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(*b*. Joachimsthal, Germany [now Jachymov, Czechoslovakia]. 11 September 1798; *d*. Königsberg, Germany [now Kaliningrad, R.S.F.S.R.], 23 May 1895), *mineralogy, physics, mathematics*.

Neumann extended the Dulong-Petit law—that the specific heats of the elements vary inversely as their atomic weights—to include compounds having similar chemical constitutions. His work in optics contributed to the establishment of the dynamical theory of light, and he formulated mathematically the laws of induction of electric currents. He also aided in developing the theory of spherical harmonics. Neumann was a highly influential teacher; many of his students became outstanding scientists, and he inaugurated the mathematical science seminar at German universities.

Neumann's mother was a divorced countess whose family prevented her marrying his father, a farmer who later became an estate agent, because he was not of noble birth. Neumann was therefore raised by his paternal grandparents. He attended the Berlin Gymnasium, where he displayed an early talent for mathematics. His education was interrupted in 1814, when he became a volunteer in the Prussian army to fight against Napoleon. He was seriously wounded on 16 June 1815 at the battle of Ligny, the prelude to Waterloo. After recovering in a Düsseldorf hospital, he rejoined his company and was mustered out of the army in February 1816.

Because his father had lost all of his resources in a fire, Neumann pursued his education under severe financial difficulties. He completed his studies at the Gymnasium and in 1817 entered the University of Berlin, studying theology in accordance with his father's wishes. In April 1818 he left Berlin for Jena, where he began his scientific studies and was particularly attracted to mineralogy. In 1819 Neumann returned to Berlin to study mineralogy and crystallography under Christian S. Weiss, who became his close friend as well as his mentor. Weiss made the financial arrangements for Neumann to take a three-month geological field trip in Silesia during the summer of 1820, and Neumann was planning other trips for 1822 and 1823 when his father died. Thereafter Neumann and his mother became very close; his concern for her health and financial independence caused him to leave the university during 1822–1823 and manage her farm. Nevertheless, in 1823 he published his first work. *Beiträge zur Kristallonomie,* which was highly regarded in Germany; and on Weiss's recommendation he was appointed curator of the mineral cabinet at the University of Berlin in November 1823.

Neumann received the doctorate at Berlin in November 1825; and in May 1826, together with Jacobi and Dove, he became a *Privatdozent* at the University of Königsberg. Dove and Neumann were destined to assume the physics and mineralogy courses, respectively, of Karl G. Hagen, who had been teaching botany, zoology, mineralogy, chemistry, and physics. In 1828 Neumann was advanced to the rank of lecturer, and in 1829 he was named professor of mineralogy and physics. He married Hagen's daughter, Luise Florentine, in 1830; they had five children before her death in 1838. He married Wilhelmina Hagen, her first cousin, in 1843.

Neaumann's early scientific works, published between 1823 and 1830, concerned crystallography; in these he introduced the method of spherical projection and extended Weiss's work on the law of zones (law of rational intercepts). At Königsberg, however, he was influenced by Bessel, Dove, and Jacobi; and he began to concentrate on mathematical physics. His first two important papers were published in Poggendorff's *Annalen der Physik und Chemie* (23 [1831], 1–39 and 40–53); the first was entitled "Untersuchung über die spceifisehe Wärme der Mineralien" and the second "Bestimmung der specifischen Wärme des Wassers in der Nähe des Siedpuncktes gegen Wasser von niedriger Temperatur," In the first article Neumann investigated the specific heats of minerals and extended the Dulong-Petit law to include compound substances having similar chemical constitutions. He arrived at what has been termed Neumann's law, that the molecular heat of a compound is equal to the sum of the atomic heats of its constituents. In the second paper Neumann considered the specific heat of water. In earlier investigations physicists had noticed that when equal quantities of hot and cold water are mixed the temperature of the mixture is lower than the arithmetic mean of the temperatures of the original quantities. This result was generally interpreted as being due to a progressive decrease in the specific heat of water from the point of fusion to that of vaporization, a conclusion that appears to be validated by a number of experiments. Neumann disclosed errors in these experiments and concluded instead that the specific heat of water increases as its temperature increases. He failed to determine, however, that an increase occurs over only a portion of the temperature range from fusion to vaporization.

In 1832 Neumann published another important paper, again in Poggendorff's *Annalen,* "Theorie der doppelten Strahlenbrechnung abgeleitet aus der Gleichungen der Mechanik." Many physicists and mathematicians of the period were concerned with determining the conditions under which waves are propagated in ordinary elastic bodies so that they might develop a model which could serve as the optical medium; that is, they wished to evolve an elastic-solid theory of the ether in order to promote the undulatory theory of light. In his article Neumann reported obtaining a wave surface identical with that determined earlier by Augustin Cauchy, and he succeeded in deducing laws of double refraction agreeing with those of Fresnel except in the case of biaxial crystals.

Neumann encountered difficulty in explaining the passage of light from one medium to another. He attempted to overcome this obstacle in an article entitled "Theoretische Untersuchungen der Gesetze, nach welchen das Licht an der Grenze zweier vollkom-men durchstchtigen Medien reflectirt und gebrochen wird," published in *Abliandlungen der Preussischen Akademie der Wissenschaften,* mathematische Klasse ([1835], 1–160). In this paper Neumann raised the question of the mathematical expression of the conditions which must hold at the surface separating the two crystalline media, and he adopted the view that the density of the ether must be identical in all media.

Neumann and his contemporary Wilhelm Weber were the founders of the electrodynamic school in Germany, which later included, among others, Riemann, Betti, Carl Neumann, and Lorenz. The investigations and analyses of this group were guided by the assumption, held originally by Ampère, that electromagnetic phenomena resulted from direct action at a distance rather than through the mediation of a field. Neumann's major contributions were contained in two papers published in 1845 and 1848, in which he established mathematically the laws of induction of electric currents. The papers, transmitted to the Berlin Academy, were entitled "Allgemeine Gesetze der inducirten elektrischen Ströme" and "Ober ein allgemeines Princip der mathematischen Theorie inducirter elektrischer Ströme."

As a starting point Neumann took the proposition, formulated in 1834 by F. E. Lenz after Faraday's discovery of induction, that the current induced in a conductor moving in the vicinity of a galvanic current or a magnet will flow in the direction that tends to oppose the motion. In his mathematical analysis Neumann arrived at the formula E.Ds =—ν C.Ds, where Ds is an element of the moving conductor, E · Ds is the elementary induced electromotive force, *v* is the velocity of the motion, C.Ds is the component of the inducing current, and ∊ is a constant coefficient With this formula Neumann was able to calculate the induced current in numerous particular instances. At present a common formulation is E = — dN/dt, where E is the electromotive force generated in the circuit through which the number of magnetic lines of force is changing at the rate of dN/dt.

Continuing his analysis Neumann noticed a way in which the treatment of currents induced in closed circuits moving in what is now termed a magnetic field might be generalized. He saw that the induced current depends only on the alteration, caused by the motion, in the value of a particular function. Considering Ampere's equations for a closed circuit, Neumann arrived at what is known as the mutual potential of two circuits, that is, the amount of mechanical work that must be performed against the electromagnetic forces in order to separate the two circuits to an infinite distance apart, when the current strengths are maintained unchanged. In modern notation the potential function, *vii'*is written:

ds .ds' is the scalar product of the two vectors ds and ds', and r their distance apart. If a fixed element ds' is taken and integrated with respect to ds, the vector potential of the first circuit at the point occupied by ds is obtained. Maxwell arrived at the concept of vector potentials by another method and interpreted them as analytical measures of Faraday's electrotonic state.

According to his contemporaries, only a small portion of Neumann's original scientific work was published. But he was an extremely effective teacher, and he made known many of his discoveries in heat, optics, electrodynamics, and capillarity during his lectures, thinking that priority of discovery extended equally to lectures and publications. Thus he made numerous contributions to the theory of heat without receiving credit; on occasion he thought about raising questions concerning priority but never did.

In 1833, with Jacobi, Neumann inaugurated the German *mathematisch-physikalische* seminar, employing such sessions to supplement his lectures and to introduce his students to research methodology. Gustav Kirchhoff attended these seminars from 1843 to 1846; his first papers on the distribution of electrical conductors, and H. Weld's development of the photometer and polarimeter, were among the direct results of Neumann's seminars. Neumann pleaded continually for the construction of a physics laboratory at Konigsberg, but his hopes were thwarted during his tenure as professor; a physics institute was not completed at Konigsberg until 1885. In 1847, however, the inheritance from the estate of the parents of his second wife enabled Neumann to build a physics laboratory next to his home, the facilities of which he shared with his students. He retired as professor in 1873, although he continued his seminar for the next three years. He maintained his good health by making frequent walking tours throughout Germany and Austria, and he was still climbing mountains at the age of eighty.

Throughout his life Neumann was an ardent Prussian patriot. He aided in keeping peace in Konigsberg during the uprisings of 1848. He pleaded continually for the unification of Germany under the leadership of Prussia, and in the early 1860's he made numerous political speeches supporting Bismarck and the war against Austria. At the fiftieth anniversary of his doctorate in 1876, he was congratulated by the crown prince, later Wilhelm II; and he received honors from Bismarck in 1892 as a veteran of the campaign of 1815. Neumann was a corresponding member of every major European academy of science; he received the Copley Medal of the Royal Society in 1887.

BIBLIOGRAPHY

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Princip der mathematischen Theorie inducirter elektrischer Ströme, no. 36 (Leipzig, 1892); and *Theorie der doppelten Strahlenbrechnung,* no. 76 (Leipzig, 1896). Other books are *Beiträge zur Kristallononrie* (Berlin-Posen, 1823); *Über den Einfluss der Krystallflächenbei der Reflexion tsks Lichtes und über die Intensität die gewöhnlichen and ungewöhnlichen Strahls* (Berlin, 1837); and *Beiträge zur Theorie dcr Kugelfunktionen* (Leipzig, 1878). Some of his lectures were published in *Vorlesung üher mathematischen Physik gehalten an dcr Universität Künigsberg von Franz Neumann,* Carl Neumann, C. Pape, Carl Vondermühll, and E. Dorn, eds., 5 vols. (Leipzig, 1881–1887). His collected works were published as *Franz Neumanns Gesammelte Werke,* 3 vols. (Leipzig, 1906–1928).

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