1780. (R. L.*)

INDUCTION (from Lat. *inducere,* to lead into; cf. Gr. ἐπαγωγή) in logic, the term applied to the process of discovering principles by the observation and combination of particular instances. Aristotle, who did so much to establish the laws of deductive reasoning, neglected induction, which he identified with a complete enumeration of facts; and the schoolmen were wholly concerned with syllogistic logic. A new era opens with Bacon, whose writings all preach the principle of investigating the laws of nature with the purpose of improving the conditions of human life. Unluckily his mind was still enslaved by the formulae of the quasi-mechanical scholastic logic. He supposed that natural laws would disclose themselves by the accumulation and due arrangement of instances without any need for original speculation on the part of the investigator. In his *Novum Organum* there are directions for drawing up the various kinds of lists of instances. For two hundred years after Bacon's death little was done towards the theory of induction; the reason being, probably, that the practical scientists knew no logic, while the university logicians, with their conservative devotion to the syllogism, knew no science. Whewell's *Philosophy of the Inductive Sciences* (1840), the work of a thoroughly equipped scientist, if not of a great philosopher, shows due appreciation of the cardinal point neglected by Bacon, the function of theorizing in inductive research. He saw that science advances only in so far as the mind of the inquirer is able to suggest organizing ideas whereby our observations and experiments are colligated into intelligible system. In this respect J. S. Mill is inferior to Whewell: throughout his *System of Logic* (1843) he ignores the constitutive work of the mind, and regards knowledge as the merely passive reception of sensuous impressions. His work was intended mainly to reduce the procedure of induction to a regular demonstrative system like that of the syllogism; and it was for this purpose that he formulated his famous Four Methods of Experimental Inquiry. His work has contributed greatly to the systematic treatment of induction. But it must be remarked that his Four Methods are not methods of formal proof, as their author supposed, but methods whereby hypotheses are suggested or tested. The actual proof of an hypothesis is never formal, but always lies in the tests of experiment or observation to which it is subjected.

The current theory of induction as set forth in the standard works is so far satisfactory that it combines the merit of Whewell's treatment with that of Mill's; and yet it is plain that there is much for the logician of the future to accomplish. The most important faculty in scientific inquiry is the faculty of suggesting new and valuable hypotheses. But no one has ever given any explanation how the hypotheses arise in the mind: we attribute it to "genius," which, of course, is no explanation at all. The logic of discovery, in the higher sense of the term, simply has no existence. Another important but neglected province of the subject is the relation of scientific induction to the inductions of everyday life. There are some who think that a study of this relation would quite transform the accepted view of induction. Consider such a piece of reasoning as may be heard any day in a court of justice, a detective who explains how in his opinion a certain burglary was effected. If all reasoning is either deductive or inductive, this must be induction. And yet it does not answer to the accepted definition of induction, "the process of discovering a general principle by observation of particular instances": what the detective does is to reconstruct a particular crime; he evolves no general principle. Such reasoning is used by every man in every hour of his life: by it we understand what people are doing around us, and what is the meaning of the sense-impressions which we receive. In the logic of the future it will probably be recognized that scientific induction is only one form of this universal constructive or reconstructive faculty. Another most important question closely akin to that just mentioned is the true relation between these reasoning processes and our general life as active intelligent beings. How is it that the detective is able to understand the burglar's plan of action?—the military commander to forecast the enemy's plan of campaign? Primarily, because he himself is capable of making such plans. Men as active creatures co-operating with their fellow-men are incessantly engaged in forming plans and in apprehending the plans of those around them. Every plan may be viewed as a form of induction: it is a scheme invented to meet a given situation, an hypothesis which is put to the test of events, and is verified or refuted by practical success or failure. Such considerations widen still farther our view of scientific induction and help us to understand its relation to ordinary human thought and activity scientific investigator in his inductive stage is endeav to make out the plan on which his material is constr The phenomena serve as indications to help him in frami hypothesis, generally a guess at first, which he procee verify by experiment and the collection of additional In the deductive stage he assumes that he has made ou plan and can apply it to the discovery of further detail. I the capacity of detecting plans in nature because he is wo form plans for practical purposes.

There are good recent accounts of induction in Welton's *M of Logic*, ii., in H. W. B. Joseph's *Introduction to Logic*, an W. R. Boyce Gibson's *Problem of Logic*; see also Logic. (H. S

INDUCTION COIL, an electrical instrument consistin two coils of wire wound one over the other upon a core sisting of a bundle of iron wires. One of these circuits is ca the primary circuit and the other the secondary circuit an alternating or intermittent continuous current is pa through the primary circuit, it creates an alternating or in mittent magnetization in the iron core, and this in turn cre in the secondary circuit a secondary current which is ca the induced current. For most purposes an induction coi required which is capable of giving in the secondary circ intermittent currents of very high electromotive force, and attain this result the secondary circuit must as a rule cons of a very large number of turns of wire. Induction coils a employed for physiological purposes and also in connexion w telephones, but their great use at the present time is in connexi with the production of high frequency electric currents, f Röntgen ray work and wireless telegraphy.

The instrument began to be devoloped soon after Faraday discovery of induced currents in 1831, and the subseque researches of Joseph Henry, C. G. Page and W. Sturgeon on the induction of a current. N. J. Callan described in 1836 the construction of an electromagnet with two separate insulated wires, one thick and th other thin, wound on an iron core together. He provided th primary circuit of this instrument with an interrupter, and found that when the primary current was rapidly intermitted, a series of secondary currents was induced in the fine wire, o high electromotive force and considerable strength. Sturgeon in 1837 constructed a similar coil, and provided the primary circuit with a mercury interrupter operated by hand. Various other experimentalists took up the construction of the induction coil, and to G. H. Bachhoffner is due the suggestion of employing an iron core made of a bundle of fine iron wires. At a somewhat later date Callan constructed a very large induction coil containing a secondary circuit of very great length of wire. C. G. Page and J. H. Abbot in the United States, between 1838 and 1840, also constructed some large induction coils.[1] In all these cases the primary circuit was interrupted by a mechanically worked interrupter. On the continent of Europe the invention of the automatic primary circuit interrupter is generally attributed to C. E. Neeff and to J. P. Wagner, but it is probable that J. W. M'Gauley, of Dublin, independently invented the form of hammer break now employed. In this break the magnetization of the iron core by the primary current is made to attract an iron block fixed to the end of a spring, in such a way that two platinum points are separated and the primary circuit thus interrupted. It was not until 1853 that H. L. Fizeau added to the break the condenser which greatly improved the operation of the coil. In 1851 H. D. Rühmkorff (1803–1877), an instrument-maker in Paris, profiting by all previous experience, addressed himself to the problem of increasing the electromotive force in the secondary circuit, and induction coils with a secondary circuit of long fine wire have generally, but unnecessarily, been called Rühmkorff coils. Rühmkorff, however, greatly lengthened the secondary circuit, employing in some coils 5 or 6 m. of wire. The secondary wire was insulated with silk and shellac varnish,

Early histor.

[1] For a full history of the early development of the induction coil see J. A. Fleming, *The Alternate Current Transformer*, vol. ii. chap. i.

and each layer of wire was separated from the next by means of varnished silk or shellac paper; the secondary circuit was also carefully insulated from the primary circuit by a glass tube. Rühmkorff, by providing with his coil an automatic break of the hammer type, and equipping it with a condenser as suggested by Fizeau, arrived at the modern form of induction coil. J. N. Hearder in England and E. S. Ritchie in the United States began the construction of large coils, the last named constructing a specially large one to the order of J. P. Gassiot in 1858. In the following decade A. Apps devoted great attention to the production of large induction coils, constructing some of the most powerful coils in existence, and introduced the important improvement of making the secondary circuit of numerous flat coils of wire insulated by varnished or paraffined paper. In 1869 he built for the old Polytechnic Institution in London a coil having a secondary circuit 150 m. in length. The diameter of the wire was 0·014 in., and the secondary bobbin when complete had an external diameter of 2 ft. and a length of 4 ft. 10 ins. The primary bobbin weighed 145 lb, and consisted of 6000 turns of copper wire 3770 yds. in length, the wire being ·095 of an inch in diameter. Excited by the current from 40 large Bunsen cells, this coil could give secondary sparks 30 in. in length. Subsequently, in 1876, Apps constructed a still larger coil for William Spottiswoode, which is now in the possession of the Royal Institution. The secondary circuit consisted of 280 m. of copper wire about 0·01 of an inch in diameter, forming a cylinder 37 in. long and 20 in. in external diameter; it was wound in flat disks in a large number of separate sections, the total number of turns being 341,850. Various primary circuits were employed with this coil, which when at its best could give a spark of 42 in. in length.

Construction. A general description of the mode of constructing a modern induction coil, such as is used for wireless telegraphy or Röntgen ray apparatus, is as follows: The iron core consists of a bundle of soft iron wires inserted in the interior of an ebonite tube. On the outside of this tube is wound the primary circuit, which generally consists of several distinct wires capable of being joined either in series or parallel as required. Over the primary circuit is placed another thick ebonite tube, the thickness of the walls of which is proportional to the spark-producing power of the secondary circuit. The primary coil must be wholly enclosed in ebonite, and the tube containing it is generally longer than the secondary bobbin. The second circuit consists of a number of flat coils wound up between paraffined or shellaced paper, much as a sailor coils a rope. It is essential that no joints in this wire shall occur in inaccessible places in the interior. A machine has been devised by Leslie Miller for winding secondary circuits in flat sections without any joints in the wire at all (British Patent, No. 5811, 1903). A coil intended to give a 10 or 12 in. spark is generally wound in this fashion in several hundred sections, the object of this mode of division being to prevent any two parts of the secondary circuit which are at great differences of potential from being near to one another, unless effectively insulated by a sufficient thickness of shellaced or paraffined paper. A 10-in. coil, a size very commonly used for Röntgen ray work or wireless telegraphy, has an iron core made of a bundle of soft iron wires No. 22 S.W.G., 2 in. in diameter and 18 in. in length. The primary coil wound over this core consists of No. 14 S.W.G. copper wire, insulated with white silk laid on in three layers and having a resistance of about half an ohm. The insulating ebonite tube for such a coil should not be less than ¼ in. in thickness, and should have two ebonite cheeks on it placed 14 in. apart. This tube is supported on two hollow pedestals down which the ends of the primary wire are brought. The secondary coil consists of No. 36 or No. 32 silk-covered copper wire, and each of the sections is prepared by winding, in a suitable winding machine, a flat coiled wire in such a way that the two ends of the coil are on the outside. The coil should not be wound in less than a hundred sections, and a larger number would be still better. The adjacent ends of consecutive sections are soldered together and insulated, and the whole secondary coil should be immersed in paraffin wax. The completed coil (fig. 1) is covered with a sheet of ebonite and mounted on a base board which, in some cases, contains the primary condenser within it and carries on its upper surface a hammer break. For many purposes, however, it is better to separate the condenser and the break from the coil. Assuming that a hammer break is employed, it is generally of the Apps form. The interruption of the primary circuit is made between two contact studs which ought to be of massive platinum, and across the break points is joined the primary condenser. This consists of a number of sheets of paraffined paper interposed between sheets of tin foil, alternate sheets of the tin foil being joined together (see LEYDEN JAR). This condenser serves to quench the break spark. If the primary

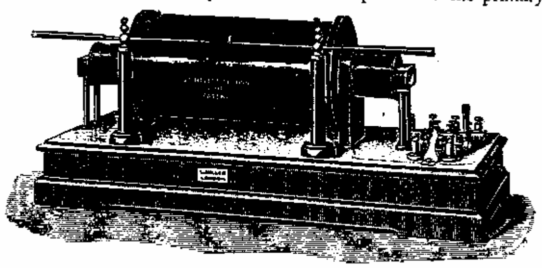

FIG. 1.

condenser is not inserted, the arc or spark which takes place at the contact points prolongs the fall of magnetism in the core, and since the secondary electromotive force is proportional to the rate at which this magnetism changes, the secondary electromotive force is greatly reduced by the presence of an arc-spark at the contact points. The primary condenser therefore serves to increase the suddenness with which the primary current is interrupted, and so greatly increases the electromotive force in the secondary circuit. Lord Rayleigh showed (*Phil. Mag.*, 1901, 581) that if the primary circuit is interrupted with sufficient suddenness, as for instance if it is severed by a bullet from a gun, then no condenser is needed. No current flows in the secondary circuit so long as a steady direct current is passing through the primary, but at the moments that the primary circuit is closed and opened two electromotive forces are set up in the secondary; these are opposite in direction, the one induced by the breaking of the primary circuit being by far the stronger. Hence the necessity for some form of circuit breaker, by the continuous action of which there results a series of discharges from one secondary terminal to the other in the form of sparks.

The hammer break is somewhat irregular in action and gives a good deal of trouble in prolonged use; hence many other forms of primary circuit interrupters have been devised.

Interrupters or Breaks. These may be classified as (1) hand- or motor-worked dipping interrupters employing mercury or platinum contacts; (2) turbine mercury interrupters; (3) electrolytic interrupters. In the first class a steel or platinum point, operated by hand or by a motor, is periodically immersed in mercury and so serves to close the primary circuit. To prevent oxidation of the mercury by the spark and break it must be covered with oil or alcohol. In some cases the interruption is caused by the continuous rotation of a motor either working an eccentric which operates the plunger, or, as in the Mackenzie-Davidson break, rotating a slate disk having a metal stud on its surface, which is thus periodically immersed in mercury in a vessel. A better class of interrupter is the mercury turbine interrupter. In this some form of rotating turbine pump pumps mercury from a vessel and squirts it in a jet against a copper plate. Either the copper plate or the jet is made to revolve rapidly by a motor, so that the jet by turns impinges against the plate and escapes it; the mercury and plate are both covered with a deep layer of alcohol or paraffin oil, so that the jet is immersed in an insulating fluid. In a recent form the chamber in which the jet works is filled with coal gas. The current supplied to the primary circuit of the coil travels from the mercury in the vessel through the jet to the copper plate, and hence is periodically interrupted when the jet does not impinge against the plate. Mercury turbine breaks are much employed in connexion with large induction coils used for wireless telegraphy on account of their regular action and the fact that the number of interruptions per second can be controlled easily by regulating the speed of the motor which rotates the jet. But all mercury breaks employing paraffin or alcohol as an insulating medium are somewhat troublesome to use because of the necessity of periodically cleaning the mercury. Electrolytic interrupters were first brought to notice by Dr A. R. B. Wehnelt in 1898 (*Elektrotechnische Zeitschrift*, January 20th, 1899). He showed that if a large lead plate was placed in dilute sulphuric acid as a cathode, and a thick platinum wire protruding for a distance of about one millimetre beyond a glass or porcelain tube into which it tightly fitted was used as an anode, such an arrangement when inserted in the circuit of a primary coil gave rise to a rapid intermittency in the primary current. It is essential that the platinum wire should be the anode or positive pole. The frequency of the Wehnelt break can be adjusted by regulating the extent to which the platinum wire protrudes through the porcelain tube, and in modern electrolytic breaks several platinum anodes are employed. This break can be employed with any voltage between 30 and 250. The Caldwell interrupter, a modification of the Wehnelt break, consists of two electrodes immersed in dilute sulphuric acid, one of them being enclosed by a glass vessel which has a small hole in it capable of being more or less closed by a tapered glass plug. It differs from the Wehnelt break in that there is no platinum to wear away and it requires less current; hence finer regulation of the coil to the current can be obtained. It will also work with either direct or alternating currents. The hammer and mercury turbine breaks can be arranged to give interruptions from about 10 per second up to about 50 or 60. The electrolytic breaks are capable of working at a higher speed, and under some conditions will give interruptions up to a thousand per second. If the secondary terminals of the induction coils are connected to spark balls placed a short distance apart, then with an electrolytic break the discharge has a flame-like character resembling an alternating current arc. This type of break is therefore preferred for Röntgen ray work since it makes less flickering upon the screen, but its advantages in the case of wireless telegraphy are not so marked. In the Grisson interrupter the primary circuit of the induction coil is divided into two parts by a middle terminal, so that a current flowing in at this point and dividing equally between the two halves does not magnetize the iron. This terminal is connected to one pole of the battery, the other two terminals being connected alternately to the opposite pole by means of a revolving commutator which (1) passes a current through one half of the primary, thus magnetizing the core; (2) passes a current through both halves in opposite directions, thus annulling the magnetization; (3) passes a current through the second half of the primary, thus reversing the magnetization of the core; and (4) passes a current in both halves through opposite directions, thus again annulling the magnetization. As this series of operations can be performed without interrupting a large current through the inductive circuit there is not much spark at the commutator, and the speed of commutation can be regulated so as to obtain the best results due to a resonance between the primary and secondary circuits. Another device due to Grisson is the electrolytic condenser interrupter. If a plate of aluminium and one of carbon or iron is placed in an electrolyte yielding oxygen, this aluminium-carbon or aluminium-iron cell can pass current in one direction but not in the other. Much greater resistance is experienced by a current flowing from the aluminium to the iron than in the opposite direction, owing to the formation of a film of aluminic hydroxide on the aluminium. If then a cell consisting of a number of aluminium plates alternating with iron plates or carbon in alkaline solution is inserted in the primary circuit of an induction coil, the application of an electromotive force in the right direction will cause a transitory current to flow through the coil until the electrolytic condenser is charged. By the use of a proper commutator the position of the electrolytic cell in the circuit can be reversed and another transitory primary current created. This interrupted flow of electricity through the primary circuit provides the intermittent magnetization of the core necessary to produce the secondary electromotive force. This operation of commutation can be conducted without much spark at the commutator because the circuit is interrupted at the time when there is no current in it. In the case of the electrolytic condenser no supplementary paraffined paper condenser is necessary as in the case of the hammer or mercury interrupters.

High Frequency Coils.

An induction coil for the transformation of alternating current is called a transformer (*q.v.*). One type of high frequency current transformer is called an *oscillation transformer* or sometimes a *Tesla coil*. The construction of such a coil is based on different principles from that of the coil just described. If the secondary terminals of an ordinary induction coil or transformer are connected to a pair of spark balls (fig. 2), and if these are also connected to

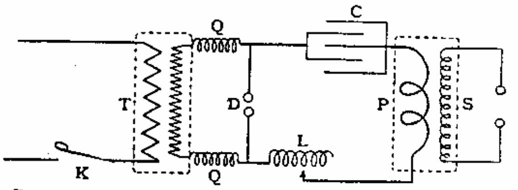

FIG. 2.—Arrangements for producing High Frequency Currents.
T, Transformer or induction coil.
Q, Q, Choking coils.
D, Spark balls.
C, Condenser.
L, Inductance.
P, Primary circuit of high frequency coil.
S, Secondary circuit.

a glass plate condenser or Leyden jar of ordinary type joined in series with a coil of wire of low resistance and few turns, then at each break of the primary circuit of the ordinary induction coil a secondary electromotive force is set up which charges the Leyden jar, and if the spark balls are set at the proper distance, this charge is succeeded by a discharge consisting of a movement of electricity backwards and forwards across the spark gap, constituting an oscillatory electric discharge (see ELECTROKINETICS). Each charge of the jar may produce from a dozen to a hundred electric oscillations which are in fact brief electric currents of gradually decreasing strength. If the circuit of few turns and low resistance through which this discharge takes place is overlaid with another circuit well insulated from it consisting of a large number of turns of finer wire, the inductive action between the two circuits creates in the secondary a smaller series of electric oscillations of higher potential. Between the terminals of this last-named coil we can then produce a series of discharges each of which consists in an extremely rapid motion of electricity to and fro, the groups of oscillations being separated by intervals of time corresponding to the frequency of the break in the primary circuit of the ordinary induction coil charging the Leyden jar or condenser. These high frequency discharges differ altogether in character from the secondary discharges of the ordinary induction coil. Theory shows that to produce the best results the primary circuit of the oscillation transformer should consist of only one thick turn of wire or, at most, but of a few turns. It is also necessary that the two circuits, primary and secondary, should be well insulated from one another, and for this purpose the oscillation transformer is immersed in a box or vessel full of highly insulating oil. For full details N. Tesla's original Papers must be consulted (see *Journ. Inst. Elect. Eng.* 21, 62).

In some cases the two circuits of the Tesla coil, the primary and secondary, are sections of one single coil. In this form the arrangement is called a *resonator* or *auto transformer*, and is much used for producing high frequency discharges for medical purposes. The construction of a resonator is as follows: A bare copper wire is wound upon an ebonite or wooden cylinder or frame, and one end of it is connected to the outside of a Leyden jar or battery of Leyden jars, the inner coating of which is connected to one spark ball of the ordinary induction coil. The other spark ball is connected to some point on the above-named copper wire not very far from the lower end. By adjusting this contact, which is movable, the electric oscillations created in the short section of the resonator coil produce by resonance oscillations in the longer free section, and a powerful high frequency electric brush or discharge is produced at the free end of the resonator spiral. An electrode or wire connected with this free end therefore furnishes a high frequency glow discharge which has been found to have valuable therapeutic powers.

Theory of Oscillation Transformers.

The general theory of an oscillation transformer containing capacity and inductance in each circuit has been given by Oberbeck, Bjerknes and Drude.[1] Suppose there are two circuits, each consisting of a coil of wire, the two being superimposed or adjacent, and let each circuit contain a condenser or Leyden jar in series with the circuit, and let one of these circuits contain a spark gap, the other being closed (fig. 3). If to the spark balls the secondary terminals of an ordinary induction coil are connected, and these spark balls are adjusted near one another, then when the ordinary coil is set in operation, sparks pass between the balls and oscillatory discharges take place in the circuit containing the spark gap. These oscillations induce other oscillations in the second circuit. The two circuits have a certain mutual inductance M, and each circuit has self inductance L_1 and L_2. If then the capacities in the two circuits are denoted by C_1 and C_2 the following simultaneous equations express the relation of the currents, i_1 and i_2, and potentials, v_1, and v_2, in the primary and secondary circuits respectively at any instant:—

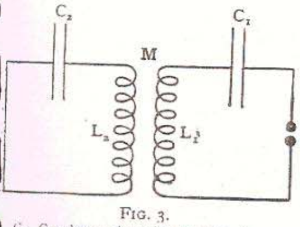

FIG. 3.

C_1, Condenser in primary circuit.
C_2, Condenser in secondary circuit.
L_1, Inductance in primary circuit.
L_2, Inductance in secondary circuit.

$$L_1\frac{di_1}{dt} + M\frac{di_2}{dt} + R_1 i_1 + v_1 = 0,$$

$$L_2\frac{di_2}{dt} + M\frac{di_1}{dt} + R_2 i_2 + v_2 = 0,$$

R_1 and R_2 being the resistances of the two circuits. If for the moment we neglect the resistances of the two circuits, and consider that the oscillations in each circuit follow a simple harmonic law $i = I \sin pt$ we can transform the above equations into a biquadratic

$$p^4 - p^2\frac{L_1C_1 + L_2C_2}{C_1C_2(L_1L_2 - M^2)} + \frac{1}{C_1C_2(L_1L_2 - M^2)} = 0.$$

The capacity and inductance in each circuit can be so adjusted that their products are the same number, that is $C_1L_1 = C_2L_2 = CL$. The two circuits are then said to be in resonance or to be tuned together. In this particular and unique case the above biquadratic reduces to

$$p^2 = \frac{1}{CL} \cdot \frac{1 \pm k}{1 - k^2},$$

where k is written for $M/\sqrt{(L_1L_2)}$ and is called the *coefficient of coupling*. In this case of resonant circuits it can also be shown that the maximum potential differences at the primary and secondary condenser terminals are determined by the rule $V_1/V_2 = 2\sqrt{C_2}/\sqrt{C_1}$. Hence the transformation ratio is not determined by the relative number of turns on the primary and secondary circuits, as in the case of the ordinary alternating current transformer (see TRANSFORMERS), but by the ratio of the capacity in the two oscillation circuits. For full proofs of the above the reader is referred to the original papers.

Each of the two circuits constituting the oscillation transformer taken separately has a natural time period of oscillation; that is to say, if the electric charge in it is disturbed, it oscillates to and fro in a certain constant period like a pendulum and therefore with a certain frequency. If the circuits have the same frequency when separated they are said to be isochronous. If n stands for the natural frequency of each circuit, where $n = p/2\pi$ the above equations show that when the two circuits are coupled together, oscillations set up in one circuit create oscillations of two frequencies in the secondary circuit. A mechanical analogue to the above electrical effect can be obtained as follows: Let a string be strung loosely between two fixed points, and from it let two other strings of equal length hang down at a certain distance apart, each of them having a weight at the bottom and forming a simple pendulum. If one pendulum is set in oscillation it will gradually impart this motion to the second, but in so doing it will bring itself to rest; in like manner the second pendulum being set in oscillation gives back its motion to the first. The graphic representation, therefore, of the motion of each pendulum would be a line as in fig. 4. Such a curve

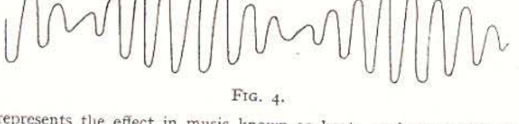

FIG. 4.

represents the effect in music known as beats, and can easily be shown to be due to the combined effect of two simple harmonic motions or simple periodic curves of different frequency superimposed. Accordingly, the effect of inductively coupling together two electrical circuits, each having capacity and inductance, is that if oscillations are started in one circuit, oscillations of two frequencies are found in the secondary circuit, the frequencies differing from one another and differing from the natural frequency of each circuit taken alone. This matter is of importance in connexion with wireless telegraphy (see TELEGRAPH), as in apparatus for conducting it, oscillation transformers as above described, having two circuits in resonance with one another, are employed.

REFERENCES.—J. A. Fleming, *The Alternate Current Transformer* (2 vols., London, 1900), containing a full history of the induction coil; *id.*, *Electric Wave Telegraphy* (London, 1906), dealing in chap. i. with the construction of the induction coil and various forms of interrupter as well as with the theory of oscillation transformers; A. T. Hare, *The Construction of Large Induction Coils* (London, 1900); J. Trowbridge, "On the Induction Coil," *Phil. Mag.* (1902), 3, p. 393; Lord Rayleigh, "On the Induction Coil," *Phil. Mag.* (1901), 2, p. 581; J. E. Ives, "Contributions to the Study of the Induction Coil," *Physical Review* (1902), vols. 14 and 15. (J. A. F.)

INDULGENCE (Lat. *indulgentia*, *indulgere*, to grant, concede), in theology, a term defined by the official catechism of the Roman Catholic Church in England as "the remission of the temporal punishment which often remains due to sin after its guilt has been forgiven." This remission may be either total (*plenary*) or partial, according to the terms of the Indulgence. Such remission was popularly called a *pardon* in the middle ages—a term which still survives, *e.g.* in Brittany.

The theory of Indulgences is based by theologians on the following texts: 2 Samuel (Vulgate, 2 Kings) xii. 14; Matt. xvi. 19 and xviii. 17, 18; 1 Cor. v. 4, 5; 2 Cor. ii. 6-11; but the practice itself is confessedly of later growth. As Bishop Fisher says in his Confutation of Luther, "in the early church, faith in Purgatory and in Indulgences was less necessary than now. . . . But in our days a great part of the people would rather cast off Christianity than submit to the rigour of the [ancient] canons: wherefore it is a most wholesome dispensation of the Holy Ghost that, after so great a lapse of time, the belief in purgatory and the practice of Indulgences have become generally received among the orthodox" (*Confutatio*, cap. xviii.; cf. Cardinal Caietan, *Tract. XV. de indulg.* cap. i.). The nearest equivalent in the ancient Church was the local and temporary African practice of restoring lapsed Christians to communion at the intercession of confessors and prospective martyrs in prison. But such reconciliations differed from later Indulgences in at least one essential particular, since they brought no remission of ecclesiastical penance save in very exceptional cases. However, as the primitive practice of public penance for sins died out in the Church, there grew up a system of equivalent, or nominally equivalent, private penances. Just as many of the punishments enjoined by the Roman criminal code were gradually commuted by medieval legislators for pecuniary fines, so the years or months of fasting enjoined by the earlier ecclesiastical codes were commuted for proportionate fines, the recitation of a certain number of psalms, and the like. "Historically speaking, it is indisputable that the practice of Indulgences in the medieval

[1] See A. Oberbeck, *Wied. Ann.* (1895), 55, p. 623; V. F. R. Bjerknes, (1895), 55, p. 121, and (1891), 44, p. 74; and P. K. L. Drude, *Ann. Phys.* (1904), 13, p. 512.

<u>X</u>

Extract from

Fleming J.A.,

The Alternative Current Transformer in Theory and Practice,

Vol.2, London: The Electrician Printing and Publishing Co. Ltd., 1903.

THE ALTERNATE CURRENT TRANSFORMER

IN THEORY AND PRACTICE.

BY

J. A. FLEMING, M.A., D.Sc. (Lond.),

PROFESSOR OF ELECTRICAL ENGINEERING IN UNIVERSITY COLLEGE, LONDON;
LATE FELLOW AND SCHOLAR OF ST. JOHN'S COLLEGE, CAMBRIDGE;
FELLOW OF UNIVERSITY COLLEGE, LONDON;
MEMBER OF THE INSTITUTION OF ELECTRICAL ENGINEERS;
MEMBER OF THE PHYSICAL SOCIETY OF LONDON;
MEMBER OF THE ROYAL INSTITUTION OF GREAT BRITAIN;
ETC., ETC.

VOLUME II.

THE UTILIZATION OF INDUCED CURRENTS.

LONDON:
"THE ELECTRICIAN" PRINTING AND PUBLISHING COMPANY, LIMITED,
SALISBURY COURT, FLEET STREET, E.C.

1892.

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 $2\frac{1}{2}$ 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

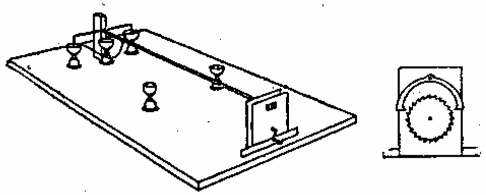

Fig. 3.—Callan's Electro-Magnetic Repeater, or Vibrating Contact Breaker.

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

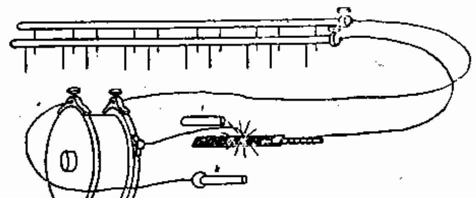

Fig. 4.—Sturgeon's Induction Coil with Wooden Core.

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

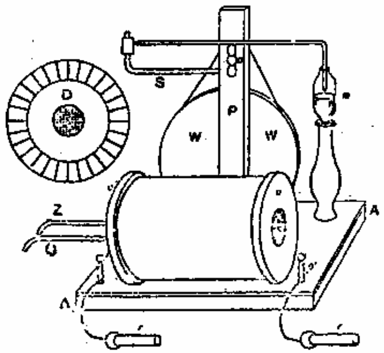

Fig. 5.—Sturgeon's Induction Coil.

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

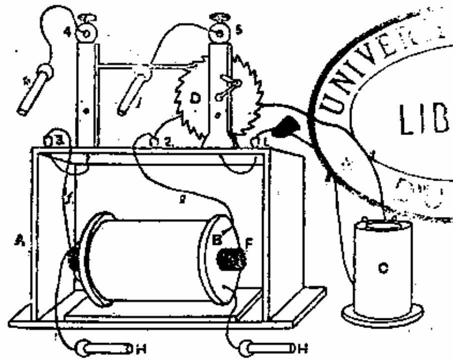

Fig. 6.—Sturgeon's First Induction Coil.

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

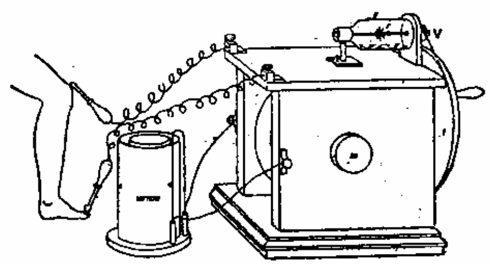

FIG. 7.—Clarke's Induction Coil.

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

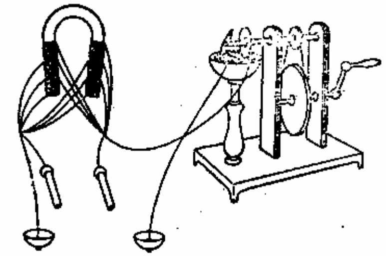

FIG. 8.—Barker's Revolving Contact Breaker, or Mercury Break.

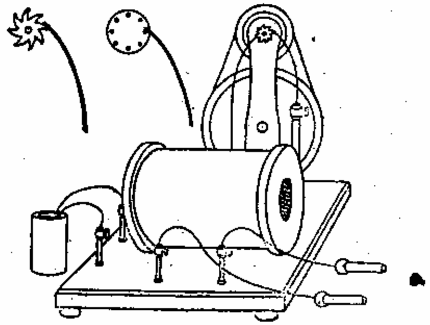

FIG. 9.—Nesbit's Induction Coil.

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

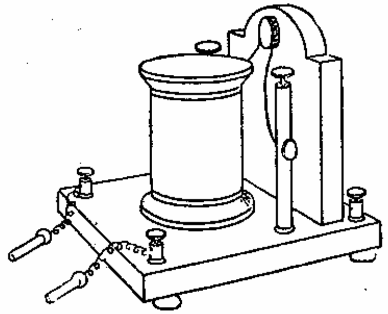

FIG. 10.—Uriah Clarke's Coil. (Side elevation.)

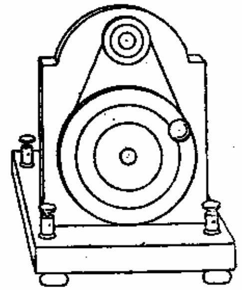

FIG. 11.—Uriah Clarke's Coil. (Back view.)

appears from what he says that at first he used lengths of tton-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-

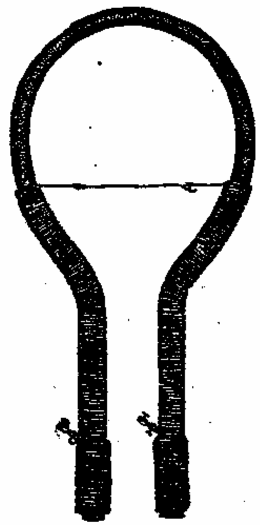

Fig. 12.—Dr. Callan's First Induction Coil (1836), with thick and thin wire Circuits.
Still preserved at Maynooth College.

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 [illegible] three separate coils or rings. The inner diameter of each coil [illegible] ring is 5·75in., and the outer diameter is 21in. Two of the [illegible] are 3in. in thickness, and one is 4in. The rings are so [illegible]ged on the primary coil as to divide its entire length into [illegible] equal parts, the planes of the rings being perpendicular to [illegible] axis of the coil. In each ring both ends of the wire are [illegible]jecting, so that the separate coils can be joined in series [illegible] 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

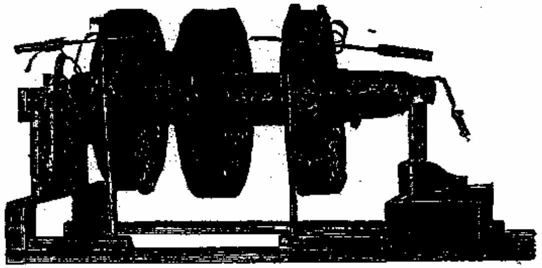

Fig. 13.—Dr. Callan's Large Induction Coil completed in 1863. Still preserved at Maynooth College.

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