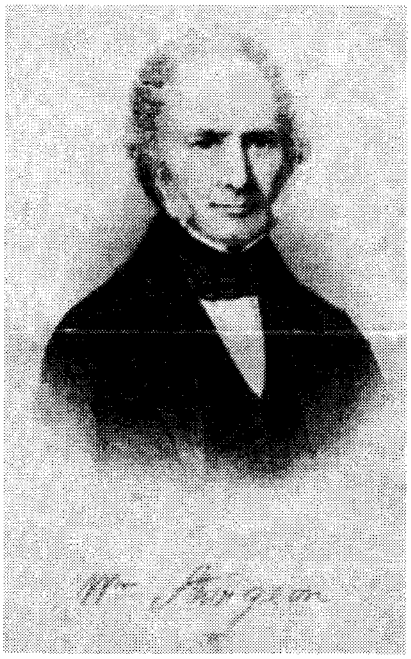
William Sturgeon – Father of the Electric Motor.

David Dew-Hughes

William Sturgeon is notable for the construction, among many demonstrations, discoveries and inventions, of the first practical, electric motor capable of producing useful work. He had previously invented the iron-cored electromagnet and the spring-contact commutator. Both of these inventions were crucial to the development of rotating electrical machines. For these three achievements alone he deserves to be much more widely remembered and honoured.

He was born in Whittington, Lancashire, on 22 May 1783, in a cottage, which though much altered, still exists and is now known as Croft House. His birthplace is commemorated with a blue plaque. His father was John Sturgeon, a shoemaker, who came from the neighbourhood of Dumfries, and married Betsy Adcock, daughter of a small shopkeeper in Whittington. The Sturgeons had three children, William, Margaret who married John Coates, and Mary who died in infancy. John Sturgeon had a local reputation as a salmon poacher, and William was compelled, at night, to wade up the Lune with a torch in his hand while his father speared the fish that were attracted by the light. His mother died when he was ten years old. At the age of thirteen, he was apprenticed to a shoemaker at Old Hutton, Westmorland. Not content with exacting a slavish drudgery during the week, his employer compelled William to carry gamecocks from one part of the country to another, to "change their walks". Despite the hardship of his existence, William acquired some proficiency in music, and some mechanical arts, in addition to the skills as a shoemaker. One of the celebrations of the Preston Guild took place during his apprenticeship, and he and a fellow apprentice determined to attend. They went without leave from their master, and William financed the trip by cleaning clocks on the way, a skill he had acquired in Old Hutton.



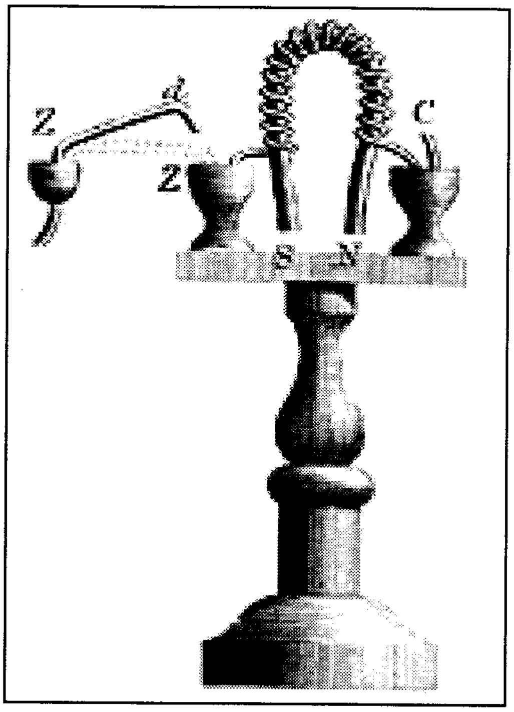
Dissatisfied with his position as a journeyman shoemaker, and seeing little prospect of improving his condition, in 1802 he enlisted in the Westmorland Militia. Enlistment in the time of war may have been an acceptable way of terminating an apprenticeship, which normally would be expected to last for seven years or until his twenty-first birthday. Two years later he volunteered as a private in the 2nd Battalion of the Royal Artillery, stationed at Woolwich. Soon after joining the RA he married Mary Hutton, a widow who kept a shoe shop in Woolwich. They had three children, John and Elizabeth, twins, and Ann, all of whom died in infancy.

Despite this being the time of the Napoleonic Wars, William never saw active service. He was stationed for some time in Newfoundland, and the experience of violent electric storms there first turned his attention to the contemplation of electrical phenomena. His interest in natural phenomena thus excited, he prepared himself for their further study by teaching himself to read and write. A sergeant had a collection of books, to which he gave William access. He studied mathematics, various languages, optics and other aspects of natural philosophy. He kept up his craft as bootmaker, providing most of the officers with footwear, and acquired further practical skills, such as lithography. He left the Army in 1820, at the age of 37; his conduct having been "altogether unimpeachable", though he never rose above the rank of bombardier. He briefly took up his old trade of bootmaking in Lancaster, but at the instance of his wife, he moved back to Woolwich to be near her family. They took up residence at 8 Artillery Place, Woolwich.

The Royal Military Academy at Woolwich had a large concentration of scientific minds. Peter Barlow, Samuel Hunter Christie (son of the founder of the well-known firm of auctioneers) and Olinthus Gilbert Gregory all taught mathematics; James Marsh [1] taught practical chemistry. Sturgeon had purchased an old lathe and began the construction of scientific instruments. These were initially for the furtherance of his own studies in natural philosophy, but such was his success in their construction that he soon found a ready market among the London instrument makers. This brought him into contact with the local men of science, with whom he founded the Woolwich Literary Society.

In order to appreciate Sturgeon's contributions it is necessary to recount the early history of electromagnetism. Oersted had long suspected that there was a connection between electricity and magnetism. Arago and Sir Humphrey Davy had separately showed that iron could be magnetised by an electric current. Oersted discovered that an electric current influenced a neighbouring compass needle. This discovery was published in a pamphlet, dated 21 July 1820, and written in Latin. This was probably the last piece of important scientific news to be issued in that language. Arago carried the news of Oersted's experiments to Paris, where within a week Ampère had reproduced and extended the work. He discovered that wires carrying currents in the same direction repelled one another, and that wires carrying currents in the opposite direction attracted one another. He named this new science electrodynamics, in contradistinction to the old science of electrostatics. London scientists were not slow to follow up the interest in electrodynamics; many experiments and demonstrations were devised. In the Royal Institution Michael Faraday demonstrated the rotation of a magnet around an electric current, and of a current-carrying wire around a magnet (1821) [2]. Barlow, the above-mentioned Professor of Mathematics at the Artillery Academy at Woolwich, took these experiments further with the movement of a current-carrying wire, and then the rotation of a star wheel, between the poles of a horseshoe-shaped permanent magnet (1822). Sturgeon's first known original contribution was to replace the star wheel by a circular disc, thus inventing the homopolar machine. These experiments illustrated the phenomenon that we now call the Lorentz force.

Repeating the work of Arago and Davy, Sturgeon discovered the ease with which soft iron could be magnetised. He wrapped several turns of wire around a bar of iron [3], which became magnetised when an electric current was passed through the wire. He noticed that the magnetic field generated by the current was magnified and concentrated in the iron core. Further developments included varnishing the iron, allowing him to wind the wire more tightly on the core, thus further enhancing the magnetic field, and bending the iron bar into a horseshoe shape. An improved magnet, constructed in 1823, with the help of Francis Watkins, with 16 turns of wire, was able to attract and support 9lbs, 20 times its own weight, of metal objects.



The demonstration of electromagnetic phenomena required both a source of electricity and a magnetic field. The magnitude of the effect to be demonstrated depended upon the strength of both the electric current and the magnetic field. For a given circuit the current depended in turn upon the voltage, supplied by a series of cells. The magnetic field was initially derived from a permanent magnet. The early permanent magnets were rather weak, and the production of readily observable effects required the use of many cells. Sturgeon, by his own account, was unable to afford the large number of cells, so turned his attention to increasing the strength of the magnetic field, which object he achieved with his electro-magnet. Doing away with the necessity for a large number of cells not only achieved economy but also resulted in very compact apparatus. This in turn improved the ease with which electromagnetic phenomena could be demonstrated.

During 1824, in addition to his work on electromagnets, Sturgeon carried out studies of thermoelectricity, repeating Seebeck's experiment, and confirmed Yelin's observation of what was later called the "Thompson Effect" (electric current induced by a temperature gradient) in bismuth. He published his first papers, on thermoelectricity and magnetism, in the Philosophical Magazine. At the end of 1824, at Barlow's recommendation, he was appointed lecturer in experimental philosophy at the East India Company's Military Seminary [4] in Addiscombe. He appears to have held other local teaching positions in addition, and to have been making a good living. He gave public lectures and demonstrations, using his new, compact, equipment, at the Adelaide Gallery, at the Laboratory of Science in Lowther Arcade, and to the Western Literary and Scientific Institution, all in central London. He continued his instrument making, and produced improved versions of many pieces of apparatus designed to demonstrate various facets and phenomena of electromagnetism, such as Ampère's cylinders [5]. In 1825 he was awarded the large silver medal of the Society of Arts, and a purse of 30

guineas, for a compact set of improved electromagnetic apparatus that included his iron-cored electromagnet. A description of his apparatus was published in the Transactions of the Royal Society of Arts for 1825.

He continued to publish the results of his researches in the Philosophical Magazine. During 1826 he turned his attention to the use of electricity to ignite gunpowder. Sometime during this period William's wife died, and he married Mary Bromley of Shropshire on 19 September 1829. They had one daughter, who died in infancy. He and his wife then adopted his niece, Ellen, daughter of his sister Margaret Coates.

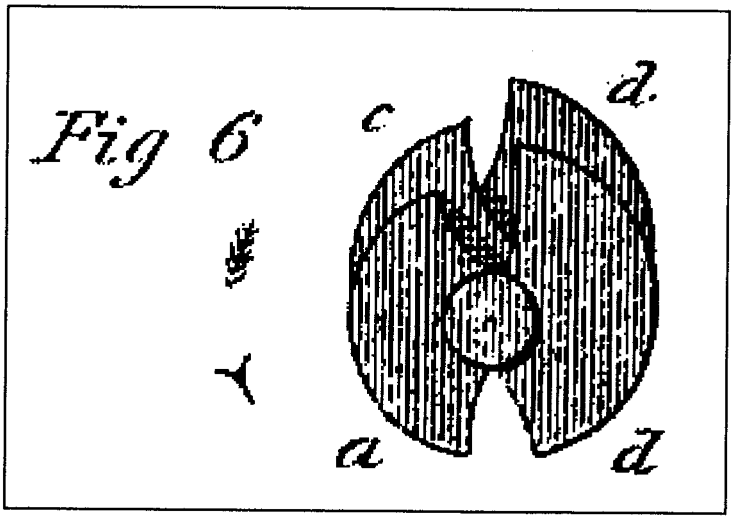
By 1830 he had become interested in electrochemistry, and proposed many improvements to electric batteries. He invented a long-lasting battery in which a cast-iron cylinder formed both the outer containment of the battery and doubled-up as one of the electrodes, with a cylinder of zinc as the other electrode. He was particularly concerned with the use of zinc as an electrode material. He demonstrated the superiority of rolled over cast zinc, and came up with the idea of amalgamating the surface of zinc with mercury to provide a uniform electrolytic action over the surface of the zinc. While continuing to submit individual papers to the Philosophical Magazine, he also attempted to publish his complete works as one book. Volume I of his Experimental Researches appeared in 1830. The manuscripts of the subsequent volumes were lost by the printer.

The development of the electromagnet had been continued by Joseph Henry of Albany, New York, later to be appointed Professor of Physics at Princeton University. Henry, after whom is named the unit of electromagnetic inductance, insulated his wires with silk (insulated wire not then being available commercially), enabling a tighter winding and hence a more powerful magnet for the same current. Henry demonstrated his new electromagnet in 1831, showed how it could send electric signals over long distances, and suggested the possibility of the telegraph. The following year Samuel F. B. Morse, painter and sculptor, first conceived the idea of an electromagnetic recording telegraph and dot-and-dash code system. The telegraph could not have been devised without Sturgeon's invention of the electromagnet, as both Henry and Morse attested.

One of the problems facing the early experimenters in electricity was the precise measurement of quantities of electricity. It is not clear whether, at this stage, the distinction between voltage, charge and current had yet been made. One method of estimating the quantity of charge passed was by the volume of gas produced by dissociation of acidulated water under what ideally should be standard conditions. This voltameter was promoted by Faraday. Sturgeon contested the validity and accuracy of this method. That the strength of magnetic field in a standardised electromagnet could be used to measure current apparently did not occur to Sturgeon. Chambers' Biographical Dictionary [6] credits him with the invention of the suspended-coil galvanometer, a claim repeated by many other writers. I can find no evidence to support this claim, either in the Annals of Electricity or in his Scientific Researches. He was sufficient of a self-publicist that he would have made mention of this invention in the Annals.

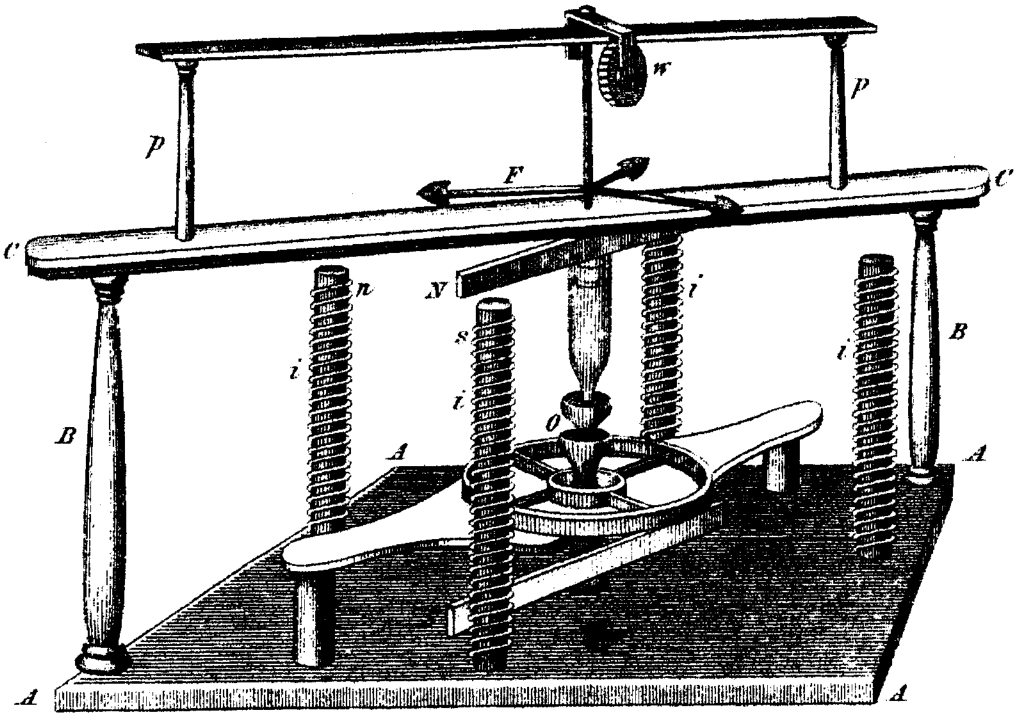
A claim that Sturgeon discovered electromagnetic induction before Faraday [7] is, however, worthy of investigation. Oersted had shown that a magnetic compass needle would move under the influence of an electric current in a neighbouring wire. It was argued that the inverse of this effect should exist, i.e. placing a magnet close to a conductive wire should cause a current to flow in the wire. Several investigators searched for this effect. It was not at first recognised that what was important was relative motion between the magnet and the wire, and that bringing a magnet close to a wire produced a transient signal which was difficult to detect. In 1831 Faraday returned to the study of electrodynamics, after a ten-year period away from the subject. He observed the transient signal by several different experiments, and recognised its significance [8]. Sturgeon had been investigating "magnetic electricity" by the use of iron filings to plot "polar magnetic lines" around a magnet. He also studied what we now know to be "eddy currents" in discs rotating in magnetic fields. He realised the importance of currents at 90° to magnetic lines, and discovered electromagnetic induction by the inverse of Barlow's wheel. Rotation of the wheel between the poles of a magnet induced an electric current in the wheel. This was a far more elegant method than that used by Faraday, in that it produced a continuous current. Sturgeon completed this work just as Faraday was publishing. The account of Sturgeon's work, in which he acknowledged the prior discovery by Faraday, appeared in the Philosophical Magazine in 1833.

On the basis of these experiments, and incorporating his electromagnets, Sturgeon began to construct rotating electrical machines, both motors and dynamos. In these machines it is necessary to reverse the direction of magnetisation, and hence of current flow, in the electromagnets once every half revolution. This was initially achieved by means of "semi-wheels" mounted on the rotating shaft and dipping into troughs of mercury. This had the disadvantage, apart from the unrecognised health hazard, that as the machine rotated mercury splashed out of the troughs and eventually became so depleted that operation of the machine ceased. Sturgeon overcame this by replacing the mercury with sprung strips of copper contacting his semi-wheels. In this way he invented the commutator, which he referred to initially as a "spring discharger" and later as the "unio-direction discharger". Sturgeon presented three lectures to the Western Literary and Scientific Institution in March 1833. The subjects were Electricity, Magnetism, and Electro- and Thermo-Magnetism. The first exhibition of his motor took place during these lectures.



The machine consisted of four long, small diameter, iron-cored electromagnets arranged on a wooden base at the corners of a square. A central spindle, parallel to the magnets, carried two permanent bar magnets, slightly shorter than the diagonal of the square, one at each end, and level with the ends of the electromagnets. At the centre of this spindle was located his unio-direction discharger. The bar magnets were arranged anti-parallel, i.e. north and south poles in opposite directions. Current flowing in one electromagnet would create a north pole at one end and a south pole at the other end. At the same time current would flow in the opposite direction in the diagonally opposite electromagnet. No current would flow in the other two electromagnets. The attraction between the bar magnets and the induced poles on the electromagnets would cause the spindle to rotate. By the action of the commutator the current would be switched to the other pair of electromagnets at the appropriate moment, and thus a rotative motion was sustained. A drawing of this motor, taken from Sturgeon's paper, is shown below.

Fig. 1



A model of what is purported to be Sturgeon's first motor is on display in the bar of The Dragon's Head Hotel in Whittington. However it bears no relation to the above, and has a much greater resemblance to one of his dynamos [9].

Faraday was the first to demonstrate that the interaction between magnetism and electricity could give rise to rotative motion. Henry devised an oscillating machine, by alternately switching electromagnets at the opposite ends of a beam, which were repelled by stationary permanent magnets. But there can be no doubt that it was Sturgeon who first showed how these phenomena could be harnessed in a machine capable of doing useful work. He must therefore be recognised as the true father of the electric motor.

Sturgeon was subsequently invited to read a paper on his magnetic electrical machine and the experiments carried out with it, before the Royal Society on 16 June 1836. Although the paper was well received, it was refused publication in the Society's Philosophical Transactions. This rejection seems to have soured Sturgeon. He founded his own journal, *The Annals of Electricity, Magnetism and Chemistry or the Guardian of Experimental Science* in October of 1836, and never again published in the Philosophical Magazine [10]. The ten volumes of the Annals contain one third of Sturgeon's 69 known publications, together with original papers by others, translations of mainland European work, and the republication of earlier papers on electricity. Sturgeon also used the Annals to criticise established scientists. The origin of his quarrel with Faraday, who refused to acknowledge Sturgeon's invention of the electromagnet, must lie in an open letter in the first volume attacking Faraday's views about the identity of various forms of electricity; "The errors you have fallen into in your Voltaic experiments are too palpable to escape notice, even of the humblest enquirer". Faraday's response appears to have been a dignified silence. Sturgeon referred to the papers of William Snow Harris on marine lightning conductors as "impotent productions". He also criticised the work of Daniell on batteries; Daniell was a colleague at Addiscombe, where he taught chemistry and geology.

An unsigned article, but presumably written by Sturgeon, in Volume III of the Annals, p 433, states: "The first rotary electro-magnetic machine of which there is any account on record, is that invented by Mr Sturgeon (Annals Vol I p 75). This engine was constructed in 1832, and appears to be the first of this class that can give motion to working models of machinery, or indeed to which any model of the kind was attached. This engine would draw light loads on a railway, pump water, saw thin pieces of metal".

At this busy time Sturgeon also concerned himself with the use of his dynamo for electroplating, and the installation of lightning conductors in ships. His original contribution to the latter was to provide multiple conductors on the several masts of sailing vessels, to reduce the current over that of a single conductor. It was in championing his own system that he crossed swords with Snow Harris. His interest in meteorological phenomena, initially aroused by the Newfoundland thunderstorms, lasted throughout his life. Copying the famous experiments of Benjamin Franklin, he made over 500 flights with kites into the atmosphere. He established that in calm weather the atmosphere is, invariably, positively charged with respect to earth, the magnitude of the charge increasing with increasing altitude. It is to be presumed that his work on lightning conductors resulted from these experiments.

In 1837 the Sturgeons moved house to Westmorland Cottage, Pomeroy Street, Old Kent Road. Experiments with electric shocks lead to the invention of the high voltage induction coil, more usually credited to Tesla. This coil is the basis of the "electro-medical machine" for what we now call convulso-therapy, and is in principal identical with the ignition coils for internal combustion engines. The same year Joseph Henry met Sturgeon on a visit to Woolwich, and commented "He is a man of great industry, has a strong mind but the want of an early discipline has rendered him not as clear in his conceptions as an other course of education would have rendered him". Henry attended one of Sturgeon's lectures; "he is a very good experimenter but an indifferent lecturer". Sturgeon was also instrumental in founding the London Electrical Society in the Spring of 1837. This was the pioneer society to specialise in the study of electricity. The first meeting, chaired by Sturgeon, was held in Clark's Laboratory of Science, Lowther Arcade (Clark was an instrument maker). The success of this first meeting prompted a move to the Adelaide Gallery, where meetings were held on Saturday evenings. The Society also published both Proceedings and Transactions, to which Sturgeon contributed papers. Sturgeon resigned from the Society in 1838, for reasons unknown, and the Society went into a decline, lasting for only six years. The Society may be regarded as the forerunner of the Institution of Electrical Engineers. Charles V. Walker, Secretary to the London Electrical Society, subsequently became President of the Society of

Telegraph Engineers on its foundation in 1871. This latter society later became the Institution of Electrical Engineers, now the largest professional society in Europe.

In 1838 Sturgeon is writing from Westmorland Cottage on the Identity or Non-identity of Electricity and Magnetism: "There are no facts on record which demonstrate an identity in Electricity and Magnetism; but, on the contrary, there are many phenomena which justify the idea of their being perfectly distinct powers of nature". One cannot take serious argument with this statement.

In 1840 Sturgeon was invited to become the Superintendent of the Royal Victoria Gallery of Practical Science, founded in Manchester the previous year. Sturgeon was in overall charge of the direction, courses of lectures and displays of apparatus of the institution, which was modelled on the Adelaide Gallery. James Joule [11], whom he knew through his contributions to the Annals, was invited to lecture. With Joule and others a small social and intellectual circle was established in Manchester. Contrary to Henry's opinion, Joule stated of Sturgeon "as a lecturer he was distinguished by his power of impressing the truths of science clearly and accurately on the minds of his auditory, and especially by the uniform success of his experimental illustrations".

Unfortunately for Sturgeon the country was experiencing an economic depression. Support for the Gallery dried up and it closed in 1842. He founded the Manchester Institute of Natural and Experimental Science in January 1843, but this failed after he gave one course of lectures on mechanical philosophy. His personal financial embarrassment became acute, and he had to give up the publication of the Annals of Electricity, as he had been providing some of the expenses of that journal himself. He did earn some money lecturing at the Mechanics Institution and the Royal Manchester Institution. He was elected to membership of the Manchester Literary and Philosophical Society in 1844, and subsequently published some papers in the Memoirs.

By this time Sturgeon was reduced to earning a living as an itinerant lecturer, taking his apparatus in a cart around the villages in the Manchester area. In 1845 Joule, soliciting support from Faraday, stated that he was "living in great poverty with no means of supporting his family beyond the precarious proceeds of his lectures". In 1847 the government of Lord John Russell made a one-off payment of £200 from the Royal Bounty Fund, and in July 1849 granted him a civil list pension of £50 pa. This was just enough to allow him to undertake his last major task, the collection of most of his papers into a quarto volume of Scientific Researches, published in Bury in 1850. This work was supported by private subscription; 283 subscribers are listed. Among these it is interesting to note:
The Library of the Non-Commissioned Officers, Royal Artillery, Woolwich (he was not forgotten by his old comrades).

Michael Faraday, DCL, FRS, etc London (their quarrel apparently composed).

And several worthies residing in the locality of his birthplace;

Mr Edmund Briggs, Fleet near Kirkby Lonsdale
R Clapham, Esq., Austwick Hall
The Rev. R Dunderdale, B.A., Leck
Thomas Eastham, Esq., Kirkby Lonsdale
The Rev. J Hutton Fisher, M.A., Vicar of Kirkby Lonsdale
Mr. John Foster, Stationer, Kirkby Lonsdale
Joseph Gibson, Esq., Whelprigg
William Gibson, Esq., Lancaster
Thomas Greene, Esq., M.P., Whittington Hall
Mr William Harris, Chemist, Kirkby Lonsdale
Mr Isaac Hudson, Wine & Spirit Merchant, Kirkby Lonsdale
Thomas Howett, Esq., FRCS, Lancaster
Henry Nutter, Esq., Cantsfield
Miss Pownall, Kirkby Lonsdale
James Sellers, Esq., MRCS, Ingleton
Richard Tatham, Esq., Low-fields, Burton-in-Kendal
Thomas H Whittaker Esq., FRCS, Kirkby Lonsdale

In 1847 Sturgeon suffered a severe attack of bronchitis, and this forced him to move from Manchester (he had various addresses in Hulme, a far from salubrious inner suburb) to the cleaner air of Prestwich (13 Wash Lane). He spent some months in Kirkby Lonsdale during 1847. Alexander Pearson, in the Annals of Kirkby Lonsdale [12], states that, in 1847 (month not recorded) four lectures on Electricity and Optics, with demonstrations, were given in the large room at the Green Dragon Inn, by William Sturgeon [13]. In the Memoirs of the Manchester Literary and Philosophical Society for 1848 are three articles. Observations on the Aurora Borealis seen at Kirkby Lonsdale, Westmorland September 28^{th}, 1847. Observations on the Aurora Borealis seen at Biggins, near Kirkby Lonsdale, on October 24^{th} 1847. Observations on the Formation of Clouds in the Locality of Kirkby Lonsdale, Westmorland, (undated). In his Scientific Researches there is a footnote signed William Sturgeon, Kirkby Lonsdale, December 13^{th} 1847.

SCIENTIFIC

RESEARCHES,

EXPERIMENTAL AND THEORETICAL,

IN

ELECTRICITY, MAGNETISM, GALVANISM,

ELECTRO-MAGNETISM, AND ELECTRO-CHEMISTRY.

WITH COPPER-PLATES.

BY WILLIAM STURGEON,

LECTURER ON NATURAL AND EXPERIMENTAL PHILOSOPHY; FORMERLY LECTURER ON EXPERIMENTAL PHILOSOPHY AT THE HONOURABLE EAST INDIA COMPANY'S MILITARY SEMINARY, ADDISCOMBE; AND LATE SUPERINTENDENT AND LECTURER OF THE ROYAL VICTORIA GALLERY OF PRACTICAL SCIENCE, MANCHESTER; EDITOR OF THE ANNALS OF ELECTRICITY, MAGNETISM, AND CHEMISTRY; AUTHOR OF ELEMENTARY LECTURES ON ELECTRICITY, ELEMENTARY LECTURES ON GALVANISM, ETC. ETC. ETC.

PUBLISHED BY SUBSCRIPTION.

BURY:

THOMAS CROMPTON, BOOKSELLER, FLEET STREET.

MDCCCL.

It is tempting to suggest that some benefactor, possibly one of those residents of Kirkby Lonsdale or its immediate neighbourhood whom later subscribed to his "Scientific Researches", offered him hospitality during his convalescence from the bronchial attack. In November 1850 he caught a cold, and died on 4 December of severe bronchitis. He is buried in Prestwich churchyard; he was a lifelong and devout member of the Church of England. His second wife, to whom his pension was transferred, survived him until 1867.

Considering the importance and originality of his contributions to science and engineering, it is quite scandalous that his only memorials are a notice in a Kirkby Lonsdale hostelry, a marble plaque in Kirkby Lonsdale Parish Church, and a recently installed blue plaque at the site of his birthplace in Whittington. No scientific unit is named after him, no equation, effect or law, no piece of apparatus bears his name. The scientific community in London was divided into two groups, the elite scientists, members of the Royal Institution and Fellows of the Royal Society one the one hand, and the practical "electricians" such as Sturgeon and the other members of the Electrical Society of London. These latter were without University degrees, and lectured at the Military Academies rather than at the Universities. Sturgeon failed to be accepted by the scientific elite, presumably due to his lack of formal education, as noted by Henry, but was regarded as being the first among the electricians. Faraday, equally, had received no formal education, and came from a background similar to that of Sturgeon. His father was a blacksmith, originally from Outhgill in Mallerstang, though Michael, whilst conceived in Westmorland, was born in London. He served his apprenticeship as a bookbinder. However he had the good fortune to become assistant to Humphry Davy at the Royal Institution and was accepted by the elite. It was Davy who told Sturgeon, on the occasion of Sturgeon's describing to him some of his early experiments "better mind your last than be dabbling in science".

Had Sturgeon more foresight or commercial acumen, the patenting of his electromagnet alone would have ensured that he died a rich man. Iron-cored electromagnets, or solenoids as they are commonly but erroneously known [14], feature in many items of technology, electric telegraphs, washing machines and dishwashers, automobiles and many more regarded as essential to modern life.

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A F Anderson, A chance encounter with William Sturgeon, IEE Electronics and Power, February 1986, pp 129-131.

F A J L James, William Sturgeon, New Dictionary of National Biography, OUP to be published.

(I am grateful to Dr James for providing me with a pre-publication copy of his article, and for directing me to Ross's account of the discovery of electromagnetic induction).

Notes.

1. Marsh's test for arsenic has produced the forensic evidence for many murder cases.
2. This is, of course, the critical discovery of the scientific principle on which electric motors depend.
3. Almost certainly wrought iron, which is magnetically very soft.
4. Variously referred to as Academy, College and Seminary.
5. Three concentric cylinders, the outer two of copper, joined by an annulus at the bottom to make a hollow vessel. The middle cylinder was of zinc and was freely suspended so that it could rotate about its axis. The copper vessel was filled with dilute sulphuric acid, and with the zinc cylinder acted as a battery. An external connection completed the circuit. A permanent magnet placed inside the inner cylinder exerted a Lorentz force on the current and caused the zinc cylinder to rotate.
6. J O Thorne, Chambers Biographical Dictionary, revised edition, St Martin's Press, New York 1969, p.1233.
7. J O Marsh and G L Hodkinson, Faraday, Sturgeon and the discovery of electromagnetic induction, IEE Weekend Meeting on the History of Electrical Engineering, Brighton, 2-4 July 1982, referred to in "From Compass to Computer", W A Atherton, San Francisco Press Inc., San Francisco 1984, p 79.
8. S Ross, The search for electromagnetic induction 1820-1831 Notes and Records of the Royal Society (1965) 20 184-219.
9. The model is, in fact, based on a design published on a BBC web site, subsequent to one of Adam Hart-Davis' programmes on "Local Heroes".
10. Note that the Philosophical Magazine should not be confused with the Philosophical Transactions of the Royal Society.

11. Joule's family owned a brewery in Salford. Joule established the mechanical equivalent of heat by measuring the temperature rise of water in a barrel (from the family brewery?) agitated by paddles performing a known quantity of work. The unit of energy is named after him.
12. Alexander Pearson, The Annals of Kirkby Lonsdale and Lunesdale – in bygone days, Titus Wilson, Kendal, (1930) pp 52-53.
13. This event is commemorated by a framed notice, produced by local calligrapher George Harrison, to be seen in the main bar of the Snooty Fox Hotel, previously the Green Dragon.
14. The term solenoid was introduced by Ampère to describe a long, coreless, coil producing a uniform magnetic field along most of its bore. The name is derived from the Greek σωλεν, used for tubes, pipes and even open gutters carrying fluids.

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The Scientific Discoveries and Inventions of William Sturgeon

In order to appreciate Sturgeon's contributions it is necessary to recount the early history of electromagnetism.
The discovery by Oersted in 1807, that an electric current can influence a compass needle, created the science of electro-magnetism.
Arago and Sir Humphrey Davy (1819) separately showed that iron could be magnetised by a current.
Ampère (1820) demonstrated the repulsion of like currents and the attraction of opposite currents. Michael Faraday demonstrated the rotation of a magnet around an electric current. The rotation of a current carrying wire around a magnet was also shown.
Peter Barlow, Professor of Mathematics at the Artillery Academy, Woolwich, demonstrated what we now call the Lorentz force, by the movement of a current carrying wire, and then the rotation of a star wheel, between the poles of a horseshoe magnet (1822).
Sturgeon's first original contribution was to replace the star wheel by a circular disc, thus inventing the Homopolar Motor.
1822: Improved Barlow's Wheel by replacing star by circular disc.
1823: Discovered ease with which soft iron could be magnetised, and invented iron-cored electromagnet.
1824: Studies of thermoelectricity - confirms Yelin's observation of "Thompson Effect" in bismuth.
1825: Improved electromagnetic apparatus. Carried out improvements to various pieces of apparatus used for popular demonstrations, such as Ampere's cylinders. Awarded Society of Arts Silver Medal and 30gns prize for a set of improved apparatus.
1826: Series of experiments on use of electricity to ignite gunpowder.
1830: Improvements to batteries. Amalgamation of Zinc with Mercury to improve its performance in cells.
1832: Magnetic electricity: use of iron filings to plot "polar magnetic lines" around a magnet. Investigation of what we now know to be "eddy currents" in discs rotating in magnetic fields. Realised importance of currents at 90° to magnetic lines. Discovered electromagnetic induction, by a much better experimental method than Faraday's, just as Faraday was publishing. Work appeared in Phil Mag 1833.
1836: Read a paper before the Royal Society describing a "magnetic electrical machine" or dynamo, and experiments carried out with it. In it he describes his "spring discharger", later called "unio-direction discharger" or commutator, invented in 1834. The Royal Society rejects his paper for publication in their Transactions. Uses his machine to provide current for electroplating.
1837: Experiments with electric shocks lead to the invention of the high voltage induction coil, more usually credited to Tesla. This coil is the basis of the "electro-medical machine" for what we now call convulso-therapy.