William John Macquorn Rankine | Encyclopedia.com

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(*b*. Edinburgh, Scotland, 5 July 1820; d. Glasgow, Scotland, 24 December 1872), *engineering, engineering education, physical science*.

Rankine was the son of David Rankine, an army lieutenant, and Barbara Grahame. Another son died in childhood. Because of poor health, Rankine received most of his early education at home, being taught at first by his father and later by private tutors. In 1836 he entered the University of Edinburgh, where he studied natural philosophy under J. D. Forbes. The following year he was introduced to railroad engineering while assisting his father, who had become a superintendent for the Edinburgh and Dalkeith Railway. Although a successful student, Rankine left Edinburgh in 1838 without a degree. He then went to Ireland and worked for four years on railroad, hydraulic, and various other projects as an apprentice to John MacNeill, a prominent civil engineer who had been Thomas Telford's chief assistant. After finishing his apprenticeship, Rankine returned to Scotland and practiced civil engineering.

By 1850, when he was elected a fellow of the Royal Society of Edinburgh, Rankine was beginning to work in both engineering and science. He was elected a fellow of the Royal Society of London (1853) and received the Keith Medal (1854) from the Royal Society of Edinburgh for his published researches into the mechanical theory of heat. Receiving this medal was an unusual distinction for a professional consulting engineer. Thus when he lectured at the University of Glasgow early in 1855, substituting for Lewis Gordon, regius professor of civil engineering and mechanics, Rankine was already well-known for his contributions to both engineering and science. When Gordon relinquished his professorship later that year, Rankine was appointed to the chair, a post he held until his death. In 1857 Trinity College, Dublin, conferred on him the degree of LL.D.

Although much of his time as regius professor was spent writing engineering textbooks and teaching, Rankine continued to act as a consultant. He also remained active in engineering and scientific societies, especially in Glasgow, where he became an extremely influential figure. In 1857 he became the first president of the Institution of Engineering in Scotland, a society of which he was the principal founder; and from 1862 he was an associate member of the Institution of Naval Architects. He enjoyed music and took delight in singing and composing his own songs. He never married.

Rankine's earliest investigations were directly related to the construction and operation of the rapidly growing network of British railroads. In 1841, while surveying on the Dublin and Drogheda Railway, he invented a technique, later known as Rankine's method, for laying out circular curves. This technique, one of the first to be based on the use of the theodolite, was more accurate and faster to use than any other then available. Occasionally he collaborated with his father, and together they performed experiments to determine the advantages of cylindrical over tapered wheels on railroad cars. They published their findings in 1842, but the latter continued to be used. Rankine also examined the serious problem of unexpected breaks in railroad axles. His conclusions, published in 1843, were generally adopted in later construction.

In 1849 Rankine began to publish papers in physical science. Initially the central theme of his theoretical researches, which he pursued while still working as an engineer, was a comprehensive theory of matter, which he called "the hypothesis of molecular vortices." In this, matter was composed of atoms, each comprising an atmosphere surrounding a comparatively small nucleus. The atmospheres consisted of innumerable vortices, or circulating streams, of matter that were elastic and automatically tended to increase their volume. The absolute temperature of an atom was proportional to the square of the vortical velocity as defined by Rankine. Although the nature of the nucleus was left vague, its function was clearly stated: the nuclei formed the luminiferous medium. Thus light and radiant heat were the vibrations of the nuclei, which exerted forces on each other at a distance. Rankine proposed this unorthodox medium largely because he could not conceive of the luminiferous ether as imagined by Fresnel, that surrounds ponderable matter and that is elastic enough to transmit transverse vibrations at the speed of light while offering no perceptible resistance to the motion of macroscopic bodies.

Rankine suggested in 1850 that double refraction could be explained by the aeolotropy of inertia of the atomic atmospheres that dampened slightly the vibratory motion of the nuclei. But in 1872 Stokes showed experimentally that double refraction could not depend on aeolotropy of inertia, a conclusion that later led to the general abandonment of this explanation. In his 1850 hypothesis Rankine also utilized his atmospheres and nuclei to analyze the elasticity of solid bodies. His analysis was based on the assumption that the elasticity could be divided into two parts, one arising from the mutual forces of the nuclei and the other arising solely from changes of volume of the atmospheres. But by 1855 he had concluded that elasticity could not be divided in this manner. Having rejected this hypothesis, he concentrated on determining the mutual relations and physical significance of the elastic constants of solids.

It was to the theory of heat that Rankine applied his hypothesis of molecular vortices most extensively, and most successfully. Probably his interest in heat and heat engines developed from his early work with railroads—in 1842 he had already attempted to reduce the theory of thermal phenomena to a branch of mechanics. He had had to delay this research for about seven years, however, because of the lack of suitable experimental data with which to compare his results. In 1849 he published preliminary formulas relating the pressure of saturation of a vapor to its temperature, and soon afterward, in 1850, published his theory based on molecular vortices. Among the various formulas he derived were relations for the pressure, density, and temperature of gases and vapors and the latent heat of evaporation of a liquid. He also obtained theoretical expressions for the real and apparent specific heats of gases and vapors. Among his conclusions was the prediction that the apparent specific heat of saturated steam must have a negative value. This conclusion was later confirmed experimentally.

Rankine then began to generalize his equations to include solids and liquids. Suggesting that his previous equations were probably valid only for perfect gases, he removed any restrictions on the shape of the atoms and vortices, except to demand that the matter in the vortices move in closed paths. By clever approximations, Rankine obtained the same equations as before and immediately concluded that they therefore applied to all substances, whether in the solid, gaseous, or liquid state.

At this time Rankine turned his attention to the problem of calculating the efficiency of heat engines. Like Clausius and William Thomson, who had been working independently on the theory of heat, Rankine attempted to derive Carnot’s law. Clausius had derived the law from the axiom that heat could not, by itself, pass from a cold to a hot body. Thomson had based his proof on a similar axiom; but Rankine knew only of Thomson’s conclusion, not the details of his derivation. Dissatisfied with Clausius’ proof, Rankine set out in 1851 to deduce the law directly from his hypothesis of molecular vortices, without the aid of extraneous axioms. He showed that the efficiency of an engine when operating on a Carnot cycle between two temperatures depends only on those temperatures. Implicit in his proof was the assumption, equivalent to the axioms that Thomson and Clausius had used, that that cycle yields the maximum efficiency possible for any engine operating between those temperatures. He obtained the efficiency as a function of the temperatures and a universal constant. Rankine’s theoretical expression differed from those of Clausius and Thomson, but numerically the differences were insignificant, as Rankine quickly pointed out. It was not until 1853 that he modified his expression for the efficiency, thus making it coincident with Clausius’ and Thomson’s.

Yet Rankine’s examination of the behavior of heat engines was merely an initial step in the evolution of his theory of heat. He developed a general theory of energy that was independent of all mechanical hypotheses and then immediately recast his theory of heal in its mold. In 1853 he distinguished between two types of energy, “actual (or sensible) energy,” which caused substances to change their state, and “potential (or latent) energy,” which replaced the actual energy lost in any change. Rankine’s examples of actual energy were thermometric heat and the *vis viva* of moving matter; and of potential energy, the mechanical powers of gravitation and static electricity. The sum of the actual and potential energies of the universe was assumed constant—a law already familiar as the conservation of energy. Rankine then proposed a law that determined the amount of energy transformed during any change of state of a substance. Apparently the actual form of the law was dictated by Rankine’s desire to make it yield Carnot’s law in the particular case of a heat engine operating on a Carnot cycle. From 1854 he began to make frequent use of his “thermodynamic function,” which he later identified with the entropy of Clausius.

In 1855 the law of the transformation of energy was assimilated by Rankine into a general theory of energy called “the science of energetics.” Rankine was the founder of this science, which assumed major importance in the 1890’s. Energetics is a striking illustration of Rankine’s boldly speculative thinking as well as of his penchant for introducing terminology. (An inveterate nomenclator, he freely invented his own vocabulary, for example, “potential energy,” to denote novel concepts or to replace terms he considered unsuitable.) Energy and its transformations, rather than force and motion, formed the basis of this science. All physical phenomena were described by changes in actual and potential energy. The rate of transformation of energy was represented by the “metamorphic function” and the equality of energy in the equilibrium state by the “metabatic function.” In the theory of heat the metabatic function was the absolute temperature.

From the mid-1850’s energetics replaced molecular vortices as the basis of Rankine’s thermodynamics. He did not abandon the use of mechanical hypotheses completely, however, and often found them useful when expounding the theory of heat to engineers. As late as 1864 Rankine maintained that any mechanical hypothesis explaining the nature of heat must resemble his vortex theory of rotational motion rather than that of Clausius, Waterston, Maxwell, and others, in which heat was the result of the linear motion of the elementary bodies of a substance. It was not until 1869 that he acknowledged the possibility of treating heat as the result of linear motion. This acknowledgment appeared in a paper in which Rankine discarded his theory of nuclei and defended the hypothesis of a gas consisting of matter without any nuclei around which to congregate. His model of the atom had become almost identical with that of Thomson. One of Rankine’s final applications of thermodynamics appeared in 1869, when he examined the propagation of finite longitudinal disturbances, later commonly called shock waves. The equations that Rankine derived for propagation in a perfect gas took into account the effects of heat conduction. These equations were later generalized by Hugoniot in 1887 and became known as the Rankine-Hugoniot relations.

Despite the acknowledged practical importance of Rankine’s thermodynamics, most nineteenth-century physicists remained opposed to its molecular foundations. In his Baltimore lectures Thomson playfully but revealingly remarked that the most important aspect of Rankine’s hypothesis of molecular vortices was its name. Maxwell, too, criticized Rankine, suggesting facetiously that his definition of the second law and much else in his thermodynamics was inscrutable, although he was careful to place Rankine alongside Thomson and Clausius as one of the founders of theoretical thermodynamics. Part of the immense success of Rankine undoubtedly derived from his ability to solve complex problems by elementary methods, to simplify the theory of heat, and to present it systematically so that engineers could understand and use it. Moreover, his numerical computations on a wide variety of heat engines, his analysis (later called the Rankine cycle) of the operation of an ideal engine employing a condensable vapor such as steam, and the calculations of the properties of steam and other gases and vapors that he continued throughout his career enhanced his reputation as a major contributor to the understanding of thermal phenomena.

Another of Rankine's major interests was naval architecture. He turned his attention to this field about 1855, after he had settled permanently in Glasgow. With friend J. R Napier, a shipbuilder, and others, Rankine wrote *Shipbuilding, Theoretical and Practical* (1866), which was intended to bring precision and theory to a British industry that was largely empirical. Rankine was the editor of and principal contributor to this treatise. He also played an active role in the Institution of Naval Architects, where he presented papers frequently and became a major contributor to the theory of the design and motion of ships. Indeed, he pursued his hydrodynamical researches, not with purely scientific intent, but primarily to improve naval design. Beginning in 1862 with an independent derivation of the trochoidal shape of waves in deep water, a result already published in 1804 by F. Gerstner, Rankine examined the rolling, dipping, and heaving motion of ships in waves. Similarly, his two-dimensional analysis of the flow of water around circular and oval bodies enabled him to determine the waterlines of a ship that would create a minimum of friction as it moved through the sea; he also calculated the efficiency of propellers. A number of his papers were devoted to the exposition of elementary ways of solving hydrodynamical problems. He devised a simple method for obtaining a graphical representation of streamlines to demonstrate propositions in hydrodynamics.

Rankine conducted most of his theoretical investigations with an eye to practical applications. To facilitate the calculation of the elasticities of various substances from an experimental knowledge of their vibratory behavior, he carried out a mathematical analysis of sound waves in solids and liquids of finite extent. He obtained diagrams of forces for such structures as arches and roofs by introducing his theorem on parallel projections of polygonal frames, which he extended in 1864 to polyhedral frames. The theorem was subsequently generalized by Maxwell in his geometrical study of reciprocal figures, and then simplified by R. H Bow for engineering use. Rankine's papers on soil mechanics also served practical ends, as did his modification of Gordon's version of Hodgkinson's formula for the strength of iron pillars.

Rankine's teaching at Glasgow combined theory with practice. Indeed the chair had been founded in 1840 to promote instruction in the application of science to engineering, and it was in this spirit that Rankine taught. He insisted that the application of pure science to engineering constituted a separate subject in its own right and campaigned vigorously for the award of diplomas and degrees in engineering studies. In 1863 the university awarded its first Certificate of Proficiency in Engineering Science but did not confer degrees in the subject until a few years after Rankine's death.

Rankine published a highly successful set of engineering textbooks. These works were extremely comprehensive and combined practical knowledge with theory, often demanding from the reader a considerable background in mathematics; they also illustrate Rankine's concern for terminological precision. (For instance, he incorporated into the manuals his earlier definition of "strain" as the relative displacement of the particles of a body, a usage that became standard.) His first textbook, *A Manual of Applied Mechanics*, appeared in 1858 and was immediately hailed as a classic. *A Manual of Civil Engineering*,, published in 1962, was unrivaled. Both books ran through numerous editions, became paradigmatic texts for later authors, and largely established the methods of engineering education in Britain and elsewhere. *A Manual of the Steam Engine and Other Prime Movers* (1859) and *A Manual of Machinery and Millwork* (1869) also saw many editions. The range and content of these manuals reflect both Rankine's versatility and the multifarious facets of his career.

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I. Orignal Works. A comprehensive list of Rankine's papers appears in the Royal Society *Catalogue of Scientific Papers*, V, 93–96; VI, 747; VIII, 696–698, although this source omits his contributions to *Engineer* and *Transactions of the Institution of Engineers in Scotland*. Most of his major papers on thermodynamics, light, elasticity of solids, energetics, and hydrodynamics are included in W. J. Millar, ed., *Miscellaneous Scientific Papers; by W. J. M. Rankine. From the Transactions and Proceedings of the Royal and Other Scientific and Philosophical Societies, and the Scientific Journals. With a Memoir of the Author by P. G. Tait* … (London, 1881).

Rankine's texts are *A Manual of Applied Mechanics* (London–Glasgow, 1858; 21st ed., 1921), with 1st ed. reprinted in *Encyclopaedia Metropolitana*, **XXXIX** (London, 1848–1858) and with trans. of 7th ed. by A. Vialay as *Manuel de mécanique appliquée* (Paris, 1876); *A Manual of the Steam Engine and Other Prime Movers* (London–Glasgow, 1859; 17th ed., 1908), with trans. of 8th ed. by G. Richard as *Manuel de la machine à vapeur et des autres moteurs* (Paris, 1878); *A Manual of Civil Engineering* (London, 1862; 24th ed., 1911), with trans, of 12th ed, by F. Kreuter as *Handbuch der Bauingenieurkunst* (Vienna, 1880); and *A Manual of Machinery and Millwork* (London, 1869; 7th ed., 1893). The posthumous eds. of these textbooks were edited and revised initially by E. F. Bamber and later by W. J. Millar. *A Mechanical Text-Book; or, Introduction to the Study of Mechanics and Engineering* (London, 1873; 3rd ed., 1884), written with Bamber, was intended to serve as an introduction to the manuals.

Rankine also published *Useful Rules and Tables Relating to Mensuration, Engineering, Structures, and Machines* (London, 1866; 7th ed., 1889), with later eds. being edited and revised at first by Bamber and later by Millar. Rankine was the corresponding and general editor of, as well as the main contributor to, *Shipbuilding, Theoretical and Practical* (London, 1866), written with **I** . Watts *et al*. He contributed a number of articles, mainly on heat, to J. P. Nichol's *Cyclopaedia of the*

Physical Sciences (London–Glasgow, 1857; 2nd ed., 1860), and an essay on the strength and qualities of wood and metals to the *Cyclopaedia of Machine and Hand Tools* (London, 1869). His inaugural lecture as regius professor, “De Concordia inter Scientiarum Machinalium Contemplationem et Usum,” was published as *Introductory Lecture on the Harmony of Theory and Practice in Mechanics* (London–Glasgow, 1856), with repr. in *A Manual of Applied Mechanics*. This lecture lucidly and eloquently presents Rankine’s views on the relationship of theory to practice in engineering.

His main nontechnical writings are *A Memoir of John Elder, Engineer and Shipbuilder* (Edinburgh, 1871; 2nd ed., Glasgow, 1883); and the posthumous *Songs and Fables* (Glasgow–London, 1874).

II. Secondary Literature. Of the few obituaries and memoirs sketching Rankine’s life, the best informed and most enlightening are P. G. Tait, in *Glasgow Herald* (28 December 1872), with a modified version subsequently appearing in *Miscellaneous Scientific Papers*, xix–xxxvi; and L. D. B. Gordon, in *Proceedings of the Royal Society of Edinburgh*, **8** (1875), 296–306. These accounts form the main sources for A. Barr’s eulogy “W. J. Macquorn Rankine, a Centenary Address,” in *Proceedings of the Royal Philosophical Society of Glasgow*, **51** (1923), 167–187; J. Henderson, *Macquorn Rankine: An Oration Delivered inthe University at the Commemoration of Benefactors on 15th June, 1932*(Glasgow, 1932), with repr. in *Engineer*, **153** (1932), 689–690; and J. Small, “The Institution’s First President William John Macquorn Rankine,” in *Transactions of the Institution of Engineers and Shipbuilders in Scotland*, **100** (1956–1957), 687–697. Other obituaries are listed in Royal Society *Catalogue of Scientific Papers*. Although these obituaries and eulogies contain brief impressions of Rankine’s science and engineering, no detailed assessment of his work has ever been written.

See also G. Helm’s interpretation of Rankine’s thermodynamics and energetics in *Die Energetik nach ihrer geschichtlichen Entwickelung* (Leipzig, 1898), 110–120; J. C. Maxwell’s witty and facetious, but very valuable, comments in his review “Tait’s *Thermodynamics”,* in Nature, **17** (1878), 257–259, 278–280; and the summaries of Rankine’s writing on the elasticity of solids in **I** . Todhunter and K. Pearson’s *History of the Theory of Elasticity and of the Strength of Materials*, 2 vols. (Cambridge, 1886–1893; repr. New York, 1960).

The only recent important accounts of any of Rankine’s work are Sir Richard Southwell’s selective survey „W. J. M. Rankine: A Commemorative Lecture Delivered on 12 December, 1955, in Glasgow,” *in Proceedings of the Institution of Civil Engineers*, **5** (1956), pt. 1, 177–193; and E. E. Daub’s article, “Atomism and Thermodynamics,” in *Isis***58** (1967), 293–303, in which the author suggests a possible influence of Rankine’s thermodynamics on Clausius.

E. M. Parkinson