It will be well for religion, as, I may venture to add, it will be well also for learning, and science, and truth in all its forms and aspects, if the same spirit which breathed and spoke in all that Dean Ramsay did and said shall increase, and spread, and deepen among us, in our various spheres and callings. We cannot but feel that in every point of view Dean Ramsay's was a career which, as it was honoured while he was spared to us, and marked by such distinctions as befitted his position in the Church and in society during his life, so it demanded some tribute and notice in this place, now that his name is withdrawn from the roll of our living Fellows. If it was not given him to further the cause of science and learning, as many belonging to the Royal Society have done, yet his teaching and example were such as all may profitably recall to memory and strive to follow and imitate.

2. Obituary Notice of Professor Rankine. By Lewis D. B. Gordon, C.E.

William John Macquorn Rankine was the son of Lieutenant David Rankine of the Rifle Brigade, younger son of Macorne or Macquorn Rankine, Esq., of Drumdow in Ayrshire, and thus of an ancient Scottish family. His mother was the elder daughter of Archibald Grahame, Esq., of Drumquhassel. He was born in Edinburgh, 5th July 1820. Rankine records of himself, "My earliest distinct recollection is that of my mother teaching me the Lord's Prayer, next my father explaining to me the character of Jesus Christ;" and further he records, "My early instruction in arithmetic and elementary mechanics and physics was mainly obtained from my father." The mutual dependency thus begun continued through as beautiful a life of mutual self-devotion between parents and son as can be pictured; for the three were rarely far separate during the fifty years the parents lived after his birth.

Rankine went to the Ayr Academy in 1828, and afterwards to the High School of Glasgow in 1830, and thence to Edinburgh, where he studied geometry under Mr George Lees; but his knowledge of the higher mathematics was chiefly obtained by private study. He records that in 1834 "My uncle Archibald Grahame

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gave me a copy of 'Newton's Principia,' which I read carefully; this was the foundation of my knowledge of the higher mathematics and dynamics and physics." He read the Principia in the original Latin, and in after life recommended his pupils so to read this work of paramount authority and reputation; "for," said he, "modern science has added no new principle to the dynamics of Newton; what it has done is to extend the application of dynamical principles to phenomena to which they had not been previously applied; in fact, to the correlation of the physical sciences—or, in other words, what is denoted by the convertibility of energy." Thus, at the early age of fourteen, had Rankine begun to discipline his mind and train his analytical powers on Newton's model of unquestionable definition and exhaustive demonstration, characteristics of the many works on cognate subjects he was himself in after years to contribute for the education of engineers of every class, and for the advancement of physical science. For two years, from 1836 to 1838, Rankine was a student in the University of Edinburgh, and took the courses of Natural Philosophy, Chemistry, Natural History, and Botany. He continued for two sessions under Professor Forbes; and the first year gained the gold medal for "An Essay on the Undulatory Theory of Light," and the extra prize (gold medal) for "An Essay on Methods in Physical Investigation." At this period, too, he read much metaphysics, chiefly Aristotle, Locke, Hume, Stewart, Degerando. The whole tendency of his mind was to the digestion and assimilation of the highest human knowledge. But the *res angusta domi* demanded that he should take a profession; and at this period none was more in vogue, or apparently more promising of abundant employment, than that of a civil engineer.

Rankine having for a short time assisted his father, who was superintendent of the Edinburgh and Dalkeith Railway, in 1838 became a pupil of Mr M'Neil (afterwards Sir John M'Neil), whose practice in Ireland was varied and extensive. Accordingly, for four years Rankine was actively employed as a pupil on various surveys and schemes for river improvements, water works, and harbour works, and on the Dublin and Drogheda Railway. While on this work, he contrived and practised a method of "setting out curves" by chaining and angles at the circumference, since known as *Rankine's method.* He was much loved and respected by his numerous fellow-pupils, several of whom have attained high professional status. His pupilage ended, Rankine returned to Edinburgh, and was occupied for some time in the preparation and publication of an "Experimental Inquiry into the Advantages attending the Use of Cylindrical Wheels on Railways."

The theoretical investigation, and the deductions from the results of the experiments, conducted by his father and himself, are characterised by the same completeness in every respect as his more important and more famous writings of maturer years. But cylindrical wheels never came into use. It was "too late" to begin an obvious improvement, or there was no time to think of it; and yet, taking everything into consideration, the wheels would be better cylindrical, so formed that they should retain that shape for the longest time.

In 1842–43 various papers were sent to the Institution of Civil Engineers, and prizes were granted for them. There is one on "The Fracture of Axles," in which the importance of continuity of form and fibre was first shown, and the hypothesis of spontaneous crystallisation disproved. The conclusions of this paper were generally accepted and acted upon in the construction of axles.

In 1844–45, and afterwards till 1848, Rankine was employed under Messrs Locke and Errington on various railway projects promoted by the Caledonian Railway Company, of which his father had become secretary. But from 1842 onwards his mind had been much occupied in perfecting himself in the use of the higher analysis and in its application to the mechanics of molecular vortices.

Rankine's first investigation of the principles of the mechanical action of heat appeared in a paper received by the Royal Society of Edinburgh in December 1849, and published in their Transactions, vol. xx. It is based on what he calls "the hypothesis of molecular vortices;" that is to say, the supposition that the motions of which Davy showed thermotic heat to consist are of the nature of vortices—whirls or circulating streams. This is the part of the hypothesis that is specially connected with the phenomena of the mechanical action of heat; but in order to connect these with some other phenomena, Rankine makes the further suppositions that the whirling motion is diffused in the form of atmospheres round nuclei, which may be either bodies of a special kind or centres of condensation and attraction in the atmospheres; and that radiance, whether of heat or light, consists in the transmission of a vibratory motion of the nuclei, by means of forces which they exert on each other.

The *quantity of heat* in a body is the energy of its molecular vortices; the *absolute temperature* of the body is the same energy divided by a specific co-efficient for each particular substance. A *perfect gas* is a substance in which the elastic pressure is sensibly that which varies with the centrifugal force of the vortices only; and the intensity of the pressure, according to the known principles of mechanics, must be proportioned directly to the energy of the vortices, and inversely to the space that they occupy. In substances not *perfectly gaseous*, the elasticity is modified by attractive or cohesive forces. When the deviation from the perfectly gaseous state is small, the effects of such forces may be approximately represented by series, in terms of the reciprocal of the absolute temperature. Rankine had previously published an example of the use of such series, in a paper on the Elasticity of Vapours (Edin. Phil. Journal, July 1849), and he also applied them with success to the elasticity of carbonic acid and some other gases (Phil. Mag. 1851). *Sensible heat* is the energy employed in varying the velocity of the whirling particles; *latent heat* the work done in varying the dimensions of their orbits, when the volumes and figures of the spaces in which they whirl are changed. The force which keeps any particle in its orbit is equal and opposite to the centrifugal force of that particle; therefore the work done in varying the orbits of the particles is proportionate to their centrifugal forces, therefore to the energy of the vortices, therefore to the *absolute temperature*. And to compute that quantity of work, or latent heat, when a body undergoes a given variation of dimensions, the *absolute temperature* is to be multiplied by the corresponding variation of a certain function of the dimensions and elasticity of the body. This function is computed by taking the rate of variation with temperature, of the external work done during the kind of change of dimensions under consideration.

Such is an outline of the method by which Rankine deduces the second law of thermodynamics, or general equation of the mechanical action of heat, from the hypothesis of molecular vortices, by means of known dynamical principles. The quantity whose variation being multiplied by the absolute temperature gives the latent heat, corresponding to a given change of dimensions at that temperature, is expressed in Rankine's earlier papers by symbols, but is not designated by a special name.

In a paper read in January 1853 (Edin. Trans. xxi) he proposes the name *Heat Potential;* and in a paper read to the Royal Society of London, January 1854, he gives to the same quantity, with a certain additional term, depending on changes of temperature, the name of "Thermodynamic Function,"—a name which has since been adopted by various other authors.

In Rankine's paper of 1849, the chief applications of the general equation of thermodyamics are as follow:—The values of *apparent* as distinguished from *real specific heat*, for gases and vapours under various circumstances. The demonstration that the apparent specific heat of a vapour kept constantly at the pressure of saturation, while its volume varies, is *negative* for most fluids at ordinary temperature—in other words, that steam, for example, tends to become *partially liquified when it works expansively*, contrary to what had been previously believed. This fact was first verified experimentally by M. Hirn of Colmar. And the demonstration that the total heat of evaporation of a perfect gas increases with temperature at a rate equal to the completed specific heat of the gas at *constant pressure.*

In the paper read December 1850, he deduced from *Joule's Equivalent* the value 0·24 for the specific heat of air, and concluded that the previously received value 0·2669 must be erroneous. This was exactly verified by Regnault's experiments, but not till more than three years afterwards.

In a paper read April 1851 (Edin. Trans. vol. xx. 205) he deduced from the general equation of thermodynamics, as given in his paper of 1849, the following law of the efficiency of a perfect heat engine,—that the *whole heat expended is to the heat which disappears in doing mechanical work, as the absolute temperature at which heat is received to the difference between the temperatures at which it is received and rejected.*

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In Rankine's paper of 1849, groups of circular vortices were supposed to be arranged in spherical layers round the atomic nuclei, in order to simplify the investigation. On the 18th December 1851, he read a paper (Edin. Trans. xx. p. 425) in which it was shown that precisely the same results as to the relations between heat, elasticity, and mechanical work, follow from the supposition of molecular vortices of any figure arranged in any way. In a long series of papers he applied the principles of thermodynamics to various practical equations relating to the steam-engine and other heat engines, and he was the author of the first separate treatise in which the science of thermodynamics was set forth with a view to its practical application (A Manual of the Steam-Engine and other Prime Movers, 1859). In two papers read to the Philosophical Society of Glasgow in 1853–1855 respectively, he pointed out how the laws of thermodynamics and of electrodynamics might be regarded as particular cases of general laws applicable to *energy* in the abstract, and especially to transformation between the two great classes of "actual and potential" energy.

Clausius, who, it is well known, discovered the second law of thermodynamics consentaneously with Rankine, having taken occasion in 1866 to lay great weight on his having adopted no special hypothesis on the molecular constitution of bodies, but to have deduced the second law from general principles, Rankine, in an address to the Philosophical Society of Glasgow, concluded an eloquent justification of the mechanical hypothesis of molecular vortices in these words:—"I wish it to be clearly understood that although I attach great value and importance to sound mechanical hypothesis as means of advancing physical science, I firmly hold that they can never attain the certainty of observed facts; and accordingly, I have laboured assiduously to show that the two laws of thermodynamics are demonstrated as facts independent of any hypothesis; and in treating the practical application of those laws, I have avoided all reference to hypothesis whatsoever."

In March 1854 he was awarded the Keith medal of the Royal Society of Edinburgh for the researches above summarised, mostly in his own words. His name and fame had become European. He was elected Fellow of the Royal Society of London, and contributed to that Society many papers of permanent interest in the course of the next sixteen years.

From January to 20th April 1855, Rankine lectured for Professor Gordon at Glasgow College, on "Applied Mechanics" and the "Application of Thermodynamics to the Theory of the Steam-Engine." These lectures were of so high a character of usefulness, and delivered in so masterly a manner, that steps were immediately taken to get Rankine appointed to the professorship on the resignation of Mr Gordon. The Queen's commission appointing him Regius Professor of Civil Engineering and Mechanics was dated November 7, 1855.

On the 3rd of January 1856 he delivered his introductory lecture "On the Harmony of Theory and Practice in Mechanics," an essay full of practical wisdom. In November 1856 the introductory lecture "On the Science of the Engineer," was delivered, and concludes thus:—"Let the young engineer then be convinced that the profession which he studies is not a mere profitable business, but a liberal and a noble art, tending towards great and good ends, and that to strive to the utmost to perfect himself in that art, and in the sciences on which it depends, is not merely a matter of inclination or of policy, but a sacred duty."

Rankine's whole career as a professor exemplified this view of the profession of an engineer. By efforts, which to ordinary men seem altogether impossible, he published in rapid succession four manuals of "Mechanical and Engineering Science and Practice," on the best models for arrangement, but original in the treatment of many subjects,—always lucid in definition and demonstration, and replete with applications to examples of the practice of experienced men in all departments.

The students of engineering during the previous existence of the Professorship had gradually awakened to the necessity of acquiring some preliminary scientific instruction, and Rankine's style of teaching at once incited them to far higher efforts. It is unquestionable that his scientific works generally, and his manuals of applied science especially, have done more to break down the long persistent fallacy of a discrepancy between rational and applied mechanics, between theory and practice in engineering, than any previous publications whatever, and the influence of his systematic scientific teaching is spreading true principles of engineering design in this country, as the works of Navier, Poncelet, Morin, and Weisbach had done many years previously on the engineering practice of France and Germany. I say advisedly, that in far fewer cases now-a-days do we see the strength and stability which ought to be given by the skilful arrangement of the parts of the structure, supplied by means of an imposing massiveness involving a lavish expenditure of material and labour—that is, money—than twenty years ago was usual.

His complete knowledge of foreign languages enabled him to correspond with such men as Weisbach, Zeuner, Verdet, and other professors of applied mechanics on the Continent, to the mutual interest and advantage of all. He also corresponded in German with Poggendorf, Clausius, and Helmholz. Each of the manuals has gone through many editions,—that on the "Steam Engine," &c., nine; "Applied Mechanics," seven, and so on.

In 1862 he effectually called the attention of the Senate of the University to the manner in which the usefulness of the Chair of Civil Engineering and Mechanics was impaired through its being isolated from other branches of study, and induced the authorities to establish a systematic curriculum of study and examination in all the sciences bearing on engineering, followed by the granting of certificates to the successful candidates; a measure which led to a steady and continuous increase in the number and efficiency of the students in the engineering department of the University; and it could, indeed, scarcely be otherwise, seeing that William Thomson taught Natural Philosophy, and Rankine taught its applications. His style of lecturing was attractive; he never failed or faltered in an exposition or demonstration; and his power of illustration of the details of steam-engine practice, for example, was unusually lucid from his knowledge of the chemistry of the subject being co-extensive with his mechanical and physical knowledge. He at once gained the confidence of thoughtful students, and during the first session, that in which he lectured for Professor Gordon, he contracted an intimacy with Mr J. R. Napier, a shipbuilder and engineer, ambitious to emancipate his business from being that of one of mere empiricism, and this friendship, as it ripened, proved of great consequence to the whole science of shipbuilding and steam propulsion.

In 1856 he first projected a treatise on shipbuilding, which he ultimately finished in 1866, and published in conjunction with J. R. Napier and others. Of this treatise it may be said it is unique of its kind. It has recently been published in German.

In the autumn of 1857 he contrived a theory of skin resistance of ships, based on experiments furnished by J. R. Napier, and in the next year applied it with complete success to the steam-ship "Admiral," verifying his theory.

The work on shipbuilding occupied much of his spare time. He records at several intervals, from 1863 to 1866, brief notes, such as "Working hard at Treatise on Shipbuiling," "Researches on Neöids," "Stream lines." In 1866 the folio treatise was published. Rankine wrote the greater portion of it, and was the editor. The preparation of this treatise led to a series of researches on fluid motion, which are acknowledged to be of the highest importance, and they certainly belong to the most abstruse parts of mathematical science. Rankine's genius overcame all difficulties, and the "Theory of the Propagation of Waves," the "Theory of Waves near the Surface of Deep Water," and his investigations on plane water lines in two dimensions, *i.e.*, of the lines of motion of water flowing past a ship, advanced, in his hands, the application of science to naval architecture as much as his discovery of the second law of thermodynamics did that of the theory of the steam-engine and other heat engines. For, the practical use of his theory of oögenous water-lines reproduces *known* good forms of water-line, and even reproduces their numerous *varieties*, which differ very much from each other. In fact, there is no form of water-line that has been found to answer in practice which cannot be imitated by means of oögenous neöids—that is, ship-shape curves generated from an oval.

Besides Mr J. R. Napier, the late John Elder was the intimate friend of Rankine, and the bold improvements introduced by that distinguished engineer in marine steam machinery were constantly discussed with Rankine, whose scientific aid in insuring success was gracefully and munificently acknowledged by Elder's widow, by the gift of a large endowment to increase the emoluments of the chair of Civil Engineering and Mechanics.

Rankine's professional business was that of a consulting engineer, and in this capacity he made several reports to his clients of permanent value. One, "On Canal Haulage," is of great interest, and another "On the Explosion of the Tradeston Flour-Mills."

He was consulting engineer of the Highland Society of Scotland.

This sketch of the leading incidents of the scientific works which have made Rankine's name and fame represents, though very feebly, the more permanent portion of his usefulness to his profession and to his generation. But besides these great works, he contributed about 150 papers of greater or less importance to philosophical journals, mechanics' magazines, and to "The Engineer" in particular; generally expositions of such questions as the day or week suggested connected with engineering and mechanics; and it has been truly said—"With him thought was never divorced from work, both were good of their kind; the thought profound and thorough—the work a workmanlike expression of the thought." "Few, if any, practical engineers have contributed so much to abstract science, and in no case has scientific study been applied with more effect to practical engineering."

Rankine was a steady attendant at the meetings of the British Association, and took an active part as President of Section G, or Secretary of Section A, or otherwise in these meetings, where he had a universal acquaintance, and was universally respected and esteemed. He was a member of the "Red Lion's" Club.

In 1857 he took the most active part in founding the "Institution of Engineers in Scotland." He was the first President. It has proved a successful and eminently useful institution.

The outward lustre of Rankine's career is of course derived from his scientific work, but there was an inner halo surrounding him, which to his friends shone even brighter than the outward lustre. He was a true gentleman, gentle, chivalrous, self-forgetting, and scrupulously truthful, a patient listener, a quiet expounder. He supported applause without feeling the weakness of vanity. He had not a vestige of the spirit of rivalry, being of a thoroughly genial temperament. In his judgment of other men he obeyed the pious injunction of Thomas à Kempis, "Ad hanc estiam pertinet, non quibuslibet hominum verbis credere, nec audita vel credita mox ad aliorum aures effundere."

His health for several years in his early youth was feeble, and he occupied himself much with the theory of music, and practised the piano and violoncello. Though too much occupied in after life to allow of his attaining much proficiency, he could always interest and amuse his friends by singing his own songs to his own music, always gay and cheery. "The Coachman of the Skylark" in 1854, "The Engine-driver's Address to his Engine" in 1858, and "The Mathematician in Love," and "The Three-foot Rule," somewhat later, had a grotesque gracefulness of humour which were irresistible. His appearance was highly prepossessing, as the Fellows of the Royal Society of Edinburgh well know. His social qualities were the admiration of his acquaintances and the delight of his friends. Full of anecdote and information, he was an ornament to society, of which he was always the least obtrusive member, but often the centre of attraction. Everything he did he did well. Singing, croquet, or bézique, he used to join in them cordially, and intent on the moment's amusement.

His first great grief was the death of his father in May 1870. Rankine's affectionate and devoted nature was deeply moved, and he himself began soon after to experience symptoms of decay of his hitherto vigorous health. When, in April 1871, his excellent mother died, he was for a time quite absorbed by his grief for her loss. His own health became more and more unsatisfactory. Especially his eyesight became very weak, and during 1872 he had to employ an amanuensis and an assistant in his class work, one of his pupils, M. Bamber.

He visited his more intimate friends much during the summer of this year, where he could enjoy rest, and quiet, and amusement. But his health gradually gave way, and towards the end of November his medical friends perceived that the great mind of Rankine was giving way.

On the 24th December he died, leaving a noble record of genius to future generations, and a sweet memory to those of his contemporaries who knew him personally.