STEWART, Balfour (1828–1887)
Stewart was born in Edinburgh on 1 November 1828, the son of William Stewart, a tea merchant, and Jane Clouston, the daughter of a minister. He gained his earliest scientific education from his uncle, Charles Clouston, a minister of Stanwick and meteorologist, and seems to have been a strong Presbyterian from his youth. He attended a school in Dundee and at the age of 13 attended St. Andrew's University although he shortly moved to Edinburgh University where, during the 1845–46 session, he studied natural philosophy under James David FORBES.

Leaving Edinburgh without a degree, he joined a cousin's merchant business in Leith, a venture that took him to Australia where he published papers on physiological optics and lunar geology. Choosing a career in science over business, Stewart returned to Britain in 1855 and in February 1856 began working as Assistant to John WELSH, Superintendent of the Kew Observatory, where he built a thermometric instrument. By this time Kew Observatory was run by a committee of the British Association for the Advancement of Science (notably Edward SABINE and John Peter GASSIOT) who used the observatory as a centre for implementing Sabine's programme of global magnetic measurement, for meteorological and solar observation, and for verifying and standardising meteorological instruments. Stewart's scientific interests from the 1850s reflected the major goals of this large-scale project: correlating the temporal periods of sun-spot cycle and terrestrial magnetic disturbances, and correlating variations of the earth's magnetic field with changes in physical forces within and outside the earth.

In 1856 Stewart returned to Edinburgh University where he worked as Forbes's teaching and research assistant, while studying mathematics under Philip KELLAND. Stewart acquired skills in teaching mechanics and mathematical physics, and experimental expertise in the areas that interested Forbes: radiant heat, meteorology, and terrestrial magnetism. But as Gooday points out, these diverse researches were unified in Stewart's growing interest in cosmical physics.

Stewart's celebrated researches into Pierre Prevost's 'Law of Exchanges', published in 1858, built on earlier investigations of Forbes, Macedonio Melloni and others. Stewart presented experimental evidence and theoretical arguments supporting the claims that radiation was a function of volume rather than surface area, and that for thin plates made from any material, and at all temperatures, the wavelengths of absorbed and emitted radiation are equal. Although Stewart's radiation researches won him a Royal Society Fellowship (1862) and Rumford Medal (1868), many physicists preferred Kirchhoff's independent approach to the 'radiation law' because it was theoretically more rigorous and immediately suggested solutions to such puzzling phenomena as the dark lines of the solar spectrum.

Stewart continued developing his meteorological interests while in Edinburgh, assisting his former employer Welsh with the 'Magnetic Survey of Scotland'. Stewart was therefore the obvious choice to succeed Welsh who died in May 1859. As the new Superintendent of Kew Observatory, he supervised the reduction of magnetic measurements made with Welsh's self-recording magnetographs, oversaw general barometric, hydrometric, and thermometric observation, completed the Scottish magnetic survey, assisted Warren de la RUE's photoheliographic work, and verified meteorological instruments for such clients as the Admiralty, the Board of Trade, and commercial optical firms. Stewart's link with the British Association and reputation as an arbiter of precision instruments made him a clear choice for joining the British Association Electrical Standards Committee (1863–1869).

Stewart's publications of the 1860s and early 1870s reflected private research interests and the Kew programme. He extended his work on radiant heat: he showed (in 1860) that his radiation law also applied to polarised light, and in experiments done with Peter Guthrie TAIT from 1864, explored the breakdown of the radiation law in the case of a body rotating in an enclosure at constant temperature, the experimenters suggesting that the observed rise in the temperature of the rotating body was partly due to friction between the body and the luminiferous ether. His publications also extended the Kew programme of precision measurement of daily magnetic variation, irregular magnetic disturbances, sunspots, and aurora. Unlike Sabine and other members of the Kew committee, Stewart went beyond merely tabulating correlations between temporal variations of meteorological and solar phenomena. From the early 1860s Stewart began constructing a causal theory to explain these cosmical relations, arguing (in 1860) that terrestrial magnetic storms, earth currents, and aurora were secondary effects caused by changes in the size and nature of primary electric currents emanating from the sun. Similarly, in the mid-1860s he began the first of many investigations of the connection between sunspots and the positions of the planets Mercury and Venus. In collaboration with his assistant Benjamin Loewy and de la Rue, Stewart used sunspot observations made at Kew and by the astronomer Richard CARRINGTON to show that the average size of sunspots reached maxima and minima when their distance from the inner planets was greatest and smallest respectively. Stewart probed the possible solar-planetary interaction in later publications: he attempted to show that the variation of sunspot activity between 1780 and 1870 could be regarded as the superposition of three oscillations whose periods coincided with those of planetary conjunctions. The puzzling effects of celestial phenomena on the earth—notably magnetic storms, aurora, rainfall, and wind—remained the principal focus of Stewart's researches until his death and was one reason for his vigorous support of the Royal Society's Solar Physics Committee founded in 1878.

In 1867 Stewart was appointed Secretary of the Royal Society's Meteorological Committee, a position that considerably increased his workload since he now had to manage a wider range of meteorological measurements and supervise the installation of instruments at various stations run by the Meteorological Office. Stewart's new position exacerbated tensions between him and his Kew employers. Stewart tried to persuade them that observations of cosmical-meteorological phenomena had to be used to frame laws and elucidate causes—to turn meteorology into a branch of exact physical science (Gooday 1987). Sabine and his allies, however, were not happy with Stewart's natural philosophical digressions, maintaining that the sole business of such places as Kew was routine collection and reduction of observations. Stewart's dissatisfaction with his employers reached a head in 1869 when he resigned from the Meteorological Committee and, reluctantly, threatened to resign as Kew Superintendent. Stewart was frustrated at not being able to promote 'Physical Meteorology' and angry with Sabine and Gassiot for thwarting his proposed scheme for reducing meteorological observations between 1857 and 1870—a scheme that implicitly discredited Sabine's cruder reduction methods and that aimed at elucidating the causal connections between solar activity and terrestrial magnetism. Stewart long remained bitter about Kew politics and expressed his views in numerous articles on physical meteorology published in *Nature* during the 1870s.

Stewart's hopes for propagating his own brand of meteorology were raised in May 1870 when Henry ROSCOE invited him to apply for the chair of natural philosophy at Owens College, Manchester, a position that required the professor to superintend a practical physics teaching laboratory. Stewart was swiftly appointed the following July although he was obliged to continue as Kew Superintendent until 1871. In November 1870 he was badly injured in a railway trip between Manchester and Kew which prevented him from taking up his professorial duties until autumn 1871. On his return to Owens, Stewart implemented a programme of lecturing and laboratory instruction that would give many illustrious Owens students, including John Henry POYNTING and J. J. THOMSON, their first and most important lessons in experimental physics. Although his teaching ambitions were initially hampered by the small size of the Quay Street laboratory, in 1872 he moved to a larger laboratory on Oxford Road for which he was given several grants for teaching assistants and apparatus.

According to Arthur SCHUSTER, who worked as an unpaid assistant in Stewart's laboratory, Stewart was 'not a good lecturer and had difficulty in keeping order in the lecture rooms' but was an 'inspiring teacher' in the laboratory (Schuster 206). Experiences overseeing precision measurement at Kew and exchanges with fellow laboratory director Tait gave Stewart plenty of ideas about superintending a teaching laboratory. In classes on mechanics, heat, optics, electricity, magnetism, and meteorological measurement, he wanted to bring students into 'intimate contact with nature herself' and instil mental discipline, as well as inculcate skills in instrumental manipulation, accurate measurement, and close attention to experimental errors. Unlike other directors of the new physics laboratories, Stewart also encouraged students to pursue experiments outside the system of regimented laboratory instruction, emphasising the importance of investigating anomalous or 'residual' phenomena. Stewart articulated many of his pedagogical ideals in his first textbook, *Lessons in Elementary Physics* (1870), which went through several editions. Stewart's teaching, like that of William THOMSON at Glasgow University and his own at Kew, stressed the importance of learning through participating in cutting-edge research and he invited many Owens students to assist him with cosmical-meteorological observations (some of which were conducted from an observatory built in his garden). Stewart's ability to pursue this work owed much to the fact that he delegated much laboratory to 'demonstrators' such as Thomas Core and Schuster, although by the late 1870s, and with rising student numbers, Stewart was forced to supervise more practical work, and with Core revised the physics course to include more exercises in the kinds of meteorological measurement he had supervised at Kew (Gooday 1987). In 1880 Stewart negotiated successfully to hire an additional demonstrator, William Haldane Gee, with whom Stewart wrote the widely used *Lessons in Practical Physics* (1885–1887), volumes which raised Stewart's already considerable status as one of the foremost Victorian teachers of experimental physics.

From the late 1860s Stewart developed interpretations of his work on radiation and cosmical meteorology that helped propagate the new energy physics developed by Thomson, Tait other fellow 'North British' physicists, and gained him a reputation far beyond scientific circles. In articles in 1868 issues of *Macmillan's Magazine* (written jointly with Norman LOCKYER) and in his best-selling *Conservation of Energy* (1873), Stewart drew on powerful economic, political and social analogies to explain the physical principles of energy conservation and the universal tendency towards the dissipation of heat. Stewart expanded much of this material in the *Unseen Universe* (1875), an anonymous (and from 1876, signed) work he wrote with Tait. It aimed to show that the 'presumed incompatibility between Science and Religion does not exist' (*Unseen Universe*, 1875, p. vii) and, like many popular works written by 'North British' physicists, sought to combat the materialistic and irreligious uses to which John TYNDALL and others were putting physics. The *Unseen Universe* argued that the most sophisticated views of matter and energy were entirely consistent with Christian teachings. The only way of reconciling the widespread (and credible) belief in God, the principle of continuity in nature, and the strong evidence for universal dissipation of heat was to suppose the existence of an eternal and ethereal unseen universe intimately connected with the transient visible universe. The unseen universe could store vibrations accompanying thought (thus providing a physical theory of human immortality) and accumulate dissipated energy that would be returned to the visible universe as apparent miracles. Despite a highly mixed critical response, the work was an instant popular sensation, reaching a 17th edition in 1901. Buoyed by this success, Stewart and Tait penned a sequel, the anonymous *Paradoxical Philosophy* (1878), which rehashed the central arguments of *Unseen Universe* in the form of fictional dialogues.

Stewart's preoccupation with the connection between the visible and invisible universes, and his long interest in pursuing 'residual' phenomena, underpinned his interest in psychical research. Although sceptical of alleged communications from disembodied spirits, he joined the Society for Psychical Research (SPR) and participated in its investigations of telepathy. As SPR president (1885–87) he upheld the growing evidence for telepathy and spearheaded proposals to investigate the physical phenomena of spiritualism. In his final year he backed the parliamentary career of George STOKES, a physicist with whom he shared strong beliefs in solar physics, Christian spirituality, and Unionist politics. He died in Ireland on 19 December 1887.

BIBLIOGRAPHY

An Elementary Treatise on Heat (1866)
Lessons in Elementary Physics (1870)
Conservation of Energy (1873)
[Stewart, B. and P. G. Tait], *Unseen Universe; Or Physical Speculations on a Future State* (1875)

[Stewart, B. and P.G. Tait], *Paradoxical Philosophy* (1878)
Stewart, B. and W. H. Gee, *Practical Physics* (1885–87)

Further reading

Gooday, G., 'Precision Measurement and the Genesis of Physics Teaching Laboratories in Victorian Britain', (unpublished Ph.D. Dissertation, University of Kent at Canterbury, 1989), chapter 7.
Heimann, P., 'The *Unseen Universe*: Physics and the Philosophy of Nature in Victorian Britain', *British Journal for the History of Science* **6** (1972), 73–79.
Siegel, D., 'Balfour Stewart and Robert Gustav Kirchhoff: Two Independent Approaches to "Kirchhoff's Radiation Law"', *Isis* **67** (1976), 565–600.
Schuster, A., *Biographical Fragments* (London, 1932)

RICHARD NOAKES