On the 250th anniversary of the discovery of electrical conductivity

L. N. Kryzhanovskiĭ

Usp. Fiz. Nauk 155, 129–132 (May 1988)

A history of the discovery of electrical conductivity and of its realization is presented, based on 17th and 18th century primary sources. An account of the life of the discoverer of this phenomenon is given.

While preparations were underway for the conference on applied superconductivity in 1986 (Baltimore, MD, USA), the historic article of J. G. Bednorz and K. A. Müller, which reported the discovery of high-temperature superconductivity, was still unknown.[1] Nevertheless, the conference proceeded precisely under the heading of the history of physics. A symposium dedicated to the 75th anniversary of the discovery of superconductivity was conducted within the framework of the conference. In particular, a detailed scientific biography of H. Kamerlingh-Onnes, the discoverer of superconductivity (1911) and Nobel laureate (1913),[2] was presented. Much has already been written about the 1987 Nobel laureates, Bednorz and Müller, and about their discovery. Undoubtedly, much more will yet be written. But in the chain of discoveries "conductivity"—"superconductivity"—"high-temperature superconductivity", there has been almost no coverage of the first link—"conductivity". It is expedient to fill this gap.

In contrast to the other two discoveries mentioned, it is impossible to date precisely the discovery of simply "conductivity", although corresponding experiments of 250 years and even further in the past are well known. For the historian of this question, the fundamental difficulty consists of the interpretation of the facts pertaining to the 17th and 18th centuries. However, it is possible to consider that the discovery we are interested in had been consciously comprehended with the introduction of the terms "conductor" and "nonconductor", 250 years ago.

The experiment, based on electroconductivity (to use contemporary terminology) was formulated as far back as the 17th century. Its author was Otto von Guericke (1602–1686), best known for his experiments with the Magdeburg hemispheres. Guericke observed that a hand-rubbed sulphur sphere transmitted its power to attract lightweight objects to a linen thread one ell in length, the end of which, hooked to a stick, was located right against the sphere. The attraction was observed up to an inch away from the thread's lower end.[3] Guericke did not use the already-existing terms "electrical" and "electricity" when describing such experiments. Also, the above-cited experiment with a linen thread was not repeated with other materials or in different variations, so it is hardly possible to speak of the discovery of electrical conductivity in the stated time period (Guericke completed his account in a manuscript in 1663).

At the beginning of the 18th century, Francis Hauksbee (died, 1713) introduced a glass tube which had been rubbed with a dry hand, paper, fabric, or fur, as a source of "electric force".

Using a glass tube (or wand), Stephen Gray (1666–1736), the chief hero of our narrative, repeated Guericke's experiment on a massive scale.[4]

In 1729, Gray discovered a series of objects to which the tube could transmit the "electric force". These were: wooden rods and wires (iron and brass), which Gray placed in the tube (through a cork); hempen string, which he fastened to the tube or pushed into it, etc. For his experiments in the transmission of electricity, Gray would attach a ball of ivory, cork, or lead, with a hole through it, to the end of the wooden rods, or else hang the ball from the end of the string or wire. The maximum distance of indoor "electricity transmission" along a string or wire hung from the tube did not exceed one meter, while the maximum distance of horizontal indoor "electricity transmission" along linked-together wooden conductors (in both cases with a ball at the end) was not more than 5.5 meters, including the length of the tube.

Gray would confirm that the "electric force" was transferred to objects by using a bit of fluff, which could be attracted to the object, be repelled from it, hover in the air, again be attracted, etc., as in Guericke's experiments. He would also use a test thread, which would be attracted to the charged bodies (Guericke also observed this). Another way would be to use a brass plate, which usually lay on a small piece of board, and could be attracted by objects located over it at a height of up to several inches.

Wishing to transmit electricity over a greater distance, on 19 May 1729, Gray conducted a succesful experiment. While standing on a balcony, he suspended an 8-meter line, corresponding to the height of the balcony, from a glass tube which he held in his hand. An ivory ball was at the end of the line. Below was Gray's assistant, who determined the presence of a charge by using a brass plate (on a small board). Gray had no doubt that he would have been able to transmit electricity in such a manner even from the dome of St. Paul's cathedral in London.

Such experiments were but modifications of Guericke's experiment with a linen thread.

Gray still did not have a well-defined conception of conductors and insulators. He spoke in identical terms about the conduction of electricity, for example, to a lead sphere or to an ivory ball. Gray in fact was using his spheres simply to fix the position of the string, wire, etc., while the tube was being rubbed.

Gray decided to attempt the transmission of electricity along the horizontal in order to resolve his question—how far was it possible to transmit electricity? To do this, he suspended a string on nails driven into a wooden beam at the

 0038-5670/88/050456-03$01.80

same height. As usual, there was a ball at the end of the string, which hung over a brass plate. The experiment was a failure. The brass plate lay motionless. Gray came to the generally correct conclusion that the electricity went into the beam.

Gray was able to overcome this difficulty thanks to an outstanding idea by Wheler, together with whom Gray experimented in the summer of 1729. Father Granville Wheler (died, 1770) proposed that the transmission line (or, in Gray's terms, the line of communication) be supported by silk cord, instead of being suspended on nails driven into a board. The very first such experiment, conducted on 2 July 1729 at about 10 o'clock in the morning, as Gray scrupulously reported, surpassed all expectations. The horizontal section of the line of string was fastened at one end to a glass rod. From there it extended to a silk cord, which was stretched out at right angles to the line. The silk cord was not in direct contact with the nails, which were driven into the opposing wall of a barn. Rather, it was attached to pieces of string. An ivory ball was suspended at the end of the line. The hanging portion of the line was about 2.5 meters long, while the overall length of the line was equal to about 25 meters. When the rod was rubbed, the brass plate was attracted to the ball and hung from it for some time.

Replacing the silk cord with a metal wire, Gray again got a negative result: the brass plate lay motionless. Gray understood that the experiment's success was caused not by the fineness of the cord, but by a property of the silk. Conducting subsequent specialized experiments, Gray became convinced that out of all silk cords, the best insulating qualities were possessed by cords of blue color.

On 5 August 1729, Gray "showed that it was possible to transmit electricity, not by touching the transmission line to the tube, but simply by holding the tube close to the line", that is, in later terminology, with the aid of electrostatic induction.

Gray's work spurred the French scientist Charles-François de Cisternai du Fay (1698–1739) toward investigations in electricity, as he himself writes about this.[5,6] Du Fay's classification of objects into conductors and nonconductors of electricity was more precise than Gray's. The terms "conductor" and "nonconductor were introduced not later than 1738,[7] by an English scientist of French origin, the Hugenot John Theophilus Desaguliers (1683–1744), who had replaced Francis Hauksbee in the post of curator of experiments for the Royal Society (London). Previously, William Gilbert (1544–1603) divided all objects into electrical and nonelectrical, depending on their capability of being electrically charged by friction.[8] Du Fay formulated a connection between the named classifications: "objects . . . , which are the least electrical in and of themselves (that is, the least inclined toward electrostatic charging—L. K.), are the best suited for transmitting electric force over a distance".[9]

Let us summarize the results of the foregoing as well as certain other experiments in the transmission of electricity over a distance.

By the end of the thirties in the 18th century, the following were succesfully employed as conductors: linen thread (Guericke, 1663), hempen string, undried wood, metallic wire (Gray, 1729), damp cat gut (Desaguliers, 1738); as nonconductors: silk (Wheler in an experiment set by Gray, 1729), horse hair (Gray, 1729), glass and sealing wax (Du Fay, 1733), dry cat gut (Desaguliers, 1738).[10] The length of the electrical lines achieved several hundred meters.

The prerequisites for the invention of the electric telegraph were created by means of these investigations. As is known, the first for all practical purposes useful telegraph, based on an electromagnetic principle, was built in 1832 by the Russian scientist and inventor Pavel L'vovich Shilling (1786–1837).

Until recent times, scientific historians have had at their disposal extremely meager biographical information about the discoverer of electrical conductivity, Stephen Gray. "It is amazing", wrote T. Thompson in his *History of the Royal Society*, "that no biographical memoirs have survived about a man to whom the science of electricity is so much in debt" (cited from Ref.[11]). However, in 1979 the first detailed study appeared of a biographical nature devoted to Gray.[12]

The Gray family lived in Canterbury. Stephen's grandfather and great-grandfather were blacksmiths, but his father was a dyer. Stephen was baptised in the Church of All Saints on Best Lane (Canterbury) on 26 December 1666. He was probably born several weeks before that date. Stephen and one of his brothers, like their father, became dyers. This profession was apparently not profitable, as Gray did not have enough money for "books, instruments, and other materials", as he writes in one of his letters. There is no reliable information about Gray's education.

The works of Gray were published in "Philosophical Transactions" from 1696 on. His first works were concerned with optics, astronomy, and meteorology. However, Gray's early works on electricity were not published in the official journal of the Royal Society. This is explained by the parallel activity of Hauksbee in this area. More importantly, it is also explained by the hostile relations between Newton, who was president of the Royal Society for an unbroken period of time from 1703 right up to his death in 1727, and Flamsteed, an astronomer and member of the society (subsequently excluded "for nonpayment of dues"), who was Gray's patron. During Newton's presidency, the Royal Society published only one of Gray's works. It was Gray's first publication on electricity. It is contained in the "Philosophical Transactions" for 1720 (Ref. 13, vol. 6, pp. 490–492). The work is notable for its great novelty. In particular, in this work Gray demonstrated that it was possible to electrify by friction such substances as silk threads, ribbons, paper, and fur. The effect was verified by the attraction to the threads, etc., of lightweight objects, occasionally at a distance of 8–10 inches. The effect was strengthened with preliminary preheating (this is explained by the removal of moisture). When Gray brought his hand up to electrified objects in darkness, light and crackling would eminate from them (as in experiments with glass, Gray noted). The substances named subsequently found wide use, not only in scientific research, but also in practical applications of electricity.

From 1719, and right up to his death, Gray was a Charterhouse pensioner. This charitable institution in London was founded in the 17th century by the Cartesians. It was intended for unmarried men of the Church of England (originally, for retired naval captains, etc.). His arrival at Charterhouse, which was not easy to get into, freed Gray from the difficult work of a dyer, and allowed him to devote himself full time to science.

In 1731, Gray became history's first recipient of the Copley Prize. Copley (died, 1709) was a member of the Royal Society, who bequeathed to the society 100 pounds sterling, so that an award be issued for achievement in the field of natural sciences (in 1736, the society decided that, in place of a monetary award, the gold Copley Medal would be awarded; among Russian scientists, D. I. Mendeleev and I. P. Pavlov were awarded the Copley Medal). Gray was chosen as a member of the Royal society in 1732. Gray died on 25 February 1736.

[1] J. G. Bednorz and K. A. Muller, Z. Phys. KI. B **64**, 189 (1986).
[2] R. de Bruyn Ouboter, IEEE Trans. (v. MAG-23) 354 (1987).
[3] O. von Guericke, Experiments Nova (ut vocantur) Magdeburgica de Vacuo Spatio, Jansson, Amstelodami, 1676, p. 244.
[4] S. Gray, Phil. Trans. **37**, No. 417, 18 (1731/1732).
[5] C. F. Du Fay, Hist. de l'Ac. Paris, 233 (1733).
[6] C. F. Du Fay, Phil. Trans. **38**, No. 431, 258 (1733/1734).
[7] J. T. Desaguliers, *Ibid* **41**, pt. I, No. 454, 193 (1739/1740).
[8] W. Gilbert, About the Magnet, Magnetic Bodies, and the Great Magnet—the Earth [Russ. transl. of earlier Latin original, AN USSR Press, M., 1956].
[9] C. F. Du Fay, Hist. de l'Ac. Paris, 4 (1733).
[10] L. N. Kryzhanovskiĭ, Electricity (in Russian) No. **11**, 75 (1987).
[11] S. Gray, Bibliographisch-literarisches Handwörterbuch zur Geschichte der exacten Wissenschaften/Ges. von J. C. Poggendorff, Barth, Leipzig, 1863, Vol. 1, p. 943.
[12] D. Clark and L. Murdin, Vistas Astron. **23**, pt. 4, 351 (1979).
[13] *The Philosophical Transactions of the Royal Society of London, from their Commencement, in 1665, to the year 1800* (Abridged) In 18 vols. Baldwin, London, 1809.

Translated by R. S. Prokop