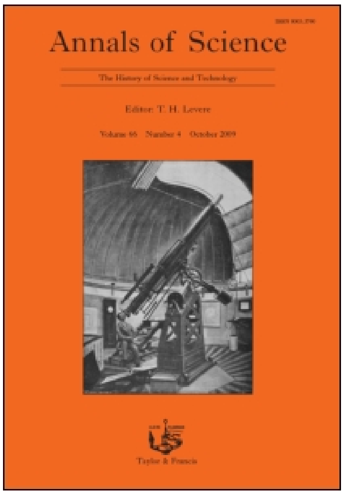

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Forming new physics communities: Australia and Japan, 1914-1950

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Forming New Physics Communities: Australia and Japan, 1914–1950

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Summary

In 1914, the physics discipline had reached a very similar stage of development in Australia and Japan. A generation later the paths of development had considerably diverged. A systematic comparison of the evolution of physics in the two countries during these years identifies factors—political, economic and cultural—that led to this divergence, but it also uncovers a number of underlying parallels.

Contents

1. Introduction

In a previous publication,[1] we described the process by which the science of physics became established in Australia and Japan during the final quarter of the nineteenth and the first years of the twentieth century. We argued that, despite the great cultural differences between the two countries—one a widely dispersed European settler community that had simply swept the original native inhabitants from their land, the other a densely populated nation with a strong indigenous culture that differed profoundly from the European one—there were important similarities in the patterns of development of physics in the two cases. We pointed out that, because physics was first established in the two countries at precisely the same period, the discipline being transferred was in principle the same. Hence the similarities in the patterns of historical development that emerged from our analysis could with some confidence be attributed to certain general features of the physics discipline at this period. On the other hand, features of the history of science characteristic to each country, but not otherwise easily recognizable, were brought to the fore by our making the comparison we did. Many of the differences that emerged appeared to derive not so much from underlying differences in culture as from straightforward political circumstances and, in particular, from the fact that Australia was a subsidiary unit within the British Empire while Japan was an independent nation-state.

[1] R. W. Home and Masao Watanabe, 'Physics in Australia and Japan to 1914: A Comparison', *Annals of Science*, 44 (1987), 215–35, and 'Errata', ibid., 45 (1988), 446.

As the end point of our study, we took the year 1914 and the outbreak of the First World War. It was at that point, we felt, or soon thereafter, that the historical paths we were tracing began to diverge noticeably. Here, we carry the study forward in time and try to identify the factors that brought this about. We believe that, as before, a comparison between the two countries casts their separate developments in a new and interesting light, and at the same time illuminates various general features of the history of the physics discipline in the twentieth century that do not always receive sufficient attention.

In 1914, in both countries, the number of practising physicists remained very small. This directly reflected the public perception of the discipline and its actual role in public affairs and the economy. Physics continued to be seen, except by a few leading practitioners, as a subject having its chief importance in the educational realm. Most physics graduates working in both Australia and Japan continued to be employed as teachers in universities or technical colleges, or in secondary schools. In Australia, in the years following the establishment in the 1850s of the first universities, even the educational role ascribed to the subject was confined initially to the general curriculum, it being seen as a necessary part of the education of a gentleman that he acquire some understanding of the physical workings of the world. In Japan, however, from the very beginning of westernization in the early 1870s, and increasingly in Australia from the mid-1880s, physics acquired a more utilitarian image as an ingredient essential to the training of engineers and doctors and of scientists of a more 'practical' kind such as chemists. Most Japanese, in fact, saw Western science, including physics, in a wholly utilitarian light and failed to recognize that it was part of a wider, Western culture very different from their own. As a result, creative scientific thinking was not much cultivated in Japan. In both countries, the best of those few students who decided to concentrate on physics went to Europe for their advanced training. Many of the Australians who did so subsequently found positions in Britain or in other parts of the British Empire and were thus permanently lost to the Australian scientific community. Japanese students, however, invariably returned home at the conclusion of their studies, carrying their new-found skills with them. A few physics graduates found work in observatories, whether astronomical or geophysical, and in Japan a few more found employment in government or in the military; but in neither country was there a significant demand for physicists as such. Some of those employed at the universities engaged in research, and so too did some observatory staff. Those who did invariably sent their best work to Europe for publication, but, in Japan, a local, Japanese-language publishing network was also established, employing a newly developed Japanese scientific vocabulary. Geophysical investigations predominated in both countries, together with research in electricity and magnetism, much of the latter being directed towards questions of relevance to the then newly emerging electrical power industry. There was a heavy emphasis on the experimental aspects of physics and correspondingly little development of theoretical physics after the German pattern. Neither quantum theory nor relativity theory had much impact at first, though the latter did attract a small group of enthusiasts in Japan.[2] That it found even that level of support

[2] In our previous paper, in which we mentioned only the work of the young Jun Ishiwara, we significantly underestimated the extent of Japanese interest in relativity theory. Others who published on this subject at an early stage were Toshinojō Mizuno, Kajūrō Tamaki, Ayao Kuwaki and Kinnosuke Ogura. See Maurice Lecat, *Bibliographie de la relativité* (Brussels, 1924), and Tsutomu Kaneko, 'Einstein's Impact on Japanese Intellectuals', in *The Comparative Reception of Relativity*, edited by Thomas F. Glick (Dordrecht, 1987), pp. 351–79.

reflected strengthening links between Japanese and German scientists that were steadily displacing the earlier British domination of Japanese science. In Australia, however, British science was to remain paramount for several decades yet.

By the 1950s, the situation was very different. In Australia, despite a period of excitement and growth during the Second World War and afterwards, the physics community remained small and for the most part scattered, and could still to a large extent be seen as an offshoot of the much larger British community. Theory remained weak. One major experimental research group had, however, emerged from the wartime activity, in the rapidly advancing field of radio astronomy in which the Australians for a time led the world, while the foundations of a strong optical astronomy group had also been laid. Yet most Australian physics research remained fairly humdrum. Moreover, compared with Japan, very little Australian research was concerned with applications, even in the field of radio where Australia had by this time also built up a significant amount of physics-based manufacturing industry. Generally speaking, that is to say, in Australia physics remained an academic concern of a relatively small number of individuals, devoted to the pursuit of abstract knowledge.

In Japan, however, while abstract investigations were by no means neglected and indeed perhaps constituted, in the work of the Nobel prize-winners Hideki Yukawa and Shinichirō Tomonaga, the country's greatest contributions to science, a much greater fraction of the total scientific effort in physics was by then being directed by a rapidly increasing army of workers towards practical ends. Before and during the Second World War, the Japanese physics community expanded in response to the demands of a government dominated by military interests. The débâcle of 1945 not only left Japanese industry in ruins, it saw the destruction by the occupation forces of prime research facilities, above all the cyclotrons developed for nuclear physics research by Yoshio Nishina and his group. Yet within a few years, Japanese physics had become an industrialized laboratory pursuit,[3] underpinning major physics-based manufacturing enterprises and contributing significantly to the so-called 'Japanese economic miracle'. Such a rapid recovery and indeed expansion of activity bespeaks an underlying strength in the Japanese physics community such as had certainly not yet been developed in 1914. A principal aim of the present investigation is to identify, through our comparative approach, the chief factors leading to the building up of this strength during the intervening period. At the same time, our comparison brings out some persistent weaknesses in Japanese physics that had still to be overcome at the end of the period covered by our enquiry. We do not restrict the discussion to physics at the research level, because we are convinced that the strength of a research physics community in the modern world is closely linked to the existence of a strong employment base for low-level, run-of-the-mill applied physics.

2. Australia

In the latter years of the nineteenth century, the astronomical observatories in Melbourne, Sydney, and Adelaide (and, from 1896, Perth) were probably Australia's most powerful and prestigious scientific institutions. Their work included a substantial amount of practically orientated geophysical observing. Meteorology, in particular, loomed large among their responsibilities, to the point where it frequently overshadowed more traditional astronomical work. Those involved made a number of useful advances in instrumentation, their handling of data was sophisticated and up-to-date,

[3] See J. R. Ravetz, *Scientific Knowledge and Its Social Problems*, chapter 2.

and they achieved the first clear picture of the overall weather patterns of much of eastern Australia. Pendulums were swung in the 1890s to determine the gravitational acceleration, *g*, in various locations. Geomagnetic recording also loomed large, especially at Melbourne where the elements of the Earth's field had been systematically recorded since the late 1850s. Little seismological work was done, however, in comparison with what was being done in geologically active Japan. Indeed, even in the twentieth century, systematic seismological observing was for many years left to a small privately-run observatory maintained by the Jesuits at their Sydney college, Riverview. Only in recent years has a network of recording stations been established, as part of the world-wide system that has been set up to detect underground nuclear explosions.

The new century saw a sharp decline in the fortunes of the colonial observatories, as they lost two of the major functions that had traditionally been used to justify their existence. On the one hand, in conjunction with the federation in 1900 of the six previously separate Australian colonies, the traditional observatory function of providing a local time service gave way to a unified national time service supplied by a single observatory, Melbourne, and disseminated by the intercolonial telegraph (or, later, radio) network. Secondly, in 1907 the meteorological responsibilities of the observatories were transferred to the newly created Commonwealth Bureau of Meteorology. Encroaching city lights made serious astronomical research increasingly difficult, while in Melbourne the electrification of nearby tramway routes led to the relocation in 1919 of the Observatory's magnetometers to a new site remote from both city and Observatory.

Australia's earlier, active programme of geophysical research did not survive these developments. In particular, the new Commonwealth meteorological service, in sharp contrast to its predecessor institutions, largely confined itself to routine recording work. To be sure, a small research division was created in 1921 and flourished briefly under its first director, Edward Kidson.[4] When he left in 1927, however, to become director of New Zealand's meteorological service, Australian research in this field sharply declined. So far as geomagnetic research was concerned, Melbourne's magnetometers, converted in the 1860s to automatic recording, continued to amass data, but staff reductions resulted in a loss of expertise and an ever-increasing backlog of unprocessed records. By the 1910s, the Observatory had to look for assistance in recalibrating its instruments to visiting staff from an American institution, the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The Carnegie Institution, a private research organization with a major commitment to the study of the Earth's magnetic field, conducted extensive field surveys in Australia in the 1910s, and then in 1919 established a fully equipped geomagnetic observatory at Watheroo, Western Australia, that regularly transmitted data to Washington for analysis until 1947, when the entire facility was handed over to the Australian government.

The decline of the old colonial observatories and their programmes of geophysical research was not compensated for by any marked expansion of laboratory-based physics. Here, the universities continued to dominate the scene; but the universities, one in each State capital, remained tiny institutions committed overwhelmingly to undergraduate teaching. Within the university curriculum, physics retained its image as a 'service' subject rather than a discipline to be studied in its own right, and research continued to be seen more as the hobby of the professor—if he had time and the inclination for it—than as an essential part of the life of a university department.

[4] *Edward Kidson*, compiled by Isobel Kidson (Christchurch, no date given [1941?]).

Indeed, during the First World War, physics research ceased almost entirely. Physics was not a reserved or even a recognized occupation,[5] and both staff—including the professor of physics at Sydney and the lecturer-in-charge at Queensland—and students enlisted for military service in large numbers, along with fellow Australians from all walks of life. Those who remained behind struggled to maintain a teaching programme of any kind, being assisted, at least in the larger institutions of Sydney and Melbourne, by young female graduates employed on a temporary basis until the men who had enlisted returned.

In Japan, industrialization was rapidly proceeding at this period and was given a further boost by the war; and though physics as yet had little direct input into manufacturing, the discipline indirectly profited as the expansion of industry generated a demand for more and more engineers to whose training a considerable exposure to undergraduate-level physics was deemed essential. Not so, however, in Australia. There, the economy continued to be dominated by agriculture and mining, industrialization had proceeded no further than the development of light manufacturing to supply the small local market for clothing, fabricated goods and the like, and the vast majority of the much smaller number of engineers being trained found employment not in manufacturing but in government or semi-government agencies such as the railway, highway, sewerage and water authorities.[6] To be sure, the war brought home to Australia's leaders the fragility of the nation's lines of communication with its traditional suppliers of manufactured goods and led them to encourage the growth of secondary industry including, in 1916, the establishment of the nation's first steel works. For many years after that, however, Australian manufacturing industry remained small-scale and for the most part technically unsophisticated. It was a constant complaint, for example, of the Defence Department's Munitions Supply Board throughout the inter-war period that Australia's manufacturers were unable to supply orders reliably to specification.[7]

Such an environment did nothing to stimulate an increased demand for undergraduate physics teaching, let alone for fully-fledged physicists. In consequence, the number of lecturing staff employed by the universities, and hence the pool of potential university-based research workers, remained miniscule. A brief surge in enrolments with the return of the troops at the end of the First World War was reflected in a rise in the number of lecturing staff, but by the mid-1920s the wave had passed, and staff numbers had declined again—though never quite to pre-war levels. Graduate student numbers likewise remained very low, though not quite as low as prior to the war. Moreover, the highest qualification available remained the Master's degree, so that the best students still found it necessary to go elsewhere—inevitably, to Britain—for their advanced training. The pattern continued to be that a student would do a year (or perhaps two) of research after completing the Bachelor's degree and then either win a scholarship and go to Britain, or abandon research and seek employment.

As to employment, the 1920s and 1930s saw an appreciable though very slow increase in the number and range of jobs available in Australia to people with

[5] Russell Moseley has noted that in Britain during the First World War, the title 'physicist' did not officially exist, and that physicists wishing to register in the government service had to do so under the category of 'chemist'; Moseley, 'Tadpoles and Frogs: Some Aspects of the Professionalization of British Physics, 1870–1939', *Social Studies of Science*, 7 (1977), 423–46 (p. 434).

[6] B. E. Lloyd, 'In Search of Identity: Engineering in Australia, 1788–1988' (Ph.D. dissertation, University of Melbourne, 1988), chapter 5.

[7] A. T. Ross, 'The Politics of Secondary Industry Research in Australia, 1926–1939', *Historical Records of Australian Science*, 7, part 4 (1989), 373–92.

qualifications in physics. This was in due course reflected in the number of people seeking to complete degrees in physics and, eventually, in the number of people employed in university physics departments to teach them.

At first, most of the expansion occurred in Melbourne, which following federation in 1900 functioned as temporary national capital until the opening of the new capital, Canberra, in 1927. Melbourne was thus where various science-orientated government departments established their headquarters and, eventually, their laboratories. It was in Melbourne that the Commonwealth Meteorological Bureau, for example, established both its main office and its research division. So, too, did the Postmaster General's Department where the laboratory, founded in 1925, was devoted to telephone and later also radio technology.[8] The Defence Department likewise established its Munitions Supply Laboratories (MSL) in Melbourne, at Maribyrnong, and equipped them with, among other things, a basic set of physical measurement standards. In the absence of a fully-fledged national standards laboratory, MSL quickly became the nation's *de facto* reference centre for metrological purposes, and an occasional employer of physicists. Again, when the Commonwealth government decided in 1927 to purchase a large quantity of radium for medical purposes and in due course established the Commonwealth Radium Laboratory (later the Commonwealth X-Ray and Radium Laboratory) to manage it, this laboratory too was set up in Melbourne, in the grounds of the University.[9] Finally, when an Australian Radio Research Board was set up in 1926 under the newly constituted national science research organization, the Council for Scientific and Industrial Research (CSIR), it established one of its two research groups in Melbourne, within the University's Department of Natural Philosophy.[10] To be sure, none of these laboratories employed a large scientific staff. Nevertheless, their concentration in Melbourne was so marked that to physicists elsewhere in the country, the city's long-term dominance of the field seemed assured. A. D. Ross, for example, the professor at the University of Western Australia, busily organizing, at this time, an Australian branch of the London-based Institute of Physics, was convinced that 'the majority of the Corporate Members is likely to be always in Victoria'.[11]

The presence of the government laboratories was not the only basis for Melbourne's pre-eminence within Australian physics during the 1920s. In addition, its observatory remained, despite its problems, by far the best equipped in the country, while the University's Department of Natural Philosophy under its new professor, Thomas Howell Laby, offered a more specialized and research-orientated training for its students than did sister departments elsewhere.

Laby had been an early Australian recipient of an 1851 Exhibition science research scholarship. This had enabled him to spend several years, 1905–1909, as a research student under J. J. Thomson at the Cavendish Laboratory in Cambridge, where he had become immersed in the leading problem of early twentieth-century experimental physics, the study of the new ionizing radiations and the ionization they produced. He had also begun the collaboration with the British physicist G. W. C. Kaye that led to the publication in 1911 of the first of many editions of the well known Kaye and Laby *Tables of Physical and Chemical Constants and some related Mathematical Functions.*

[8] Ann Moyal, *Clear across Australia: A History of Telecommunications* (Melbourne, 1984), p. 125.
[9] J. F. Richardson, *The Australian Radiation Laboratory: A Concise History, 1929–1979* (Canberra, 1981).
[10] W. F. Evans, *History of the Radio Research Board, 1926–1945* (Melbourne, 1973).
[11] Ross to E. Kidson, 25 June 1926; Australian Institute of Physics (AIP) files, Basser Library, Australian Academy of Science, Box 86/13.

Laby's research interests carried the Melbourne department in the 1920s into what were, for it, quite new directions, especially into work on X-rays, on precision measurement, and later on the propagation of radio waves in the atmosphere. To all these areas he brought a spirit of critical exactitude that earned for the work of the department international respect and a reputation as (in Mark Oliphant's words) 'the only worthwhile school of physics in the Dominions'.[12]

The extent to which Laby emphasized research in the training of physicists was new to Australia, and he encouraged his gradually expanding lecturing staff, too, to keep up their research. Several of the latter group were former students of his who had subsequently spent some time at the Cavendish Laboratory. Extraordinarily close links developed, in fact, between Laby's department and the Cavendish—now under Ernest Rutherford's direction—during this period. Laby and Rutherford had come to know each other towards the end of Laby's own period at the Cavendish, and through the years their acquaintance ripened into warm friendship. The two men corresponded regularly,[13] and whenever Laby visited England—which he did regularly—he and his family stayed with the Rutherfords. Likewise, Rutherford stayed with the Labys when he visited Melbourne. The emphasis on research in Laby's department left his students exceptionally well placed in the competition for 1851 Exhibition scholarships, and no fewer than twelve of them gained the award during the inter-war period. All went to the Cavendish, as did several other Melbourne students (including Laby's favourite, H. S. W. Massey) on other scholarships. Rutherford trusted Laby's judgement and always found a place in his laboratory for any student he recommended. Laby, for his part, was careful to recommend only those students in whom he had complete confidence: the others had to rest content with such experience as they could acquire in Australia. When it came to filling a lectureship, a Cavendish man would always be preferred, and Laby relied heavily on Rutherford's advice in making his choice.

Nor was Laby's department alone, either in sending its best students to the Cavendish Laboratory or in looking first to Cambridge when it came to recruiting new lecturing staff. The same pattern prevailed in all the other physics departments in the country. Only the number of students involved and the closeness of Laby's personal links with Rutherford were exceptional.

As had been the case before the First World War, however, by no means all the students who went to England subsequently returned to Australia. It continued to be the case that many of those who went away stayed away. Well regarded Laby's department may have been, but it, like the new government laboratories, remained small and its sister departments in the other universities even smaller. Vacancies did not appear very often, and many of the students who went away found at the completion of their courses in Britain that there were no jobs at all open in Australia for physicists. Though many were keen to return home, they found themselves forced to take up positions in Britain instead—something which, as citizens of the Empire, they had no difficulty in doing—and so were lost, in many cases permanently, to their native land. The drain of young physics talent to Britain that had set in prior to the First World War considerably increased in the years between the wars.

The strength of the link with Britain and its almost exclusive focus on the Cavendish Laboratory had a further consequence for Australian physics in so far as it dictated the

[12] M. L. E. Oliphant to Mrs. B. Laby, 24 June 1946; Laby papers, University of Melbourne Archives.

[13] Rutherford's contribution to the correspondence, together with drafts of some of Laby's letters to him, are preserved among Laby's papers, University of Melbourne Archives.

image the discipline was to take in Australia for at least two generations. Physics, as practised in Australia at this period, was an almost exclusively experimental science working very much in the 'string and sealing wax' mould for which the Cavendish under J. J. Thomson and later Rutherford became notorious. To be sure, this in part merely reflected the chronic shortage of research funds available to Australian physicists at the time; but there was also a tendency to make a virtue out of necessity and maintain that better funding did not guarantee better physics, and that the best physics of all used relatively simple and inexpensive apparatus in clever ways to produce fundamental new insights into the workings of nature.

At the same time, little research was done of a theoretical kind, and such as was done emerged from university departments of mathematics, not physics, and would usually have been better described as research in applied mathematics than as research in physics. There was no public discussion of the theory of relativity in Australia until 1921, when a session was devoted to the subject at the first post-war congress of the Australasian Association for the Advancement of Science. This was sparked by A. S. Eddington's widely publicized announcement late in 1919 that observations taken at St Helena during an eclipse of the Sun had confirmed Einstein's prediction of the gravitational deflection of light rays, and was fuelled by the knowledge that several major expeditions were being planned to remote regions of the Australian outback to repeat the observations during another total solar eclipse that was to be visible there in September 1922.[14] However, in 1921 and subsequently, Australian discussions of relativity, such as they were, were dominated by mathematicians and not always adequately informed philosophers.

The appearance of the new quantum mechanics prompted an informal seminar on the subject at the University of Melbourne in 1927. The meetings were organized by a member of the mathematics department, Maurice Belz, but a number of physicists attended including two upper-level students, H. S. W. Massey and C. B. O. Mohr, who subsequently pursued quantum mechanical themes in their Master's dissertations. The seminar itself, however, lasted less than a term.[15] A session was devoted to quantum mechanics at a conference of Australian physicists—the first such conference to be held—at Canberra in August 1928. The discussion was introduced by Massey and Mrs. G. H. Briggs, a Sydney-trained physicist who with her husband, a lecturer in physics at the University of Sydney, had returned to Australia not long before after spending an extended period in Cambridge, but who thereafter reverted to being a housewife.[16] At a second conference, held in Melbourne twelve months later, only Massey and Mohr contributed papers on quantum mechanical topics.[17] Thereafter, however, both men proceeded to the Cavendish, taking their interest in the new ideas with them, and active interest in the subject in Australia seems to have evaporated. During the 1930s some university-based physicists and physical chemists found they had to master new quantum mechanical algorithms—for example, Pauling's theory of molecular orbitals—that came to drive experimental inquiry in their particular fields of research,

[14] *Report of the AAAS* (Melbourne, 1921), pp. 1–18, 357; Jeffrey Crelinsten, 'William Wallace Campbell and the 'Einstein Problem': an Observational Astronomer Confronts the Theory of Relativity', *Historical Studies in the Physical Sciences*, 14 (1983), 1–91 (pp. 61 ff.).

[15] Information about the seminar comes from an interview with C. B. O. Mohr, 7 March 1980.

[16] *Conference of Australian Physicists, Canberra. 15th to 18th August, 1928: Proceedings and Abstracts of Papers*; AIP files (loc. cit. footnote 11).

[17] *Conference of Australian Physicists, Melbourne, 20th to 23rd August, 1929: Proceedings and Abstracts of Papers*; AIP files (loc. cit.).

and once or twice a set of lectures was offered by the local mathematics department to help them do so.[18] However, not until Mohr returned to Australia in 1947, to a position at the University of Melbourne, did an Australian university physics department offer formal courses in quantum mechanics or initiate a programme of theoretical research in this area.

The only area in which Australian physics achieved international standing in the period between the wars was radio research. As noted earlier, an Australian Radio Research Board was founded in 1926. This set up research groups at the universities in Melbourne and Sydney with funding from the federal government, chiefly through the Post Office, in recognition of the potential importance of radio as a means of communication in such a huge but sparsely populated country. The Melbourne group focused on signal interference ('atmospherics'), those in Sydney took up the study of the ionosphere; and the latter group, in particular, soon made important contributions to understanding. Graduate students from the two host departments were recruited into the research programme in significant numbers, while the emergence of a local electronics manufacturing industry, spearheaded by the partly government-owned Amalgamated Wireless Australasia Proprietary Limited (AWA), created new employment opportunities for physicists and radio engineers. By 1939, Australia had built up a pool of advanced technical expertise in this area and was making significant contributions at the research level.

These developments in radio science apart, however, Australian physics had in fact gained remarkably little in strength since the early years of the century. Largely confined to undergraduate teaching in tiny and impoverished universities hundreds of kilometres apart that had themselves lost much of the impetus they had once seemed to be developing, the discipline had not yet found a role for itself in an economy dominated by the production of wool and wheat. Physics research was a luxury in which few were able to indulge in any systematic way, and an alarmingly high fraction of the brightest young talent continued to be lost to Britain. The discipline was not even represented on the nation's Council for Scientific and Industrial Research, the research activities of which had been largely concentrated on the needs of the rural sector. The various physics-related government laboratories that had been set up, though potentially of great significance for the growth of the discipline, as yet employed only a handful of physicists between them. The low level of manufacturing meant that, outside the radio industry, there were few if any jobs available in applied physics or physics-related engineering technology; and with only a small proportion of the population proceeding to the final years of secondary schooling, there were not many schoolteaching jobs open for physics graduates, either. In 1939, when the first national organization for physicists was formally constituted—characteristically, an Australian Branch of the London-based Institute of Physics—it could boast only fifty-five 'corporate' members (that is, professionally qualified physicists as distinct from students and interested members of the general public) in the whole country (see Table 1).

The year 1939 in fact marked the turning point for physics in Australia. Some time before, the government had at last concluded that the rural industries on which the nation's economy was based could no longer be expected to provide sufficient employment for the population. Building up the manufacturing sector seemed the only alternative, one that would at the same time provide useful insurance should war come—something that appeared increasingly likely—and leave Australia again cut off

[18] Interview with H. C. Corben, 27 February 1989.

Table 1. Number of Australian corporate members of the Institute of Physics.

Year	Number	Year	Number
1923	3	1937	?
1924	7	1938	?
1925	?	1939	55
1926	17	1940	70
1927	18	1941	82
1928	?	1942	83
1929	18	1943	115
1930	?	1944	134
1931	?	1945	137
1932	21	1946	143
1933	30	1947	158
1934	21	1948	197
1935	?	1949	204
1936	30	1950	246†

† Includes new membership grade of 'Graduate'.

from its traditional sources of manufactured goods. The decision was made to extend the work of CSIR into research in support of secondary as well as primary industry. As a result, significant numbers of new employment possibilities at last opened up for the nation's physicists, in a National Standards Laboratory to which the first appointments were made early in 1939, and an Aeronautical Research Laboratory intended to provide scientific back-up for planned new aircraft and automobile manufacturing industries. Later in the same year, a secret Radiophysics Laboratory was set up within CSIR to undertake co-ordinated research with British scientists on what came to be known as radar, and also a Lubricants and Bearings Section was created that undertook a considerable amount of research on friction and the physics of surfaces in connection with the manufacture of aero-engines.

During the war years, these new laboratories expanded dramatically. So, too, did the Munitions Supply Laboratories, the Meteorological Bureau, and the other government physical laboratories established earlier on. Moreover, as the nation found itself thrown more and more on its own resources, Australian industry expanded and greatly increased in technological sophistication. A war-time optical industry was created from nothing, and there was a remarkable improvement in radio and telephone communication systems and a consolidation of the manufacturers supplying them. There was also a sudden increase in demand for graduates with a background in physics from the armed services, especially to work with radio and radar equipment. At the height of the emergency, many raw young graduates were immediately rushed into jobs without any opportunity to complete their training; but even so, the number of fully qualified physicists in the country increased two and a half times in six years.[19]

The number almost doubled again by 1950. This was despite the flood of young scientists to Britain (and now also the U.S.A.), once the war ended, to undertake higher

[19] Home, 'The Beginnings of an Australian Physics Community', pp. 3–34 in *Scientific Colonialism: A Cross-Cultural Comparison*, edited by Nathan Reingold and Marc Rothenberg (Washington, D.C., 1987); idem, 'Between Classroom and Industrial Laboratory: The Emergence of Physics as a Profession in Australia', *Australian Physicist*, 20 (1983), 163–7; idem, 'Science on Service, 1939–1945', in *Australian Science in the Making*, edited by Home (Sydney, 1988), pp. 220–51.

degree studies. The number continued to climb steeply during the 1950s as local Ph.D. programmes were at last established and Australia began providing advanced training for its own research workers.

Physics went through a boom period in Australia, as elsewhere, during these years. Though the success of the atomic bomb project in the United States had unleashed the terrors of nuclear war on a previously unsuspecting world, it also seemed to promise untold riches in the form of cheap supplies of energy. At the same time, the achievements of the physicists in the wartime development of radar were at last made public. Physics suddenly became a glamour science in which the demand for trained researchers far outstripped supply. Student numbers swelled and so, too, in response, did university physics departments. To staff them and the new government laboratories, trained physicists were recruited in considerable numbers from elsewhere, chiefly from Britain, so reversing the direction of flow for the first time in two generations.

The first tentative Australian initiative in relation to atomic energy came in 1947, with the formation of a small atomic physics unit within CSIR, several members of which were seconded soon afterwards to the new British atomic research station at Harwell. The group, which included chemists and engineers as well as physicists, remained in Britain until 1955, when it returned to Australia to become the nucleus of the newly created Australian Atomic Energy Commission with its research establishment at Lucas Heights, near Sydney. Meanwhile, the Australian government had also encouraged the ambitions of L. H. Martin, Laby's successor in the chair of physics at Melbourne, to concentrate the research activities of his department on nuclear physics. Martin's appointment in 1948 as the Australian government's Defence Scientific Adviser testifies to the important place that physics, and atomic physics in particular, now held in government thinking. Nuclear physics also figured large in the planning of the new, research-orientated Australian National University established in Canberra in the post-war years. One of the four founding schools that constituted the University was a Research School of Physical Sciences, and the man chosen to direct it was a leading authority on nuclear physics, the Australian-born and Rutherford-trained M. L. E. Oliphant. Large sums were expended on a protracted but ultimately unsuccessful attempt to build a 10 Gev proton synchrotron, intended as a national facility for high-energy nuclear physics research.[20] At the University of Sydney, Harry Messel, appointed in 1952 to the long-vacant chair of physics, took advantage of the public interest in the subject to launch a Nuclear Research Foundation to raise additional funds for his department. The dramatic success he achieved quickly transformed the department's research capabilities in, ironically, fields mainly other than nuclear research. It simultaneously gave academic physics a new image throughout the country.[21]

Much the most striking developments in post-war Australian physics came, however, from CSIR's Radiophysics Division. At the war's end, the large team of research physicists and engineers that had been assembled to work on radar was not dispersed in the way that the much larger United States group was. Some members of the team took up developmental work on civilian applications of radar, others for a few years pursued research on large-scale electronic computers before they

[20] S. Cockburn and D. Ellyard, *Oliphant: the Life and Times of Sir Mark Oliphant* (Adelaide, 1981).

[21] *Ever Reaping Something New: A Science Centenary*, edited by David Branagan and Graham Holland (Sydney, 1985), chapter 4.

were diverted to other tasks. A large group directed by the new chief of the Division, E. G. Bowen, applied their radar techniques to the study of clouds and the seeding of them in attempts, ultimately unsuccessful, to make rain. Another group, under J. L. Pawsey, turned their radar equipment towards the heavens and immediately made a series of fundamental and exciting discoveries that carried Australia to the forefront of the then new field of radio astronomy. Here, Australian physicists for the first time experienced the heady feeling of leading the world with their research.[22]

The other physics-based divisions within CSIR (and later the CSIRO) also continued to grow apace. The largest was the National Standards Laboratory, which divided in 1946 into three separate divisions of Physics, Metrology, and Electrotechnology. The wartime Lubricants and Bearings Section became a full-scale Division of Tribophysics, while a new Division of Chemical Physics grew out of the swollen Division of Industrial Chemistry and became a centre for Australian research on advanced scientific instrumentation.[23] The Division of Aeronautics, however, was transferred in 1949 from CSIR to the Department of Supply where, together with the Maribyrnong laboratories and the newly established Long-Range Weapons Establishment at Salisbury and Woomera in South Australia, it provided a strong physics presence within the expanding Defence scientific complex. Physics was also well represented in another new government scientific organization, the Commonwealth Bureau of Mineral Resources, where a substantial geophysics group was brought together.

On Mount Stromlo, the Commonwealth Observatory entered a new and expansionary phase, even as the old Melbourne and Adelaide observatories finally expired. Its work was enhanced by a greatly expanded staff, substantial new equipment, strengthening links with the radio astronomers and, eventually, a new site on Siding Spring Mountain in northern New South Wales. With the establishment of the National University, the Observatory became a *de facto* department of the Research School of Physical Sciences, a move that greatly benefited both groups. By the 1960s Mount Stromlo had joined the Radiophysics Division as an institution of world standing, and Australian optical astronomers stood ready to take on a major new instrument that would consolidate their position in their field for years to come, the Anglo-Australian Telescope.[24]

In many ways, therefore, Australian physics came of age in the post-war world. Australian industry, however, failed to keep pace. Born, much of it, in the hothouse environment of the wartime emergency, Australian manufacturing found protection after the war behind import restrictions and high tariff barriers. It developed as a small-scale, inward-looking, import-replacement activity which, with a few honourable exceptions, was content to buy the fruits of overseas research rather than invest in research of its own. In such an environment, and with a number of its leading practitioners evincing a disdain for industrial and applied work that they had learned in the Cavendish Laboratory under Rutherford, Australian physics found itself distanced from production and reverted again to being a largely academic activity. To be sure,

[22] W. T. Sullivan, III, 'Early Years of Australian Radio Astronomy', in Home (footnote 19, 1988), 308–44; *The Early Years of Radio Astronomy*, edited by W. T. Sullivan (Cambridge, 1984); A. C. B. Lovell, 'Joseph Lade Pawsey, 1908–1962', *Biographical Memoirs of Fellows of the Royal Society of London*, 10 (1964), 229–43.

[23] J. B. Willis, 'The CSIRO Division of Chemical Physics, 1944–1986', *Historical Records of Australian Science*, 7, part 2 (1988), 153–77.

[24] S. C. B. Gascoigne, 'Australian Astronomy since the Second World War', in Home (footnote 19, 1988), 345–73.

there was now work for physicists in Australia outside the walls of academe, as there had scarcely been previously; but it was of the more humdrum, routine kind. In an age where industrial advance was becoming due, more and more, to advances in applied physics, Australia failed to keep pace.

3. Japan

The First World War affected Japan quite differently from Australia. Far from national development being more or less halted for the duration, as happened in Australia, the Japanese economy experienced a major boom. At the time, the textile industry predominated within the manufacturing sector, but the war saw a major expansion of heavy industry as the supply of goods previously imported became exhausted. Between 1915 and 1920 the machine tools industry, for example, averaged an astonishing growth rate of 28 per cent per annum, while electricity, metals and chemicals averaged annual increases in production of 17·6 per cent, 10·7 per cent and 8·8 per cent respectively.[25] During the war years, as a result of import blockages on new equipment, these industries worked at a relatively low technical level using a hastily assembled and largely unskilled workforce. In the 1920s, however, they were transformed by the increasing use of electricity and the widespread introduction of new, power-driven machines. Employment in heavy industry increased very little but production rose considerably. A labour surplus developed, but at the same time a core of workers skilled in the new techniques was gradually built up.[26]

The increasing technical sophistication of Japanese industry during this period saw a growing demand for trained engineers and managers as well as skilled factory workers. This led to a tremendous expansion of the higher education system. Prior to the war, just three national universities had been established, namely the University of Tokyo (1877), Kyoto University (1897), and Tohoku University (1911).[27] As part of the post-war development additional national universities were established, namely Hokkaido University (1930), Osaka University (1931), Kyushu University (1939), and Nagoya University (1942). Two others were founded within Japan's recently acquired colonial empire, Keijo University at Seoul, Korea (1924), and Taihoku University at Taipeh, Taiwan (1928). Many national senior high schools and professional schools were created. Some of the professional schools in medicine, engineering or commerce were subsequently raised to the status of college or university, and the higher normal schools in Tokyo and Hiroshima were made, respectively, the Tokyo and Hiroshima Universities of Letters and Science. In addition, a number of private universities were established under a new ordinance, promulgated in 1918, that permitted this. However, in contrast to the national universities, where physics and the other sciences figured prominently in the academic programme, few of the private institutions could afford to establish schools of science. Only Waseda University in Tokyo managed to do so.

Even more so in Japan than in Australia, the main practice of the universities in the years during and after World War I continued to be teaching and absorbing the latest developments elsewhere, rather than actual research. The Japanese higher education system for the most part aimed simply to imitate Western learning and Western laboratory practice. In Japan, in contrast with modern Western countries, knowledge

[25] Takafusa Nakamura, *Economic Growth in Prewar Japan* (New Haven, Connecticut, 1983), p. 145.
[26] Ibid., chapter 6.
[27] The word 'Imperial' was prefixed to the names of the various national universities up to the end of World War II, but here we use the present titles.

had been considered traditionally as something to be learned from venerable teachers and authoritative books, not as something to be sought through investigations of one's own,[28] and the habit proved hard to break. Thus modernization continued to be generally regarded as introducing up-to-date knowledge and practice from the most developed countries, and this fully met the needs of an industrial sector committed to imitation of the products of Western nations rather than innovation.

A further constraint on science in the Japanese universities arose from the way in which university government was organized around professorial chairs, each chair commanding its own budget that supported a small and rigorously hierarchical unit centred on the professor. Though the system resembled that which had operated so successfully in Germany, it instead functioned in Japan to inhibit research on account of the traditional traits of *seniores priores* and factionalism as well as a traditional tendency to regard knowledge as something akin to private property, to be passed on from a master to a chosen disciple rather than being subjected to open and critical examination. Such habits also served to block co-operation between members of different units, whether in arranging collaborative research or in promoting the advance of knowledge through the exchange of opinions or of personnel. Public investment in research was not encouraged where knowledge was not considered as common human property to be shared and promoted for the benefit of mankind.

In earlier years, as we have noted, geophysical observing in the form of meteorological, seismological, gravitational and geomagnetical recording was a major activity within both Japanese and Australian physics. In Japan, as in Australia, such work subsequently declined dramatically as a proportion of the nation's total effort in physics. For example, papers on geophysical topics comprised 26·7 per cent (116 papers) of all papers on physics appearing in the periodical publications of the Tokyo Physico-Mathematical Society in the period 1885–1919, whereas papers on these topics comprised only 3·9 per cent (40 papers) of the much larger number published by the successor society, the Physico–Mathematical Society of Japan, in the period 1920–1944 (see Table 2).[29]

As in Australia, much of the geophysical work that was done came to be concentrated in specialist government organizations, and to be conducted at a fairly routine level. Meteorological work, for example, came to be dominated by the Central Meteorological Observatory in Tokyo, the central bureau of the Japanese Meteorological Service. This co-ordinated the activities of a large number of local observatories belonging to the prefectures. It standardized and checked the instruments used in the local observatories and issued instructions as to what observations were to be made. The resulting data were sent to Tokyo for analysis and publication. Commencing in 1922, the Tokyo observatory also served as a training college for meteorological observers to staff the prefectural institutions.[30] Meteorological work was also undertaken at two other government institutions that were independent of the Central

[28] William Wheeler, an American science teacher at Sapporo Agricultural College, noted this disposition in the Japanese academic tradition as early as 1878; *Second Annual Report of Sapporo Agricultural College* (Tokyo, 1878), pp. 11–5.

[29] Nihon Butsuri Gakkai (Physical Society of Japan), *Butsurigaku-shi Shiryō Seiri Tokubetsu Iinkai Hōkoku* (Report of the Special Committee for Compiling History of Physics Material) (Tokyo, 1985), pp. 8–32. The Tokyo Physico–Mathematical Society was renamed the Physico–Mathematical Society of Japan in 1918.

[30] *Scientific Japan, Past and Present* (Kyoto, 1926), chapter 2.

Table 2. Statistical analysis of papers on physical subjects published in the periodical publications of the Tokyo Physico-Mathematical Society, 1884–1919, and the Physico-Mathematical Society of Japan, 1920–1944.

Physical subjects	Papers	%
Period 1885–1919		
Geophysics	116	26·7
Spectroscopy and radioactivity	66	15·2
Solids and liquids	49	11·3
Electricity	41	9·4
Magnetism and metals	38	8·8
Optics	27	6·2
Astronomy	27	6·2
Atomic structure and electron theory	24	5·5
Heat and statistical mechanics	14	3·2
Sound	10	2·3
Relativity	8	1·8
Hydrodynamics	6	1·4
Miscellaneous	8	1·8
Total	434	
Period 1920–1944		
Properties of matter (excepting metals)	143	13·9
Nucleus	141	13·7
Spectroscopy and radioactivity	131	12·8
Hydrodynamics (including aerodynamics)	100	9·7
Quantum mechanics and elementary particles (including cosmic rays)	84	8·2
Heat and statistical mechanics	68	6·6
Electricity	60	5·8
Magnetism and metals	49	4·8
Sound	47	4·6
Geophysics	40	3·9
Optics	39	3·8
Astronomy	38	3·7
Solids and liquids	37	3·6
Relativity and cosmology	32	3·1
Miscellaneous	17	1·8
Total	1026	

Observatory in Tokyo, namely the Imperial Marine Observatory at Kobe and the small Aerological Observatory for upper-atmosphere work, set up at Tateno near Tsuchiura in 1920.

Significant geomagnetic and volcanological records had been compiled since the early Meiji period. A geomagnetic observatory was established at Kakioka in 1913 and several vulcanological stations were set up at about the same time. In neither of these fields, however, did the work go much beyond mere data recording.

Seismological investigations had been among those taken up most actively by the initial group of imported British professors, above all by John Milne. They inspired a number of their students to work in this area, including Seikei Sekiya—appointed to a chair of seismology, the first in the world, at the University of Tokyo in 1886—

Fusakichi Ōmori and Akitsune Imamura. The Seismological Society of Japan, established by Milne and his colleagues, flourished for a number of years but then went into decline. It was eventually dissolved in the 1890s as this field, too, was taken over by a central government agency, the Earthquake Investigation Committee, that was set up following a bout of severe earthquakes in 1891. During the following few decades, the Committee published a large number of reports, Ōmori being by far the most prolific contributor. For the most part, these reports comprised mere routine observatory data along with generally fruitless attempts at obtaining statistical regularities therefrom. However, Ōmori also did pioneering work on earthquake zoning, identifying areas of greater and less risk, and made some important innovations in seismological instrumentation.[31] The great Tokyo earthquake of 1923 brought new life to this field. A Department of Seismology was created at the University of Tokyo in 1924, and an Earthquake Research Institute was established within the University a year later that promoted both observational and theoretical studies. In addition to continuing long-term observations on possible links betwen earthquakes and geomagnetism and gravity respectively, studies were undertaken concerning, for example, fluctuations of the Earth's crust and earthquakes, the propagation of seismic waves, and mechanisms that might lead to the occurrence of an earthquake.[32]

The establishment in this way of an independently funded research institute associated with a teaching department was one means of overcoming the chronic lack of direct funding for university research. A rather earlier example had seen the creation of an Aeronautical Research Institute at the University of Tokyo in 1918, while the Iron and Steel Institute established at Tohoku University in 1919 under the dynamic direction of Kōtarō Honda (renamed the Research Institute for Iron, Steel and Other Metals in 1922) quickly became one of the nation's outstanding scientific institutions, specializing in the metallurgy of iron and steel and the magnetic properties of matter. Founded in 1924 and led by Hidetsugu Yagi, the Saito Laboratory of Electrical Communication was also located at Tohoku University.

Much the most important development along these lines, however, was the establishment of the Institute of Physical and Chemical Research in 1917.[33] With substantial funding from the government, the imperial family and private and corporate donors, the Institute embodied the hopes of leading Japanese scientists of taking Japanese industry beyond its imitative phase to create new industries based on research-generated inventions. Both its financial resources and its immediate contribution to Japanese industry fell short of the hopes of its founders—indeed, it was able to support its activities only by the sale of patents and, later, by incorporating itself and operating several factories in its own right. However, the Institute did offer a much more satisfactory and better funded research base for a number of Japan's leading physical scientists than they had previously enjoyed. In 1921, a new Director, Masatoshi Ōkōchi, reorganized the Institute into the familiar pattern of a series of

[31] Ibid., chapter 13 (by Torahiko Terada and Takeo Matuzawa); *Dictionary of Scientific Biography*, x, 210–1, art. 'Omori, Fusakichi'.

[32] Yōichirō Fujii, *Nihon no Jishingaku* (Seismology in Japan) (Tokyo, 1967), pp. 111–5, 147–66, 231–5; Nihon Kagakushi Gakkai (History of Science Society of Japan), *Nihon Kagaku-Gijutsu-shi Taikei* (History of Science and Technology in Japan), xiv: *Chikyū Uchū Kagaku* (Science of the Earth and Universe) (Tokyo, 1965), pp. 18–9, 368.

[33] Kiyonobu Itakura and Eri Yagi, 'The Japanese Research System and the Establishment of the Institute of Physical and Chemical Research', in *Science and Society in Modern Japan: Selected Historical Sources*, edited by S. Nakayama, D. L. Swain and E. Yagi (Cambridge, Massachusetts, 1974), pp. 158–201; Eikoh Shimao, 'Some Aspects of Japanese Science, 1868–1945', *Annals of Science*, 46 (1989), 69–91.

independent units, each led by a chief scientist who had complete control of the budget, staff and research programme of his laboratory. Initially there were fourteen chief scientists, by 1942 there were thirty-three. Most chief scientists simultaneously held a university chair; for them, their Institute laboratory made up for the lack of research facilities associated with their university appointments. For some, however, including Yoshio Nishina following his appointment as a chief scientist in 1931, the position with the Institute was a full-time one.

Promising young scientists also benefited from the system because although the Institute did not confer degrees, it did provide facilities for research leading towards a doctoral degree awarded by one of the universities. Such facilities were simply not available in the universities themselves. The formation of the Institute was thus a major step towards Japan's achieving self-sufficiency in training its own researchers in the physical sciences. The fruits of this were seen within only a few years, when Yukawa completed the work for which he was subsequently awarded the Nobel prize, before ever travelling outside Japan.[34]

Prior to this time, experience in one of the leading overseas laboratories had been an essential part of the training of the leading Japanese physics researchers. A few outstanding young scholars went overseas within a few years of graduating, others had to work in university teaching posts for a number of years before being granted overseas leave. Most had only a single opportunity. Whenever they went, they found themselves in an environment where everything, and above all the language, was wholly foreign to them. Together with more general cultural differences, the language barrier hindered Japanese abroad from fully absorbing Western ways of thinking and attitudes to learning. Wherever they went for their overseas study, Japanese scientists remained foreigners, temporary visitors rather than permanent immigrants. Australians, by contrast, when they went to Britain, experienced no such difficulties of language or culture to hinder their assimilation: indeed, in both their own minds and those of their hosts, they were to all intents and purposes British. In contrast to the position with visiting Japanese, if job opportunities arose in Britain, there were no barriers to prevent Australians taking them up.

Whereas Australian physicists always went to Cambridge, however, their Japanese counterparts by now invariably went to one of the major German schools. The style of physics that they absorbed was thus rather different from the 'string-and-sealing-wax' experimentalism learned by Australians working in the Cavendish Laboratory under Rutherford. In Germany, theory occupied a much more prominent place, though one by no means divorced from experiment; and the major advances in physical theory that culminated in the development of quantum mechanics were being worked out there, and at the Bohr Institute in Copenhagen, during the 1920s.

Yoshio Nishina was particularly fortunate to spend several formative years in Europe at this exciting time. A spell at the Cavendish Laboratory in 1921 during the early days of Rutherford's directorship was followed by eighteen months at Göttingen and then no fewer than five years, 1923–28, at the Bohr Institute. Here he witnessed the creation of quantum mechanics at first hand. The so-called Klein-Nishina formula that he introduced in 1928 as a relativistic quantum theory of Compton scattering subsequently found experimental support and became one of the verifications of Dirac's theory. Nishina returned home soon afterwards via the United States, and then

[34] Shimao (footnote 33) indicates that in the Institute's first twenty-five years, 118 people earned doctoral degrees through work done in the Institute.

worked in Hantarō Nagaoka's laboratory at the Institute of Physical and Chemical Research until his own appointment three years later as a chief researcher at the Institute.

The effects of the First World War and its aftermath convinced at least some influential Japanese of the need to build a research base that would enable the nation's industry to break out of the imitative mould in which it had been cast, which had been shown to leave Japan so vulnerable to the swings of economic fortune. As we have seen, the founders of the Institute of Physical and Chemical Research were driven by thinking of this kind. The Institute, however, was merely the most important of a number of research institutions created in these years. Previously there had been only a few small government laboratories, including an Electrotechnical Laboratory established by the Ministry of Communications in 1891, the Tokyo Industrial Laboratory (1900), the Central Bureau of Weights and Measures (1903), and the Railway Research Office (1910). In addition to those that have already been mentioned, there were now created the following research institutions that promoted research in the physical sciences: the Shiomi Physical and Chemical Research Institute, a small private institute in Osaka, founded in 1916; the Osaka Industrial Research Institute (1919); the Army Research Laboratory (1919); and the Naval Experimental and Research Establishment (1923). In addition, the Electrotechnical Laboratory was nationalized in 1918. In this period, too, a number of industrial laboratories were founded, by companies such as the Tokyo Electrical Company, Mitsubishi Mining, Mitsubishi Paper Manufacturing, Mitsubishi Shipbuilding, Asahi Glass, Furukawa Industries and Sumitomo Industries.[35]

The foundation of these new laboratories undoubtedly created a greater demand for graduates in physics, chemistry, and engineering to staff them. The number of scientists employed was in most cases at least an order of magnitude greater than in the new Australian laboratories being created at about the same time. Funding for research remained grossly inadequate, however, despite the introduction in 1918 of a system of research grants disbursed by the Ministry of Education, and the creation at about the same time of the first non-profit foundations concerned with supporting science. Few industrialists saw beyond imitation or recognized a need for research-based innovations in their companies' products. Even at the Institute of Physical and Chemical Research, as we have seen, the funding for research fell well short of expectations. Physics research in Japan in the 1920s remained fragmentary and small-scale, despite the promising institutional initiatives that had been taken.

Tetu Hirosige has identified the period around 1930 as an important turning point in the history of science in Japan.[36] In particular, he has pointed to the creation in December 1932 of the Japan Society for the Promotion of Science (JSPS) as a key development in the modernization of Japanese science. Generously funded by both government and private endowments, the Society disbursed very much larger sums for scientific research than had previously been available. It also played a central role in directing Japan's research efforts into closer co-ordination with the nation's industrial and military policies. A government programme of rationalizing Japanese industry

[35] *Scientific Japan* (footnote 30), chapter 14, 'Learned Institutions'; Itakura and Yagi (footnote 33).

[36] Tetu Hirosige, 'Social Conditions for Pre-war Japanese Research in Nuclear Physics', in Nakayama *et al.* (footnote 33), 202–20, originally published in Japanese, *Kagakusi Kenkyu* (Journal of History of Science), no. 63 (1962), 110–9, and in English, *Japanese Studies in the History of Science*, 2 (1963), 80–93. Hirosige, *Kagaku no Shakaishi: Kindai Nihon no Kagaku Taisei* (Social History of Science: The Modern Japanese Scientific System) (Tokyo, 1973), pp. 123–30.

through mergers and liquidations had been set in place some years earlier, in 1929, in a further attempt to enable Japanese products to compete more strongly on world markets, and JSPS steered scientific investigations into key areas such as steel and other metallurgical research.

In addition, the influence of the military in Japanese life increased dramatically through a series of political upheavals in the early 1930s. These included the so-called 'Manchurian incident' of September 1931, which has usually been taken as the beginning of fifteen years of continuous warfare for Japan culminating in the débâcle of August 1945; the assassination in May 1932 of the then Prime Minister by a group of naval officers; Japanese withdrawal from the League of Nations in February 1933; and a full-scale revolt in February 1936 by elements of the army which, though itself unsuccessful, left the military in effective control of the government. Not surprisingly, in these circumstances research fields of high priority to the armed services, such as aeroplane fuel and radio, likewise received generous treatment from JSPS. However, the Society did not create laboratories of its own. Instead, it channelled funds into existing laboratories.

The various laboratories of the Institute of Physical and Chemical Research, led as they were by many of Japan's most outstanding researchers, were well placed to benefit from the JSPS largess. In the process, Japanese research in physics entered a new era as not just radio research but also, and much more surprisingly, research on cosmic rays and nuclear physics received a massive boost in funding. Hirosige has discussed possible reasons for this latter development in a period long before there was any prospect of nuclear physics research finding economic or military applications. He concludes that it probably derived from support from the influential Takematsu Okada, director of the Central Meteorological Observatory, and the expectation that work on cosmic rays, a very new field at this time, would have a direct spin-off into upper-atmosphere meteorology and hence would be of immediate relevance to military aviation.[37]

Nishina's laboratory at the Institute of Physical and Chemical Research was the principal beneficiary. Following his return to Japan in late 1928, Nishina had worked hard to introduce his fellow physicists to the novelties of quantum mechanics. He delivered a famous course of lectures on the subject at Kyoto University in May 1931 to an audience that included Yukawa, Tomonaga and Shōichi Sakata, destined to become within a few years Japan's leading theoretical physicists.[38] Soon afterwards, Nishina was appointed a chief scientist at the Institute of Physical and Chemical Research and began to build up his laboratory.

A second site for nuclear physics research emerged during the 1930s in the Physics Department at the newly founded Osaka University, where Yukawa was appointed a reader and to which Seishi Kikuchi transferred in 1934 from Shōji Nishikawa's laboratory at the Institute of Physical and Chemical Research. Kikuchi had already, in 1928, done outstanding work on the diffraction of electrons, independently of and almost simultaneously with the Nobel prizewinning work of C. J. Davisson and L. H. Germer. Now, taking advantage of the new funding arrangements for university-based research made possible by the creation of the JSPS, he was responsible for building a Cockroft–Walton machine for the Osaka department. Later in the decade, both

[37] Hirosige (footnote 36, 1974), especially pp. 214–6.

[38] Yukawa recounts his own early fascination with quantum mechanics in his autobiography, '*Tabibito*' (*The Traveler*) (Singapore, 1982).

Nishina's laboratory and the Osaka group also received large grants from Japanese business houses awash with money generated by a booming war-based economy, that they applied to the construction of major early-generation cyclotrons. Yukawa's return to Kyoto University in 1939 saw the development there of a third nuclear physics research group, in this case one chiefly orientated towards theory.

Nishina's laboratory was important to Japanese physics in another way. Nishina had, during his time in Europe, fully absorbed the cultural values of Western science, and in his own laboratory he succeeded in breaking down the traditional hierarchical and proprietorial Japanese attitude to learning in favour of open collaboration and free discussion. He also played a major role in the founding in 1932 of a nationwide study group on nuclear physics that transcended the barriers between research groups. Nishina's example exerted a profound influence on those who worked with him, including such outstanding figures as Yukawa and Tomonaga. As a result, not only his group at the Institute of Physical and Chemical Research, but also the groups of younger physicists at the new national universities at Osaka and later Nagoya were full of intellectual vigour and free of the traditional feudalistic and bureaucratic stiffness that prevailed elsewhere. At Nagoya after the war, the new approach, so important in enlarging research horizons, also found concrete expression at the level of university governance when Sakata and his colleagues replaced the traditional idea of an all-powerful professor with that of a democratically based departmental council empowered to determine departmental policy. Their system came to be widely imitated in science departments around the country.

Thus during the 1930s, Japanese physics became much more strongly focused than before, with a heavy concentration on research activity in fields favoured by JSPS funding. Moreover, as time went on that funding was increasingly channelled to research groups rather than to individuals (see Figure 1). No longer was there room for the likes of Torahiko Terada (1878–1935) whose research in the 1910s and 1920s, excellent in its way, had exemplified aspects of a traditional Japanese approach to nature in ranging widely over the physics of actual phenomena rather than the idealized

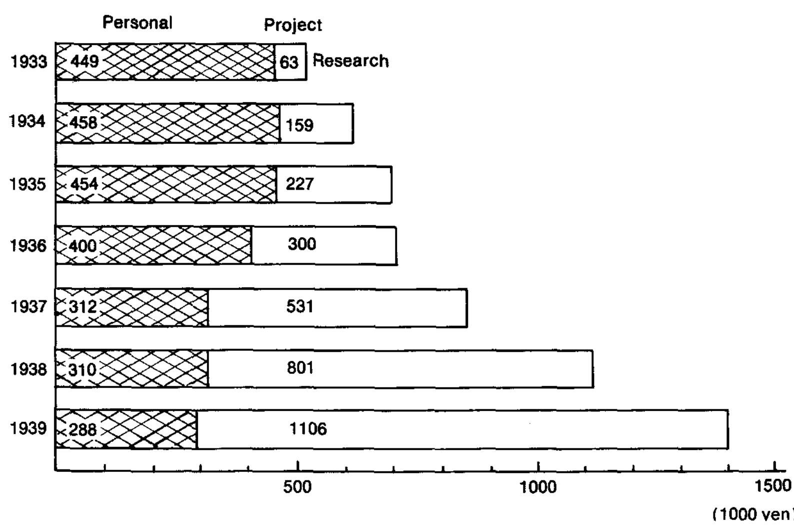

Figure 1. Funding of research by the Japan Society for the Promotion of Science: Proportions of personal research grants and grants for co-operative research projects, 1933–1939 (T. Hirosige, 'Social Conditions for the Researches of Nuclear Physics in Pre-War Japan', *Japanese Studies in the History of Science*, 2 (1963), 80–93 (p. 85); republished here by permission).

and abstract situations favoured by more orthodox physicists.[39] As we have seen, JSPS favoured fields of industrial or military significance—or, as one suspects may have been the case with cosmic ray research, where proponents of the work could at least mount a plausible case as to its military significance.

In the field of radio, Japanese research produced the Yagi antenna that dominated receiving systems for a number of years, and that during the war was widely used by Allied as well as Japanese designers of radar equipment.[40] So far as nuclear study was concerned, Japanese workers entered the field at a very early stage. Great difficulties were at first experienced in getting the major equipment, especially the cyclotrons, operational, but these were in due course overcome. Experimental cosmic ray research was the exclusive preserve of the Nishina laboratory, where long runs of highly reliable data were recorded. The most exciting work that was done, however, was in the realm of theory, above all by Yukawa who developed a particle-exchange theory of nucleon-nucleon interaction that predicted the existence of a new particle, the meson, intermediate in mass between an electron and a proton or neutron. The discovery in 1937 of a cosmic-ray particle of approximately the right mass drew favourable attention to his theory, which however received much stronger support with the identification ten years later, also in cosmic rays, of a different particle, the π meson, that fitted his predictions much more satisfactorily. In the late 1930s, Japanese theorists and cosmic-ray researchers worked together to advance understanding of the new particles. During these same years, Tomonaga was also honing his skills as a theoretician. The first of the fundamental contributions to the field of quantum electrodynamics for which he was eventually to receive the Nobel prize, the so-called super-many-time theory, was published in 1943. More generally, as Hirosige has noted,[41] Japanese theorists profited from the close contacts they enjoyed at this period with their more experimentally orientated colleagues. Such contacts were promoted by the open, collaborative style of research that Nishina encouraged, and by the approach to the funding of physics research adopted by the JSPS.

In July 1937, Japan launched a full-scale military assault against China but, instead of gaining the swift victory that had been anticipated, soon found itself bogged down in a protracted conflict. In response, a National General Mobilization Law was enacted in March 1938 that led, amongst many things, to a much larger budget than ever before to support scientific work and a crash programme to enhance the general level of technical skill in the population. The teaching of science and engineering underwent a further sudden expansion, in both public and private institutions—indeed, many private universities first acquired science and engineering departments at this time. Between 1941 and 1945 the number of new graduates in these fields was almost double what it had been in the corresponding period a decade earlier.[42] Though the ratio of scientists

[39] Shimao (footnote 33), pp. 78–80. Terada's disciple Ukichirō Nakaya did do some beautiful work on snowflakes that was very much in Terada's style; but even this was seen as being of meteorological and hence of military significance!

[40] The popularity of Yagi arrays in Japanese wartime radar equipment is noted in U. S. Naval Technical Mission to Japan reports E-01 and E-03, 'Japanese Submarine and Shipborne Radar' and 'Japanese Land-based Radar' (December 1945).

[41] Hirosige (footnote 36, 1974), p. 213. There are reminiscences by a number of Japanese cosmic ray researchers from this period in *Early History of Cosmic Ray Studies: Personal Reminiscences with Old Photographs*, edited by Yataro Sekido and Harry Elliot (Dordrecht, 1985).

[42] In the period 1931–1935 there were 8880 new science and engineering graduates, while in the period 1941–1945 the number was 15904 (*Monbusho Nenpo* [Annual Report of the Ministry of Education], nos. 60–4 [1937] and 70–4 [1951]).

Table 3. Number of scientists and engineers per 10 000 of the Japanese population.

1915	1920	1925	1930	1935	1940	1947†
2·6	4·1	5·9	8·4	10·7	14·2	27·6

† Figures not available for 1945.

and engineers to the population at large was, even then, still somewhat lower than in the most advanced western nations, it had dramatically increased in the course of a generation, as shown in Table 3.[43]

In 1940, a general plan for the mobilization of science was introduced. Much of the expanded scientific effort went, of course, into increasing production in the heavy and chemical industries to serve the immediate needs of the military for armaments, but physics also benefited. Many young graduates were immediately conscripted into the armed services and became technical officers, others went to work in war-related industrial concerns where the results they achieved were sometimes quite dramatic.

Nowhere was this more so than in relation to the manufacture of optical equipment. During the 1914–18 War Japan, like many other countries, had found itself exposed by its complete dependence on Germany for optical glass. Experiments in glass manufacture were subsequently carried out by the Nippon Optical Company, mainly in an attempt to replicate German glass and to gain control of the optical constants from one melt to the next. Production remained on a very small scale until 1942, but between then and 1945 no less than 130 tonnes of optical glass were produced. A post-war team of American investigators described the expansion of output during this period as 'phenomenal' and noted that by then Japan possessed 'fairly modern and efficient optical factories' and 'capable scientific personnel who understand modern optical requirements'.[44] The result was that wartime Japan achieved, virtually from nothing, a very substantial output of optical munitions, and in the process developed a pool of expertise, very much larger than the one that grew up in Australia during these same years, upon which a major new export industry could be based in the post-war years.

Even in such a notably successful instance of applied physics, however, the limitations of Japanese science and industry that were by then traditional are apparent. In this and many other instances, the wartime efforts of Japanese physicists were directed, like those of their Australian counterparts, not at abstract issues but at solving immediate problems of production. Various post-war intelligence reports suggest, however, that in this situation most Japanese scientists still tended to see their task as being confined to imitating a western product or technique rather than extending to devising a new solution. In the case of optical munitions, we are told:

> No startling or new optical developments or lens systems were found. The Japanese contented themselves with copying the constants of the optical systems from Germany and the instruments from the United States. Their main problem was to vary the curvatures and separations and, in other cases, to increase the

[43] Solomon B. Levine and Hisashi Kawada, *Human Resources in Japanese Industrial Development* (Princeton, New Jersey, 1980), p. 71.

[44] U.S. Naval Technical Mission to Japan report X-05, 'Japanese Optics' (December 1945), p. 1.

> number of elements in any particular type of lens system so as to make it perform almost as well as the original when Japanese-made glass was substituted for Shott glasses.[45]

Similarly, in the case of electronic equipment:

> Japanese technicians appear... to have been aware of the necessity for improving on current practice and for discovering satisfactory substitutes for scarce materials required for the most important functions. A certain amount of research was accordingly carried out in various laboratories, although little of this work appears to have reached a practical stage. In any case, much of it seems to have been based upon the published reports on similar experiments performed previously in western countries.[46]

Such failings were widespread and perhaps inevitable, given the rate of expansion of the physics workforce during the war years. Even in the best of circumstances, it would have been impossible for any higher education system that was growing at such a pace to train so many more young people in the ways of research. Nor was there the time available to do so. As in Australia, raw young graduates were being rushed straight to the laboratory bench. It also remains the case, however, that science education in Japan was still geared much more to rote learning, to the imparting of an already defined body of knowledge, than it was to fostering a spirit of critical inquiry. In other words, it was poorly adapted to training people in the ways of research at all. In Japan, the habit of imitating the technical achievements of others remained deeply ingrained.

Nevertheless, as we have seen, Japan had during the 1920s and 1930s built up a few first-rate physics research laboratories. These, too, expanded in the new environment of national mobilization, when much greater funding than ever before became available to support their research. Of course this came at a price, in the form of the laboratory's research being directed, to some extent at least, into areas of significance to the armed services. Many of the nation's leading scientists were far from enthusiastic, however, about supporting the war-mongering of Japan's military-dominated government, and were content, wherever possible, to use the additional money that was now available to advance their existing research programmes. Nishina's laboratory, for example, continued its long-running series of cosmic ray investigations with additional backing, from 1942, from a co-operative arrangement with the Central Meteorological Office to study correlations between cosmic rays and meteorological phenomena.[47] In addition, work continued on the cyclotrons. Keeping existing programmes going in this way became more and more difficult, however, as the war steadily turned against Japan.

During the war, Nishina's laboratory, together with others in Kyoto and Osaka, were engaged to undertake research on the construction of an atomic bomb. Nishina's laboratory had been an early contributor to the study of nuclear fission following its discovery by Hahn and Strassmann in 1939, with Nishina's own research group collaborating with chemists from the University of Tokyo in studying the products of uranium fission induced by a beam of fast neutrons generated from their cyclotron. Several reports by the group had appeared in English in *Nature* and *Physical Review* in 1940 and 1941, as well as in the Japanese journals. A series of small grants from both the

[45] Ibid., p. 27.
[46] Idem, report E-19, 'Japanese Electronic Equipment Construction Materials', p. 1.
[47] Hirosige (footnote 36, 1974), p. 212.

Army and the Navy were followed by two large grants from the Army Aviation Bureau in June and December 1944. Construction of the Nishina laboratory's second and much larger cyclotron was completed in 1944 and this was then used to measure the capture cross-section of U-235 for slow neutrons, establishing the possibility of a chain reaction. Some work was also done on methods for separating uranium isotopes. However, the entire project remained relatively small-scale, partly because of the continuing narrow research base of the Japanese physics community, partly because of the lack of materials and poor co-ordination. Moreover, Nishina's laboratory was badly damaged during an air raid in April 1945. At the end of the war, more than half the funds allocated remained unspent.[48]

The prosecution of the war produced severe distortions in the Japanese economy. Then, during the last months of fighting, massive Allied bombing raids laid waste large areas of Japan's urban and industrial centres. Following the Japanese surrender in August 1945, there were severe shortages of food, clothing, fuel, housing and most raw and processed materials. The nation's scientific facilities were, like everything else, either destroyed or crippled by shortages. Some facilities that survived the war—most notably the cyclotrons that were seen, ludicrously, as a threat to America's monopoly of the atomic bomb—were destroyed soon afterwards by the American occupation forces. Japanese physics, along with the rest of Japanese society, had to start again.

What were not destroyed, however, were the technical skills that had been learned by large numbers of young Japanese in the preceding period, that could now be brought to bear on the task of post-war reconstruction. Economic recovery proceeded apace, being accelerated by the emergency demands for Japanese goods and services resulting from the outbreak of the Korean War in June 1950. Physics graduates found ready employment in areas of applied physics such as properties of matter that related to the needs of manufacturing industry, and were soon being produced in greater numbers than ever before, following a further massive expansion of the Japanese education system initiated by the occupation authorities.

At the research level, theoretical physics recovered quickest. Here, no special facilities or equipment were required, and moreover Japan already had a group of first-rate investigators specializing in the area of elementary particle physics. Japanese physics as a whole, but especially those working in this field, received enormous encouragement from the award of the 1949 Nobel prize for physics to Yukawa for his prediction of the meson. Further stimulation came from holding the 1953 International Congress for Theoretical Physics in Tokyo and Kyoto. This brought the younger Japanese researchers into contact with leading overseas workers and led to a flourishing of international exchanges. It also prompted the creation of new research institutions, especially the conversion of Yukawa Memorial Hall, built in 1952 in Kyoto, into an Institute for Theoretical Physics which, though part of the University of Kyoto, was open to researchers from elsewhere as well.

In 1955, an Institute for Nuclear Study was inaugurated in Tokyo. Though attached to the University of Tokyo, this was a new kind of institute for Japan, a national research centre, equipped with big facilities, run by the scientists themselves

[48] Nihon Kagakushi Gakkai (History of Science Society of Japan), *Nihon Kagaku-Gijutsu-shi Taikei* (History of Science and Technology in Japan), Volume XIII, *Butsuri-Kagaku* (Physical Sciences) (Tokyo, 1970), pp. 441–71; E. Yagi and D. J. de Solla Price, 'Japanese Bomb', *Bulletin of the Atomic Scientists*, 18, no. 9 (November 1962), p. 29; Hirosige (footnote 36, 1973), 214–20; Deborah Shapley, 'Nuclear Weapons History. Japan's Wartime Bomb Projects Revealed', *Science*, 199 (1978), 152–7; Charles Weiner, 'Retroactive Saber Rattling', *Bulletin of the Atomic Scientists*, 34, no. 4 (April 1978), 10–2.

and open to common use, which promoted exchanges of personnel and accepted graduate students from various universities to use its equipment. It constituted a new and more democratic type of Japanese research organization, free from the fetters that characterized the traditional closed, hierarchical structures; and it provided a model for similar national research centres in other fields that were subsequently established. Epitomizing, as it did, the openness that Nishina had espoused a generation earlier and embracing the field in which he himself had worked, the Institute for Nuclear Study took Japanese physics into a new age.[49]

4. Australia and Japan

On reflecting upon the developments described in this paper, one is struck, above all, by differences in scale. There were many more graduates in physics, applied physics, and physics-based engineering in Japan than there were in Australia, and Japanese research groups tended to be significantly larger than Australian ones. In part, of course, this merely reflects a difference in the size of the population of the two countries: in 1940, Japan's population was over 100 million while Australia's was only about 7 million. There were, however, other factors at work as well. Before 1914, only a minority of the Japanese people had been caught up by the process of westernization set in train at the time of the Meiji restoration. Significant parts of Japanese manufacturing remained rooted in traditional practices, and Japan remained dependent on western suppliers for the more sophisticated industrial products that it needed. In particular, western learning had not penetrated far into the general population through the nation's school system. The small community of Japanese physicists was thus drawn from, and interacted with, only a small fraction of the overall population; the discipline's effective population base was probably not much larger than it was in Australia. After 1945, however, this was no longer the case. The dramatic expansion of the whole education system meant that western learning was now potentially available to the entire Japanese population.

In a sense, then, the rough comparability that we detected in our earlier paper between Australian and Japanese physics in 1914 merely reflected the fact that, up to that time, only a fraction of the Japanese people had made serious contact with any facet of western learning. The growing differences in scale that we see thereafter reflect the spread of western learning into an ever-increasing segment of the Japanese populace. By 1945, though the proportion of scientists and engineers in the total population remained less, as we noted, than in the leading western countries, it was now at least of the same order of magnitude.

The vast majority, however, of this new wave of technically trained Japanese were applied scientists and engineers, not researchers. They constituted an enormous new base of skilled manpower on which the Japanese economy could be rebuilt following the disasters of 1945—the foundation, indeed, of subsequent Japanese prosperity—but not a likely base for new, physics-led industrial initiatives. These did not begin to emerge until some years after the war.

When one restricts consideration to research-orientated physicists, though there are still certainly more in Japan than in Australia, the difference is not so great. Granted that the Japanese establishments were usually somewhat larger, government depart-

[49] Nihon Kagakushi Gakkai (footnote 48), 475–83, 506–10; Nihon Butsuri Gakkai (Physical Society of Japan), *Nihon no Butsurigakushi* (History of Physics in Japan), 2 vols (Tokyo, 1978), I, 35–41, 340–51, 374–79; II, 555–8.

ments in the two countries operated more or less the same range of physical-science laboratories and observatories (with the addition of a seismological research group in Japan). In both countries, during the period in question the observatories came to play a much less significant role within the nation's physics community than they had earlier. Japan had many more universities than Australia, but we have seen that few of the private ones had science departments until the 1940s, and even after that they did not offer adequate opportunities for research to their lecturing staff. The physics departments in the much smaller number of national universities were roughly comparable to those of the Australian universities so far as staffing went. Except, however, for its Radio Research Board—and that never had more than a handful of researchers at any one time—Australia had nothing during the inter-war period remotely comparable to Japan's Institute of Physical and Chemical Research, which in time enabled several of Japan's leading physicists to build up sizeable on-going research groups. On the other hand, once CSIR began building up its physical-science laboratories during the war years, Australia did acquire research groups of comparable size to the Japanese ones, if not quite so many of them.

As for funding for research, we have seen that even in Japan's national universities, there was too little to support a significant programme of experimental research unless the professor went out and obtained some. In Australia, by contrast, most physics departments could support some research, so long as it was not too expensive, out of their own resources. Despite this, Japanese researchers were generally better off since throughout the period under consideration there were grants available, albeit small ones, from the Ministry of Education and elsewhere. In Australia though, if the department's funds were insufficient, there were few alternative sources that could be tapped. (One reason that Laby's department stood out from the others in Australia was that he did succeed in finding other, if modest, sources of funds.) In addition, in Japan some of the leading workers gained appointment to the Institute of Physical and Chemical Research and, with it, access to the considerable funds available to support the work of each Institute laboratory. Once the JSPS was created in 1932, very substantial funds became available to Japanese investigators, while even larger sums could be tapped by an enterprising laboratory chief such as Nishina from prospering business houses and then, following the national mobilization later in the decade, from the government.

The consequences for Japanese physics were twofold. On the one hand, as has been noted, research did come to be more narrowly concentrated on topics of military or industrial significance (although the massive support given to cosmic ray and nuclear physics research suggests that such relevance could on occasion be broadly defined). Individual Japanese physicists undoubtedly lost some freedom of choice as to the research topics they would pursue. Yet on the other hand, by doing so they were able to contemplate projects that were completely out of the question for their Australian counterparts. While Australian physics remained small-scale, scattered and firmly locked in the 'string-and-sealing-wax' era, the Japanese were entering the era of 'big science', working in teams and investing enormous sums on a series of cyclotrons, developing a new set of instrumental skills as they went along. In less dramatic ways, too, for example, by making possible the acquisition of a large cloud chamber for use by one of the cosmic ray research groups,[50] the scale of funding placed Japanese physics in

[50] Hirosige (footnote 36, 1974), 211. The instrument in question was used to make one of the first determinations of the mass of the meson.

a different league. Once again, it was the war that led to the first Australian steps in the same direction, when a large and well-funded group of radio researchers was brought together in the Radiophysics Laboratory. Here, too, the concentration of effort paid off handsomely, both in the development of locally appropriate radar technology during the war and in the extraordinary post-war successes of the group in the new field of radio astronomy.

It does not necessarily follow, of course, that in physics, bigger is always better. Individuals or small groups can do excellent work, while larger and well-funded teams can produce very little. Instances of both kinds emerge from the history of Australian and Japanese physics at this period. On the one hand, one might cite D. F. Martyn of the Australian Radio Research Board, who with occasional collaborators did some excellent work on the physics of the ionosphere during the 1930s. On the other, there is the Cancer Research Committee of the University of Sydney, which spent large sums deriving from a public appeal on biophysical research related to the treatment of cancer that came to nothing,[51] and the equally large sums invested by the JSPS in radio research[52] with equally little positive outcome.

What emerges from these latter instances and from the contrasting success of Honda's and later Nishina's laboratories, and later still of the Radiophysics Laboratory in Australia, is how important it is to the success of a large project that the leadership has previously had firsthand experience in a major laboratory. In both the Cancer Research Committee in Sydney and the radio research groups in Japan, it was precisely the craft skills deriving from such experience that were missing. Learning the ways of scientific research is very much a 'hands-on' process from which one acquires something of a sixth sense for pitfalls on the one hand and promising leads on the other. In the situation of both Australia and Japan at the end of World War I, the only way for young physicists to gain such experience was to go overseas. Honda and Nishina did so and then, following their return to Japan, provided in their own laboratories the first local opportunities for young Japanese to learn the 'tricks of the trade' at an advanced level. Young Australians went abroad for the same reason, but then, as we have noted, having learned the skills, few were able to find positions back in Australia. None had the opportunity to put those skills to work in running a laboratory of their own in Australia, prior to World War II. Thereafter, especially in the Radiophysics Laboratory, they did, and the situation of Australian physics dramatically changed as a result, with new opportunities opening up for young Australians to learn the research craft at more than an introductory level within Australia.

There is a sense, therefore, in which Australian science was at this time following the same path as the Japanese had already traversed some years earlier, in establishing a few substantial research groups under research-wise leaders. Given that, as we have argued, the two physics communities were at roughly identical stages of development *c.* 1914, the question arises, why did Australian physics reach this next level of development so much more slowly than occurred in Japan?

As before, we suggest that the explanation lies in large measure in wider political issues. Japan was a populous, proud, and independent nation with new confidence in itself following major military victories over China and Russia and successful engagement on the Allied side in World War I, keen to take a still more prominent place

[51] Hugh Hamersley, 'Cancer, Physics and Society: Interactions between the Wars', in Home (footnote 19, 1988), 197–219.

[52] Hirosige (footnote 36, 1974), 214.

on the world stage. Armed strength based on continued industrial expansion was seen as the key to achieving this, and this required building up the technical skills of the workforce and (at least in the minds of some influential Japanese) an expansion of research of relevance to industry and the military.

Australia, on the other hand, remained a small cog within the world-wide British empire. Federation had brought the six Australian colonies under a single government but this remained subservient to Britain's in a number of important respects. Most Australians continued to regard themselves as British first, Australian only second.

This has immediate consequences for Australian physics. It meant, as we have seen, that it acquired a very strong British (and indeed specifically Cambridge) orientation in which theory was understated, at least in comparison with Germany, and large equipment and the large teams required to run this were frowned upon. It also often meant, however, acceptance of an 'efficiency' model of the imperial economy in which Britain was the manufacturing hub, processing raw materials produced by the colonies and then re-exporting these to them, and to the world, in made-up form. In this scheme, Australia and the other colonies would concentrate, so far as scientific research was concerned, on investigations germane to their primary industries, while the sciences having more of a bearing on manufacturing, of which physics was one, would be reserved for Britain. For those who espoused views such as these—and in Australia in the 1920s they extended even to individuals in the higher echelons of government—the 'brain-drain' of talented young Australian physicists was no bad thing but was precisely what ought to be happening. It was in Australia's interest to keep British physics strong, and it would be a waste of scarce Australian resources to invest in any substantial way in physics research in Australia.

The Great Depression of the early 1930s put paid, in Australia, to thinking such as this and led governments of all political hues to look to an expansion of manufacturing industry to solve (or at least ease) the nation's economic woes. At the political level, this led to much friction between Australian and British governments as the latter saw traditional markets for British manufactured goods being threatened by locally-based competition. At the scientific level, as we have seen, it led to a long-delayed expansion of research capability in fields such as physics that were seen to have a bearing upon manufacturing industry. By then, however, Australia had fallen a long way behind, and it took another decade to build up a research group comparable in strength to those that had already been established in Japan.

Nevertheless, it can be seen that, even up to the early 1950s, even though the most successful research was done in different fields in the two countries, at an institutional level there were significant parallels between the Australian and Japanese research physics communities. Australia, however, lagged ten to fifteen years behind Japan in developing front-rank research groups, chiefly as a result of its subservient political situation during the inter-war period as a member of the British Empire. In addition, Japan had large numbers of skilled applied physicists and engineers who had no counterpart in Australia: it was upon these that the massive subsequent expansion of Japanese physics-based manufacturing in the late 1950s and the 1960s was built.

Yet to introduce modern science to a non-Western country such as Japan is not just a matter of introducing science as an institution—that is, as a body of knowledge, systems of education and research, and so on. It also involves adopting and assimilating a new kind of intellectual activity. A new concept of knowledge, a new attitude towards knowledge, a new method of securing knowledge, must be learned. Until these elements are integrated with the traditional ones, the transfer remains incomplete. In earlier sections of this paper, we remarked on how, in Japan, the traditional view of knowledge as something to be learned from teachers and books rather than through investigations of one's own persisted throughout the period under discussion. Within this context, science continued for the most part to be taught as a body of information to be memorized and techniques to be absorbed, not as an on-going process of inquiry. Moreover, with the very important exception of Nishina's laboratory and the groups linked with it, science and, more broadly, learning in general continued to be practised in Japan mostly within rigidly hierarchical structures that inhibited innovative thinking by the more junior members of the group. These structures fostered a proprietorial attitude towards knowledge among the more senior members that in turn discouraged co-operative research with other groups. Thus, in Japan, with respect to physics as well as the other sciences, attitudes generally persisted that prevented the discipline's full flowering, even in quite recent times, as a creative intellectual activity. Their doing so was assisted, as we have seen, by the cultural barrier that confronted Japanese when they came to study, think and communicate in languages entirely different from their own. The parallels we have observed at an institutional level do not easily extend to the inner realm of ideas.

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