William Thomson, Lord Kelvin

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William Thomson, Lord Kelvin was rightly revered in his own time for his work across a range of scientific disciplines. Mathematician, theorist and experimenter, inventor and engineer, he was one of the founders of thermodynamics, the follower of Faraday in unifying the theory of electricity and magnetism, and the leading theorist, inventor and engineer in the development of electrical communication.

Thomson was born in Belfast in 1824, the son of Margaret Gardner and James Thomson who was the professor of mathematics in the city's Academical Institution. After his wife's death, James Thomson moved to the University of Glasgow in 1832, and his family were educated almost wholly by himself until his sons, James and William, were old enough (at twelve and ten respectively) to start attending university classes. James senior took an active interest in the Glasgow Philosophical Society (GPS) and became a member in 1839. The Society also had a junior section and in 1841 John Thomson, son of William Thomson, Professor of Medicine (one begins to see why the Glasgow College was called the Thomsonian University), gave a talk on the steam engine with the demonstration of a working model built by James junior, who had in the previous year been secretary of the Models and Manufactures Committee for the 1840 meeting of the British

Association in Glasgow. James had joined the junior section of the GPS in 1840 although it was not until William returned to Glasgow from Cambridge and Paris that he took up his membership.

CAMBRIDGE AND PARIS

William began his studies in Cambridge in 1841 but even before his move south, he had shown his mathematical powers in his understanding and enthusiasm for the work of Fourier. While at Cambridge, apart from the grinding labour of the Mathematical Tripos, he worked mainly on electricity, but also developed a keen and lasting interest in geophysical problems; this interest had been stimulated by his mathematical coach, William Hopkins, who is remembered as a founding father of geophysical studies in Britain. In 1845 William graduated as second wrangler in the Tripos examination and took first place in the subsequent Smith's Prize exam.

After his election to a Cambridge fellowship, Thomson, on the advice of his friends, went to practise experimental methods in the Paris laboratory of Victor Regnault, the most distinguished worker in thermal physics of the time. At the same time he became acquainted with members of the Paris group of mathematical theorists, to whom he in turn introduced the earlier fundamental work of George Green.

The Natural Philosophy chair at Glasgow had been an objective for William for several years, since the occupant, William Meikleham, a founder member of the GPS and a good friend of the Thomson family, was elderly and in poor health. William duly returned to Glasgow in 1846 to take up the professorship.

GLASGOW AND THE PRINCIPLES OF HEAT

During William's study absence, James junior had transferred to the senior section of the GPS and gave talks, in 1841 on power losses in hydraulic engineering and in 1842 on a new design of river boat. In this period also he had begun to consider the effect of tidal drag on the movement of the earth and moon. In 1842, the newly appointed Professor of Engineering, Lewis Gordon, spoke to the GPS on the design of dynamometers. Loss of power in all its forms was to be a permanent strand in the thinking of the Thomson brothers. In 1842, for example, they were recorded watching the filling of a canal lock near Manchester and discussing the loss of mechanical energy as the water came to rest. Through the conduit of James and the GPS, William became involved with a group of academically interested civil and power engineers including Lewis Gordon, J. R. Napier and William Macquorn Rankine soon after his return to Glasgow. This group were keenly interested in heat engines, losses and efficiency. In 1846-7, James was working on his design of a vortex water turbine with inward flow, and in 1847 William presented to the GPS *A Notice of Stirling's Air Engine*, a subject already well known but not well understood.

At this time the only lucid, though incomplete, account of the principles of heat engines was that produced by the French engineer, Sadi Carnot, in 1824 which Thomson probably knew through an even less complete account by Emile Clapeyron. Carnot's theory was based on an analogy with hydraulic engines in which he supposed the work done by a heat engine was to be drawn from the fall of heat from higher to lower temperature without loss of heat, just as work done by a water wheel is drawn from the fall of water from an upper to a lower level without loss of matter. In spite of the falsity of this supposed conservation of heat, Carnot and his successors contrived to give a correct account of a number of phenomena, and these successes made it hard to accept the contrary rule, that in an ideal heat engine the work done is in an invariable proportion to the heat which disappears.

Already in 1847, James Prescot Joule had presented to the British Association meeting at Oxford the results of his careful experiments which showed that, in dissipative fluid flow, the energy lost reappeared as an equivalent amount of heat. Thomson was present during Joule's talk and was deeply impressed by the potential importance of the result; however, it seems that his reservations about its accuracy were only finally dispelled by the repetition of some of Joule's results in his own laboratory.

In 1848 Thomson obtained a copy of Carnot's original memoir from Lewis Gordon, professor of engineering at Glasgow. One consequent suggestion was that it should be possible using a reversible engine as a heat pump to freeze large amounts of water at freezing point without expenditure of energy. In late 1847 or early 1848, James had remarked that since water expands on freezing, work would be done by that expansion against the ambient pressure, and deduced that the freezing point of water should be lowered by applied pressure. William subsequently designed an ether thermometer to measure the small temperature shift and succeeded in verifying the effect. In 1849 he also presented a full and clear account of Carnot's theory to the Royal Society of Edinburgh.

THE LAWS OF THERMODYNAMICS

Joule's continuing careful work had by now convinced the Thomson brothers that dissipated mechanical or electrical energy was transformed to heat in unvarying proportion but they remained unconvinced of the reverse. On the other hand, a general law of conservation of energy, now formalised as the First Law of Thermodynamics, was a speculative commonplace with European thinkers and it was Rudolf Clausius in 1850 who combined that with the statement that 'heat cannot of itself pass from a cooler to a hotter body' (or, colloquially, 'all refrigerators need power to drive them') to formulate a correct theory of thermodynamics. Thomson was happy then and later to admit Clausius' priority in publication, but insisted, probably correctly, that he had independently reached equivalent conclusions before reading Clausius' paper. What record remains of his discussions at this time with Macquorn Rankine and his brother James makes this highly likely. It is also true that William was as bad at reading other people's work as he was at listening to other people talk. The German physicist, von Helmholtz, has an anecdote of an evening in their company in which both brothers held forth fluently on different topics, neither listening for a moment to the other. He adds that James, having the more concentrated mind, usually won through in the end. William, after someone had uttered a couple of sentences, was commonly inspired to some thought of his own which he developed in entire disregard of its continuing relevance. Since this also happened when he was 'listening' to himself, and particularly in his lectures, students needed a good deal of mental agility to profit from him. The most able, on the other hand, found him difficult but inspiring.

Thomson adopted a more elaborate expression of the Second Law: 'It is impossible, by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects'.

Both Thomson and Clausius re-established the theorem of Carnot, that, working between given source and sink of heat, no engine can be more efficient than a reversible engine, and showed what this efficiency must be. Thomson had earlier observed that this led to a possible absolute scale of temperature, and somewhat later showed with Joule how, by measuring the dissipative flow of a gas, the gas thermometer could be corrected to the absolute scale. His great paper on *The Dynamical Theory of Heat*, published in the *Transactions of the Royal Society of Edinburgh* in 1851, fully established the bases of thermodynamics with a clarity only perhaps surpassed when Clausius reissued his own 1850 paper in a much improved version in 1864. A stream of further papers by an increasing number of workers including James Clerk Maxwell and capped, much later, by Caratheodory set classical thermodynamics in essentially its permanent form.

During this period, Thomson's personal life proved no less challenging than his professional life. His father died in the

Glasgow cholera epidemic of 1849, and his brother James migrated to Belfast where he became a professor of civil engineering. In 1852 William had married Margaret Crum, a lively and attractive young woman of some literary skill and chemical knowledge. However, not long after the marriage, Margaret fell ill and suffered chronic pain and weakness with few remissions until her death in 1869. Thomson's destruction of all his personal papers leaves almost no record of their life together, but one surviving letter shows her as an affectionate wife and an acute supporter, as she rebukes him for letting a colleague (C. F. Varley) take rather too much credit for their work together.

What Thomson had done by the age of thirty would have been a remarkable life's work for a distinguished scientist yet he continued an almost frenetic output of work in theorectical science and practical application for more than forty years, his dominant interest moving from the science of energy to the science of communication.

William Thomson in 1876 (from an engraving in Nature*).*

CABLES AND NAVIGATION

While continuing work on the thermodynamics of elastic and electrical phenomena, especially the thermoelectric circuit, he took up a suggestion made by Helmholtz in 1847 and developed six years later the theory of the electric oscillations which are universal in modern communication. A paper presented to the Philosophical Society of Glasgow (as the GPS had become) by John Thomson and Macquorn Rankine in 1852 on telegraphic communication between Great Britain and Ireland shows the attention now being given in Glasgow and other commercial centres to such possibilities.

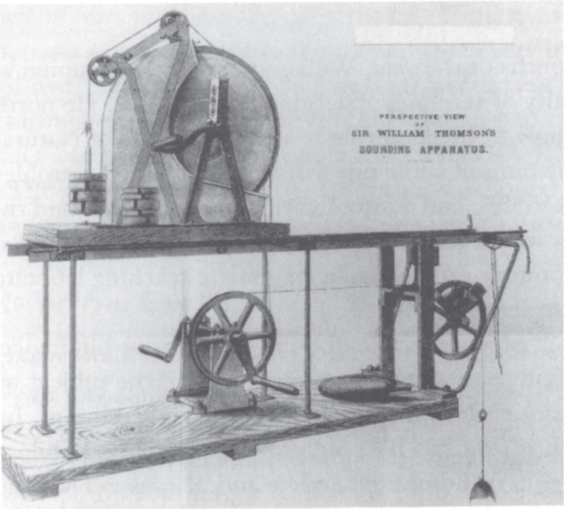
During the 1840s electric telegraphy using overhead land lines was widely developed, and by about 1848, the use of guttapercha as an insulator made underground and undersea cables equally possible. A serious limitation on these new cables was delayed transmission. For example, a later test on the multiple underground cable from London to Manchester found that with a total of 1500 miles of cable a pulse applied at one end was not perceptible at the other end until two seconds later. In 1854, Michael Faraday showed that this arose from the large electric charge immobilised in polarising the dielectric, and, with some prodding from G. G. Stokes, Thomson supplied a complete analysis of (noninductive) cable transmission by the end of the year. Working with given materials, he showed that reduced delay required both a larger conductor and a larger relative thickness of the insulator. Thomson also gave an analysis of the resulting economic problem of relating capital expense to subsequent income.

The unwelcome expense arising from recognition of this analysis made cable entrepreneurs easy victims of 'practical' charlatans promising easy and cheap results. Common sense and Willy Thomson prevailed only after a good deal of wasted effort.

The final success of the transatlantic cable depended not only on the devotion of seamen and engineers but on Thomson's systems of standardisation, measurement and detection, and he received the public recognition of a knighthood in 1866. Moreover, his experience at sea during the cable-laying turned his attention further to marine engineering and navigation.

The substitution of iron for wood in shipbuilding had raised interest in the dependence of compass readings on the attitude of a ship, arising firstly from the permanent magnetisation of the hull during building (and varying as a result of wave- and weather stresses in successive voyages) and secondly, from the induced magnetisation due to the Earth's local field. S. D. Poisson had addressed the problem in 1824, as had G. B. Airy again in 1838, but neither in a form suitable for application. Archibald Smith of Jordanhill, who might have been a serious competitor for Thomson's chair, gave a complete account of the matter using Fourier's harmonic analysis after considerable discussion with the Thomson brothers and J. R. Napier, and his results were incorporated in the Admiralty Manual of Deviations of the Compass, in the form of correction tables to deduce the true course from the reading of a deviated compass, as well as methods to reduce the deviations. Unluckily, Smith's health failed under the strain of his legal work and he died in 1872 when Thomson was starting to develop his new compass.

Thomson's experience on the cable-laying ships had impressed him with the need for both improved compasses and improved corrections. His enthusiasm for the sea along with a substantial income from his consulting work let him buy the *Lalla Rookh* in 1870, a schooner yacht which served also as a floating laboratory. In 1876 he applied for a patent for a much improved compass with compact correcting irons, which soon became the standard equipment on merchant vessels. The Admiralty, as usual, took another decade or so to catch up. His other important contribution to navigation was his lightweight sounding machine, which enabled quick depth soundings to be taken without taking way off the ship. Traditional sounding lines, drawn back by the drag of the water, gave exaggerated depths when used from a moving vessel. Amusingly, his first full-scale model nearly failed because



A perspective view of Thomson's lightweight sounding apparatus.

he had forgotten the enormous crushing force which the turns of the sounding wire exerted on the winding drum when drawn back up from depth. The problem was solved by using a raising wheel carrying several turns of the wire, while the storage drum wound on at a tension of only a few pounds.

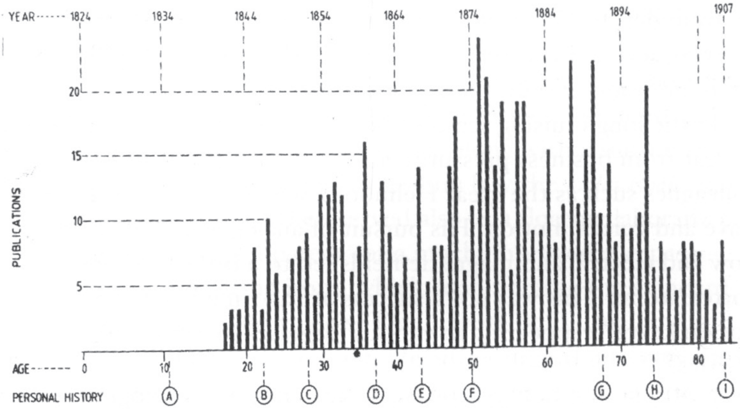
In the long cruising season, the *Lalla Rookh* became Thomson's retreat from business pressures, as well as a place to welcome colleagues such as the great Helmholtz who shared his interest in wave and vortex motion. His pursuit of analogies in heat and fluid flow and electric and magnetic fields led to a brilliant theory of vortex atoms. This was not a success at the time but the pictorial notion keeps reappearing in various disguises in 20th-century physics.

James Thomson had returned to Glasgow, succeeding Macquorn Rankine as professor of engineering in 1873. He and William applied themselves to the harmonic analysis of the tides, and in 1876 showed mechanisms for doing the analysis and for reconstituting the tidal levels for past or future times.

TEACHING AND TEXTS

For six months of the year, William was mainly occupied with his primary duty of teaching undergraduate students. He normally did the whole of the lecturing to the two classes of Natural Philosophy himself while one assistant conducted a problem class, marked exercises, and assisted with demonstrations and the laboratory, which for many years served as a research and standardising laboratory rather than a systematic teaching laboratory in the modern sense.

The lack of a modern textbook was a serious hindrance, though Thomson's way of inventing much of the subject while he taught meant that no text could be completely relevant. In 1860 Peter Guthrie Tait had become professor of natural philosophy at the University of Edinburgh and he and Thomson had much in common. They embarked on a *Treatise on Natural Philosophy* whose first (and last) volume appeared in 1867. This became the standard text of advanced dynamics in English for the rest of the century.



A diagrammatic representation of Thomson's remarkable published output. A: Matriculation; B: Chair; C:First Marriage; D: Serious Injury; E: Knighthood; F:Second Marriage; G: Peerage; H: Retiral from Chair; I: Death (produced by J. T. Lloyd in The Physics Teacher, *January 1980).*

An *Elements of Natural Philosophy*, constructed mainly by omitting the mathematics from the *Treatise* contained some very ingenious proofs but had deficiencies as a student text, and in later years when lecturing began to be deputised, the deputies had effectively to construct a lecturing text from notes of Thomson's previous lectures. The general introductory course that developed as a result survived with little change well into the 20th century.

THE AGE OF THE EARTH

Another main strain in Thomson's work was his permanent interest in geology and geophysics. At Cambridge he had written a prize essay on the figure of the Earth, whose main conclusion was that the Earth must have solidified at a date when the length of the day was not much different from its present value, and his inaugural dissertation at Glasgow was on *De caloris distributione per terrae corpus*. The supposition that the Earth was already solid now appears unsound, but accepting that, it was hard to reconcile the known outflow of heat through the Earth's solid surface, with any reasonable initial temperature, with an age greater than about 200 million years – very much less than the geological record of rock deposition seemed to require.

Equally, he proposed that the evolution of living forms must require a similar extent of time. Thomson was deeply religious, though latitudinarian in his practice, and, accepting the argument from design as basic to belief, took Darwinian arguments less seriously than they perhaps deserved. He returned repeatedly to this topic over the years, both at the Geological Society of Glasgow, of which he was president from 1872 to 1893, and at meetings of the British Association. Only at the end of his life did the contradiction between physical reasoning and geological evidence as to the age of the Earth start to be resolved with the realisation that radioactive minerals constituted a considerable heat source inside the Earth.

Thomson did much less work on the optical than on the electrical properties of materials, but tried obsessively to find a mechanical model for the supposed medium which supported the propagation of light. It was clear that light should be an electric wave of some sort, but a self-consistent mechanical theory was unattainable. Thomson came nearer than anyone else with a beautiful but complex model of connected vortices, but by 1884 when Thomson, now Lord Kelvin, gave his marvellous Baltimore Lectures to 'professorial fellow-students in physical science' acknowledged leadership in electromagnetic theory was passing to his younger friend and colleague, James Clerk Maxwell.

William Thomson, Lord Kelvin, was a leading figure in science and engineering for the world and for his city. He was modest and generous, not only respected but loved by almost all his associates, and by far the greatest figure among the members and Presidents of the Royal Philosophical Society of Glasgow.