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Emilius Lenz
(1804–1865)

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ABSTRACT

Emilius Lenz is a famous Russian physicist of German origin, academician, professor at St. Petersburg University, and later its rector, doctor of philology, privy councilor ... He took part in Kotzebue's trip around the world on the sailing sloop Enterprise. Lenz is known for his fundamental work on electromagnetism and the study of the thermal effect of electric current.

The author of the law stating the direction of induced current (Lenz's law) and co-author of the law on the thermal effect of electric current (Joule–Lenz law). He carried out several significant studies on the effect of current on dissimilar conductors, developed methods for calculating electromagnets for building electrical machines.

Legends circulated about his wonderful lectures on physics and physical geography, they were remarkable for their amazing clarity and systematicity.

Throughout his life, Lenz was engaged in research in the field of physics. Lenz's contribution to science can hardly be overestimated. Emilius Lenz was an exceptionally versatile scientist. He was the author of textbooks on physics for high school, worked on the galvanic gilding of the domes of the Cathedral of Christ the Saviour in Moscow, on the problem of lighting Nevsky Prospekt in St. Petersburg. Lenz was a physicist in the broadest sense of the word. He never closed himself on «pure theoretical science», always tried to apply the results of his discoveries in practice.

Keywords: *Lenz, history of transport, Joule–Lenz law, Lenz's law, Faraday–Maxwell–Lenz law, ballistic galvanometer, electromagnet, alternating current.*

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On January 29, 1865, 155 years ago, at the age of 60, in Rome a Russian scientist of German origin Emilius Lenz, one of the founders of electrical engineering, died suddenly. Lenz is the author of the law (1833) named after him, a scientist who experimentally substantiated the Joule–Lenz law (1842), who created methods for calculating electromagnets (together with B.S. Jacobi), who discovered reversibility of electrical machines. His name is associated with the discovery of the law that determines thermal effects of the current, and the law that determines direction of the induced current.

Emilius Lenz was a professor and rector of the Imperial St. Petersburg University (1863–1865), a full member of the Russian Geographical Society since September 19 (October 1) 1845.

The founder of the modern doctrine of electrical and magnetic phenomena Emilius Christianovich Lenz [1–10] was born on February 24 (12 according to the old style), 1804 in the city of Dorpat (now Tartu, Estonia) in the family of the chief secretary (senior official) of the city magistrate. In 1820, at the age of 16, he graduated from the gymnasium with honours and first entered the Faculty of Science at the University of Dorpat (now Tartu). Then, for material reasons, the young man transferred to the theological faculty, but did not stop his physics studies. After the second year of his studies, student Lenz participated as a physicist in conducting the observations at sea and on land in 1823–1826 during a round-the-world voyage in the Atlantic, Indian and Pacific oceans on the sailing sloop Enterprise under the command of the Russian navigator Otto E. Kotsebue. With the help of a constructed depth gauge and a bathometer (a device for taking water samples and measuring temperatures at different depths), he studied physical properties of ocean water, observed, and described in detail atmospheric phenomena and volcanic eruptions, investigated magnetic declination, developed the circulation theory of sea currents and for the first time outlined the problems of physical geography as a science. All this was the beginning of accurate observations in the field of oceanography. He proved the existence of a relationship between salinity of ocean water, the amount of solar radiation and wind strength: the least salty water is at the equator, since there is the most solar heat, and the air is inactive; under these conditions, during the evaporation process, microdroplets remain on the surface of ocean water, creating an obstacle to the action of the sun.

In 1827, Lenz defended his Ph.D. thesis in Germany at the University of Heidelberg, based on the materials of oceanographic scientific research, after their processing by the least squares' method and analysis, and moved to St. Petersburg, where he taught at school for a short time.

In 1828, Lenz's work «On salinity and temperatures of ocean water at different depths» was presented to St. Petersburg Academy of Sciences, in recognition of that he was elected an associate (assistant professor) of the Academy in physics. In 1829, the Academy sent a 25-year-old scientist to perform magnetic and gravitational observations on a scientific expedition to Mount Elbrus, where he calculated its height according to the readings of a barometer. Lenz organized the study of magnetic phenomena and pendulum swings at Nikolaev Observatory in the Caucasus, observed changes in the level of the Caspian Sea, establishing by a barometric method that its level was 30,5 m lower than that of the Black Sea, investigated the release of flammable gases to the surface in the Baku region, where he also collected oil samples.

In 1830 Emilius Lenz at the age of 26 was elected an extraordinary (supernumerary) academician of St. Petersburg Academy of Sciences. He was in charge of the physics «cabinet» (laboratory), arranged by V. V. Petrov, his predecessor [11], in which all subsequent activities of the scientist took place.

In 1831, the English physicist M. Faraday discovered and described the phenomenon of «*Magnetoelectric and voltaelectric inductions», where he gave various rules for determining the direction of induced currents. Lenz in 1833, having studied all the works in this area, established: «the induced current arising in a closed loop has such a direction that the flux of magnetic induction created by it through the area bounded by the loop tends to compensate for the change in the initial magnetic field due to which induction occurs*». This law, named after him, is fundamental in theoretical electrical engineering [12; 13] and it was included in all textbooks on electrical engineering [14; 15]. Subsequently, based on this law, mathematical relationships were obtained for the instantaneous values of currents and electromotive forces. In 1846 the German physicist F. Neumann used Lenz's law to derive the laws of electromagnetic induction. The German physicist G. L. Helmholtz in 1847, in his work on conservation of energy, also referred to this law. Consequently, Lenz was the predecessor of extension of the law of conservation of energy to the field of electromagnetic induction phenomena, i.e. generalization of the greatest physical discovery of 19th century. In a mathematical form, the phenomenon of electromagnetic induction was given in 1873 by the English physicist D. C. Maxwell. In the scientific and educational literature, at present, the quantitative Faraday–Maxwell–Lenz law for the instantaneous value of the electromotive force e is written as $e = -d\psi/dt$ (the electromotive force is proportional to the rate of change of the magnetic flux ψ, that is, the first derivative of the magnetic flux $d\psi/dt$), where the minus sign corresponds to Lenz's law.

Lenz's law helped solving the problem of accurate measurements of magnetic strength and magnetization of iron. He was one of the first authors of induction measuring instruments [16; 17], and together with the Russian physicist and electrical engineer B. S. Jacobi proposed a ballistic method for measuring the magnitude of the magnetic flux by those inductive actions that arise when the flux is created or disappeared. This method was the only current indicator in those years. It forms the basis of the modern ballistic galvanometer, used to measure small values at short-term current pulses, in which the moving part has a relatively small moment of inertia, and the result is counted by the largest deflection of the pointer.

The formulation of Lenz's law contains the idea of the principle of equivalence (reversibility) of electrical machines. He showed that Faraday's magnetoelectric induction is associated with the electromagnetic forces of the French scientist A.M. Ampère. *«The position by which a magnetoelectric phenomenon is reduced to an electromagnetic one is as follows: if a metal conductor moves near a galvanic current or magnet, then the current could cause its movement in the opposite direction; it is assumed that the stationary conductor can move in the direction of motion or in the opposite direction»*. In his work «On some experiments in the field of galvanism» the principle of reversibility of electric machines was formulated by him more clearly: *«Every electromagnetic experiment can be reversed in such a way that it will lead to a corresponding magnetoelectric experience. For this, it is only necessary to give the conductor of the galvanic current in some other way the movement that it makes in case of an electromagnetic experiment, and then a current of the direction opposite to the direction of the current in the electromagnetic experiment appears in it»*. It follows from Lenz's law that by passing currents in moving coils located between the poles of magnets, currents can be made to rotate. On the contrary, if no current is allowed into moving coils, but they will be rotated between the poles of the magnet due to an external force, then an induced electromotive force arises in them. Consequently, he was the first to come to the conclusion about the same structure and reversibility of electric machines, experimentally turning a generator into a motor. Modern collector electric machines have structural differences between generators and motors due to the peculiarities of their commutation [18; 19].

Four years later, in 1834, Lenz was elected an ordinary (full-time) academician of St. Petersburg Academy of Sciences in physics. He also performed pedagogical work at the Naval Cadet Corps, at the Artillery Academy, at the Main Pedagogical Institute, and in 1835 he was invited to the post of ordinary professor of the Department of Physics (separated from chemistry) at St. Petersburg University, in 1836 he headed the Department of Physics and physical geography. In 1840 he was elected dean of the second department of the Faculty of Philosophy, where he held this position permanently until his election as rector of the university in 1863. He wrote numerous textbooks and manuals on physics, and a manual on physics, compiled for Russian gymnasiums and published in 1839, withstood 11 editions.

The English physicist William Sturgeon invented the electromagnet in 1825. At that time, there were no data on magnetic properties of iron. Only in the joint works of Lenz with Boris Jacobi «On the laws of electromagnets», «On attraction of electromagnets» and «On the influence of current on intensity of magnetism excited in iron» were given methods for calculating electromagnets in electric machines, which were used before the laws of the magnetic circuit were established. In them, proportionality of action of the electromagnet to the current strength and the number of turns of the coil (in modern terminology, the number of ampere-turns) was established [20].

In 1841, another English physicist James Prescott Joule (Jule) published his work «On the heat given off by currents», but in the Royal Society of London (the scientific society of Great Britain), it faced some justified objections and the members demanded additional experimental clarifications from him. Lenz investigated the tangent-compass (a device for measuring current invented by Johan Jakob Nervander, checked validity and substantiated to his contemporaries the law of the German physicist G. S. Ohm and investigated the heating effect of currents, the results of which he communicated to St. Petersburg Academy of Sciences in his reports in 1842 («On the laws of release of heat by galvanic current») and in 1843 («On release of heat in wires»). In these reports, he proved the dependence of resistance of metals on temperature and the main provisions of the thermal action of current, called the Joule–Lenz law, with accurate and experimental data: the heat released by the current is proportional to resistance of the conductor, the square of the current strength, time and does not depend on any of its other properties. This was one of the prerequisites for establishing the law of conservation and transformation of energy. Currently, the Joule–Lenz law is based on calculation of electrical heating devices, the choice of cross-sections of overhead wires and cores of cable power lines, fuse-links, and thermal releases of devices for protecting electrical installations from overload and emergency modes of short circuit [21; 22].

In 1844 Lenz derived a formula for determining the current in any of the parallel-connected branches containing sources of electromotive forces, which was the predecessor of two laws for branched electric circuits, discovered in 1847 by the German scientist G. R. Kirchhoff [12–15].

In 1845 Lenz became a Full Member of the Russian Geographical Society, was elected to the Council, and until the end of his life he performed a great and versatile work in it. In 1851 he published his fundamental work «Physical Geography», which was reprinted several times in Russia and abroad. In it, he examined the structure of the earth's crust, the origin and continuous movement of the rocks that form it, and which affects the relief of the continents. Three factors were noted that cause a continuous change in the land surface: volcanic forces, the influence of waters assisted by the atmosphere and organic creatures, and the patterns of daily and annual variations in air temperature and pressure, wind activity, water evaporation, condensation of water vapour and the formation of clouds, electrical and optical phenomena in the atmosphere. The origin of the blue colour of the sky, rainbow, circles around the Sun and Moon was explained. The scientist found the reason for the slight increase in water temperature with depth in the zone south of 51 degrees south latitude and noted that a similar inversion should take place in the Arctic Ocean. Thus, he anticipated the discovery of the Norwegian Arctic explorer F. Nansen, who discovered warm Atlantic waters in the deep layers of the Arctic basin during his expedition in 1893–1896. He also found that salinity of water in the ocean changes little with depth, and in the upper layer decreases with latitude. However, the highest salinity is observed not in the equatorial zone, but in areas near the tropics due to strong evaporation. The density of water increases with latitude and depth due to a decrease in water temperature in these directions. Therefore, according to Lenz, in the World Ocean, along with currents caused by wind and the slope of the bottom surface level, there should be a general and no less strong movement of surface water from the tropical zone to high latitudes and movement of deep waters from these areas to the tropical zone. This circulation, the existence of which has been confirmed by subsequent observations, is one of the most important causes of water exchange between low and high latitudes. It also determines the flow of cold waters from the Indian, Atlantic, Pacific, and Arctic oceans into the deep layers of temperate and low latitudes. Lenz gave methodological instructions for determining velocities of currents in a navigational way and suggested that the orbits of particles in wind baths are ellipses. According to his position, the main reason for the processes taking place in the Earth's atmosphere is solar radiation, the largest part of which is absorbed by the oceans, huge reservoirs of moisture and heat. It is spent mainly on evaporation of water, causing its circulation in nature, and forming the climate on Earth. Lenz was the founder of the theory of interaction of the oceans with the atmosphere, and his work «Physical Geography», containing accurate and reliable oceanographic observations, was of great importance in development of earth sciences.

In 1846, the German physicist W. E. Weber experimentally established that, contrary to Faraday's law of electromagnetic induction, the electromotive force of electric generators when connected to an external electrical circuit is not proportional to speed of rotation of its shaft. Weber explained this by the fact that iron of the generator's magnetic circuit does not have time to accept full magnetization when the electric field changes rapidly. Lenz collected a large amount of experimental material on a magnetoelectric DC generator. He made three reports in the St. Petersburg Academy of Sciences on the work «On the influence of speed of rotation on the induction current produced by magnetoelectric machines»: in 1847, 1853 and 1857. He put forward his own explanation for decrease in the electromotive force, which is currently called the reaction of the armature when an electric current flows through it. It is necessary to consider not only the currents induced in the rotating armature of an electric machine by the magnetic field of the poles, but also currents from self-induction in the armature winding. His proposal to displace the brushes by a certain angle relative to the neutral geometric line of the collector in order to eliminate sparking is still used in electric machines (generators and motors) of direct current in the presence of additional poles with a rated power of up to 300 W, and in their absence – with a power of up to 1 kW [23; 24].

In 1853 Lenz first established the phase shift of an alternating current relative to the phase of a sinusoidal voltage, and in 1857 he invented a switch, i.e., invented a device for studying the shape of the curve of the induced alternating current. He determined the condition for the maximum useful power of the source of electrical energy when the internal resistance of the source and the external circuit are equal to each other. This condition of the mode is currently used in low-power electronic devices for telemechanics, communications, automation, and control.

Emilius Christianovich Lenz died suddenly during an overseas vacation and vision therapy in Rome on February 10 (January 29, old style) 1865 at the age of 60. He was buried in Rome at a Protestant cemetery. He established the Lenz law and the Joule–Lenz law, confirmed Ohm's law and for the first time in electrical engineering he managed to establish a connection between electromagnetic and electrodynamic phenomena [25]. For his scientific work in the field of electrical engineering and geophysics, he was elected a corresponding member of the Academy of Sciences in Turin and of the Berlin Academy of Sciences.

Emilius Lenz lived all his life in the Russian Empire, but he never learned Russian, which did not prevent him from becoming the founder of the national school of electrical engineering.

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