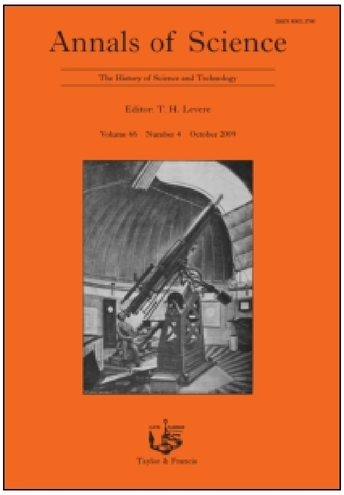

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Physics in Australia and Japan to 1914: A comparison

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Physics in Australia and Japan to 1914: A Comparison

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Summary

Physics first became established in Australia and Japan at the same period, during the final quarter of the nineteenth and the first years of the twentieth century. A comparison of the processes by which this happened in these two developing countries on the Pacific rim shows that, despite the great cultural differences that existed, and that might have been expected to have been a source of major differences in national receptiveness to the new science, there were in fact many parallels between the patterns of development in the two cases. Identifying these enables us to draw attention to a number of significant features of the physics discipline more generally at this period. Such differences as emerge in the early history of physics in the two countries seem to have arisen more from the different political situations that prevailed than from anything else; in particular they reflect the fact that Australia was a part of the British Empire while Japan was an independent political power.

Contents

1. Introduction

Physics as we know it today is, by and large, a nineteenth-century invention. Not only were many of the central theoretical structures of the science—electromagnetic theory, thermodynamics, statistical mechanics and the wave theory of light, for example—first developed then; this was also the period when it acquired both its characteristic mathematical mode of expression and its systematic concern with precise quantitative measurement. In addition, the nineteenth century saw the emergence of some of the discipline's major institutional forms including the university-based theoretical seminar and experimental research laboratory, government-funded laboratories for the establishment and maintenance of physical standards, and discipline-based learned societies such as the Physical Society of London and the Société

Française de Physique. Many of these developments, especially the institutional ones, did not occur until the last thirty years of the century.

The new-look discipline first emerged in Europe, the traditional heartland of Western science. In due course, however, it spread to various other parts of the globe. In this paper, we analyse the process whereby physics became established virtually simultaneously in Australia and Japan, two countries remote from Europe on the western rim of the Pacific Ocean, during the last years of the nineteenth and the first years of the twentieth century. This process took place, however, in very different cultural contexts in the two cases. Hence a comparative study may be expected to be especially revealing in this instance. In particular, features found to be common to the early history of physics in two such different environments are highly likely to be found upon further investigation to have been characteristic of the establishment of the physics discipline in other parts of the world as well. At the same time, a comparison of the kind proposed will enhance our understanding of the history of science in each country separately, because it will enable us to identify with much greater certainty just which features of the development in each case were specific to the country in question. If these developments had occurred at significantly different times in the two places, there would be less point to the comparison, since some of the differences discovered would then possibly be attributable to changes that had occurred in physics itself in the interim. The fact that, in the present instance, the events in question occurred simultaneously in the two places, means that such complications are avoided here; in principle, the physics being transferred to Australia was identical to that transferred to Japan.

The differences between Australian and Japanese culture in general in the late nineteenth century were, of course, profound. In Australia, the original native peoples had been completely subjugated—indeed, in many parts of the country, exterminated—by incoming waves of chiefly British settlers. Hence in studying the growth of the physics discipline there, it is a matter of studying the establishment of the science in an essentially Western cultural environment, albeit a pioneering one remote from the leading scientific centres, and initially lacking or possessing in only rudimentary form the characteristic institutional structures of modern science. Our topic becomes part of the wider question of how various parts of European intellectual life were carried by European settlers as part of their cultural baggage to the far corners of the world. In Japan, on the other hand, we find no transplanted settler society but rather a strong indigenous culture that differed profoundly from the European one. At this time, however, many Japanese had come to see traditional Japanese learning as inferior to that of the West in regard to the degree of mastery of nature that it provided. Here, the establishment of physics resulted from a strategic decision at the highest levels of government that Japan should master Western technology, and was part of the ensuing implantation of Western science in general within Japanese society.

Given these very different cultural settings, it is not surprising that our study reveals some significant differences between the ways in which physics became established in the two countries. It also, however, reveals a surprising number of similarities. Moreover, some, at least, of the differences appear to derive not so much from the different cultural settings as from straightforwardly political factors, and in particular, from the fact that Japan remained an independent power while Australia was, throughout this period, a mere subsidiary unit within that vast British Empire upon which the Sun, so it was said, never set. The similarities appear, as indicated already, to reflect certain general features of the physics discipline at this period.

2. Australia

The first European settlers arrived in Australia in 1788. For most of the century after that, scientific activity was concentrated on the botanical, zoological, and mineralogical exploration of the continent. In the early days, this work was mostly carried out by more-or-less trained collectors visiting from Europe on government-sponsored exploring expeditions or supported by wealthy private patrons such as Sir Joseph Banks. Later, an increasing proportion of this work was taken over by scientifically inclined members of the settler community who sent most of the materials they collected to leading European systematists—men such as Richard Owen or William Jackson Hooker—to whom they looked in return for advice and guidance.[1] In due course, in each of the Australian colonies, viable scientific societies were founded that provided a measure of intellectual support for local scientific work and also, through their published proceedings, a local publication outlet with some international distribution. These societies invariably depended for their scientific authority on tiny cadres of government-employed scientists such as the colony's surveyor-general, government geologist, government botanist, and government astronomer, but for their numerical strength and political support on larger groups of interested amateurs. In every case, questions of natural history dominated their meetings.

All the colonies looked to Europe for their supplies of trained scientists. The first universities were founded in the 1850s (Sydney 1852, Melbourne 1855), but not until the 1880s did they begin to offer systematic training for would-be scientists.[2] Prior to that, the science that was taught—and science was, in fact, well represented among the early professoriate—was seen as either part of a modernized liberal arts curriculum or, at Melbourne from the mid-1860s, as servicing the medical and engineering courses that were established at that time. Demonstration experiments were a feature of the lectures from the outset, but not until the 1880s were the first systematic courses of laboratory instruction introduced. Both universities were tiny institutions that produced only a handful of graduates each year. Despite this, the professors were required to teach large numbers of different courses. They had no research students, and their own opportunities for research on any but locally defined problems were virtually nil.

The expansion of university science teaching in the 1880s marked a turning point in the history of Australian physics. Prior to that time, such physics-orientated research as had been done had been concerned exclusively with questions of geophysics. As such, it was work of a rather different character from that which we generally associate with the idea of physics today, because instead of being founded upon laboratory-based experimental investigations, it was confined to passive, albeit careful and systematic, observation of various physical characteristics of the Earth such as its magnetic and gravitational fields, and the weather. Routine meteorological observing was a feature of the work of Lieutenant William Dawes in the short-lived observatory he established at Sydney soon after the arrival of the First Fleet in 1788,[3] and was likewise undertaken at other observatories founded later on, including Parramatta (1821–47),[4] Hobart (1840–

[1] Ann Moyal, *Scientists in Nineteenth Century Australia: A Documentary History* (Sydney, 1975); T. E. Burns and J. R. Skemp, editors, *Van Diemen's Land Correspondents: Letters from R. C. Gunn, R. W. Lawrence, Jorgen Jorgenson, Sir John Franklin and others to Sir William J. Hooker* (Lauceston, Tasmania, 1961).

[2] Geoffrey Blainey, *A Centenary History of the University of Melbourne* (Melbourne, 1957); H. E. Barff, *Short Historical Account of the University of Sydney, 1852–1902* (Sydney, 1902).

[3] Robert J. McAfee, *Dawes's Meteorological Journal* (Canberra, 1981).

[4] H. J. Russell, 'Astronomical and Meteorological Workers in New South Wales, 1788 to 1860', *Report of the First Meeting of the Australasian Association for the Advancement of Science, Sydney, 1888*, pp. 45–94.

54),[5] and the various astronomical observatories established by colonial governments during the second half of the nineteenth century (Melbourne 1853, Sydney 1858, Adelaide 1874, Perth 1896). The practice continued until the establishment in 1907, soon after Federation, of the Commonwealth Meteorological Bureau, when the responsibility for this work was transferred to the new organization.[6]

There was a similarly long history of recording the magnetic declination, for this was one of the recognized tasks of any nineteenth-century exploring expedition whether at sea or on land. His doing so during his voyage of circumnavigation around Australia during 1802 to 1805 led Matthew Flinders to recognize for the first time the systematic character of the errors induced in compasss readings by the increasing amounts of iron being used in the construction of ships.[7] A fully equipped magnetic observatory was established by the Royal Navy in Hobart in 1840 as part of a British-led world-wide programme of magnetic research.[8] Shortly after it ceased operating in 1854, G. B. von Neumayer began recording the magnetic field elements at his Flagstaff Observatory in Melbourne, thus initiating a series of observations that has continued almost uninterrupted to the present day through two changes of location. At first, Neumayer's work was sponsored by King Maximilian II of Bavaria; later the German immigrant community in Melbourne provided financial assistance. In due course, however, the colonial government assumed responsibility for the observations as part of the ongoing work of the Melbourne Observatory.[9]

A third category of physical investigations was also associated with the nineteenth-century colonial observatories, namely the measurement of the gravitational acceleration, g. A pendulum was swung for this purpose at the Parramatta Observatory in 1821, and the experiment was repeated on several occasions later in the century at both the Sydney and Melbourne Observatories. In the early 1890s, coordinated determinations were made at both locations.[10]

The astronomical observatories maintained by the various colonial governments were among the leading institutions of nineteenth-century Australian science. Undoubtedly they were supported, in part, for reasons of cultural pride, but the chief reasons for their existence were eminently practical ones, namely, to provide a local time service and base points for the colonial Survey Departments. The meteorological and magnetic observing that they did was likewise justified in practical terms as likely to lead to better weather forecasting and improved navigation respectively. As with their astronomial activities, however, the work that they undertook—especially in the larger establishments in Melbourne and Sydney—extended beyond what was required

[5] A. Savours and A. McConnell, 'The History of the Rossbank Observatory, Tasmania', *Annals of Science*, 39 (1982), 527–64.

[6] Art. 'Astronomy', *The Australian Encyclopedia* (Sydney, 1958), I, 278–86; W. J. Gibbs, *The Origins of Australian Meteorology* (Canberra, 1975); J. Gentilli, 'A History of Meteorological and Climatological Studies in Australia', *University Studies in History*, 5 (1) (1967), 54–88.

[7] Matthew Flinders, *Voyage to Terra Australis... in the Years 1801, 1802 and 1803* (London, 1814), Appendix II: 'On the Errors of the Compass arising from Attractions within the Ship...'

[8] Savours and McConnell (footnote 5). For details of the wider research programme that led to the founding of the observatory, see J. Cawood, 'The Magnetic Crusade: Science and Politics in Early Victorian Britain', *Isis*, 70 (1979), 493–518.

[9] Art. 'Neumayer', in *Australian Dictionary of Biography*, v, 329–31.

[10] Reports of the Gravity Survey Committee of the Royal Society of Victoria, *Proceedings of the Royal Society of Victoria*, 5 (1892), 218–21; 6 (1893), 213–20. E. F. J. Love, 'Observations with Kater's Invariable Pendulums made at Sydney during January and February, 1894', ibid., 7 (1894), 1–18. Idem, 'On the Value of Gravity at the Sydney Observatory', *Journal and Proceedings of the Royal Society of New South Wales*, 28 (1894), 62–64.

for immediate practical purposes to tasks of more general (albeit still limited) scientific significance. In particular, in the 1870s, H. C. Russell in Sydney began publishing synoptic meteorological charts covering most of south-eastern Australia that led in time to a deeper understanding of the pattern of atmospheric changes in the region.[11] R. L. J. Ellery at the Melbourne Observatory followed suit soon afterwards and, at about the same time, began publishing extensive series of magnetic field data.[12]

Work of this kind could claim a certain practical utility. Laboratory physics, however, was not perceived in nineteenth-century Australia as a science that had immediate practical applications. Hence, unlike chemistry, astronomy, and the various field sciences, it did not receive direct government support. If physics had a perceived role, it was an educational one, as an integral part of the general liberal curriculum that the universities were originally intended to teach, and an essential component of scientifically orientated courses such as medicine and engineering when these were introduced later on. In either case, it was physics teaching, not research, that was required.

Furthermore, this attitude prevailed not just in the earliest universities, in Sydney and Melbourne, but also in those founded later, in Adelaide (founded 1874), Hobart (1891), Brisbane (1910), and Perth (1912). (These were the only universities in Australia until after World War II.) Moreover, so long as the universities remained small, the teaching of physics tended to be seen as among the responsibilities of the professor of mathematics, rather than as warranting a separate appointment.

The early mathematics approintments were all outstanding graduates of the University of Cambridge mathematical tripos examinations. As such, they were well trained in Newtonian mathematical physics. All of them quickly introduced courses in physics (or 'natural philosophy') in addition to their bread-and-butter courses in mathematics. In most cases, they illustrated their physics lectures by experimental demonstrations, though at Sydney the course was more in the nature of applied mathematics, and experimental physics was taught by the natural science professor, John Smith, a graduate of the University of Aberdeen.

Outside their lecture halls, the professors were expected to provide cultural leadership in the intellectually undernourished communities in which they found themselves. There was no expectation, however, that they would undertake research. In Melbourne, W. P. Wilson became a leading supporter of the newly founded Observatory;[13] his opposite number in Sydney, M. B. Pell, became an actuarial consultant to the local insurance industry.[14] Neither took up physical research of any kind, and nor did Smith, whose interests were chiefly chemical.[15] It was a different matter with the foundation professor at Adelaide, Horace Lamb. Lamb had already had several years' experience as an active researcher in Cambridge before moving to Australia, and during his ten years in Adelaide he sent an impressive series of papers and also the manuscript of his famous treatise on hydrodynamics to England for publication.[16] Yet he was able to do this only because his research was entirely

[11] Gibbs (footnote 6), pp. 21–23.

[12] Ibid. Also R. L. J. Ellery *et al.*, *Record of Results of Observations in Meteorology and Terrestrial Magnetism made at the Melbourne Observatory*... (Melbourne, 1872–1911).

[13] Art. 'Wilson', *Australian Dictionary of Biography*, VI, 419–20.

[14] Art. 'Pell', ibid., V, 428–9.

[15] Art. 'Smith', ibid., VI, 148–50. See also *Ever Reaping Something New: A Science Centenary*, edited by D. Branagan and G. Holland (Sydney, 1985), chapters 2, 3.

[16] Horace Lamb, *A Treatise on the Mathematical Theory of the Motion of Fluids* (Cambridge, 1879).

mathematical in character and so not dependent on the availability of laboratory facilities; for while the University had furnished him with some apparatus for teaching purposes, he no more had the space or the equipment to support a serious programme of experimental research than did his fellow professors in the other colonies.[17] Furthermore, most of Lamb's early publications, and his book above all, were based on work done in Cambridge before ever he set out for Australia, even though much of the writing-up was done in Adelaide.[18]

During the middle decades of the nineteenth century, there was a rapid growth, especially in the more populous colonies, in the numbers of residents with scientific interests and expertise. It was this that made possible the formation, one by one in most of the colonies, of the first viable scientific societies. Inevitably, the early science professors became leading lights in them. Papers on physical subjects never figured largely in the work of these groups, but occasionally they did appear on the programme. Henry Kay, the officer in charge of the Hobart magnetic observatory, presented several papers to the infant Royal Society of Van Diemen's Land on work done at his establishment.[19] The directors of the astronomical observatories in the various colonies, who all played leading roles in the affairs of their local societies, all read papers to these societies from time to time. Most of these were astronomical reports, but some dealt with meteorological or other geophysical questions or with improvements to the instruments used in such work. Occasionally, one or other of the societies served as a forum at which an enthusiast who was not a professional scientist was able to present his ideas on physical topics such as the principle of conservation of energy.[20]

As noted already, however, it is to the 1880s, and to the expansion of the university commitment to science that occurred at that time, that we must look for the real beginnings of laboratory-based physics in Australia. At both Melbourne and Sydney universities, as part of a general expansion of their teaching function, several new science chairs were created early in this decade. In both cases, the new appointments included specialist professors of physics (or 'natural philosophy'). Shortly afterwards, separate degrees in science were introduced that included systematic courses of laboratory instruction in addition to the traditional lectures and demonstrations.[21] This in turn led to the construction later in the decade of substantial new physical laboratories to accommodate the practical classes.[22] The new buildings included private laboratory space for the professors, and both Richard Threlfall at Sydney and Thomas Ranken Lyle, who succeeded the initial incumbent, H. M. Andrew, at Melbourne in 1889, were of a mind to use it.

Threlfall, a close friend of J. J. Thomson's, was an outstanding experimenter who had been a demonstrator at the Cavendish Laboratory in Cambridge for several

[17] University of Adelaide, Council Minutes, vol. 1, pp. 130, 164 (University of Adelaide Archives); W. G. K. Duncan and R. A. Leonard, *The University of Adelaide, 1874–1974* (Adelaide, 1973), p. 9.

[18] See Lamb's preface to his *Treatise*.

[19] H. Kay, *Papers and Proceedings of the Royal Society of Van Diemen's Land*, 1 (1849–50), 83–87; ibid., 144–53; ibid., 255–57; ibid., 2 (1852–54), 264–87; ibid., 297–307.

[20] e.g. R. Abbott, 'The Maintenance of Energy', *Proceedings of the Royal Society of Victoria*, 1 (1888), 12–20.

[21] See the annual *Calendars* published by the various universities for details of the new courses.

[22] For a description of the new building at Sydney, see R. Threlfall, 'On the New Physical Laboratory at the University of Sydney', *Report of the First Meeting of the Australasian Association for the Advancement of Science, Sydney, 1888*, pp. 95–105, reprinted in *Building and Engineering Journal*, 2 (February 1889), 86–97.

years.[23] As soon as he arrived in Sydney, he began a spectacular study that continued for several years of the propagation of explosion-induced disturbances through sea-water; once the new laboratory was erected, he also embarked upon an ambitious programme of experimental research on the properties of dielectrics.[24] In this work he was assisted by his demonstrator J. F. Adair, likewise recruited from Cambridge, a trickle of advanced students, and various interested residents of Sydney. This was the period at which urban electricity supply systems were being installed throughout Australia, and Threlfall also established a lucrative business on the side as a technical adviser on problems of electrical generation and distribution.[25] With Adair's successor J. A. Pollock, he constructed a high-quality quartz-thread torsion balance and, using it, measured the gravitational acceleration in a wide range of eastern Australian localities.[26] In 1898, however, he resigned his chair and returned to England, and was lost thereafter to Australian science.

Lyle, an outstanding graduate of Trinity College, Dublin, took a little longer to embark upon a significant programme of research. By the late 1890s, however, he was well launched on a series of investigations both theoretical and experimental connected with a highly topical problem at the time, the generation and transmission of alternating currents. Perhaps his most important contribution was his development, independently of Steinmetz, of the now familiar complex number representation for analysing alternating current circuits.[27] Lyle, too, soon had a steady trickle of advanced students undertaking research in his laboratory. He also had the benefit of regular conversations with an outstanding physical theorist, William Sutherland, who lived quietly in Melbourne during these years without any regular academic or scientific appointment while contributing a stream of publications, including important contributions to kinetic theory, to the leading physics journals in Europe.[28]

Meanwhile, in Adelaide, Horace Lamb was succeeded in 1886 by W. H. Bragg, then a very recent graduate of the Cambridge mathematical tripos examinations. At first, Bragg's expertise was almost wholly mathematical, but in time he, too, became a highly proficient experimental physicist. In 1904 he embarked upon a major programme of research on the ionizing radiations emitted by radium and other radioactive substances. This led in rapid succession to an extensive correspondence with Rutherford and other leaders in this new field of research, Bragg's election as F.R.S. in

[23] J. J. Thomson, 'Sir Richard Threlfall (1861–1932)', *Obituary Notices of Fellows of the Royal Society of London*, 1 (1932), 45–52; R. E. Threlfall, 'Sir Richard Threlfall G.B. E., F.R.S. (1861–1932): Some Personal Memories', *Notes and Records of the Royal Society of London*, 16 (1961), 234–42; R. W. Home, 'First Physicist of Australia: Richard Threlfall at the University of Sydney, 1886–1898', *Historical Records of Australian Science* (forthcoming, December 1986).

[24] R. Threlfall and J. F. Adair, 'On the Velocity of Transmission through Sea-Water of Disturbances of Large Amplitude caused by Explosions', *Proceedings of the Royal Society of London*, 46 (1889), 496–541; Threlfall, 'On Sensitive Galvanometers', *Philosophical Magazine*, 5th series, 29 (1890), 508–10; 'The Electrical Properties of Pure Substances. Part I: The Preparation of Pure Nitrogen and Attempts to Condense It', *Philosophical Magazine*, 5th series, 35 (1893), 1–35; Threlfall, J. H. D. Brearley and J. B. Allen, 'Researches on the Electrical Properties of Pure Substances', *Proceedings of the Royal Society of London*, 56 (1894), 32–40; Threlfall and J. H. D. Brearley, 'Researches on the Electrical Properties of Pure Substances. No. 1: The Electrical Properties of Pure Sulphur', *Philosophical Transcations of the Royal Society of London*, A, 187 (1896), 57–150.

[25] The details of Threlfall's business activities are revealed by his letter-copy books from this period, now preserved in the University of Sydney Archives.

[26] R. Threlfall and J. A. Pollock, 'On a Quartz Thread Gravity Balance', *Philosophical Transactions of the Royal Society of London*, A, 193 (1899), 215–258.

[27] Art. 'Lyle', *Australian Dictionary of Biography*, x, 172–74. T. R. Lyle, *Electrician*, 41 (1898), 816–18; 42 (1898-99), 72–74, 148–51; 43 (1899), 570–71.

[28] W. A. Osborne, *William Sutherland: A Biography* (Melbourne, 1920).

1907, his return to England two years later to a chair at Leeds and, eventually, the 1915 Nobel Prize for physics that he shared with his son.[29] Once embarked on this programme of research, Bragg drew whatever advanced students he had into the work, and also several of his university colleagues. Apart, however, from this work and some related investigations of the new ionizing radiations by J. A. Pollock, who had by this time succeeded Threlfall in the chair in Sydney,[30] the 'new physics' that developed in the years after 1895 had little impact on the science in Australia until after World War I.

The transformation of Australian university physics led to changes in the pattern of publication of Australian work. Initially, everything intended for publication had been sent to Europe. For example, the Hobart magnetic observatory had been one of a chain set up under British sponsorship in different parts of the world. All of these had sent their data to England for analysis by Edward Sabine and his assistants and publication there.[31] In similar fashion, Neumayer had taken his Melbourne data with him when he returned to Germany in 1863 and had published his material there.[32] Thereafter, however, Australian work in observational geophysics and instrumentation and also the occasional discourses on physical subjects that were read to local scientific societies had tended to be published in the *Proceedings* of the local Royal Society, or, in the case of large compilations of observatory data, as separately published volumes issued by the observatory in question.[33] Now, with the rise of laboratory physics in the 1880s and 1890s, the trend towards local publication was reversed. The work being done in the university physics departments was closely connected with research being carried out in other parts of the world, and Threlfall and Lyle, and later Bragg as well, clearly wanted it to be accessible to a larger audience than merely local publication would attract. Accordingly, they took to sending the better papers emanating from their laboratories to England for publication in journals such as the *Philosophical Magazine* and the *Proceedings of the Royal Society of London.* Sometimes they would arrange parallel publication in Australia, or the publication of an abstract of a paper destined for full publication in England. The practice soon became established, however, which persisted for many years thereafter, whereby all the best work was sent to London and only the more pedestrian material was published in the local scientific journals in Australia.[34] Threlfall published one three-part paper in the American journal, *Physical Review,* while Bragg, through the intervention of Frederick Soddy, was invited to contribute a couple of papers on his alpha-particle work to the leading German

[29] E. N. da C. Andrade, 'William Henry Bragg, 1862–1942', *Obituary Notices of Fellows of the Royal Society of London,* 4 (1942–44), 277–92; *Dictionary of Scientific Biography,* II (1970), 397–400; G. M. Caroe, *William Henry Bragg, 1862–1942: Man and Scientist* (Cambridge, 1978); R. W. Home, 'W. H. Bragg and J. P. V. Madsen: Collaboration and Correspondence, 1905–1911', *Historical Records of Australian Science,* 5(2) (1981), 1–29; R. W. Home, 'The Problem of Intellectual Isolation in Scientific Life: W. H. Bragg and the Australian Scientific Community, 1886–1909', ibid., 6(1) (1984), 19–30; J. G. Jenkin, 'The Appointment of W. H. Bragg, F.R.S., to the University of Adelaide', *Notes and Records of the Royal Society of London,* 40 (1985), 75–99.

[30] J. A. Pollock, 'The Ions of the Atmosphere', *Report of the Twelfth Meeting of the Australasian Associationfor the Advancement of Science, Brisbane, 1909,* pp. 31–41 (also in *Science,* 29 [1909], 919–28); 'The Mobility of the Large Ions in the Air', *Journal and Proceedings of the Royal Society of New South Wales,* 43 (1909), 61–68; 'The Nature of the Large Ions in the Air', ibid., 198–203.

[31] See Cawood (footnote 8).

[32] G. B. von Neumayer, *Discussion of the Meteorological and Magnetic Observations made at the Flagstaff Observatory, Melbourne ... 1858–1863* (Mannheim, 1867); idem, *Results of the Magnetic Survey of the Colony of Victoria during the Years 1858–1864* (Mannheim, 1869). Some of Neumayer's results were published in Australia, viz. *Results of the Meteorological Observations taken in the Colony of Victoria ... 1859–62; and of the Nautical Observations collected and discussed at the Flagstaff Observatory ... 1858–62* (Melbourne, 1964).

[33] See n. 12 above.

[34] See R. W. Home, editor, *Bibliography of Australian Publications in Physics to 1945* (in preparation).

journals.[35] No one else contemplating publishing outside Australia seems even to have conceived the possibility of sending their work to journals other than the English ones.

This trend with regard to publication was but part of a general strengthening of imperial scientific links at this period. In large measure, this derived from changes taking place in Britain itself, where university science departments were rapidly expanding their commitment to research. For physics, the crucial development occurred in Cambridge, where the introduction of the B.A. by Research degree in 1895 granted official status for the first time to research students with first degrees from elsewhere, and led almost at once to the Cavendish Laboratory under J. J. Thomson becoming a Mecca for aspiring young physicists from all over the world.[36] Among them were many of the most promising young Australian graduates in physics. A new pattern quickly evolved whereby the best Australian students would do a year or so of introductory research at their home university in Australia after completing their first degree and then, if they could possibly afford it, go to England—almost always to Cambridge—for their advanced training. To assist them, various travelling scholarship schemes came into existence, some endowed at the different Australian universities by wealthy local philanthropists, others, like the 1851 Exhibition science research scholarships and later the Rhodes awards, established in England with the express intention of strengthening the bonds of Empire.[37]

The long-term consequences for Australian physics were disastrous. Almost overnight, the major university physics departments, which in the 1890s had shown every indication of developing research schools that would win them a place on the world physics map, were transformed, by the siphoning off of their brightest young talents, into what amounted from the research point of view to mere training schools for the Cavendish. In time, some of those who went away returned to Australia, bringing their newly acquired knowledge and skills with them. Larger numbers, however, including many of the best of them, never returned. Added to the loss of Threlfall and Bragg, whose replacements were inevitably men of lesser scientific attainments, they constituted a permanent net loss on a scale that the still tiny Australian physics community could not overcome. After an all too brief period of growth, Australian physics came almost to a standstill for another generation and more.

A seductive rationale was even found for the new situation, based on considerations of imperial efficiency. Within the wider imperial economy, so it was said, Britain provided the manufacturing base to process for the whole system raw materials produced in other parts of the empire; and from this it followed that research in scientific fields such as chemistry and physics that bore chiefly on the problems of manufacturing industry should be cultivated in Britain, while Australia and the other

[35] R. Threlfall, 'On the Conversion of Electric Energy in Dielectrics', *Physical Review*, 4 (1897), 457–79; 5 (1897), 21–46, 65–74. J. G. Jenkin, 'Frederick Soddy's 1904 Visit to Australia and the Subsequent Soddy–Bragg Correspondence: Isolation from Without and Within', *Historical Records of Australian Science*, 6(2) (1985), 153–69.

[36] *Cambridge University Calendar for the Year 1896–1897*, pp. 120–23; *A History of the Cavendish Laboratory, 1871–1910* (London, 1910); J. G. Crowther, *The Cavendish Laboratory, 1874–1974* (London, 1974).

[37] *Record of the Science Research Scholars of the Royal Commission for the Exhibition of 1851, 1891–1960* (London, 1961); *Rhodes Scholarships: Record of Past Scholars, 1903–1945* (London, 1950).

dominions should concentrate upon research, for example agricultural research, likely to benefit their primary industries.[38]

3. Japan

Prior to the middle of the nineteenth century, Japan achieved an independent cultural development of its own. It differed greatly from Western culture, and did not give birth to anything resembling what we now call modern physical science, which had its origin in the West and thus had to be imported into Japan.

Japan's first direct contact with Westerners occurred in the mid-sixteenth century when a Portuguese ship drifted ashore on a Japanese southern island. This marked the beginning of the introduction of Western religion and learning into Japan, mainly by Portuguese and Spanish missionaries. In the 1630s, however, Christianity was banned and all Europeans were excluded except the Dutch. Yet even under these restrictions the Japanese still managed to absorb some Western developments through the Dutch visitors. The interest of the Japanese was attracted more to the practical aspects, but some important basic knowledge was also partly transmitted, such as Copernican astronomy, Newtonian dynamics, modern views on human anatomy, the Linnaean system of taxonomy, and Lavoisier's chemistry. Some Western scientific knowledge, especially of astronomy, also came by way of China, where the knowledge was transmitted by the missionaries and translated into Chinese, which Japanese scholars had little difficulty in reading.[39]

During the feudal period in Japan, each clan operated its own school. There, Chinese classics constituted the traditional core of the curriculum. From about the end of the eighteenth century, however, 'Dutch' learning began to be studied as well, and by the middle of the nineteenth century, one-third of all courses of instruction consisted of scientific disciplines.[40] At the same time, the number of scholars of Western learning in Japan increased remarkably. Some of these scholars and young *samurais* trained at the clan schools were to become the earliest leaders of the Meiji development.

[38] Roy MacLeod, 'On Visiting the "Moving Metropolis": Reflections on the Architecture of Imperial Science', *Historical Records of Australian Science*, 5(3) (1982), 1–16; Barry W. Butcher, 'Science and the Imperial Vision: The Imperial Geophysical Experimental Survey, 1928–1930', ibid., 6(1) (1984), 31–43. On the history of the Australian physics community, see also R. W. Home, 'Origins of the Australian Physics Community', *Historical Studies* (Melbourne), 20 (1982–83), 383–400.

[39] For the history of science and especially of physics in Japan to the present time, see: Isao Sugimoto, editor, *Kagaku-shi* (History of Science in Japan) (Tokyo, 1967); Shigeru Nakayama *et al.*, editors, *Science and Society in Modern Japan* (Tokyo, 1974); Nihon Butsuri Gakkai (The Japan Society for Physics), editor, *Nihon no Butsurigakushi* (History of Physics in Japan), 2 vols (Tokyo, 1978), partially translated into German as *Die Geschichte der Physik in Japan* (Wiesbaden, 1984); Kenkichiro Koizumi, 'The Emergence of Japan's First Physicists, 1868–1900', *Historical Studies in the Physical Sciences*, 6 (1975), 3–108; Naohiko Hiromasa, 'Introduction and Development of Modern Physics in Japan (1868–1912)', (paper presented to the XVIIth International Congress of the History of Science, Berkeley, 1985, Scientific Section Po); and Derek J. da Solla Price, *Little Science, Big Science* (New York, 1963), pp. 98–101. For the more general history of science and technology in Japan after the mid-nineteenth century, see: Nihon Kagakushi Gakkai (The History of Science Society of Japan), editor, *Nihon Kagaku-Gijutsu-shi Taikei* (History of Science and Technology in Japan), 26 vols. (Tokyo, 1964–72); Masao Watanabe, *Nihonjin to Kindaikagaku* (The Japanese and Modern Science) (Tokyo, 1976), translated into German as *Die Japaner und die moderne Wissenschaft* (Wiesbaden, 1981); and Mitsutomo Yuasa, *Nihon no Kagaku-Gijutsu 100-nen-shi* (Centenary History of Science and Technology in Japan), 2 vols. (Tokyo, 1980–84). There exist a cumulative bibliography for science and applied science in Japan during the period 1868–88: Masao Watanabe, *Meiji-zenki Gakujutsu-zasshi Ronbun Kiji Sōran* (A Bibliography of Articles in Early Meiji Periodicals, Academic/Scientific/Technical) (Tokyo, 1971), and a related statistical work based on this bibliography: Masao Watanabe *et al.*, *Nihon no Kindaika to Kagaku* (Science, Technology, Agriculture, and the Modernization of Japan) (Tokyo, 1976).

[40] *Nihon no Kagaku-Gijutsu 100-nen-shi*, I, 18.

Japanese swordsmiths had been able skilfully to copy Western firearms in the sixteenth century, but the situation in the nineteenth century was very different. While Japan had been isolated from the outside world, the West had undergone a great transformation, science and technology having developed dramatically. Science was established as a speciality in its own right and, together with the technology connected with it, had clearly demonstrated its worth in such areas as industry, transportation, communication, and the military. Thus, when the West suddenly appeared in Tokyo Bay in 1853, in the form of four 'black ships' from America headed by Commodore Matthew Perry, Japan's leaders decided that there was no alternative but to open the country and establish a modern state based on Western principles. These the Japanese would have to learn directly from the West, from concept to actual practice.

To meet this urgent need, over ninety students were sent abroad by the Shogunate and some of the progressive local lords. Besides the Dutch language, English, German and French were also studied. Naval and army training schools were organized, an institution devoted to foreign affairs was created, and a school of Western medicine was founded by the Shogunate.

With the Meiji Restoration in 1867, traditional Chinese learning was replaced by Western learning, and the *Shōheikō* as the central institution for the study of Chinese classics was soon closed. Governmental policy was formulated to accord with the statement in the so-called Charter Oath that 'Knowledge shall be sought throughout the world, so that the foundations of the Empire may be firmly established'. Education was to play a particularly important role in the whole process of Meiji development. The government began sending students abroad in large numbers,[41] primarily to America, Britain, and Germany, and employing foreigners, mostly American, British, German, and French, to help establish a modern educational system in Japan and to teach Western science and technology. Scores of these foreign teachers were eventually brought in.

In November 1871, the Japanese government despatched a mission to Europe and America, Britain, and Germany, and employing foreigners, mostly American, British, unequal treaties, the mission's sojourn in the West for almost two years turned out to be of great use in framing the policies (including the science policies) of the government.

While in Britain, one of the deputies, Hironobu Itō, then in charge of the Ministry of Industry and later to become Premier, was introduced to William John Macquorn Rankine, professor at Glasgow University, from whom he sought advice on engineering education in Japan. Rankine suggested a radical plan, unprecedented in Britain itself. He envisaged a technical college where emphasis was placed not so much on each of the specialized subjects of engineering as on foundational disciplines such as mathematics, physics and chemistry. Rankine recommended Henry Dyer, one of his best students from the University of Glasgow, to inaugurate the scheme.[42]

Dyer arrived in Japan in 1873 and assumed the office of Principal of the newly opened College of Engineering, Kōgaku Ryō, in Tokyo, which became Kōbu

[41] That the government attached great importance to scientific disciplines is evidenced by the total numbers of students sent abroad by the Ministry of Education during the period 1868–1912: 93 for medicine, 67 for engineering, 25 for industry, 52 for science, 31 for agriculture, 27 for education, 62 for law, 20 for commerce, 50 for literature, 10 for art, 5 for music, and 2 for gymnastics. Mitsukuni Yoshida, *Nihon o kizuita Kagaku* (Science which helped build Japan) (Tokyo, 1966), p. 30.

[42] Nobuhiro Miyoshi, *Meiji no Enjinia Kyōiku* (Engineering Education during the Meiji Period) (Tokyo, 1983), pp. 16–17.

Daigakkō four years later.[43] The curriculum he introduced amounted to an integration of the British system, where emphasis was placed on training on the job, and the French and German system, where the study of theory was emphasized more. The college offered six courses, Civil Engineering, Mechanical Engineering, Telegraphy, Architecture, Applied Chemistry and Metallurgy, and Mining. Students spent the first two years in preparatory studies, the next two years in both schooling and practice, and a final two years solely in training on the job, on projects such as railways, lighthouses, telegraphic services, construction works and mines in various parts of the country.[44]

Among those who worked together with Dyer were: Edward Divers, a graduate of the Royal College of Chemistry, London, who taught inorganic chemistry; William Edward Ayrton, a graduate of London University who had worked with William Thomson and Fleeming Jenkin to install telegraphy for the Great Western Railway and who had been recommended by Thomson, who taught electrical engineering and physics; John Perry, a student of James Thomson's at Queen's University College, Belfast, also recommended by William Thomson, who taught civil engineering; John Milne, a graduate of King's College, London, who had studied geology and mineralogy at the Royal School of Mines, and who taught geology and mining; and Thomas Gray, a successor of Ayrton, who taught telegraphy. All these men were British, they co-operated well and, as we shall see, they were active in both education and scientific research. The college at which they taught produced 211 very capable graduates before merging in 1886 with the University of Tokyo, where it became the University's School of Engineering.[45]

The University of Tokyo had been established in 1877 out of a merger of various educational institutions originally belonging to the Shogunate. Here, too, the teaching was carried out initially by Westerners. In contrast with the Engineering College, however, the teachers at the University of Tokyo were drawn from various other countries, especially the United States and Germany, as well as from Britain. Naturally, each of the specialized disciplines was much more emphasized there than at the Engineering College, but the Western teachers were allowed to take less initiative in laying plans and in operating the institution. The number of Westerners was greatest in the late 1870s, but decreased rapidly during the following decade,[46] when most were replaced by Japanese trained abroad.

The School of Science of the University of Tokyo comprised five departments: Chemistry; Mathematics, Physics and Astronomy; Biology; Engineering (Mechanical and Civil); Geology and Mining. The Department of Mathematics, Physics and Astronomy was broken up into three separate departments in 1881. Physics was taught

[43] Ibid., p. 18. On Kōbu Daigakkō, see: *Kyū Kōbu Daigakkō Shiryō* (Historical Records of the Former Kōbu Daigakkō) (Tokyo, 1931).

[44] *Meiji no Enjinia Kyōiku*, pp. 21–22 and 27–37. This new method of engineering education was highly evaluated in *Nature* (16 (1877), 44): 'While England is so far behindhand in this important question, a great work has been done by the Japanese Government in the establishment of an Imperial College of Engineering at Tokei [Tokyo], an institution which gives to its students a highly scientific training, combined with actual practical experience in engineering workshops.' Soon afterwards, the method was reimported into Britain and served to produce a new kind of institution there. See W. H. Brock, 'The Japanese Connexion: Engineering in Tokyo, London and Glasgow at the End of the Nineteenth Century', *British Journal for the History of Science*, 14 (1981), 227–43.

[45] *Tokyo Daigaku Hyakunen-shi, Tsūshi 1* (Centenary History of the University of Tokyo, Outline History 1) (Tokyo, 1984), pp. 649–99. See also footnote 47.

[46] Masao Watanabe, *Bunkashi ni okeru Kindaikagaku* (Science in the History of Modern Culture) (Tokyo, 1963), p. 70.

as a foundation course not only in these three departments, but also in other departments and at the Medical School as well.[47]

The first physics professor at the University of Tokyo was T. C. Mendenhall, a self-taught American physicist who had been a professor at Ohio Agricultural and Mechanical College. He was succeeded by James Alfred Ewing, who had studied under P. G. Tait and Fleeming Jenkin at the University of Edinburgh before co-operating with William Thomson in the laying of submarine telegraph cables. Ewing was succeeded in turn by Cargill Gilson Knott, another Edinburgh graduate and assistant of Tait.

Thus, as in Australia, physics teaching and research in Japan, both at the College of Engineering and at the University of Tokyo, was initiated mainly by British scientists.[48] In contrast with the strong Australian links with Cambridge, however, Japan's links were mostly with the Scottish universities at Glasgow and Edinburgh. Yet in time these became weaker. Many of the leading physics students who went abroad for their advanced training went to Germany, and as they returned to positions in Japan, replacing the initial wave of foreign teachers, German influences eventually came to predominate—as, indeed, they did in Japanese science policy and politics in general.

At both Japanese institutions, physics teaching was accompanied by student laboratory exercises from the beginning. Physics students also sometimes participated in their professors' research, for example in measuring the gravitational acceleration and in geomagnetic investigations. They thus learned the method of research in practice. This had a great educational effect on Japanese who had previously been accustomed to learning mostly from books. Physics students also took courses in pure and applied mathematics, including such physics-related topics as geometrical optics, the transmission of heat, statics and dynamics.[49]

Most of the academic societies for basic and applied scientific studies were started between 1877 and 1890. The Mathematical Society of Tokyo, predecessor of the Japan Society for Physics, was inaugurated in 1877 with 55 members comprising scholars of Japanese mathematics (*wasan*), scholars of the newly introduced Western mathematics, and naval and army mathematicians. Its journal began in the next year, and included papers on statics and dynamics (and later astronomy). This society became the Tokyo Mathematico-Physical Society in 1884.[50]

In addition to the periodicals issued by the specialist scientific societies, two more general periodicals were established that published scientific papers and had a great influence on Japanese intellectuals of the time. These were *Gakugei Shirin*, first

[47] *Tokyo Teikoku Daigaku Gojūnen-shi* (Fifty-Year History of Tokyo Imperial University), I (Tokyo, 1932), 615–66; *Tokyo Daigaku Hyakunen-shi* (footnote 45), pp. 451–55.

[48] Concerning the lives and activities of Western science teachers in Japan, see: Mitsukuni Yoshida, *Oyatoi Gaikokukjin 2, Sangyō* (Employed Foreigners 2, Industry) (Tokyo, 1968), and Masuzō Ueno, *Oyatoi Gaikokujin 3, Shizen Kagaku* (Employed Foreigners 3, Natural Science) (Tokyo, 1968). Among the British teachers, J. A. Ewing, C. G. Knott and J. Milne are entered in the *Dictionary of Scientific Biography* (New York), IV (1971), 500–501, VII (1973), 413, and IX (1974), 406–407, respectively. Detailed accounts of the American science teachers are given in Masao Watanabe, *Oyatoi Beikokujin Kagaku Kyōshi* (Science across the Pacific) (Tokyo, 1976).

[49] *Nihon no Butsurigaku-shi* (footnote 39), I, 99–103.

[50] The Tokyo Mathematico-Physical Society became the Japan Mathematico-Physical Society in 1918, before dividing in 1946 into two separate societies, the Japan Mathematical Society and the Japan Society for Physics. Other scientific societies inaugurated in these early days were the Chemical Society (1878), which became the Tokyo Chemical Society in 1879, the Tokyo Geographical Society (1879), the Engineering Society (1879), the Seismological Society of Japan (1880), the Science Society (1882), the Meteorological Society of Japan (1882), the Hydrographical Society (1884), and the Electrical Society (1888). Ibid., pp. 113–38.

published in 1877, and *Tōyō Gakugei Zasshi*, first published in 1881, the latter journal being modelled after the British journal *Nature*.[51] In the meantime, foreign sojourners in Japan had started their own societies, such as the Deutsche Gesellschaft für Natur- und Volkskunde Ostasiens (1873) and the Asiatic Society of Japan (1874), which published *Mitteilungen* and *Transactions* respectively. As the number of newly founded academic periodicals increased, so also did the number of published scientific articles. In the early stages, the contributors were mostly Westerners, but by the late 1880s the majority were Japanese. Once introduced, scientific activities were rapidly promoted, and the Japanese soon took over what had been initiated by the Westerners.[52]

The introduction and adaptation of Western science and technology were expedited in all aspects. The telegraphic service had already been started in 1868. The solar calendar was introduced and the lunar calendar officially abolished in 1872. The Tokyo Meteorological Observatory was established in 1875, and the Tokyo Astronomical Observatory, attached to the University of Tokyo, was created in 1888 out of a merger of existing observatories.[53] A committee for the translation of physics terminology into Japanese was set up in 1883 and within five years was able to publish a *Dictionary of Physics Terminology, Japanese, English, French and German*,[54] which enabled Japanese scientists and teachers to write on and teach physics in their own language using a standardized technical vocabulary.

Kyoto University was established in 1897 with a School of Science and Engineering consisting of Departments of Mathematics, Physics, Chemistry (pure and applied), Civil Engineering, Mechanical Engineering, and Mining and Metallurgy. Thus, Japan's second physics department came into existence.[55] However, here, as at Tokyo, the number of graduates each year remained small.[56]

Of the scientific papers published in and outside Japan by Japanese authors and by Western sojourners in Japan, a large fraction dealt with earth science. This was particularly the case with the Western sojourners, for whom geophysics was a major area of interest.[57] Soon afterwards, this area of investigation was also taken up by Japanese researchers, natural calamities such as the earthquake and the typhoon being typical of nature in Japan. The British professors John Milne, Thomas Gray and James Alfred Ewing were the principal initiators of seismology in Japan. They started the investigation of earthquakes, made seismometers, created the Seismological Society of Japan, and published papers in the *Transactions* of this society. They were followed by Seikei Sekiya, Fusakichi Ōmori and Akitsune Imamura. In 1886, at the University of Tokyo, Sekiya was made professor of seismology, the first in the world.[58] As

[51] Ibid., p. 120.

[52] Masao Watanabe, 'The Emergence of Japan in the International Scientific Community', *Human Implications of Scientific Advance: Proceedings of the XVth International Congress of the History of Science, Edinburgh, 10–19 August 1977*, pp. 183 and 189–90 (Diagrams I, II and III).

[53] *Nihon no Butsurigaku-shi* (footnote 39), I, 119.

[54] *Butsuri Gakujutsugo Wa-Ei-Futsu-Doku Taiyaku Jisho* (Tokyo, 1888), 5 + 93 + 84 + 88 pp.

[55] On the history of Kyoto University, see *Kyoto Daigaku Shichijūnen-shi* (Seventy Year History of Kyoto University) (Kyoto, 1967).

[56] *Nihon no Butsurigaku-shi* (footnote 39), I, 111, Chart 3-5-1. Masao Watanabe *et al.*, *Nihon no Kindaika to Kagaku* (footnote 39) p. 6, Fig. 1–13. The percentages of the 101 graduates of the School of Science of the University of Tokyo up to 1887 are: Chemistry 42·6, Mathematics, Physics and Astronomy 32·7, Earth Science 14·9 and Biology 9·9.

[57] *Nihon no Kindaika to Kagaku*, p. 5, Figs. 1–7, 1–8, 1–9 & 1–10. Of the 646 scientific papers published by Western sojourners in Japan up to 1887, 330 (51·1%) belonged to Earth science.

[58] For the history of seismology in Japan, see Charles Davison, *The Founders of Seismology* (Cambridge, 1927); Yoichiro Fujii, *Nihon no Jishingaku* (Seismology in Japan) (Tokyo, 1967); and Mampei Hashimoto, *Jishingaku Kotohajime* (The Beginning of Seismology in Japan) (Tokyo, 1983).

Mendenhall correctly stated in 1900, 'Japan has become within twenty years a vast seismological laboratory in which seismic phenomena are being used as never before. Indeed, modern seismology had its birth there.'[59] However, theoretical aspects of seismology, such as the study of the transmission of seismic waves in relation to the internal structure of the Earth, did not develop in Japan until after the 1920s.

The first nationwide measurement of geomagnetism in Japan was carried out by Edmund Naumann during 1882–83. Naumann was a German geologist and a teacher at one of the predecesor schools of the University of Tokyo. C. G. Knott, somewhat critical of his results, repeated it with his Japanese colleague Tanakadate and various students. Tanakadate, still not quite satisfied with these results, performed more extensive investigations during the years 1893–96 with several young graduates and students, and published his results in a voluminous work in 1904.[60]

Gravity measurements were undertaken by Ayrton and Perry in Tokyo together with their students at the College of Engineering. They used a pendulum made of a wire 10 m in length. After they returned to Britain they published the results in the *Philosophical Magazine* in 1880.[61] In the same year, Mendenhall with his students at the University of Tokyo measured gravity by means of a Kater's pendulum of length 1 m, both in Tokyo and at the summit of Mt Fuji.[62] Tanakadate and other Japanese physics students went to Sapporo in 1881, to Okinawa in 1882, and to Ogasawara in 1884, to measure gravity by means of a new Kater's pendulum and a Polta's pendulum of period 1 second.[63]

A Geodetic Committee was created in 1899 to take charge of systematic gravity measurements in Tokyo and other cities in Japan in the years 1899–1901, and also to undertake a comparison of gravity between Tokyo and Potsdam. Nagaoka was the leader of this group. His teams further continued gravity measurements in various parts of Japan during the years 1901–08.[64]

In 1895, it was proposed to the International Association of Geodesy that, in order to make accurate observations of the variation of latitude which had been pointed out by K. F. Küstner in 1885, six collaborating latitude observatories, located at the same latitude, 39°8′N, and almost equally distant from each other on the globe, should be created. Mizusawa in northern Japan was to be one of the sites, and accordingly the Mizusawa International Latitude Observatory was set up by the Japanese government at the end of the year 1898 with Hisashi Kimura, an astronomy graduate of the University of Tokyo, as director.

The observational data from this observatory for the year 1900 showed considerable discrepancies as compared with European and American data. However, it turned out that this was not due to any lack of experience on the part of the Japanese scientists. On the contrary, Kimura realized that a new 'Z-term' (or 'Kimura term') needed to be introduced into the accepted formula for the variation of latitude. He published his

[59] T. C. Mendenhall, 'Publications of the Earthquake Investigation Committee—in Foreign Languages, Numbers 3 and 4: Tokyo—1900', *Science*, new series, 12 (1900), 678.

[60] *Nihon no Butsurigaku-shi* (footnote 39), I, 164–67, 179.

[61] The value they obtained was 979·82 cm/s^2 (cf. the presently accepted value, 979·763 cm/s^2). Their work was immediately criticized by J. Herschel (different from the famous J. F. W. Herschel); Ayrton and Perry responded, and eventually William Thomson settled the dispute. Ibid., p. 167.

[62] The values they obtained were 979·84 cm/s^2 and 978·86 cm/s^2 respectively. From these results, Mendenhall computed the mean density of the Earth at 5·77 g/cm^3 (cf. the presently accepted value of 5·52 g/cm^3). Ibid., pp. 167–168, and *Oyatoi Beikokujin Kagaku Kyōshi* (footnote 48), pp. 101–102.

[63] *Nihon no Butsurigaku-shi* (footnote 39), I, 168.

[64] Ibid., pp. 168–69.

paper in the *Astronomische Nachrichten* and also in the American *Astronomical Journal* in 1902, as well as in a Japanese periodical, and his discovery became recognized world-wide.[65]

The central institution for meteorological observation in Japan was the Tokyo Meteorological Observatory, founded in 1875 (renamed Chuo Meteorological Observatory in 1887). A German, Erwin Knipping, and the American, T. C. Mendenhall, each carried out systematic meteorological observations. Knipping and Jiro Kitao, a Japanese returnee from Germany, published theories of typhoons in 1888 and 1887–95 respectively. Takematsu Okada, a physics graduate of the University of Tokyo, published a theory of the Japanese rainy season in 1910.[66]

So far as laboratory research was concerned, the study of magnetism was a feature of the physical sciences in Japan at this period. J. A. Ewing, the above-mentioned British professor, was the discoverer of 'magnetic hysteresis'. He began his study of magnetism, so important for the development of electrotechnology, while in Japan, and this was taken up by two Japanese, Hantarō Nagaoka and Kōtarō Honda.[67] Both Nagaoka and Honda graduated from the University of Tokyo and afterwards went to Europe to study for several years. Nagaoka later became well known for his proposal of the Saturnian atomic model of 1903. Honda was to be highly successful in his work in physical metallurgy, particularly in producing new kinds of permanently magnetic steel.

The following statistics indicate the general trend of physical research in Japan in these early days. Between 1868 and 1894, during the course of their respective sojourns in Japan or soon afterwards, eleven Western science teachers (6 British, 2 American, 2 German and 1 French) published a total of 228 papers in physical science. Of these, 177 were on geophysical topics, including 113 on seismology (Milne 68, Ewing 14, Gray 8), 37 on meteorology (Knipping 27), and 22 on electricity (Ayrton 8, Perry 6).[68] As for the Japanese, 37 scientists (32 of whom were graduates of the University of Tokyo) between 1880 and 1907 published 337 papers in physical science, of which 122 were on magnetism, 26 on light, 26 on seismology, and 21 on gravity. A total of 77 dealt with geophysical topics.[69]

4. Australia and Japan

At one level, physicists in both Australia and Japan were quick to respond to new developments in physics in Europe. For example, when Hertz gave his famous experimental proof of the existence of electromagnetic waves in 1888, Hanichi Muraoka in Munich immediately sent a report to Japan, and Nagaoka tried the same experiment and reported on it. Experiments on electromagnetic waves and on wireless telegraphy ensued and were successfully carried on by Japanese physicists and electrical engineers. Meanwhile in Australia, Richard Threlfall discussed the implications of Hertz' work in a major address to the Australasian Association for the

[65] Ibid., pp. 170–71.

[66] Ibid., pp. 174–77. For the history of meteorology in Japan, see: Kishōchō (The Meteorological Agency), editor, *Kishō Hyakunen-shi* (Centenary History of Meteorology in Japan), 2 vols (Tokyo, 1975).

[67] *Nihon no Butsurigaku-shi* (footnote 39), I, 188–98. For biographical accounts of H. Nagaoka and K. Honda, see: *Dictionary of Scientific Biography* (New York), IX (1974), 606–607 and VI (1972), 479–80, respectively, and K. Itakura, T. Kimura and E. Yagi, *Nagaoka Hantarō Den* (A Biography of Hantarō Nagaoka) (Tokyo, 1973).

[68] *Nihon no Butsurigaku-shi* (footnote 39), I, 150, Chart 3-7-2.

[69] Ibid., pp. 152–53, Chart 3-7-3. *Note added in proof*—We now realize that these statistics are somewhat incomplete and so indicate general tendencies only.

Advancement of Science in January 1890, and even included a question about its theoretical aspects in his final-year examination paper in the previous year.[70] Again, the discovery of X-rays by W. C. Röntgen in 1895 was at once reported in the Australian press, and to Japan by Nagaoka who was at that time studying in Berlin. Both Japanese and Australian physicists repeated the experiments without delay. By 1897, X-ray equipment was readily available from Australian scientific supply houses, while an instrument-maker in Kyoto had started constructing and dealing in X-ray apparatus for teaching purposes.[71] Yet despite the interest aroused by novelties such as these, Australian and Japanese work seldom extended beyond successful repetitions of some of the more sensational experiments into active research that would further understanding of the phenomena in question. More generally, for a number of years physicists in both countries failed to become actively engaged in experimental research in the new 'atomic' physics. The outstanding exception here was Bragg's work on radioactive emanations.

Few became engaged, either, with questions of theory, and certainly no research 'schools' emerged in this area. In December 1903, Hantarō Nagaoka proposed his well known Saturnian model of the atom. His paper appeared in the following year in the *Memoirs* of the Tokyo Mathematico-Physical Society, *Nature* (in abstract), the *Philosophical Magazine*, and *Physikalische Zeitschrift*. His theory attracted the attention of some of the leading European physicists. It was, however, criticized by G. A. Schott of University College, Aberystwyth, and never became influential. In particular, though in other ways Nagaoka greatly influenced the development of Japanese physics, none of his compatriots took up and developed his theory of the atom.[72] In a very similar way, no Australian physicist took up William Sutherland's work on kinetic theory, despite its obvious importance.

In their emphasis on scientific studies, the higher educational institutions in both Australia and Japan were very much of a piece with the new universities of Britain and the United States, and rather different from the 'classical' European model. In Australia, physics was initially seen as a part of a modernized general course of study. Following the creation in the early 1880s of separate faculties of science in the various Australian universities, the teaching became more specialized, as it had been in the Japanese institutions of higher learning from the beginning. Yet most people who studied physics—very few of whom completed majors in the discipline—saw it as having a largely educational role, a necessary part of the training of doctors, engineers, and more 'practically' orientated scientists such as chemists, not as a discipline to be pursued in its own right. Only a few leading practitioners such as Threlfall cherished larger ambitions for their subject. In Japan, the increasingly strong German influence led physicists to see their subject, somewhat sooner than did most of their Australian counterparts, as something to be pursued for its own sake. Here too, however, the vast majority of those taking courses in physics did so not in order to become physicists but as part of their training for a career in some other field such as engineering or medicine.

In both countries, most of the laboratory research of the university professors of physics reflected a 'practical' view of the subject, for it bore upon one of the most

[70] Ibid., pp. 209–11. Threlfall, 'The Present State of Electrical Knowledge', *Report of the Second Meeting of the Australasian Association for the Advancement of Science, Melbourne, 1890*, pp. 27–54; also University of Sydney, *Calendar*, 1889, p. cxliv.

[71] *Nihon no Butsurigaku-shi* (footnote 39), I, 211–13; Hugh Hamersley, 'Radiation Science and Australian Medicine, 1896–1914', *Historical Records of Austrlian Science*, 5(3) (1982), 41–63.

[72] *Nihon no Butsurigaku-shi* (footnote 39), I, 214–22, 231–32.

exciting engineering developments of the age, the generation and transmission of electric power by means of alternating currents. Systematic geophysical observing—of weather patterns, the Earth's magnetic and gravitational fields and, in Japan, earthquakes—was the other major preoccupation in these scientifically little explored lands. Often, and especially in Australia, this work was done at the local observatory rather than at the university. By comparison, the 'new' physics of X-rays, radioactivity, and the quantum theory, the cultivation of which was, along with the development of work on standards and precision measurement, beginning to give physics a disciplinary identity of its own, was not, with one or two exceptions, pursued in concentrated fashion by Australian and Japanese physicists, whether in university or observatory.

In Japan, this emphasis on 'relevant' laboratory research was undoubtedly at least partly a reflection of the highly practical aims of the entire Westernization process. In both countries, however, a further explanation also suggests itself; namely, that there may have been a tendency—perhaps largely unconscious—to leave the more rapidly moving areas of physics research to those who were closer to the centre of things. We know that when W. H. Bragg in Adelaide did eventually take up research on radioactivity, he was acutely aware of the delays in communication due to his distance from Europe, and fearful that the work he was reporting might have already been done by others, without his being aware of it. Similar fears may have deterred others altogether from taking up such questions. It is difficult, however, to draw meaningful generalizations here, because the number of individuals involved is so small that idiosyncratic personal choices dominate events. Yet, at the very least, what happened in Australia and Japan does serve to remind us that developments in physics at this time were by no means confined to those areas of 'modern' physics research upon which physics texts and historians' discussions alike have since tended to concentrate. A great deal of solid and sometimes very challenging work continued to be done throughout our period in other fields of physical investigation such as geophysics and electricity and magnetism; and it was these other fields that dominated physics 'on the periphery'.

We also find a lack of impact, initially, of either quantum theory or the theory of relativity in both countries (with the exception, in Japan, of the work of the young Jun Ishiwara on relativity). This highlights a different point that we suspect may also have applied more generally to the physics discipline on the periphery at this time, especially in those parts of the world where British influences predominated. We refer here to the heavily experimental orientation of the work done, and the generally low level of engagement with questions of theory. This is particularly evident in the Australian case, despite the outstanding exception of William Sutherland. There, the creation of separate chairs of physics in the 1880s seems to have institutionalized a separation between experimental work, clearly the responsibility of the physics professor, and theory which, in so far as it was pursued at all, was pursued by the mathematics professor. Physics tended to be seen, as it was at the Cavendish Laboratory under Maxwell and Rayleigh, as the science of precision measurement. A somewhat similar situation prevailed in Japan, despite the creation of a chair of theoretical physics at the University of Tokyo in 1901. The disciplinary distinction that this development implies was not the thorough-going one that was being institutionalized in Germany at this period. It extended only to teaching, the incumbent of the new chair being expected to teach the more mathematical aspects of classical physics. To be sure, Nagaoka, who was appointed to it, had trained in Germany and is chiefly remembered today for an excursion into the realm of physical theory. Even he, however, spent most of his research time on experimental work.

We have indicated that the relative lack of engagement with theory may merely reflect a somewhat British view of the subject. However, a low level of theoretical activity has also been identified by Basalla and others as characteristic of 'colonial' scientific communities more generally.[73] In another respect, too, it seems that this terminology, originally developed in the context of sciences such as botany, zoology, and mineralogy, may also be applied to the practice of physics in countries such as Australia and Japan in our period. Here, we have in mind the heavy emphasis on questions of observational geophysics that has been referred to already. This was, of course, perfectly legitimate scientific work, and it is natural that it should have been taken up at an early date. It was also, however, work that could *only* be done locally, and it therefore may have served to furnish those engaging in it with the same sense of intellectual security that Donald Fleming attributes to colonial naturalists studying materials peculiar to their local environment.[74] Here, their claims to authority were unassailable, whereas in matters of general experimental physics they were in competition with physicists from all parts of the world. Yet from another point of view it seems paradoxical to regard working in these fields as signifying a 'colonial' scientific outlook, since it was precisely in these fields—as demonstrated, for example, by the case of seismology in Japan—that these countries on the periphery were eventually able for the first time to shed their colonial scientific status and attain an independent scientific standing. What is striking about the early stages of physics in Australia and Japan is not the fact that location-specific observational work was done, but the extent to which the subject was dominated by work of this kind; and it is this dominance—which of course implies a relative paucity of general laboratory-based research—that warrants the use of the label 'colonial' in this context.

So far, then, as the subject-matter and general perception of the discipline was concerned, the pattern of development was similar in Australia and Japan. At the level of practice, physics, it appears, amounted to very much the same thing in the two countries in the early phase of its development. Where differences emerge, such as in the emphasis in Japan on seismological work, specific local conditions provide an obvious explanation.

At a deeper level, however, important culturally-derived differences remained. Though the practice of physics was transferred to Japan quickly and effectively, most Japanese scientists and, indeed, most of those involved in the Westernization of Japan, did not quite realize how deeply these disciplines were rooted in Western culture. Consequently, although they were eager to introduce the bulk of the new scientific knowledge, they did not pay much attention to how this could be adapted to their own cultural environment. The frequently used phrase, *wakon-yōsai* ('Japanese spirit and Western know-how') well represents the basic attitude of the Japanese intellectuals of the time.

In both countries, physics was introduced primarily at government institutions (centralized, in Japan, under a national authority). However, in contrast to what happened in Australia, in Japan scientific activity was promoted as part of a national project spurred on by immediate national needs. Science was eagerly pursued, but, as just pointed out, not as a part of Western culture. Creative thinking was not very much

[73] George Basalla, 'The Spread of Western Science', *Science*, 156 (1967), 611–27.

[74] Donald Fleming, 'Science in Australia, Canada and the United States: Some Comparative Remarks', *Proceedings of the Xth International Congress of the History of Science, Ithaca, 1962* (Paris, 1964), pp. 179–96.

cultivated. Japanese scientists who attained to the first rank generally produced their best results either during their period of study in the West or soon afterwards.

We also wish to point to important similarities in the institutional structures that emerged in the two countries, similarities that were, we suspect, also a feature of the physics discipline in many other parts of the world as well. Granted, leading physicists in both countries saw their discipline as something to be pursued for its own sake. Nevertheless, in practice, it functioned chiefly at the educational level, as a service subject for students seeking careers in other fields. Only very small numbers of people sought to take up physics as a career. Very few openings appeared for specialist physicists during the period discussed here, virtually all those that did being university or observatory positions. In Australia, science teaching at a secondary or technical school was the only alternative area of employment that utilized a university training in physics. In Japan, too, teaching was the principal avenue of employment, but some physics graduates also found jobs in government or in the military.

In Australia, the paucity of physicists was exacerbated by the fact that those few were scattered among several widely separated population centres. No such problem existed in Japan where, even after the establishment of Kyoto University, most physics activity was centralized in Tokyo. In Australia, there was never, during our period, a sufficient number of physicists in any one centre to sustain a local physics society, and as a result the roughly annual meetings of the inter-colonial Australasian Association for the Advancement of Science (founded in 1888) assumed a particular importance. In Japan, however, the Tokyo-based Mathematico-Physical Society was able to function as a viable *de facto* national society.

In Japan, American and French influences were felt at the beginning, and there were also continuing links with Germany that became stronger with the years. In both countries, however, the greatest influence in physics in the early stage of its establishment was British, and in Australia it remained so. Yet the nature of the relationship with British physics differed profoundly from one case to the other. Though numbers of Japanese students went to Britain for their advanced training, they always remained Japanese and were constantly aware that they were there solely to help modernize their country. There was never any doubt that in due course they would return to Japan. Contrariwise, when British physicists took up positions in Japanese institutions, no matter how warmly they were received, they always remained foreigners, and were always regarded as but high-salaried temporary employees necessary for the creation of a modern Japan. In Australia, on the other hand, imported British professors of physics were in most respects indistinguishable from the thousands of other recent immigrants from Britain, or their immediate descendants, who made up the bulk of the white population. Furthermore, when Australian students went to Britain, they at once merged with the local population. For most Britons and most Australians of the time, Australians *were* British; they simply lived further out of ear-shot of Bow-bells than most of their fellow citizens. It was therefore seen as just as 'natural' for a Briton from Australia as it was for one from, say, Yorkshire, to be appointed to a physics post in a British university, provided only that he was sufficiently talented and had received the necessary advanced training. It also made it perfectly natural for a British physicst, once appointed to a position in an Australian university, to retain it for many years, or even for life. Whereas the Australian appointments were always open-ended, the foreign professors who were brought to Japan invariably were appointed for a limited term only, and were expected to leave once they had served out their contracts.

However, the very closeness of the relationship between British and Australian physics, though it undoubtedly brought many advantages for Australia, in the long run held Australian physics in a state of dependency on Britain for much longer than might otherwise have been the case. In particular, it made it all too easy for bright young Australians who went to Britain for their advanced training to remain there. There was throughout our period—and indeed for very much longer—a constant siphoning off of much of the best Australian talent in physics to Britain. By contrast, Japan's political and cultural independence prevented a similar state of dependency persisting in her case. So, too, did the fact that Japan had a language of her own, for this made the development of a local scientific publishing network essential. In Australia, with English as the national language, it was all too tempting to remain dependent on British scientific journals and publishing houses.

Thus we observe, in both Australia and Japan, an educationally and experimentally orientated physics, overlaid with a significant amount of geophysical observing, being introduced at almost exactly the same period, in the 1870s and 1880s, in very much the same way. This was done by importing a number of foreign physics teachers into newly-established science teaching programmes in the infant universities. In each case the principal influence was initially British. The science was equally new to both cultural environments, as indeed it was in Britain and America at this same period under its new guise as the science of precision measurement. In Australia it was accepted simply as a part of the larger inheritance from Britain; in Japan it was introduced as part of a deliberately adopted Westernizing policy. For a time, the practical effects were the same in the two cases. In addition to geophysical observations, such research as was undertaken was chiefly in the field of electricity and magnetism, often in relation to contemporary problems of electrical communication and power transmission. Though the universities soon began offering advanced as well as undergraduate training, both countries continued to send numbers of their brightest students overseas, to Europe, for their advanced work. Whereas the Japanese students invariably returned to Japan, however, many of the Australians did not, to the permanent impoverishment of the Australian physics community. Hence, though in both countries the numbers of practising physicists remained very low and the science they did thus unable to achieve the depth and continuity necessary to establish an independent status of its own, the Japanese community of physicists nevertheless grew steadily in strength and independence, whereas its Australian equivalent remained marginal for much longer within a larger imperial scientific culture. Questions of political dependence or independence thus had profound consequences, even for the development of such an apparently apolitical subject as physics appeared to be in the decades prior to World War I.

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