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.