AUSTRALIAN SCIENCE

in the making

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AUSTRALIAN SCIENCE in the making

edited by

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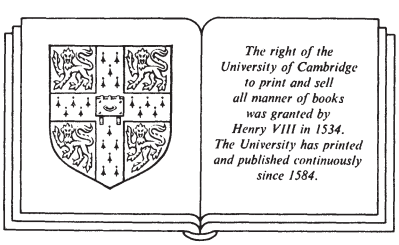

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CONTENTS

LIST OF ILLUSTRATIONS

Introduction

The year 1988 marks the 200th anniversary of the European settlement of Australia. Long before that, the Aboriginal people who inhabited the land had developed their own modes of understanding the Australian environment and the natural processes occurring within it. Prior to the arrival of the first white settlers, scientific exploration of the continent had been started by visitors from Europe, most notably Lieutenant James Cook and the scientists who accompanied him aboard the barque *Endeavour* during its exploration of the eastern Australian seaboard in 1770.

Following white settlement, a steady trickle of visiting scientists came from Europe to investigate Australia's unfamiliar flora and fauna, its rocks and soils and sky, its native peoples. A few of the settlers also took an interest in such things. It was many years, however, before Australian scientists ventured beyond investigating their local surroundings to tackle more general questions that were in the mainstream of scientific study elsewhere. Except for a few remarkable but isolated individuals, it took many more years before they could even begin to claim parity, as they do today, with fellow scientists in the leading centres of Europe, North America and Japan.

The present volume has been brought together, under the aegis of the Australian Academy of Science, to mark the bicentenary of white settlement. Its theme is 'Man's attempts to understand Nature in an Australian environment'. The book does not claim to be comprehensive in its coverage of the history of science in Australia. Instead, it takes up a number of more restricted questions bearing on the central theme.

Science of course recognizes no national boundaries. Scientific advance depends on successful cross-fertilization of ideas and techniques. Scientists everywhere depend on a free flow of information. They need to know about the work of fellow scientists at home and abroad, and they need to have their own work incorporated into the accepted body of scientific knowledge: this has been the case ever since modern science first emerged, in a few countries of

western Europe, during the seventeenth century. At first glance, therefore, a volume confined to the history of science in one country would appear to be unnaturally constrained. If science is one, and universal, there can be no distinctive French or Japanese or Australian science worth studying as such.

Yet though scientific discourse is international, its practice is at the same time socially bound. Individual scientists inevitably work within the confines of the societies in which they live as well as of the scientific disciplines to which they contribute. The most challenging task facing the historian of science today is to delineate, in any particular case, the interlocking intellectual, social and economic strands that shaped the work of individuals and groups and thus determined events, and very often the social strands will be best defined within a particular linguistic or geographical or national context. Hence, even if 'Australian science' is, strictly speaking, a phrase that lacks content, to study the history of science as it has been practised in Australia remains an intellectually coherent thing to do.

Indeed, it is imperative that such studies be undertaken. Science has in modern times become a powerful social and economic force, the effects of which are apparent in every facet of daily life. To study the place of science in social and economic life and the way in which this has changed as science itself has changed in the course of the past 200 years is thus to focus on one of the central historical questions of our time. From this point of view, the history of Australian science is a vital part of the general history of the nation.

Despite such an obvious truism, until relatively recently all too few scholars have paid serious attention to the subject. In a scientific age, Australians need to develop a better understanding of their nation's scientific past. The publication of the present volume will, it is hoped, help to engender a wider appreciation of this at the same time as it opens up a number of possible new lines of historical investigation.

Yet the history of Australian science is not just the history of science in Australia, so that interest in these topics should not be confined to Australians. Australia is but one of many 'new' nations to which western science was initially quite foreign, but which in recent times have developed, more or less successfully, a scientific culture of their own. Readers more familiar with developments elsewhere are likely to find instructive parallels and in some cases contrasts in the Australian experience.

On the one hand, because the incoming white settlers simply pushed aside or, all too often, exterminated the original inhabitants of the land, we do not find in Australia as we do in, say, China and Japan, an interweaving of traditional culture with western scientific values. Rather, as several of the chapters that follow make clear, science developed in Australia — as it did in other 'settler' societies such as Canada, Argentina and New Zealand — as part of the cultural baggage that the settlers brought with them from their European homelands. On the other hand, in both kinds of 'new' environment, settler society or traditional one undergoing westernization, the same questions arose. These concerned, above all, the maintenance of connections with the scientific heartlands of western Europe, the structuring of relationships with the scientific leaders there, and the small size of the local scientific population and the inhibiting effect on the work of individuals of the

resulting lack of regular contact with other researchers working on similar problems. There was the same concern, as well, with developing local supporting institutions (libraries, museums, publishing houses, universities, learned societies), a climate in which scientific work was encouraged, linkages with a growing technical and industrial base and, in general, with developing scientific self-sufficiency.

From the point of view of the formerly imperial powers, yet other questions spring to mind — concerning, for example, the place of science in the rise and fall of imperial hegemony in the modern world, the stability (or instability) of cultural and intellectual forms translated to new environments, the impact of discoveries made in the colonies on science at the metropolitan centre. Here, too, the Australian experience is likely to suggest answers of considerably wider relevance.

Inevitably, therefore, a central theme of a book such as this becomes the changes that have occurred during the past 200 years in the relationship between scientists working in Australia and those in the leading scientific centres in Europe. In this regard, some important ideas have been developed by historians in recent years.

In particular, the American historian Donald Fleming has suggested, on the basis of a comparison of the history of science in Australia, Canada, and the United States, that the science that was practised in these three countries until relatively recent times shared certain features that could reasonably be described as 'colonial'. He notes, in particular, what he calls 'the phenomenon of absentee landlordship' among nineteenth-century naturalists, 'the dominion of European students of natural history over their collaborators on the periphery'. Naturalists in the new territories, anxious to secure recognition from Europe, sent descriptions and specimens to leading authorities such as the Hookers, father and son, at Kew Gardens in London; but it was to the latter that the higher task fell — that of collating the particulars thus supplied them in order to reach some more general understanding. Fleming insists, however, that this is not to be seen as 'a limitation clamped upon a subject race of investigators by their overlords'. On the contrary,

> For the colonial investigator himself, natural history was the ideal refuge from the more perilous enterprise of embarking upon theoretical constructions by which he would be pitched into naked competition with the best scholars of all countries. To be a forager for Linnaeus or correspondent of the Hookers might be an identity in science purchased by bondage to the local and particular; but it was also a shelter against the more bracing winds that would promptly blow upon any man who tried to grapple with undifferentiated Nature in physics.[1]

In addition, Fleming argues, 'the practical associations of natural history were greatly enhanced by its appearing to be the intellectual aspect of pioneering'; as a result, natural history reconnaissance became 'an acceptable style of scientific endeavour in the new societies themselves'.

Fleming also points to the habit of colonial investigators in Australia and Canada completing their training 'at home' rather than in the colonies, with the ablest then finding positions in Britain; of talented young British scientists finding their initial appointments in colonial universities but returning to positions in Britain at the first plausible opportunity; and of

colonial scientists continuing to look to election to a British institution, the Royal Society of London, as the ultimate accolade of their work. 'Colonialism in science owed much of its tenacity', he suggests, 'to academics of the second rank, Englishmen who did not succeed in rebounding from exile, native colonials who had no choice but to return home after their studies abroad because nobody tried to detain them'. These men were intellectuals, nevertheless, who felt alienated by the indifference of the communities in which they found themselves to the life of the mind. In compensation, 'they called in the old world to redress the psychological balance of the new, kept their affiliations with Britain in repair, and recovered the sense of belonging to a larger community in which colonial values did not prevail'. In Australia this situation persisted, Fleming implies, at least until the Second World War.

These challenging ideas have been elaborated by another American historian, George Basalla, into a diffusionist model, which he claims has general application, in which science is seen as spreading from its original home in western Europe to other parts of the world.[2] Basalla delineates three different phases in this process, one of which parallels Fleming's 'colonial' science. In his scheme, however, it is preceded by a period in which such science as was done in the new land was done by visitors who, after sampling the new environment, returned to Europe and published their results there, and is followed by one in which local scientists 'struggl[ed] to create an independent scientific tradition'. Moreover, Basalla portrays the relationship between metropolitan scientific centre and colonial periphery in more mechanistic and less psychological terms than Fleming.

According to Basalla's schema, the second, 'colonial science' phase begins when local residents — whether settlers or native citizens — take up scientific pursuits. It is 'dependent science' in the sense that its practitioners look to an external scientific culture in the European heartland for their advanced training, for books and laboratory equipment, for the publication of their work, for recognition. In the succeeding phase there is a conscious attempt to establish local alternatives so that a scientist's major ties will come to be 'within the boundaries of the country in which he works'.

A number of criticisms of the Basalla schema have been published, many of which have drawn heavily on the Australian experience.[3] In particular, Basalla's claim that his model applied universally has been widely challenged, as has his assumption that there was a single western scientific ideology waiting to be diffused into new scientific territories. The variety of historical experience has been much richer and more complex, it has been argued, than his model allows. Attempts to apply the model in detail to particular cases have led each time to the conclusion that, for one reason or another, it cannot be done in any straightforward way. More generally, Basalla has been accused of neglecting the essentially interactive nature of the scientific links that develop between metropolis and province, whereby the science practised at the centre can be powerfully influenced by inputs — usually of new information — from the colonies. He has also been criticized for treating science in isolation and failing as a result to take proper account of the political, economic and social forces that have brought about the changes he describes and that maintain the relationship of scientific dependency even after formal political ties are cut.

He has failed, in short, to take proper account of the ultimately political character of science itself within such a framework of dependency.

Despite such reservations, however, there remains a fairly general consensus that, even in the absence of overt political links, the science practised in a developing country can often properly be described as colonial. Yet what that label implies, beyond the existence of a relationship of dependency of some kind on the science of a metropolitan centre or centres, is a matter of controversy. The precise nature of the relationship seems to vary from country to country and also over time.

In the Australian case, there is universal agreement that after an initial period (corresponding to Basalla's Phase I) in which the only science done was merely an extension of metropolitan science, carried out by temporary visitors from the metropolitan centres, there ensued a period of colonial science characterized, at least initially, by the colonial scientist-collector sending his materials 'home' to Kew Gardens or the British Museum for analysis and description by metropolitan savants. The basis of scientific decision-making and authority remained firmly in Europe; Australian workers could not aspire to become recognized authorities even on Australian materials. Moreover, with no facilities for providing even the most rudimentary training in science — these came only with the founding of the first universities in Sydney and Melbourne in the 1850s — the Australian colonies remained entirely dependent, scientifically speaking, on imported skills. Furthermore, the number of trained people in the country long remained too small to form self-sustaining institutions or to maintain locally based scientific publication outlets.

The same relationship of dependency existed even in sciences such as astronomy and geophysics, where Australia's location in the southern hemisphere gave it peculiar advantages for certain kinds of observing. Here, too, it was not until after 1850 that sufficient Australian resources could be mustered to sustain a significant programme of locally directed scientific work. Until then, Australia served merely as a convenient fixed platform for temporary observatories established under direct British aegis, whether on Dawes Point at Sydney Cove in 1788, at Parramatta under Governor Brisbane in the 1820s, or at Hobart in the 1840s.

The pattern of Australian scientific work changed dramatically during the latter half of the nineteenth century. Though scientific exploring remained important, this now tended to be carried out under local rather than European auspices. Collectors continued to scour the bush for specimens but, as time went by, more and more of the material collected found its way into newly founded Australian museums of natural history. Furthermore, the notion, perhaps first expressed by Leichhardt in the 1840s, that type specimens and other reference or unique materials ought to remain in or at least return, after description, to Australia, came to be increasingly widely held.[4]

The second half of the century saw the establishment in the various colonies of a range of other scientific institutions besides museums, all of them now under local control. The founding of universities in Sydney and Melbourne has already been mentioned; Adelaide and then Hobart later followed suit, as did Brisbane and Perth shortly after the turn of the century. Initially, only a liberal

arts course centred on the classics and mathematics was provided but the sciences were also strongly represented in the curriculum from the outset. In time, separate laboratory-based degree courses in science and engineering were introduced and also, in the larger universities, degrees in medicine.

In addition, a majority of the colonies established observatories during this period. Government astronomers, appointed to run them, became dominant figures in colonial scientific circles and were usually responsible not just for astronomical work (including their colony's time service) but also for routine geomagnetic and meteorological observing and for making the fundamental geodetic determinations for government survey purposes. In Queensland and Tasmania, where observatories were not established, government meteorologists were appointed instead. Other sciences, too, received support from newly formed colonial legislatures. Several colonies appointed government botanists, of whom Ferdinand von Mueller in Victoria is by far the best known. With rumours of gold in the air, New South Wales appointed a government geologist, albeit only temporarily, in 1850. Victoria set up an excellent Geological Survey in 1852, and most of the other colonies later followed suit. Public health officials were appointed and likewise government analysts to undertake assays and to oversee the quality of water and food supplies.

These developments, together with the increasing numbers of doctors, school teachers and other professional men required to service the waves of immigrants attracted by the gold rushes and their aftermath, led to a rapid growth, especially in the more populous colonies, in the numbers of residents with scientific interests and expertise. Viable scientific societies became a possibility for the first time and were formed one by one in most of the colonies during the middle third of the century. Each colony, sooner or later, came to have a 'Royal Society' patterned after the London model, with its own journal, which became the basis of exchange agreements with scientific societies elsewhere. Such societies provided both suitable outlets for local scientific work and a mechanism whereby local workers could keep in touch more satisfactorily with what was being done in other parts of the world. The growth of public reference libraries in the different colonial capitals also helped in the latter regard.

Nevertheless, Australian science continued to be quintessentially 'colonial' in character, remaining largely observational and descriptive in style rather than experimental and laboratory based, and being concerned almost exclusively with local questions rather than with topics of more general relevance. Furthermore, scientists in the different colonies remained more or less isolated from each other. For intellectual support and encouragement they generally looked not to their fellow colonists but to the scientific community 'at home' in Britain, and if they did venture on to topics of more than local concern, it was to the English journals rather than their local Royal Society transactions that they sent their work for publication — naturally so, because that was where the relevant readership was, not in Australia.

An important change in attitude can be discerned during the 1880s. It was during this decade, for example, that the universities in Sydney and Melbourne dramatically expanded their commitment to science. (The much

smaller University of Adelaide followed suit 15–20 years later.) Talented new professors and lecturing staff, mostly from Britain, were appointed and new laboratories were constructed. Soon, the first research students appeared. Furthermore, many of the new professors were already active researchers, with a mind to keep it up; and their interests were by no means confined any longer to local questions. Publications by them and their students began to appear with increasing frequency in the international journals.

The impact of a number of science-based technological advances also first began to be felt during this period. The first telephone services were introduced in the larger cities, as well as the first municipal electrification systems. Chemical and metallurgical industries mushroomed. Major improvements in public health services followed the general acceptance of the germ theory of disease. Soon afterwards, science began to be applied in the countryside as well, through the establishment of scientific services within colonial departments of agriculture.

In addition, Australian scientific workers were now somewhat less isolated than they had been. The introduction of steamships and the opening of the Suez Canal had halved the time of the journey from Europe. The resulting improvement in the mail service made it possible for the first time for scientific workers in Australia to keep reasonably up to date with the international journal literature in their field and even to take part in some cases in scientific debates in the pages of journals such as *Nature*. Within Australia, improvements in transport helped to bring scientists in the different colonies closer together and made possible the formation of the first inter-colonial scientific organization, the Australasian Association for the Advancement of Science (AAAS), founded in 1888. The Association at first met roughly annually, later at approximately two-year intervals. Its meetings quickly established themselves as the highlight of the Australian scientific calendar, offering those attending welcome opportunities to exchange opinions and establish a basis for subsequent correspondence. They remained so until the growth of specialist societies, especially in the years after the Second World War, challenged the association's hegemony.

The Australian scientific community remained small, however, and the imperial connections continued strong. Even in 1939, Australian scientists tended to see themselves and their work very much within the context of a larger British scientific network. Travelling scholarships such as the 1851 Exhibition science research awards (established in 1891) and the Rhodes scholarships (established in 1904) strengthened the links by taking many of Australia's best young science graduates to England for further training. A significant proportion, including some of the best of them, did not return.

Several chapters in this book explicitly take up questions concerning Australia's scientific links with Britain and, in almost all of the chapters, such questions are present implicitly. Indeed, they can scarcely be ignored, and much work remains to be done adequately to explore their ramifications for the history of Australian science. Scientific work, the production of new scientific knowledge, is an inherently social process if for no other reason than that such knowledge needs to be certified by the wider scientific community of the day. Certification, however, implies authority, something that was long

denied the small and scattered groups of Australian scientific workers. For example, when data on the southern skies collected at Sydney's Parramatta Observatory were found to disagree with those recorded by Sir John Herschel during a visit to the Cape of Good Hope, the immediate (and subsequently justified) assumption among the world's astronomers was that the Sydney observations must be in error.[5] Likewise, though there had been many reports from Australia that monotremes laid eggs as well as suckled their young, it took a telegram from a visiting British authority, W.H. Caldwell, to convince the zoologists of Europe.[6] The story of colony and metropolis is thus, in science as in so much else, a story of a struggle for authority. Meanwhile, the strong political and cultural ties with Britain ensured that the authorities to whom Australian scientific workers looked were British rather than, say, French or German.

A major contributing factor to the maintenance of power relations of this kind was the chronic isolation of Australian scientific workers. Active scientists need to interact constantly with their fellows, exchanging information, opinions and ideas and drawing encouragement from such contacts. They need such exchanges to publicize their work and to offer it up for certification. In most scientific fields, however, such interaction was long impossible in Australia because there were too few scientists and those few were too widely scattered among the major population centres. The formation of viable scientific societies in the various colonies in the second half of the nineteenth century was a first step towards facilitating interchanges, but it usually remained the case that, at best, only a tiny handful of active workers could be mustered in any particular scientific field, even in Melbourne or Sydney. The establishment of AAAS created opportunities for occasional meetings with larger groups of specialists. Being relatively infrequent, however, such meetings scarcely constituted an adequate solution to the problem. For the most part, individual Australian scientists were thrown back on their own devices. Lacking the support of informal networks of intellectual exchange such as their peers in the metropolitan scientific centres enjoyed, their only recourse was to do the best they could, alone, and then submit their work directly to formal scrutiny by the metropolitan authorities.

In these circumstances, it is small wonder that most Australian scientists continued to focus their attention, as Fleming has noted, on questions arising from the local natural environment. Here, they could retain (or establish) a measure of intellectual control; occasionally, as von Mueller did, they could even themselves gain the status of authorities in their special fields.

Once they took up more general questions, as W.H. Bragg did in 1903–4 when he embarked upon a major investigation of the ionizing radiations emitted by radioactive substances, they found themselves almost literally on their own. Through attending the AAAS congresses regularly, Bragg had already built up a network of friends and correspondents within Australia's nascent community of physical scientists. Once fairly launched on his study of radioactivity, he exploited this network by sending out drafts of his paper for comment. The responses he received offered encouragement and some useful criticism. None of his correspondents were researching similar problems, however, and hence no-one was able to go beyond this and provide detailed,

penetrating feedback such as Bragg now needed. Where friendly exchanges with fellow physicists had previously sufficed, these were no longer enough. Bragg was now suffering, as have a number of other scientists working in Australia who have reached the first rank in their particular fields, from a more refined form of isolation, 'the isolation of the élite'.[7] Until relatively recently, if an Australian scientist reached the top rank in his or her speciality, there was virtually no chance that there would be another researcher within striking distance within Australia who was equally knowledgeable in that speciality. Yet researchers working at this level seem to feel, quite acutely, a need for close and regular personal contacts with other leading researchers in their field. Bragg's response to the new situation in which he found himself was all too characteristic of scientists working 'on the periphery' — he sought a job in England. As he wrote to Ernest Rutherford, the unquestioned leader of research in his field: 'I would be glad to go to England for many reasons: you must not mind my saying that one of these is to be near people like yourself'.

During the 1914–1918 war, Australian scientists, like their compatriots from other walks of life, flocked to support the allied cause. Scientific work was not a reserved occupation, and many scientists simply joined the fighting services. In some cases, however, their special skills were recognised by the authorities. For example, many Australian chemists were recruited to go to England to help to develop the munitions industry there, while Australian geologists, working as miners under the leadership of Sydney's Professor Edgeworth David, performed remarkable service in the trench warfare on the western front.

For many of the Australians involved, the war brought with it a heightened sense of their Australian-ness. In its aftermath, several new and consciously Australian institutions claiming nation-wide coverage and authority were founded — the Australian National Research Council, the Australian Chemical Institute (later the Royal Australian Chemical Institute) and the Institution of Engineers, Australia. Nevertheless, throughout the 1920s most Australian scientists continued to see themselves within a larger, imperial framework.[8] The popular vision of an integrated imperial economy in which Britain possessed the factories while the Empire supplied the raw materials and markets for the finished goods implied that Australian scientists would concentrate on fields relating to agriculture and mining, whereas the British would concentrate on sciences such as physics. The overwhelming emphasis on agricultural research in the early years of the Council for Scientific and Industrial Research (CSIR), formed in 1926, in part reflected this doctrine, though it also reflected the more parochial political and economic circumstances within Australia at the time that had led to the council's creation.[9]

The economic collapse of the early 1930s brought an end to imperialist dreams of this kind. Already, however, local needs had been working against them. CSIR's charter explicitly envisaged the organization's undertaking research that would assist manufacturing as well as the agricultural sector, especially through the establishing of physical and engineering standards. An early and highly successful involvement in radio research led the way in non-agricultural research. Then during the late 1930s, as war clouds gathered

again and Australia began at last to build up its manufacturing capability, major CSIR divisions of Aeronautics and Industrial Chemistry were founded, and also the long awaited National Standards Laboratory.

The Second World War had a much more dramatic impact on Australian science than had the First. With invasion threatening and traditional British sources of supply cut off, Australia was forced to look to its own resources for essentials that had always previously been imported. As the existing science-based industries such as munitions and electronics expanded, they demanded more and more scientifically trained staff. University scientists worked to create new industries where none had existed before in fields such as pharmaceuticals and optical components. Physicists and engineers were recruited in large numbers to work on a new invention of strategic importance — radar. By war's end, it was clear that Australian science had undergone an irreversible change in line with the general industrialization of the nation's economy. The number of scientists working in all fields had greatly increased, and the demand for their services did not decline with the coming of the peace. Moreover, no longer did Australian science look quite so automatically to England for leadership and research opportunities. For some, the United States had become an enticing alternative, but others looked forward to Australia making its own, independent contribution to the new, scientific age that seemed to have been ushered in with the explosion of the first atomic bombs and the promise of 'atoms for peace'.

The post-war period saw a continued rapid expansion of Australian scientific institutions. CSIR, reconstructed in 1949 in the wake of a savage and unprincipled political attack as the Commonwealth Scientific and Industrial Research Organization (CSIRO), remained pre-eminent as it spawned more and more divisions. The majority of these conducted research in areas related to primary industry, but those relating to manufacturing industry also grew in numbers and strength.[10] No longer, however, did the organization confine itself to the applied research envisaged by its creators. Instead, it was urged that the ideal for CSIRO was something closer to a 50–50 'mix' of applied and basic research. University research likewise expanded, at first as a result of the creation of the Australian National University (ANU) in Canberra, later with the injection of Commonwealth funds on a large scale into the state university system. The commitment of the universities to post-graduate education grew steadily following the introduction of the PhD degree in the late 1940s. The increased funding made available by the Commonwealth government in the 1960s led to the development of substantial research schools in several of the state universities as well as at ANU, and a general enhancement of research activity throughout the system. As a result, young scientists no longer needed to go abroad to complete their training. The local scientific community had at last become self-sustaining.

Moreover, there were many more job opportunities for science graduates outside CSIRO and the universities than there had ever been before. The Department of Defence emerged as a major employer of research scientists, as did the Australian Atomic Energy Commission, established in 1955. In the area of medical research, several small existing privately or semi-privately

funded research foundations, the best known of these being Melbourne's Walter and Eliza Hall Institute of Medical Research, expanded dramatically. Together with the new John Curtin School of Medical Research at the ANU, they earned the nation an enviable reputation in this field that was crowned in the early 1960s by the award, in quick succession, of Nobel Prizes for medicine and physiology to two Australian scientists, F.M. Burnet and J.C. Eccles. In some other fields, most notably radio astronomy, Australian scientists found themselves in the vanguard of world research. In almost all fields, they could now hold their own.

During these same years, the impact on Australian society of new, science-based technologies became ever more pervasive. Revolutionary changes in communications[11] and, more recently, the rapid spread of computer technology are but the most visible signs of a thorough-going invasion of science into all aspects of daily life. This has been accompanied by — indeed, has been dependent on — a rise in the level of scientific and technical skill in the general population, much of it provided, as in earlier periods, by waves of immigrants entering the country. The degree of scientific and technical sophistication of Australia's manufacturing and service industries is now incomparably higher than it was in 1945. The primary sector, too, has been transformed and its productivity dramatically enhanced under the impact of modern science.

Yet in comparison with most other countries, in Australia scientific research remains confined to a disturbing degree to public institutions. Though Australian science has attained a high level of achievement, Australian industry has failed to keep pace. The longstanding tendency of the nation's manufacturers to purchase the results of foreign industrial research rather than investing in such research themselves, and to limit their horizons to import-replacement manufacturing rather than looking to export markets, has left their companies vulnerable and ill-equipped to meet foreign competition in a manufacturing environment increasingly dependent in the 1980s on the exploitation of new scientific discoveries and techniques. It remains a moot point whether Australia can build a modern science-based industrial economy or whether, in Australia, science will remain on the margins of the nation's economic life.

The chapters that follow open windows on to various aspects of Australia's scientific past. Many of the events described may be unfamiliar to the average reader but they are of considerable historical interest nonetheless. Chapters have been selected in an attempt to provide breadth of coverage both chronologically and in terms of subject-matter. The decision was made at an early stage in the planning, however, that treatment of a relatively small number of topics in some depth was to be preferred to skimming lightly over a greater number. As a result, many readers will doubtless be pained to discover that their own favourite subject has been overlooked. It is to be hoped that publication of this volume will spur them to take up their pens for themselves. In far too many cases, almost everything remains to be done.

'Science' often tends to be equated with 'modern western science', in which case the history of Australian science would begin with the first European contacts. There are, however, other ways of viewing nature's workings besides

the one that evolved in western Europe. People have been living in Australia for at least 40 000 years and, as L.R. Hiatt and Rhys Jones argue below, they learned long ago to classify the objects making up their immediate environment on the basis of a close and detailed knowledge of their properties and behaviour. Many of the categories they enunciated were similar to those later adopted by European scientists, others were not; in either case the Aborigines' systems of classification gave them a remarkable intellectual mastery of their surroundings. Sometimes, non-Aboriginal botanists or zoologists have successfully used knowledge gained from the Aborigines as the basis of their own investigations; in places like Arnhem Land the detailed knowledge that the Aborigines have of the regional flora remains ahead of that of modern science. Aboriginal natural knowledge is, however, embedded in a totemic religious system, an explanatory structure very different from the structure that developed in European science and one that has very different implications as far as the conceptualization and control of nature are concerned. Hiatt and Jones see a tendency for totems to figure as objects of contemplation and argue that, in its more contemplative aspects, Aboriginal totemism represents an attempt to epitomize the structure of the cosmos, based, as was Plato's philosophy, on a notion of archetypes or ideal forms.

It is doubtful whether the first European scientists visiting Australia, convinced as they were of the superiority of both their science and their religion, would have seen any merit at all in Aboriginal totemism, even if it had been accessible to them. In fact, cultural preconceptions and barriers of language and custom long made Aboriginal patterns of thought as inaccessible to those arriving from Europe as the European mode of thinking was to the Aborigines. As Miranda Hughes' account of the interchanges between a group of Tasmanian Aborigines and the French scientists who visited them briefly in 1802 makes clear, mutual incomprehension was the inevitable outcome even when, as in this case, the visitors had come with the best of intentions and explicit instructions to evaluate the native societies they encountered by their own internal standards rather than by European ones. As Hughes indicates, the difficulties of interpretation that the French confronted in studying the Tasmanians are unavoidable in anthropological research. All that one can do is recognize their existence and work to mitigate their effects. As Hughes' discussion of the rival accounts of the Tasmanians prepared by Baudin and Péron reveals, some investigators succeed in doing this more than others.

Hughes' account is valuable from another perspective, too. Histories of 'white' Australia inevitably emphasize the British roots and continuing British connections of the various colonies. The contributions of other European nations, though often significant, are all too frequently overlooked. As far as the scientific exploration of the continent was concerned, the French were particularly active; indeed, the various French sea-borne expeditions, of which the one led by Baudin was probably the most successful of all, achieved a great deal more than most of the rival British expeditions. The massive collections of Australian materials assembled on these voyages still survive in France and remain a major scientific as well as historical resource. Hughes' chapter serves to remind us that 'white' Australia was not an exclusively British preserve.

Sybil Jack's concern is not, however, with the assembling of collections of Australian materials for study by the scientists of Europe, but with the growth of scientific consciousness among the early white settlers in Australia. The structure of society and the conditions of life in the early colonial period were, she argues, generally unfavourable to science. The attitude of the governing classes was crucial, but for the most part the government did not encourage the pursuit of science. There was no substantial leisured class, some members of which might take up the subject, and neither were there sufficient professional men with scientific interests. Jack challenges the accepted, more positive assessments of early Australian science. Throughout the period to 1850, in her view, science made very little headway in establishing itself in Australia's white settler community.

The story is very different in the years after 1850, when colonial science rapidly increased in strength and international standing. Two chapters focusing on different but overlapping periods consider in detail the relationship between metropolis and province in nineteenth-century science. Robert A. Stafford describes the manifold lines of influence whereby the British geologist Sir Roderick Murchison promoted the geographical exploration, scientific investigation and settlement of the Australian continent for the greater glory of the British Empire. He shows at the same time how Murchison's defence of his own geological theories, developed in a quite different part of the world, long shaped the development of Australian geological understanding. Murchison emerges as one of the greatest of all patrons of imperial science, rivalling or even surpassing in influence Robert Owen at the British Museum and the Hookers, father and son, at Kew Gardens.

The Hookers play a major role in A.M. Lucas' account of the career of nineteenth-century Australia's greatest scientist, Ferdinand von Mueller. Lucas shows, on the one hand, how Mueller drew support and intellectual sustenance from the Hookers and other leading British botanists and men of influence and, on the other, how he himself dispensed patronage to collectors and others who assisted him throughout the Australian colonies. Mueller rendered thanks to his patrons and encouraged his proteges by naming species or geographical features in their honour. As an active explorer and, later, patron of exploration, and as the country's pre-eminent taxonomic botanist, he had every opportunity to dispense favours of this kind. Once himself elected to learned and scientific societies, he also had the opportunity, of which he made extensive use, to honour friends and acquaintances by nominating them, too, for membership. Not only, then, did the patronage system link metropolis to colony in nineteenth-century science, it also here played an important role in generating support for science within the colonial environment itself.

The chapter by Ian Inkster and Jan Todd is likewise concerned with the support for science in the Australian colonies in this period and, more generally, with the place of science in colonial society. Inkster and Todd highlight the 'utilitarian and localized profile' and 'pragmatic empirical emphasis' of most Australian science during the second half of the 19th century. Few Australian scientists, they suggest, took on the wider intellectual and cultural responsibilities of their European counterparts.

Inkster and Todd stress the importance for the scientific enterprise of larger movements in the economic and social structures of the various colonies. The boom of the 1850s and the accompanying rapid increase in population, especially in Victoria, the subsequent narrowing of the resulting economic gap between Victoria and New South Wales, the growing prosperity of South Australia, the boom of the 1880s and the depression and subsequent recovery of the 1890s all directly affected the level of colonial scientific activity. So too, they argue, did the infrastructure of cultural institutions, especially mechanics' institutes, that generated support for science within a broad spectrum of the colonial population. Within the institutions of science itself, it was not until the 1880s that the preoccupation of colonial scientific societies with 'pragmatic issues of development' began to give way to 'a more consistent offering of original scientific papers'. Finally, they argue on the basis of a number of case studies that in the period from the mid-1890s to around 1910, there was a significant change in the nature of Australian economic development, and that this was based on efficiency gains deriving from specific applications of scientific knowledge. Science came to be recognised at about this time, they suggest, as a potential asset rather than a mere commodity.

Two other chapters consider developments in Australian science in its colonial heyday in the second half of the 19th century. Barry W. Butcher focuses on a public dispute between the founding professor of Australia's first medical school, George Britton Halford, and the famous British naturalist, Thomas Henry Huxley. He shows that although this was ostensibly over certain points of detail in the comparative anatomy of monkeys, gorillas and Man, it was in reality part of a much larger 19th-century debate over Man's place in Nature. Abstruse questions of taxonomy are shown to be no mere matters of fact but to be inextricably bound up with the taxonomist's more general philosophical stance.

In the wake of the publication of Darwin's *Origin of Species*, the debate between Halford and Huxley and their respective supporters could perhaps have occurred anywhere in the then scientific world. However, Butcher shows how, in certain respects, its course was mediated by the colonial environment in which Halford was working. In particular, he points to the very different reactions of metropolis and province to Halford's contributions to the discussion. In the small colonial scientific community, the newly arrived professor achieved a great success by defending a position that had broad support from local social and intellectual élites. He did so, however, only at the expense of his scientific reputation internationally. Arguments developed for and applauded by a colonial audience were found seriously wanting when read by his scientific peers in Britain. Butcher does not speculate on why this should have been so, but the question is worth asking, nevertheless, especially when one recalls that almost all the leaders of Melbourne intellectual life at the time had themselves but recently arrived from Europe. There are important implications here for our understanding of the nature of scientific authority and of the way in which this is achieved.

George Bindon and David Philip Miller take up one of the questions raised in the chapter by Inkster and Todd, namely the conditions governing the

successful application of science to industrial production in a peripheral economy such as that of late 19th-century Australia. They do so by considering the remarkable case of the growing influence of a cadre of chemists within the Colonial Sugar Refining Company (CSR), the Australian company that came to dominate the sugar industry in the south-west Pacific region during this period. The relative paucity in Australia in more recent times of industry-based or industry-financed research and development has become a matter of notoriety. Bindon and Miller show how, in the case of CSR in the late 19th century, an 'aggressive innovative strategy' based on the work of the company's chemists became an integral part of the company's approach and in the process transformed the economic circumstances not just of CSR but of the entire Australian sugar industry. The science involved was not in any sense fundamental research; indeed, much of the work was routine testing and analysis. What was significant was the way in which scientific techniques were appropriated in a systematic way to bring about major improvements in the efficiency of the production processes employed by the company. Chemists skilled in the requisite techniques were initially imported from Europe without the company being really aware at first of their potential. Later, they were trained within the company. Strikingly, there was almost no input from Australia's institutions of higher education or from other support structures of late 19th-century Australian science identified by Inkster and Todd.

This study by Bindon and Miller raises a number of questions of long-term significance about Australian science in its relations with industry. Was CSR unique in launching a successful programme of industrial research and innovation at this period? It certainly appears to have been. Why was this so? Why did other sectors of Australian industry then and subsequently fail to create equally innovative enterprises? And why was there, even in the case of CSR, so little interaction with the nation's universities and other institutions in which scientific knowledge and manpower were supposed to be created? There is a striking contrast here with what happened in Germany and the United States, in particular.

Finally, this chapter brings home the importance, in studying the history of science, of not confining one's attention to the 'high flyers' of scientific research. Especially in the case of nations on the scientific periphery where genuine high-flyers are relatively scarce, doing so has degenerated all too often into hagiography of the second-rate. The work of Bindon and Miller shows that important insights for the wider history of the nation can flow from adopting a less élitist stance.

The same may be said, in respect of a later period, of the chapter by Hugh Hamersley, which charts the rise during the 1920s and 1930s of new, medically orientated career opportunities for physicists in Australia. These arose in connection with the spread of radiotherapeutic methods for the treatment of cancer. Hamersley shows how the development of the new techniques led to a recognition that the services of specialist physicists were required to oversee standards of dosage and the physical measurements associated with treatment, and how, in the process, the Commonwealth was able to expand its influence in comparison with the states in this new area of public health responsibility.

By tracing the sorry history of the research undertaken under the aegis of the University of Sydney's Cancer Research Committee, Hamersley also highlights some of the difficulties confronting any attempt to establish a major scientific research programme in Australia at this period. The techniques of scientific research are not easily learned from books. They include a substantial element of craft knowledge that is best learned through apprenticeship to an established top-rank researcher. Unfortunately, none of the University of Sydney professors who unexpectedly found themselves responsible for administering huge sums of money contributed by the public for cancer research had had that kind of experience, which at the time could only be acquired by going overseas. The same problem would have arisen at most other Australian centres at that time. Though those involved doubtless did their best, they were out of their depth. Major commitments were made in regard to the investigations to be pursued where a more research-wise group would almost certainly have adopted a more sceptical and cautious approach; and, as the research programme expanded, there was no-one who could adequately supervise the work or provide the leadership that the mostly young and inexperienced researchers who had been engaged to do it required. By the time someone who had had experience of high-level research, the young physicist V.A. Bailey, joined the group, the major decisions had already been made. Bailey's doubts were over-ridden and, soon afterwards, he severed all links with the work. Within a few years, the entire research programme disintegrated, leaving almost nothing to show for the huge sum of money invested in it.

There is a striking contrast between this story and that of Melbourne's Walter and Eliza Hall Institute of Medical Research, which is a principal focus of the chapter by F.C. Courtice. During the same years in which Sydney's Cancer Research Committee floundered, the Hall Institute went from very modest beginnings, with vastly fewer funds at its disposal than were available in Sydney, to become a significant centre of research with a growing international reputation. The difference cries out for explanation, which seems to lie in the different calibre of scientific leadership in the two cases. Whereas in Sydney the research programme was directed by a committee, no member of which had worked for any length of time in an active research environment, at the Hall Institute the direction was for many years in the hands of a single, strong individual, C.H. Kellaway, who had himself worked in several of the world's leading research centres in his field. Kellaway exercised direct personal control over the Institute's research programme, he recruited some outstanding young scientists, including F.M. (later Sir Macfarlane) Burnet, and he made sure that in due course they too had an opportunity to gain experience in leading laboratories in Britain. Under Kellaway's leadership and later that of Burnet, the Hall Institute went from strength to strength, culminating in the award of a Nobel Prize to Burnet in 1960 for his work, done at the Institute, on acquired immunological tolerance.

The rise of the Hall Institute is, however, but part of the wider theme of Courtice's chapter, which charts the growth of Australian medical research from the days of J.T. Wilson and his school in Sydney in the 1890s to the 1960s. During that time, Courtice argues, Australian medical science achieved

national independence. In earlier days, as he shows, Australian medical scientists were crucially dependent on their links with leading researchers in England for both their advanced training and, more generally, to help them maintain contact with the leading edge of research in their respective fields. Wilson himself and most of his group came from Britain and all eventually returned there. One of the group, C.J. Martin, in due course became a key figure linking Australian and British workers and research institutions. Later, Kellaway's teacher, Sir Henry Dale, played a similar role. Independence came in the years after the Second World War with the expansion of a number of previously small institutes, including the Hall Institute, and the foundation of the John Curtin School of Medical Research at the ANU. Now, for the first time, Australia could provide sustained opportunities for front-rank research in several fields of medical science. Instead of promising young Australian medical scientists having to go overseas to learn the most advanced techniques, Australian institutions began attracting outstanding young researchers from other parts of the world. Burnet's Nobel Prize and that awarded to J.C. Eccles three years later for his work on the transmission of nerve impulses not only rewarded outstanding individual achievements but also provided public recognition of Australia's new-found standing in this field.

The chapter by R.L. Burt and W.T. Williams charts the rise to maturity of a very different category of Australian scientific work, dealing with the controlled introduction of new plant species into Australia. Their concern, however, is not so much the emergence of a self-sustaining high level of Australian research in this field — though this is implicit in the story they tell — as the application of increasingly scientific methods to the age-old question of the transfer of plant and animal species between different parts of the globe. In particular, they contrast the more-or-less undisciplined importation of new plant species into Australia in the period prior to 1930 with the increasingly systematic effort made thereafter to identify, and then establish in Australia, useful and much-needed cultivars that did not at the same time threaten to become pests in the way that, earlier, blackberry and prickly pear had done.

Burt and Williams see the formation in the late 1920s of a Plant Introduction Section as one of the original units within CSIR's Division of Economic Botany (soon re-named Plant Industry) as an important step, which for the first time provided some co-ordination of Australian activities in this area. However, it is to the years immediately after the Second World War that they date the major transformation of the field. Previously, species had been accepted more or less randomly and their utility then investigated. Now, prior ecological and soil surveys enabled specific requirements to be laid down for new plant types, which were then sought out on plant-hunting expeditions sent in increasing numbers to other parts of the world. Detailed classificatory and recording schemes essential to such work were developed. More recently, Australian scientists have participated in the establishment of genebanks for various cultivated plants. Though the ownership of genetic resources has in recent years become a matter of considerable international sensitivity, Australia's record, Burt and Williams argue, of making germplasm freely available from its collections, has been good.

This is not the only chapter in which the Second World War appears as a major turning point in the history of science in Australia. The chapter, 'Science on service, 1939–1945', focuses on the war years themselves and the impact of the war on Australian science, and points, in particular, to a shift in the balance of the nation's scientific power that occurred at this period. Prior to the war, the agricultural sciences had dominated the Australian scientific scene, most obviously in the emphasis given to them within CSIR. The growth of Australian manufacturing industry that began in the 1930s and accelerated dramatically during the war led to a great expansion of activity in the physical sciences, even as agriculturally orientated research was held temporarily in check. After the war, the situation did not revert to its pre-war state; on the contrary, the major shift that had occurred in the distribution of Australia's scientific resources was maintained in the peace.

During the war, it is argued, much of the work that was done by Australia's scientists was not front-rank research but was of a fairly routine problem-solving kind associated with the build-up, under war-induced 'hot-house' conditions, of the nation's manufacturing capacity. In many cases, the scientists in their laboratories themselves became directly involved in production. The numbers of people engaged in scientific work expanded rapidly. Young graduates (or even undergraduates) were pressed into the work without prior training in research, on the assumption that this could be provided later. Large new physical-science laboratories mushroomed, especially within CSIR, devoted for the time being to essential war-related work but in advance of any clear idea of how they would relate to the needs of Australian industry once peace returned. Hence, on the one hand, the war led to a rapid rise in Australia's level of scientific and industrial sophistication, but on the other, it both created short-term problems that had to be resolved once it was over and opened up major new issues of long-term science policy.

The chapter by Woodruff T. Sullivan, III, describes in detail how one of the biggest new CSIR divisions, the Radiophysics Laboratory, made the transformation to peace-time conditions and, in the process, became a world leader in a brand-new field of scientific research, radio astronomy. Sullivan surveys the Laboratory's exciting achievements in the first few years of radio astronomical research and provides an evocative picture of the way the work of the radio astronomy group was organized by its leader, J.L. Pawsey, with the support of the Chief of the Laboratory, E.G. Bowen.

The remarkable and continuing success of the Australian radio astronomers during this period raises in a particularly striking way the question of the conditions under which science in a 'new' country such as Australia can come to achieve parity with the established science of the Old World. For in this case Australia unquestionably did achieve parity — indeed, it probably did better than that. Sullivan points to certain structural features of post-war Australian science that led to the large group of radio physicists and engineers that had been brought together for the war-time radar project staying together afterwards rather than dispersing, as happened in the United States and Britain. As a consequence, the Australian radio astronomy group was for some time considerably larger than any other in this field. The old problem of the isolation of the élite, of the outstanding individual scientist remote from his

peers, thus not a problem here. Also, many technicians and a lot of the most advanced electronic equipment of the day were left over from the radar work.

Isolation was still, however, a consideration. Sullivan describes in some detail the measures that Pawsey and Bowen took to ameliorate the problem and to make the Australian work known. At the same time, they had enough confidence in what they were doing to establish a policy of publishing most of the group's results in Australian journals rather than the international scientific journals traditionally used by aspiring scientists on the periphery. Interestingly, Macfarlane Burnet adopted a similar publication policy, at about the same time.[12] For the first time, Australian scientists had attained a sufficient degree of authority in their respective fields to make this declaration of scientific independence.

The chapter by S.C.B. Gascoigne is another story of Australian science attaining independence and maturity. Gascoigne extends the story of Australian radio astronomy beyond the point, in the early 1950s, where Sullivan leaves off; but he does so within the context of a broad survey of Australian astronomy as a whole in the post-war period.

In optical as well as in radio astronomy, the Second World War emerges as a major turning point; and in this field, too, though somewhat more slowly than in the case of radio astronomy, Australian work came to rank consistently with the best in the world. The key was the acquisition of suitable instruments, namely the Mount Stromlo Observatory's 74-inch reflecting telescope and, later, the 150-inch Anglo-Australian Telescope constructed on Siding Spring Mountain, NSW. Radio astronomy, too, gradually became more and more the preserve of the large instrument, and the Parkes radio telescope in particular. As the scale of the instrumentation increased, the telescopes concerned came to be treated as national facilities, open to any researcher who could present a suitable proposal. The whole chapter vividly conveys the excitement of contemporary astronomy and the important role that Australian workers have come to play in this field.

The Anglo-Australian Telescope operates under the control of the Anglo-Australian Telescope Board, one of many new scientific institutions established in Australia in the post-war era to oversee the expenditure of Commonwealth Government funds on scientific research. Prior to the Second World War and for a number of years after it, CSIR/O was the locus for virtually all Commonwealth scientific activity outside the Department of Defence and the rather specialised interests of the Department of Health. When the government needed advice on scientific matters, it naturally turned to its Council for Scientific and Industrial Research, this being one of the purposes for which the Council had been set up in the first place. With the proliferation of Commonwealth scientific agencies in the post-war period and also the increasing commitment of the Commonwealth to supporting scientific research in the universities, CSIRO came to be seen in a very different light, as merely the largest of the government agencies competing for the limited public funds available for science. Its privileged position as government scientific adviser came under increasing challenge from scientists outside the organization who pressed for the formation of a more broadly representative Science Advisory Council.

The final chapter in this volume, by Ron Johnston and Jean Buckley, describes the evolution of Australia's science policy system in response to this growth and profileration of institutions. A further factor they identify is an increasing public scepticism during the 1960s and 1970s about the benefits supposed to flow from untrammelled scientific research. They see a steady expansion of bureaucratic control over science from about 1965 onwards, leading to a seemingly endless series of inquiries, the formation of a Commonwealth Department of Science — the demise of which in July 1987 came too late to be considered by them — and eventually, in 1979, the passage of legislation establishing the Australian Science and Technology Council (ASTEC), which had already existed in interim form for several years.

Contrary, however, to the hopes of those who had first pressed, over 20 years before, for the formation of a body like ASTEC, neither it nor the other elements of science policy bureaucracy that have been established have served to represent the interests of scientists to government. Together with the massive growth of government expenditure on research that has occurred in the post-war years has come an increasing desire on the part of government to control and direct more of that expenditure into commercially exploitable fields of research. Here, it is felt, in the development of new, science-based technologies, lies the key to the restructuring of the Australian economy.

On all fronts, Australian science has gained remarkably in strength since 1945 and has on any reasonable criterion at last established its independence. Many individual Australian scientists do outstanding work that ranks at least on a par with that of the leading scientific nations. Unfortunately, Australia's industrial base has not developed at the same pace. Australia is still producing far too few technically trained people, and far too many of the nation's managerial class are woefully ignorant of matters scientific. These problems, rather than any relating to science itself, are likely to restrict the role of science in Australia's short-term economic future. If they can be resolved, the range of technical expertise and of expertise in working at the frontiers of knowledge that is now available within the Australian scientific community will be found to be a priceless national resource.

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This volume had its origins in the deliberations of the Bicentennial History of Science Committee established by the Australian Academy of Science in 1981 with the enthusiastic support of the then President of the Academy, Dr L.T. Evans, FAA, FRS. It has profited greatly from the support and encouragement of members of the committee and especially the committee's chairman, Professor J.M. Swan, FAA. Other members of the committee were H.C. Bolton, L.A. Farrall, R.W. Home, J.W. McCarty, C.B. Schedvin (until September 1982) and D.F. Waterhouse, FAA, FRS. From the outset, it was hoped that the project would lead not just to the production of a worthwhile book but more generally to a heightened interest in studying the history of science in Australia. To that end, two highly successful conferences were held at the Australian Academy of Science, one in August 1982 with an organizing committee chaired by H.C. Bolton, the other in February 1985, organized by Ian Inkster and David Philip Miller. Financial support for the first of these was provided by the James Kirby Foundation. In addition, a *History of*

Australian Science Newsletter was launched with financial support from the Academy, and a general invitation was issued to scholars at home and abroad to submit manuscripts with a view to their being included in the volume. These manuscripts were then subjected to formal refereeing. In the event, the task of selecting contributions for inclusion in the volume proved a difficult one and several valuable essays had to be turned away.

Vital secretarial support for the project has been provided by staff of the Department of History and Philosophy of Science at the University of Melbourne, especially by Lynne Padgham and Renae Stoneham. Valuable assistance has also been provided from time to time by officers of the Australian Academy of Science, in particular Peter Vallee and Rosanne Clayton. A large number of busy people who must remain anonymous gave freely of their services as referees of the various papers submitted. To all of these, named and unnamed, to Robin Derricourt and Marjorie Pressley of Cambridge University Press, and above all to John Swan, I record my grateful thanks.

Notes

1 Donald Fleming, 'Science in Australia, Canada, and the United States: Some comparative remarks', *Proceedings of the 10th International Congress of the History of Science, Ithaca, 1962*(Paris, 1964), 179–96; p. 182.
2 George Basalla, 'The spread of western science', *Science*, 156 (1967), 611–22.
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6 Kathleen G. Dugan, 'The zoological exploration of the Australian region and its impact on biological theory', in Nathan Reingold and Marc Rothenberg, eds, *Scientific Colonialism*(op. cit., n.3), pp. 79–100; esp. pp. 88–95.
7 R.W. Home, 'The problem of intellectual isolation in scientific life; W.H. Bragg and the Australian scientific community, 1886–1909', *Historical Records of Australian Science*, 6(1) (1984), 19–30.
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10 *Historical Directory of Council for Scientific and Industrial Research and Commonwealth Scientific and Industrial Research Organization, 1926–1976* (Melbourne, 1978).
11 Ann Moyal, *Clear across Australia: A History of Telecommunications* (Melbourne, 1984).
12 Frank Fenner, 'Frank Macfarlane Burnet, 1899–1985', *Historical Records of Australian Science*, 7(1) (1987), 39–77.

PART I:
Early days