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John Henry Carver 1926–2004

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John Henry Carver made distinguished contributions to national and international physics, not only through his research in nuclear physics, atomic and molecular physics, and planetary atmospheric physics, but also as a scientific administrator. His years as the Elder Professor of Physics at the University of Adelaide saw him enter the field of rocket-based atmospheric physics by forging strong links with the nearby Weapons Research Establishment through which he had access to rockets to fly equipment developed in his laboratory and, eventually, to launch a small satellite developed and built by his team. This led to his appointment to the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, which he chaired for the record term of twenty-five years. As an academic administrator he was equally distinguished, serving on numerous boards and committees of the University of Adelaide before moving to Canberra as Director of the Australian National University's Research School of Physical Sciences, a position he held for fifteen years. In addition, he served with distinction on numerous national and international scientific advisory bodies. He was a passionate advocate for his School and his leadership will be long remembered.

John Henry Carver, Elder Professor of Physics at the University of Adelaide from 1961 to 1978, and Director of the Research School of Physical Sciences (later the Research School of Physical Sciences and Engineering) at the Australian National University (ANU) from 1978 to 1992, died on 25 December 2004 after a long illness.

It is illustrative of the many facets of John Carver's distinguished career that five authors were chosen to cover it adequately in this memoir. He was a national and international scientific statesman and a skilled administrator, but first and foremost he was a physicist with broad interests in both nuclear physics and atomic and molecular physics. His switch from one field to the other in mid-career, and his achievements in both, not only reflected his pragmatism, as we shall see later, but also his professional versatility.

Early Days

John Henry (JHC) was born in Homebush, New South Wales, on 5 September 1926, the sixth in a line of John Carvers. The Carver family had been prosperous 'gentlemen farmers' for centuries in the Sessay-Thirsk area of the North Riding of Yorkshire. JHC's great-grandfather was the last of that family to have lived on the land. His death in 1839, when JHC's grandfather, John Carver IV, was only 2, forced the family into difficult circumstances. As a consequence, while

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still a youth, the young John Carver had to seek employment in an industrial town further south. Obtaining his qualification as an engine fitter at Newcastle-upon-Tyne, he then followed his trade in other cities in the north of England. His only son, John Fawdington Carver (JFC), JHC's father, was born in Sunderland, county Durham, in 1877. John Carver IV died when JFC was only 13 years old, so that family, too, was placed in difficult financial circumstances, and JFC was obliged to seek employment at an early age. He quickly rose, however, to become a shop manager before feeling the need to migrate to Australia in 1905, aged 27, for the sake of his wife's health. When she died, JFC was left with two young daughters.

JFC was 48 when he married for the second time. His new wife, JHC's mother, was Flora Heath before her marriage. Flora, born in 1897, was also English, being the daughter of Henry Heath and an English-born mother of Italian and French parents. Henry Heath migrated from England to Australia with his family when Flora was only 11. He eventually established an electrical shop in the Sydney suburb of Rose Bay, trading as Heath and Son. The shop existed until quite recently, although no longer owned by the family.

John's half-sisters were aged 17 and 12 when he was born so they did not figure as prominently in his early childhood as did his younger brother, Ted. Although the boys' educational paths diverged when they were quite young, they remained close during their boyhood and young adulthood and well after the two had embarked on different careers. For the two boys, life in an outer suburb of Sydney seems to have been typical of the uncomplicated lives of lads of their background and era—a life that Ted describes as 'a really happy childhood'. There were ducks and hens to feed, and rabbits to shoot from the sleep-out with a 0.22 rifle given to the boys by their father.

The Carver family lived among a rich variety of people including the 'characters' of their neighbourhood. Reminiscing about those days, Ted remembers having been told that on the day he was born, the doctor who had been called to his mother was asked by one of the neighbours, a 'bushy', to sew on the finger he had just cut off. Not surprisingly, the doctor declined!

John and Ted saw a great deal of their maternal grandparents. The electrical shop in Rose Bay owned by their grandfather was a happy hunting ground and the scene of early experiments, not all of them successful. One of John's caused a blackout in the shop and the immediate neighbourhood! Nevertheless it was perhaps here, tinkering in the shop, mending electrical appliances and some radio sets, that John first got a taste for physics. 'Radio fascinated me' he said later when reminiscing about those early days.[1]

There were also family holidays to the Blue Mountains when the parents, the grandparents and the boys, together with their holiday gear and their English sheepdog Bobby, were all packed into the family's 1926 Studebaker. These were happy and carefree days that laid the foundation for John's close relationship with his own wife and family, who meant so much to him and of whom he was immensely proud.

Carver's early schooling took place at Flemington Primary School. It seems that right from the outset he was a serious student. He went on to what was then Homebush Junior Boys' High School where, in the third year, he took the Intermediate Examination. Then it was on to Fort Street High School for Years 5 and 6 and the award of a university scholarship at the end of his final year. According to Ted, John 'always pushed himself ' and it clearly paid off, as he went through university entirely on scholarships.

It seems that at Fort Street it had been customary for students to go on to study law, but when John went through 'a lot of the bright people were going into science.… Our physics master was a very good teacher.… He taught us to appreciate doing difficult things. In those couple of years we did a lot of laboratory work—complicated and brightening'.

There was an added inducement to enter science. Carver left school with an entrance scholarship to the University of Sydney during the closing years of the Second World War, 'when science—physics in particular—was a very important and glamorous subject. A lot of

[1] This quotation, and those included later without attribution, are from the interview with John Carver recorded for the Australian Academy of Science.

us felt that if we couldn't get into science, we might try engineering or medicine'.

Academic Career

Undergraduate Days in Sydney

John Carver's undergraduate days were both challenging and successful. Concentrating on physics and mathematics, he was accepted into upper streams in both. In the mathematics upper stream 'you got twice as much lecturing material as in the pass class, and you really had to work hard at it'. Clearly he did, as the continuous scholarships through university days attest.

Third-year students of those immediate post-war years benefited from a very intensive course in electronics, giving them knowledge and experience that would serve Carver and many of his fellow students well in their future research careers. For them it was not a case of assembling off-the-shelf electronic units but of building their own equipment from scratch, often from surplus military components that were in abundant supply.

In his third and fourth years, Carver took courses in electricity in gases from V. A. Bailey who specialized in that subject. These gave him a grounding in atomic and molecular physics that was to stand him in good stead in later years. Then followed his MSc year when, joining a research group headed by R. E. B. Makinson, he was introduced to research in nuclear physics. The project he was given necessitated the construction of many different types of Geiger counters, an experience that Carver said he found extremely valuable. To solve the poor performance of one of these devices, he drew on the knowledge he had gained from Bailey's course on electricity in gases. That work led to his first publication (with G. K. White) in *Nature* (1). It was essentially a paper on atomic and molecular physics. In the light of the later development of his career there is a nice symmetry here: his next paper, written while at Cambridge and also published in *Nature* (2), was to be on nuclear physics.

Overseas for Postgraduate Studies at Cambridge

As with other Australian universities, PhD courses were in their infancy at Sydney. They had in fact been introduced only a year or two before Carver left for overseas to continue his postgraduate studies, thus following the path of the ablest science graduates of his time. Learning from his supervisors about the then new ANU scholarships to study abroad, Carver applied for one and was successful. Scholarship holders were to take their higher degree overseas but were expected to return to the ANU upon their completion. Earlier, Marcus Oliphant had spoken to him about opportunities in his department at Birmingham but, persuaded by Victor Bailey's argument that you must 'go to Oxford or Cambridge, otherwise it will be just like going from Sydney to Sydney', Carver elected to apply to Cambridge.

Thus 1949 saw him travelling to England, of course by ship, in the company of others on a similar quest, his tourist-class fare almost completely covered by his scholarship's travelling allowance of £75. There he was met by P. B. Treacy, ahead of him at Sydney by a year and then at Cambridge courtesy of an 1851 Exhibition scholarship. The two were later to become staff members in the same department at the ANU.

At that time Lawrence Bragg was head of the Cavendish Laboratory at Cambridge, and Otto Frisch was head of Nuclear Physics. Carver's first task was to select a supervisor. There was a younger person in the department, D. H. Wilkinson, who was seen as the brightest of his generation and a rising star. Carver chose Wilkinson as his supervisor, even though he was only a few years older than himself. It was the beginning of a fruitful partnership and a friendship that long outlasted the three and a half years that Carver was Wilkinson's student.

Return to Australia and First ANU Appointment

In 1953, with his PhD degree awarded for a thesis entitled 'Some Studies in Nuclear Photodisintegration', Carver returned to Australia to take up an appointment in the ANU's (then) Research School of Physical Sciences, headed by Marcus Oliphant who had moved to Canberra from Birmingham. About a year later, he became one of the first residents of University House when it opened in 1954. He was appointed Bursar of the House in 1955, a post he held until 1958.

Carver had fond memories of those early years at University House, as well he might for it was there that he met his wife, then Mary ('Molly') Fielding. In those early years of the

Figure 1. Three John Carvers at the opening of the John Carver Building, June, 1994. Photo: Darren Boyd/Coombs Photography, Australian National University.

ANU, qualifications for residence in the House were somewhat restrictive but CSIRO scientific staff were welcomed in order to boost the number of residents. Mary, fresh from England to take up an appointment as an entomologist at the CSIRO's Black Mountain laboratories, was among them. Thus 1955 saw the Carvers' marriage, with University House the venue for their wedding reception. In due course they had four children: John, Jane, Mary Ann and Robert. John followed in his father's footsteps and became a scientist. His son John, shown in Figure 1 with his father and grandfather at the opening of the building named in JHC's honour (see later), is the eighth in this line of John Carvers.

Appointed first to the untenured position of Research Fellow in the School's new Department of Nuclear Physics headed by E. W. Titterton, Carver was soon promoted to the tenured position of Fellow, then to Senior Fellow in 1960. Commenting on this period later in a recorded interview with Hazel de Berg, he said:

> the philosophy was, and I certainly believed in it at that time, that we were going to do some quick experiments in nuclear physics, and Oliphant and his team were going to build the proton synchrotron, with which we would all get Nobel prizes by discovering the antiproton as we came in and did a few quick experiments on that. Of course that hasn't quite worked out …
>
> The lab was an exciting place, and the university was an exciting place … because we all believed that it had good places to go, and that it was doing something really good for Australia.

Adelaide Days as the Elder Professor of Physics

Carver's first association with the ANU came to an end in 1961 when he accepted an appointment as the Elder Professor of Physics at the University of Adelaide to succeed Leonard Huxley.

Later in life, he recalled that at that time he had begun to think about his future career in nuclear physics. He had looked forward to the excitement and discoveries that were in prospect with the ANU proton synchrocyclotron, but those prospects were dashed when that project was terminated. World-wide, a new generation of large, high-performance accelerators was commencing operation and it was clear to him that they would provide the new fundamental insights into the structure of matter. Carver had been at the forefront of exciting new research, and he recognized that Canberra would not be in the 'big league' of high-energy physics in the future. He also made it clear in later years that he liked the 'simple' experiments that characterized the early days of nuclear physics, and in 1960 it was clear that they, too, would soon be a thing of the past.

Nevertheless, Carver had not considered applying for the chair of physics at Adelaide until Marcus Oliphant urged him to do so. The decision to apply must have been a difficult one for him. The Physics Department in Adelaide had no facilities with which to carry out research in nuclear physics, nor was there any likelihood of his being able to secure the large funds necessary to start a significant experimental programme. On the other hand, the nuclear physics programme at the ANU was rapidly gaining in strength with the acquisition of more powerful accelerators, and Carver's work in the field was already well known. Nevertheless, ever the pragmatist, he saw not only a major opportunity to run his own show but also, as Oliphant pointed out to him, the research opportunities afforded by the proximity of the

Weapons Research Establishment (WRE), now part of Australia's Defence Science and Technology Organisation (DSTO). WRE was only some 30 km from Adelaide and at that time it was engaged in rocketry through its launch facility at Woomera. So Carver recognized the scientific opportunities presented by three powerful factors: (1) a new field of research, (2) the fact that Woomera was the only rocket range in the world with a good view of the southern sky and (3) the excellent engineering facilities afforded by WRE.

The move to Adelaide would entail his embracing an entirely new research field—a research programme in atmospheric physics based on instrumentation for rockets launched at Woomera and laboratory-based experiments in atomic and molecular physics. Yet after a brush with this field in his early days in Sydney, he had done no subsequent research in it, so in a sense the move to Adelaide would entail starting a new research career.

On his appointment, some shook their heads and wondered at the wisdom of the University appointing such a young professor. Although not yet 35, he was not as young as one of his illustrious predecessors, W. H. Bragg, who was only 23 when appointed. It was a courageous but wise decision that paid off handsomely, not only for him but also for the University.

Carver's style of leadership in Adelaide was through 'walking around', visiting laboratories regularly. It was a source of continuing amusement to his students that these visits seemed to occur at precisely 5 p.m. every time. He was enthusiastic about everyone's research but impatient with slowness, particularly in the writing up of results. On one occasion he presented a group of students with a draft manuscript that he had written on their behalf, simply asking them to fill in the relevant numbers in the appropriate places!

In his seventeen years in Adelaide, Carver enhanced the strength of an already strong department and established strong research groups in atmospheric physics and laboratory-based molecular physics. In so doing, he became a pioneer of space physics in Australia, and was to be instrumental in Australia becoming the fourth country to launch its own satellite from within its own borders. By the time he left Adelaide, he had established an international reputation in both the science and the politics of space research.

Return to Canberra and the ANU

After the successful years in Adelaide it was time for Carver to move on to almost his last, and certainly his most influential appointment. In 1978, he was appointed to the Directorship of the Research School of Physical Sciences at the ANU. His achievements in this role are described later; it was a role he regarded as the most important job in physics in Australia.

Carver retired from the Directorship in 1992. Twice reappointed to the position, he served a record term of fifteen years, a testament to both his success as Director and the confidence his staff had in him. When his appointment came to an end, it was still not quite time for him to end his association with the ANU. The University was thinking its way through new structures, including the future role of the Academic Boards of its two components, the Institute of Advanced Studies and the undergraduate school, known as The Faculties. From 1992 to 1994, Carver was the University's Acting Deputy Vice-Chancellor and Director of the Institute of Advanced Studies. Then, finally, he was able to return to his physics. As an Emeritus Professor in his old School, he continued almost until the time of his death to work on atmospheric modelling, the subject that had fascinated him for some years and to which he had devoted whatever hours he could spare from the many demanding responsibilities he had carried for so many years.

Research in Nuclear, Space and Molecular Physics

Nuclear Physics

As indicated earlier, Carver's involvement in the field of nuclear physics began with his postgraduate studies at Sydney in the late 1940s and continued until the end of his first period at the ANU. This was a transitional period in Australian physics. At its beginning, the building of accelerators and associated detector instrumentation was seen by some as a primary goal, rather than subordinate to any specific physics (nuclear or particle) that might be addressed with such facilities (Home 2006). To some extent this was the product of the lack of funding for research in Australia; it was also because 'discoveries', in the sense of new particles or new phenomena, often came with higher energies—build the machine and the rest will follow.

(a) The Cambridge Years: 1949–53

Carver's years as a student with D. H. (later Sir Denys) Wilkinson in Cambridge were highly productive. His choice of Wilkinson as his supervisor was a wise one. Wilkinson, then himself early in his career, was an imaginative experimentalist with a profound theoretical understanding whose interests crossed the sometimes vague boundary between nuclear physics and elementary particle physics. He subsequently gained considerable stature in nuclear physics and is now seen as a doyen of the field.

Carver's project centred on measuring the energy dependence of the photodisintegration of the deuteron as a means of pinning down the effective range of the triplet neutron-proton nuclear interaction. Carver used low-energy proton beams of about 1 MeV from a Cockcroft-Walton high-tension set to generate relatively high-energy γ rays from resonant reactions such as proton capture or (p, α) reactions in specific nuclei. There seems to have been some urgency about completing the measurements before the high-tension sets, which were old and subject to frequent breakdowns, finally gave up!

The secondary beam of γ rays was used to bombard a gas proportional counter containing highly purified deuterium at high pressure. This novel counter, constructed by Carver, acted as both the target (the deuterium nuclei) and a detector for the protons that were emitted when deuterium disintegrated into its constituent proton and neutron.

In his own words:

> It was an unusual counter. As is common, it had a very fine wire down the centre. But it was quite novel – no other counter operated at this sort of pressure – and I wanted to have only one insulator, just in one end, and then a wire with a plumb-bob on the end of it. You had to set it up in the vertical. We had 100 yards to go from the old Cavendish, where I built it, down to the ground floor, out in the rough corridor and then across the courtyard to where the accelerator was. But I always got it there eventually, and didn't break the wire.

It seems that 'eventually' may have been a key word in Carver's account. Remembering those days more than fifty years later and commenting on an episode with one of the counters as an example of Carver's 'unflappability', Denys Wilkinson's recollection, as recorded in a letter to one of the authors, is a little different:

> At the end of the purification process, John picked up the device to take it to the accelerator a little too enthusiastically for the delicate 40 μm wire which snapped, the weight falling to the bottom of the counter with a merry clank. I was horrified, and expected John to commit *hara kiri* on the spot. He rather smiled and said 'Start again'. I felt like strangling him, but loved him ever since. Nowadays I suppose one would say (if one used such expressions) that he was, at his early age, remarkably laid back.

There were half-a-dozen cases of reactions that could produce discrete gamma-rays over a useful range, from the 4.4 MeV gamma-rays emitted in the ^{15}N(p, α)^{12}C* reaction to the 17.6 MeV γ rays from the ^{7}Li(p, γ)^{8}Be reaction. The reactions had to be characterized, the absolute photon flux defined and the absolute efficiency for detecting the photoprotons measured (2, 3, 6). As well as the specific interest in the case of deuterium, that was seen as a fundamental problem, Carver and Wilkinson, together with R. D. Edge, used the 17.6 MeV photons to study the photodisintegration of heavier nuclei such as ^{40}Ar (another gas) and more complex nuclei such as ^{181}Ta (4, 5, 7, 8). (Photodisintegration is the process of exciting nuclei with γ rays to sufficiently high energies that the nuclei decay by emitting nucleons, sometimes protons but principally neutrons.) The high probability for the emission of both protons and neutrons from such reactions gave hints of a nuclear phenomenon that had yet to be fully articulated but that was likely to warrant a general explanation. Photonuclear research and the properties of what became known as the Giant Dipole Resonance (GDR) quickly became a major field internationally and was the basis of much of the research carried out by Carver in Canberra.

(b) At the ANU: 1953–61

John Carver returned to the ANU in 1953 as a Research Fellow, at a time when the first PhD students arrived to carry out their research in nuclear physics at the ANU itself, rather than as ANU students with scholarships in the UK (usually at Cambridge, Oxford, Birmingham or Glasgow). In the fledgling Nuclear Physics Department, an arsenal of accelerators and detection systems was gradually growing under E. W. Titterton's leadership, in parallel with Marcus Oliphant's grand vision of building a 2 GeV cyclo-synchrotron that now resided with Oliphant in the Department of Particle Physics. Here, Carver and his students and collaborators became the almost exclusive users of another Cockcroft-Walton accelerator known as HT1 (to be followed by HT2). As in Cambridge, he used proton-induced reactions to produce photons of discrete energies for photodisintegration measurements (9–12) while, on the way, exploiting his understanding of detectors to develop new techniques.

In due course, Carver, Edge and later W. Turchinetz established a more extensive programme of photon-induced measurements using a 33 MeV electron synchrotron obtained as a gift from the UK Government in 1955 following negotiations between Titterton and J. D. Cockcroft at Harwell. This was a fortuitous and productive development for Carver because it not only allowed him to continue to build on his research at Cambridge, but also gave the group a competitive edge since the maximum energy of the synchrotron (33 MeV) was considerably higher than that available to many other groups, commonly less than 22 MeV, from betatrons. These accelerators produce a continuous spectrum of photons up to the energy of the accelerated electrons (bremsstrahlung) so they provide a much higher flux, more flexibility and a higher energy range than the resonant proton-induced reactions. There is, however, the disadvantage that the photon energy is not discrete. Hence it was important to be able to define the shape of the bremsstrahlung spectrum (14) and it became increasingly a challenge for those working in this field to extract reliable differential cross-sections as a function of energy from such integral measurements, a key requirement for exposing the underlying nuclear structure.

Carver used photodisintegration as a way of studying both the properties of the residual nuclei that were the product of the disintegrations, and the properties of the original target nuclei, mainly using activation. He developed a wide variety of techniques for the detection of low- and high-energy γ rays and β particles including, unusually for the time, γ–γ coincidences. This led, for example, to the observation (16) of collective rotational bands in the nucleus ^{178}Hf, one of the first cases observed of an experimental phenomenon that eventually led to the unified nuclear model developed by Bohr and Mottelson in the mid-to-late 1950s (see Bohr and Mottelson 1969).

Carver's interests, however, were less in the nuclear structure and more in the photodisintegration process itself. To this end, he and his group carried out comprehensive studies aimed at defining the competition between single and multiple emission of nucleons at relatively high energies (13, 15, 18, 19). These studies stimulated his interest in the problem of the angular-momentum dependence and associated statistical descriptions of nuclear level densities, leading to measurements of both the photodisintegration process and the inverse process, known as radiative capture. Some of these were carried out with G. A. Jones while Carver was on leave at the Atomic Energy Research Establishment, Harwell, UK in 1958–59 (20–23, 27, 28).

The main focus of much of the field at the time, however, was the study of the Giant Dipole Resonance in heavy nuclei, and the search for evidence of the effects of nuclear deformation. In comprehensive studies on a range of nuclei, Carver and his group confirmed that the resonance was indeed broader in spheroidal (that is, deformed) nuclei than it was in spherical nuclei, but as reported in the main publication (17) in 1959, they did not observe the predicted splitting of the resonance into two more-or-less distinct parts.

In the abstract of their paper, Carver and Turchinetz stated that 'the giant resonance … measured in this way … shows no evidence for the splitting into two components …'. Discovery of splitting in ^{181}Ta via direct neutron counting rather than activation is now credited to the group of B. W. Spicer at the University of Melbourne (Spicer *et al*. 1958) and to E. G. Fuller and M. S. Weiss of the National Bureau of Standards in Washington (Fuller and Weiss 1958) whose work was more prominent than that of the Melbourne group. Such a splitting is now accepted as a general phenomenon in deformed nuclei. There was a touch of irony in this development, given the competition that then prevailed between Canberra and Melbourne.

In 1958, Titterton obtained funding for a new tandem electrostatic accelerator that was eventually, as in other laboratories around the world, to be the catalyst for a change in the research direction of the Department. Titterton farmed out responsibilities for establishing the new accelerator and associated target areas to the permanent academic staff, with Carver designated to organize the control room. However, by the time the new machine was formally opened by the Prime Minister, Sir Robert Menzies, in May 1961, it was approaching the time when Carver was to leave the ANU to take up his appointment in Adelaide.

Rocket-based Atmospheric Physics Research in Adelaide

On taking up his new appointment at the University of Adelaide, Carver set out to pursue his new research vision. It was at this point that he changed his research field from nuclear to molecular physics. Ahead of his time, his chosen theme concerned radiative effects in planetary atmospheres. It was to be a two-pronged programme involving space research underpinned by laboratory-based spectroscopic studies of atmospheric molecules using vacuum ultraviolet radiation.

To further his space research objectives, Carver set about establishing close relations with WRE in nearby Salisbury. At the time, space physics was a risky form of science. Sounding rockets had been used for about ten years to explore the atmosphere. Later, more reliable earth-orbiting satellites were used, but the first such satellite, Sputnik 1, had been launched by the USSR only three years previously, on 4 October 1957. Rockets, despite their relatively long history, were still primitive and prone to failure—after work of a year or more, an expensive experiment might be destroyed by the explosion of the rocket on the launch pad. The vibration and acceleration forces might destroy the experiments themselves in flight, while failure of the data recording subsystem could render a perfect flight useless. Space science was no place for the faint-hearted. However, so little was known about the upper atmosphere, the interplanetary regions, and the Sun and its emissions, that important discoveries were almost guaranteed, provided nothing went wrong. It was an area of science where the simple experiment was still king.

There were, however, potential problems. The Woomera Rocket Range and WRE were established as a key part of the UK programme to develop ballistic missiles and had been operated by the Australian Government through its Department of Supply under a culture of very tight security. Unlike today, collaboration between the university sector and government laboratories was rare, even when national security was not an issue. The university sector had sought to use rocket flights from Woomera as part of the Australian contribution to the International Geophysical Year (1957–58), but to no avail. Subsequently, Australia had declined a US offer of a rocket to launch an Australian research satellite in 1960 due to a lack of interest in space research on the part of the Australian Government. Few in the university sector would have had the courage to venture into such a seemingly hostile world. Carver, however, had worked at the UK atomic energy research laboratories at Harwell and he knew that the two cultures could work together, given goodwill and perceptive leadership. He had mentors such as Oliphant who would certainly have endorsed his ideas and vouched for his reliability. To better understand his prospects, however, he visited the Director of WRE (Salisbury), R. W. McG. Boswell, and the secretary of the Department of Supply, J. L. Knott. Finding them receptive to the idea of a collaborative programme, Carver finally decided to embrace the high risks/high rewards world of space physics. While he often admitted that a lot of the assistance provided was ‘through the back door’, the engineering and technical staff at Woomera and at WRE were very co-operative and a strong collaborative programme was soon established.

The space research programme was initially directed to the study of molecular oxygen and ozone densities throughout the atmosphere. Using his background in nuclear counting techniques, Carver developed a suite of ionization chambers sensitive to ultraviolet radiation. In collaboration with B. Rofe and Rofe’s research group at WRE, these devices were employed to measure the attenuation of solar ultraviolet radiation in the atmosphere using the small Australian-developed ‘High Altitude Development’ rocket and the somewhat larger ‘Long

Figure 2. At the pre-launch of WRESAT at WRE, November 1967, with, from left to right, D. Barnsley, B. Rofe and M. W. ('Don') Woods.

Tom' rocket. The companion laboratory component, described later, was directed to the detailed study of the photoelectric processes, providing, *inter alia*, the information needed to interpret the results of the rocket flights.

In the early days of space research, opportunities often appeared 'out of the blue' and required experimenters to react quickly and commit a great deal of effort without the careful planning that is the norm in other areas of 'big science'. Carver experienced this in late 1966 when the USA offered to give WRE a 'Redstone' rocket now surplus to its needs. The USA had used Redstone rockets at Woomera for studying the physics of re-entry into the atmosphere, the Redstone being a US development from the German wartime V2 ballistic weapon; in 1960 it was used to carry the first US astronaut into sub-orbital flight and was one of the most reliable rockets of its time. The offer was remarkable and very generous, as it would include the very considerable cost of the launch itself. Carver and his WRE colleagues decided to use the Redstone to launch an Australian earth-orbiting satellite.

There was one catch however—the rocket would be launched in less than a year, whether the satellite was ready or not. WRE and Carver had not anticipated the possibility of a satellite flight and there was a great deal of work to be done, from scratch. It was decided that the scientific payload would be provided by the University of Adelaide and use the ultraviolet detectors already 'space-proven' in the rocket flights from Woomera. WRE assumed the responsibility of providing the satellite itself and commenced a complex and demanding schedule—procuring space-rated components (a difficult task); building the satellite itself; integrating the scientific instruments and eliminating all interference from the satellite's radio transmitter; testing the completed satellite in Carver's laboratory under the extremes of vibration experienced in launch and in vacuum; organizing world-wide reception of the telemetry signals; and a myriad of other tasks. Typical of the early days of space research, the seemingly impossible task was accepted with enthusiasm. The satellite would be called the 'WRE satellite'—WRESAT.

Carver and his colleagues decided to use WRESAT to extend their earlier studies of the densities of ozone and molecular oxygen in the atmosphere. To this end they would measure the ultraviolet absorption at the satellite 'sunrise' and 'sunset' that occurred every 100 minutes. They instrumented the satellite with the ultraviolet ionization chambers they had developed for their sounding rockets. Three days before the launch-date, however, the satellite instrumentation was malfunctioning badly, with little prospect of resolution. Carver, the WRE project manager, and one of the present authors (KGMcC) held a crisis meeting. The WRE project manager made it very clear—the satellite would be launched within the week whether the instrumentation was working or not. Carver and the technical staff did not lose their nerve and succeeded in resolving the problem within two days. After one aborted attempt due to a minor rocket malfunction, WRESAT soared into orbit on 29 November 1967 (Figure 2). It worked perfectly.

Looking back, WRESAT was the climax of a period of remarkable achievement in which Carver played a pivotal role in Australia's entry into space science. In the five years since he had arrived in Adelaide, he and his team had developed a space research programme, developed space-rated detectors and electronics from scratch, initiated an ambitious laboratory study of atomic processes, and now provided all the scientific instrumentation on board Australia's first satellite.

In space science, as in all pioneering science, there was a world-wide network of scientists who provided insight, technical know-how and commiseration when the inevitable disaster occurred. Carver made many crucial contacts with this network when he was an Australian delegate to the 1962 meeting in Washington, DC, of the ICSU Committee on Space Research (COSPAR) together with the chief Australian delegate, D. F. Martyn, a leader in 'pre-Sputnik' upper-atmosphere research. In particular, Carver developed strong links with the US Naval Research Laboratories (NRL) in Washington and their director, H. Friedmann. NRL had instrumented a number of the early US satellites and, in particular, had developed the SOLRAD satellite to study solar x-ray and Lyman-α emissions, a programme that, according to their colleagues T. A. Chubb and J. Lean, provided useful input to the research at Adelaide. This collaboration continued through the years: Chubb, branch leader of the NRL Upper Atmosphere Group, spent a sabbatical year at Adelaide in 1966–67, and Carver spent a sabbatical with the NRL laboratory in Washington two years later. Carver also maintained close contact with H. S. W. Massey, an expatriate Australian who was a key figure in UK space research and who had established a major programme in space research at University College, London.

The Adelaide space research programme resulted in numerous publications regarding the distribution of molecular oxygen and ozone in the southern atmosphere, and later world-wide (32, 34, 43, 45, 59, 62, 64). In these investigations, the Sun was used as the radiation source, and rocket-borne ionization chambers yielded data for the progressive extinction of solar Lyman-α with atmospheric depth. As outlined above, repeated satellite sunrises and sunsets provided the same information from WRESAT. Allied investigations yielded the solar brightness temperature (53) and estimates of the temperature in the transition region between the solar photosphere and chromosphere (52).

The day-time atmosphere is strongly affected by transport processes while it is in photochemical equilibrium at night. To investigate this equilibrium state, a series of rocket flights was made to measure the vertical distribution of ozone using the full moon as the radiation source (35, 37, 51). The reflectivity of the moon in the ultraviolet was little known, and these night-time flights provided this information as well (38, 54). This work was extended to a comparison with the ultraviolet reflectivity of terrestrial rocks (56).

In addition to the published papers, at least five PhD theses resulted from this work. A commonality of interest in molecular oxygen and ozone with the planetary scientist R. R. Meier led to Carver taking up a visiting position, as mentioned above, in Washington in 1968–69 at NRL's E. O. Hulburt Center for Space Research, leading to a lifetime association. Meier is the author of several atmospheric review articles, including 'Actinic Radiation in the Terrestrial Atmosphere' (Meier *et al.* 1997), which cites no fewer than seventeen publications by Carver and his former students. This perhaps best attests to the success of Carver in achieving his original aim, as outlined at the beginning of this section.

Molecular Physics: Research on Ultraviolet and Vacuum-ultraviolet Spectroscopy of Planetary Gases

(a) In Adelaide

In parallel with the observational programme described above, related laboratory studies were initiated on the interaction of ultraviolet and vacuum-ultraviolet (VUV) radiation with planetary gases. These studies involved both photoabsorption and photoionization and were difficult because of the weak and temperamental sources of radiation in those spectral ranges and the need for evacuation of the apparatus.

Carver was a true pioneer in the area of atomic and molecular photoionization. His paper with A. J. Blake on the determination of partial cross-sections using photoelectron spectroscopy (41) is still cited after more than forty years. Drawing on his background in nuclear physics, he developed ionization chambers for use in the VUV region (31, 39, 40, 66) and applied them to a series of measurements on planetary–atmospheric molecules (33, 41, 44, 46–50). These experimental studies advanced the field of photoelectron spectroscopy and served not only to provide fundamental insights into atomic and molecular processes such as auto-ionization, but also to provide quantitative photoionization cross-sections for constituents critical to the photochemistry of planetary atmospheres.

In addition to the photoionization studies, Carver started a programme of VUV photoabsorption spectroscopy on atmospheric molecules, once again with the goal of providing basic but vital information for the photochemical modelling of planetary atmospheres. Initially, these experiments were performed using a commercial monochromator of 1-m focal length (36, 42) but, in response to a need for much greater spectral resolution, Carver obtained funding for the construction of a 6.65-m scanning VUV monochromator (61), by far the largest of its type in the world and a major undertaking for his department. With the design led locally by D. G. McCoy, this instrument was commissioned successfully in the late 1970s, occupying a purpose-designed laboratory in a new wing in the department. Detailed quantitative spectroscopy on molecular oxygen that attracted international attention was performed using the new monochromator (58, 63, 65, 68), but unfortunately the full design specifications were never achieved, principally because of temperature-control issues.

Carver's vision in initiating the experimental VUV spectroscopic studies has been vindicated. While the measurements fulfilled the original goal of serving the needs of the planetary-atmospheric modelling community (and, indeed also the astrophysical community), unanticipated collateral benefits also arose. In particular, these studies have provided major insights into fundamental molecular structure and dissociation dynamics in the VUV region where there are many interactions between the electronic states that are difficult to treat theoretically. Thus this research programme, started in Adelaide, has resulted in a broad range of publications in the instrumental, physics, chemical physics, and planetary physics literature.

As a result of his research achievements to that time, including the Adelaide programme summarized above, Carver was awarded a DSc degree by the University of Cambridge in 1975.

(b) Later Research at the ANU

After his return to the ANU in 1978, Carver's research evolved but remained consistent with his overall vision. While there were no further direct observations of the atmosphere, whether by rocket, balloon, or satellite, the laboratory studies in molecular physics started in Adelaide continued in the Ultraviolet Physics Unit at the ANU under his supervision. Furthermore, his personal research interests became more focused on understanding the evolution of the composition and climate of the terrestrial atmosphere, following on from his earlier work in this area (55, 57).

Unable to bring the 6.65-m monochromator from Adelaide, Carver purchased a smaller 2.2-m commercial instrument as the centrepiece for the experimental studies of the Ultraviolet Physics Unit. However, as was quite usual for him and his staff and students, the performance achieved from the available instrumentation greatly exceeded expectation. Thus there was a further range of studies on the quantitative spectroscopy of molecular oxygen (75, 77, 79–85, 89, 90) that became well-cited work of central importance to the photochemistry of the terrestrial atmosphere.

Carver had a talent for identifying key molecular processes in planetary atmospheres that would benefit from experimental study. For example, papers describing the work on the aeronomic dissociation of water vapour by solar H Lyman-α radiation (71), and another on carbon dioxide photoabsorption in the Martian atmosphere (72), are both well cited. He also had an eye for a commercial opportunity, securing money from the USA for a VUV photoabsorption study of the anaesthetics enflurane and isoflurane (86), with a view to monitoring their levels during surgical procedures.

Carver was always alert to the benefits of new technology. In the 1980s, he was a keen supporter of the little-known push at that time towards a synchrotron radiation source for Australia to realize, among other benefits, a more intense source of VUV radiation for molecular photoabsorption and photoionization studies. Ironically, while the goal of an Australian Synchrotron has been achieved recently, the new facility is unsuitable for the VUV spectral range! Again, in 1987 he appointed K. G. H. Baldwin to the Laser Physics Centre in the School, specifically to establish a new VUV laser laboratory. The aim of the new facility was to increase dramatically the spectral resolving power available to the Ultraviolet Physics Unit. It was unique in its application to quantitative spectroscopy (91, 93, 94 and later publications, e.g. Dooley *et al.* 1998).

Carver's work included modelling planetary evolution and, specifically, the conditions under which life evolved on the Precambrian Earth. At that time the atmosphere had little oxygen and therefore no substantial ozone to provide an effective ultraviolet screen to allow biological evolution (69). He was also intrigued by the Earth's climatic changes on time scales of billions of years (74, 76, 96, 98, 99).

In 1980, I. M. Vardavas joined the Ultraviolet Physics Unit to work with Carver as a Research Fellow on these fundamental planetary-atmospheric problems. Vardavas developed complex radiative-transfer models for the Earth's atmosphere, guided by Carver's insight on the central physics. Their collaboration continued productively after Vardavas left the ANU in 1984. More than ten years later their collaboration culminated in their work on Precambrian glaciations (98) and the long-term climatic evolution on Earth (99). This demonstrated that the Earth's climate remained stable and not too different from the present over billions of years due to a balance between two factors: a diminishing atmospheric greenhouse effect as the Earth's surface evolved to sequester carbon dioxide more effectively from the primeval atmosphere, and the solar brightening as the Sun evolved on the Main Sequence. The final publication from the collaboration (100) was co-authored by F. W. Taylor, the Halley Professor at Oxford.

It is befitting of Carver's stature in the field of planetary physics that, one month after his death, his contribution to it was presented by Vardavas, and subsequently discussed, at a dinner of the Royal Meteorological Society in London.

Directorship of the ANU's Research School of Physical Sciences and Engineering

John Carver's penultimate and arguably his major university appointment was to the directorship of the ANU's Research School of Physical Sciences, a post he held for fifteen years.

Vision and Style

When Carver was appointed as Director of the Research School in 1978, he came with much affection for the School and a belief that he could make a difference: and that he certainly did. His vision for the School was based on the original premise on which the Institute of Advanced Studies was sold to the nation in the 1940s: 'the School should be seen as integral and valuable to the Australian nation'. He noted that by 1978 the research of the School had changed greatly since the early 1950s when Marcus Oliphant ruled supreme and nuclear physics was dominant. The research being done was no less important but Carver believed that its importance was not obvious outside the School and some was not as relevant as it could have been. He set about changing this situation and establishing the School once again as a national research treasure, the achievements of which were visible to the nation.

Carver came to the School at a turbulent time. I. G. Ross, who was Deputy Vice-Chancellor for much of the last half of Carver's Directorship, noted in a speech on John's retirement that in 1978 the School was the 'stroppiest quarter of the Campus'. The aftermath of the somewhat acrimonious severing of Earth Sciences from the School a few years earlier, the abrupt end of E. W. Titterton's reign as Director, and a stormy response to a review of the School instigated by Carver's predecessor R. Street had not died down. Finally, there was Street's sudden resignation following his appointment as Vice-Chancellor of the University of Western Australia. In that same speech Ross remarked that 'it is a measure of Carver's skill in the Director's role that from the time of his landing at ANU a kind of well-mannered calm descended.... and the School has projected a singular image of solidarity, even of unanimity, ever since'.

When Carver arrived, while there remained an emphasis on fundamental physics in the School, he nevertheless felt that a significant fraction of the School's work was 'good physics' that in American universities would be part of Engineering. He did not want to change much or chop out much, but to rearrange and make some strategic appointments. His focus was on unifying the School, pulling research together into critical-mass activities with an emphasis on 'big picture' opportunities that could bring together broader expertise and strengths across the School. Details of the resulting changes to the School will be outlined later but the aim was to unify the School's research and to enhance relevance by visibly providing an engineering focus. Carver's vision was that the School's research should cover not only outstanding fundamental physics, but also the exploitation of such research in the development of applications and even commercialization. By the end of Carver's time as Director, he had achieved his goal: the School's research covered the full spectrum from fundamental to applied, and significant commercial opportunities were being exploited. 'Engineering' was added to the School's name in 1991 and such was the cultural change in the School by that time that this was almost universally accepted.

In the 1997 interview, Carver expanded on his vision for the make-up of School as follows:

> My own view of the School, and of any large scientific organization, is that you have got to be able to accommodate people of all sorts of eccentricities. If you want brilliant people, some of them will be quiet and taciturn and want to just get on with their work all the time – and we've got some good examples of that. You don't want to push those people to go out and earn money for you. That's the last thing we would do. And you have got some others who are high fliers, who often irritate the rest of their colleagues by their brashness and the enthusiasm with which they sell their stuff. But you need those people, if they are bright enough, to come in. You must be willing to tolerate a range of eccentricities, paid for by the talent that they bring.

In this regard, it is significant that in the 1995 review of the Institute of Advanced Studies, the School Review Committee noted this mix of styles and 'eccentricities' of department heads as a real strength of the School that contributed to its broad success.

Carver had clear strategies and tactics for achieving his vision, and these were given focus by his style of leadership and academic management that were perfect for the ANU around the 1980s. He 'always' seemed to get what he wanted both within the School and for the School by good planning, logical argument and gentle persuasion. Ophel and Jenkin noted in their 1996 history of the School, *Fire in the Belly*, that during Carver's reign, 'there was always a feeling that few events occurred by chance or unexpected circumstance, everything seemed carefully orchestrated' (Ophel and Jenkin 1996, p. 140). His style bordered on the autocratic, as evidenced by the way he controlled the School's Faculty Board, its agenda, and the fact that all important decisions had been pre-decided. At the same time, senior academics in the School felt 'consulted', even though they were not usually made aware of the end game, at least initially. Carver had a way of bringing senior academics along in a sort of democracy, but on reflection it seems that it was always Carver's way that prevailed. He must have had the School on side—after all, he became the longest-serving Director and had the unanimous support of his academic colleagues in the School on the two occasions when his Directorship was extended.

During the first few years of his directorship, Carver took steps to unify the School. He introduced Founder's Day in 1981, held on or near Sir Mark Oliphant's birthday in October, to bring the whole School together in a day of celebration: it is now a much anticipated annual event. It consists of entertaining and informative talks on the School's achievements during the year and opportunities to tour the School's facilities. While mainly for current School staff, students and visitors, the invitation list extends to former School members and distinguished guests who are presented with a 'show and tell' of the School's research.

Founder's Day was a simple concept but it went a long way to solving what was a major problem when Carver arrived: how to rekindle a sense of unity and pride in the School that had been there in the early days but had been largely lost as the School had grown and become widely dispersed across campus.

Along with Founder's Day, and in keeping with his goal of bringing the School together, Carver wanted a place for the School to meet and mix, to discuss science and to socialize—a common (tea) room for the whole School. He had to wait more than a decade to achieve this, when he seized an opportunity to secure corporate (IBM) and University funding for the link building, between the Oliphant and Cockcroft Buildings, which included the common room as well as a seminar room and a conference room.

Carver's particular style as Director was central to his achieving the goals he set for the School. It was clear he had big ambitions for it: to expand its research horizons to cover a broad spectrum of fundamental and applied research; to link together the School's research more effectively; to add new strategic research thrusts; and to provide the needed research infrastructure. Ophel and Jenkin noted that 'perhaps Carver's greatest attribute was the ability to manipulate the fashions of the times and trends of University policy—invariably it seemed by anticipating them, always to the advantage of the School' (Ophel and Jenkin 1996, p. 140).

To realize the ambitious plans Carver had for the School, and to sustain high-cost physics at a world-competitive level, required enormous financial resources. Carver had the academic and political skills to secure them but his methods were decidedly non-conventional. Referring to his ability to secure money, I. G. Ross in the speech already referred to said that 'the Carver record … has been one of steady single-mindedness, giving absolutely no quarter to any other claimants'. He went on to say that 'he earned among his colleagues a particular reputation, which after some thought I will name as the ethical burglar'. Ross explained this description as follows: 'many of you will have been tempted by opportunistic fruit hanging over the fence from the neighbour's yard. John was like that, and at times he actually pulled the tree over to his side. There are (tens of) millions of dollars' worth of hardware (and research funding) in the School to prove it'.

Examples of Carver's ability to secure funds are legendary. To be able to add more engineering thrusts to the School at a meaningful level, he needed a big injection of funds, but how to achieve it? In the absence of an existing mechanism, he successfully convinced the University to set up a strategic initiative fund to support major new ventures through the reallocation of substantial recurrent funds. Of course he was ready with the first (and successful) proposal, before other Schools had a chance to comprehend this new opportunity.

There are many other examples of Carver's political astuteness and his ability to extract the funding he needed to support the School. Rectifying the sad state of the building fabric of the School (a legacy of the fact that the School's buildings dated from the early 1950s) and enhancing the research infrastructure were two further priorities. His attempts to improve the School's building fabric were long frustrated by the University's lack of funds for capital works, but a rare opportunity emerged late in 1989 when the University was given several million dollars for capital works. Seizing the opportunity, Carver pulled a near-complete building proposal from his bottom drawer. He needed more money than was available, but he convinced the University to fund a full refurbishment of the wing that previously housed Oliphant's homopolar generator. This building is now named the John Carver Building. Its basement houses the booster for the 14UD accelerator, a device that increases the performance of the machine. Carver used the prospect of acquiring the booster, offered to Nuclear Physics by the UK's Daresbury laboratory, as a trigger for the refurbishment, and negotiated University funds for its transfer.

A final example of Carver's opportunism arose in 1991 when the Government announced a 'Syndicated R&D' scheme that allowed businesses to write off or defer tax by investing in public-sector research and development. Carver saw a major opportunity for the School to enhance its research infrastructure and put forward a number of School projects to the scheme that, in 1993, secured substantial funding.

The School owes much to Carver's ability to extract preferentially any (or all) funds that were on offer at a time when it was extremely difficult to secure funding for either capital works or research infrastructure.

Carver's overall funding philosophy was based on an understanding that there were largely fixed budgets for the Schools in the Institute of Advanced Studies and that therefore, in order to expand activities significantly, it was important to shed areas that were no longer core components of physics or its applications. In practice, his approach proved correct: the School's budget always quite quickly recovered and grew despite the shedding of major bits of the School—another tribute to his political astuteness.

Focusing, Reorganizing and Redirecting the School

The period of John Carver's Directorship saw the most comprehensive restructuring of the School in its history. Guided by the overall philosophy described in the preceding section, Carver consolidated some of the School's activities into larger groups and closed some down, while others were separated from the School to create entirely new entities within the Institute of Advanced Studies. As opportunities arose, new activities were added through University strategic initiatives.

Carver's philosophy in adding new activities to the School was to anticipate new directions and opportunities for exploiting the physics research of the School. He recognized that physics was under threat in Australia and being run down in many universities, and believed it to be essential that this did not occur at the ANU. The best ways to avoid its happening, he believed, were to support the core physics research of the School (in atomic and molecular physics, optical sciences, materials physics and nuclear physics) and to link this with more applied activities in surface science, applied mathematics, laser physics, electronic materials, and applications of nuclear physics. These activities needed to be supplemented with engineering from time to time to provide both an end point and relevance to the research effort.

In pursuit of this goal, Carver persuaded the University that separate entities should be created for astronomy and astrophysics, and for mathematics. Thus, Mount Stromlo and Siding Spring Observatories became a separate entity within the Institute of Advanced Studies in 1986, and the Department of Mathematics was moved from the School in 1989 and joined with the Department of Mathematics in the Faculties to form the School of Mathematical Sciences. Both these entities became successful in their own right but retained a close connection with the School through representatives on the Faculty Board.

To replace the entities shed by the School, Carver added entirely new endeavours to bolster the engineering effort and bring visible 'relevance' to the School's research. The Department of Systems Engineering was established in 1982 through a strategic initiative of the University (although this new funding avenue was orchestrated by Carver as indicated earlier). The new department was headed by B. D. O. Anderson, recruited from the University of Newcastle. Anderson brought several control engineering colleagues from Newcastle to fill academic posts in the department, as well as recruiting other staff with telecommunications expertise. A particular emphasis of research in the new department was to be theoretically based control engineering built on strength in applied mathematics, with a focus on adaptive control of large systems having direct relevance to industrial processes. There was also a growing effort in telecommunications engineering into the 1990s, again more theoretical than practical.

An opportunity arose in early 1987 to add a further activity that fitted well with the research within Systems Engineering. At the time, the University was set to lose R. P. Brent who was, in Carver's view, the best computer scientist in the country. Carver was not prepared to let this happen and set up a small Computer Sciences Department with Brent as Head that eventually grew to three academic staff.

Having added a largely theoretical engineering activity to the School, Carver wanted to bolster the practical side and provide an engineering focus for much of the physics applications work in the School. A review of the School chaired by Denys Wilkinson in 1987 recommended that the School should exploit and expand some of its core optical-fibre, laser, and materials work. This could be achieved by introducing some practical engineering efforts to link these activities together. Furthermore, it should push into areas such as electronic materials and telecommunications. The reviewers considered these to be areas of opportunity for Australia. Hence in 1988 Carver recruited J. S. Williams from the Royal Melbourne Institute of Technology to head a new department of Electronic Materials Engineering. This proved a much more costly exercise than the introduction of Systems

Engineering some years earlier. The new department required both academic and technical staff and new infrastructure for materials and device processing and characterization. Carver managed to secure one-off infrastructure funding as well as University strategic initiative funding to establish the department.

The new departments added to the School needed outstanding leaders, and Carver had strong views as to how they should be recruited. In his own words: 'We need to get a person so good that you can march him (her) off to the Vice-Chancellor and say, "Look, this guy wants to come and work here. All he needs is $xx million a year and a few staff, and we've got him." ' That is exactly what he did: he created the new departments and secured the leaders he had identified to head them.

Some years later, commenting on the success of these initiatives, Ian Ross remarked that 'the School now [has] a leading position in Australia's engineering profile' despite its narrow presence in terms of traditional engineering disciplines, 'but it is a presence splendidly compatible with the science elsewhere in the School'.

Carver pushed another initiative very strongly before his retirement as Director. This was the formation of a new Research School built around the information sciences groups in the School. There was considerable opposition to this at the time from outside the School, and also some from inside, but in the end he had his way and the Research School of Information Sciences and Engineering was formed in early 1994. Carver believed at the time that there was likely to be considerable government funding for this type of research, as he was convinced that the industrial base of the future would depend on it. He was encouraged in this belief by the Government's funding of a Cooperative Research Centre in Robust and Adaptive Systems in 1992, hosted by the School and the Department of Systems Engineering in particular. In fact it took almost a decade before Carver's prediction of 'considerable' funding arrived in the form of NICTA, the National Information and Communication Technologies Australia centre. Federal funding for the centre was won in a bid headed by Anderson.

Not all of Carver's plans for reorganizing the School were successful. Nevertheless, his restructuring of the School, his recruiting of outstanding staff, and his expanding and enhancing of the relevance of research in the School have all been major contributors to the School's success.

ANUtech and Commercialization

Consistent with his focus on providing relevance for research in the School and adding an engineering focus, Carver was always on the lookout for opportunities to exploit the fruits of research through commercialization. He was a leading figure in the creation of ANUtech, the ANU's commercial arm, and did much to ensure that the School used it effectively to expand its funding base.

Two opportunities to commercialize School research were evident at the time Carver took over as Director. The first was a request by a Swedish university to purchase a 'surface forces apparatus' developed by J. N. Israelachvilli and G. E. Adams of the Applied Mathematics Department. This ground-breaking work that began in the mid-1970s involved an entirely new capability for measuring inter-atomic surface forces at a 1-nm level. This preceded the work on scanning tunnelling microscopy and the associated atomic force microscopy that came out of Europe in the late 1980s. The second opportunity involved S. Kaneff 's solar thermal project in the Engineering Physics Department, opening up prospects for a 'solar power station'. Kaneff had demonstrated the feasibility of using parabolic mirrors to capture and concentrate the Sun's rays to boil water, to provide the steam to drive a power generator. At a chance meeting in 1979, the then Premier of New South Wales, Neville Wran, was so impressed with Kaneff 's concept that he immediately set wheels in motion that led to the School's being offered a sizable development grant from the New South Wales Electricity Commission for developing a solar power generator at a remote location in the state.

Both of these semi-commercial opportunities convinced Carver that the University needed to be proactive in pursuing commercialization. J. Morphett, who was School Laboratory Manager at the time, recalled that the solar power contract 'put a cat among the pigeons' and Carver pushed the University to set up a company to manage it. In his 1997 interview, Carver indicated that he thought that such activities were best handled through a company rather than directly through the University or School. He saw 'physics and industry as one [continuous] web', with physics as the core but reaching out to industry to 'show people that it is useful'.

ANUtech, the company name chosen by Council, began on 31 August 1979 as a $2 company and Carver joked that he may have even provided the $2! Initial meetings of ANUtech were held in Carver's office. After an interim period, a permanent Board was established, comprising A. J. R. Yenken (Chairman), Carver, Ross, A. Copeman and J. A. Coleman, the ANU bursar, with Morphett the company's first general manager.

ANUtech's first two projects were Israelachvilli's forces apparatus and Kaneff 's solar power demonstrator. A number of surface forces instruments were manufactured, initially in the School but later by Australian Scientific Instruments (ASI), a division of ANUtech. So began a particular strength of ANUtech and ASI, namely commercialization of scientific instruments, many originating from the School. The solar power project was more demanding and involved a demonstration consisting of an array of solar dishes to supply power to the remote New South Wales township of White Cliffs.

In the early days of ANUtech, Carver played a very active role in shaping its directions and exploring the applicability of successful models for similar companies in other universities. By the end of his sixteen-year term on the Board, ANUtech had grown to a multi-million dollar company with services that included commercialization of ANU research, a patent portfolio of ANU inventions, a consultancy arm to sell ANU services, a training arm and a scientific instruments company.

There were other notable examples of successful commercialization during Carver's reign. Australian Optical Fibre Research (AOFR) was a spin-off company that originated from the vision research of A. W. Snyder. S. C. Rashleigh, a former member of the School, was given the task of setting up the company. Carver and Ross were on the Board in the early years and guided the company though some rocky times. The company quickly developed methods for coupling fibres together, and fibre couplers became the main product in its early years. AOFR was ahead of its time and was well placed to respond to the optical-fibre communications revolution in the 1990s. It is a real Australian success story, being valued at close to $4 billion at the height of the technology boom in the late 1990s. Carver pointed to one of the reasons for AOFR's success: that Rashleigh, with his strong research background, understood the need for an active research and development programme in the company that involved strong links with the School.

A further company that came out of ANU, and one that gave Carver particular pleasure, was Auspace. It arose from the work of D. S. Mathewson and others at the Mount Stromlo Observatory. It was exactly the sort of instrumentation work for satellites that Carver thought that Australia should be involved in. Again, Carver was proud of the company's successes, having been chairman of the Board for a number of years. Initially Auspace made satellite components and received an occasional satellite contract. It is now on a firm commercial footing with a strong emphasis on its core expertise, space instrumentation.

Carver especially encouraged the innovative development of instruments in the School that had begun with the surface forces apparatus and space instruments. However, although he continued to drive exploitation of the School's research, mostly through ANUtech, he believed there always needed to be a balance between fundamental enquiry and applications, and was mindful that commercialization and industry contracts should not 'pervert' the core physics focus by chasing *any* funding that was on offer.

Carver succeeded in changing the culture of the School to one in which most academics and teams were comfortable with exploiting wherever possible the fruits of their fundamental research, by pursuing appropriate industrially relevant applications. This cultural change is one of Carver's most significant legacies.

Directorship of ANU's Institute of Advanced Studies and Acting ANU

Deputy Vice-Chancellor, Research

After he retired as School Director, John Carver spent from late 1992 to early 1994 in the roles of Director of the Institute of Advanced Studies and Acting Deputy Vice-Chancellor of the University. During this period the proposal for the establishment of the new Research School of Information Sciences and Engineering (RSISE) was debated and endorsed by the Board of the Institute. It was to be a small School. Carver himself felt that the optimum size of the Research Schools needed examination, that some Schools were becoming too big and might need to divide into smaller entities such as the proposed RSISE. In an interview for *Campus Review* in 1993, he suggested that in fifteen years' time the Institute 'may consist of more but smaller units'. This was consistent with the greater 'flexibility' in the Institute's structure proposed by the committee that reviewed it in 1990 ('Stephen Report' 1990).

While still School Director, Carver had been lobbying the University to consider establishing a research park, suggesting that Acton peninsula would be an ideal location. When he moved to the Chancelry, this concept gained momentum and he commissioned consultants to develop a proposal. He presented their report to Council in mid-1993. He argued that the ANU was the best placed Australian university 'to attract high technology and social science-based enterprises to a research park', with its 'strength of intellectual presence in so many relevant fields'. The location in the Federal capital and the presence and strength of ANUtech were other advantages that enhanced the prospects of such a venture.

Despite some support from Faculty Deans and Heads of Research Schools, the proposal polarized Council, as Bruce Juddery reported in *Campus Review* and later in *The Canberra Times*. Sections of Council were irate that due process of passage and debate through the Academic Boards had not been followed. There was also concern about lack of detail, one Council member quipping that 'it could be Jurassic Park for all I know'. However, after intense and heated debate, including a tied vote broken by the casting vote of Chancellor Sir Geoffrey Yeend, the proposal passed, including endorsement of the proposed two-year budget.

That was not the end of the matter, however. There was a revolt of sorts by sections of the academic community claiming lack of both detail and internal debate for the Research Park concept. Vice-Chancellor L. Nichol withdrew his support and deferred the project until after the Academic Boards had had a chance to comment on a more detailed proposal. This delay, and other events occurring in parallel, essentially killed the plan. As Juddery reported, the Boards were uneasy with the perceived 'impact on academic values and the threatened subordination of ANU research to commercialization'. Another sticking point was that construction on the Acton peninsula was opposed by the National Capital Planning Authority. As a result, Carver's proposal was never realized.

In his 1997 interview, Carver lamented the decision: 'the site is quite a magnificent asset and we are very foolish if we don't put something down on the bits of it we still control'. However, the concept of a research park was not entirely lost. S. Serjeantson, when she became Director of the Institute, built on Carver's initiative to convince Council to approve a more modest proposal that resulted in the construction of an 'Innovations Building' close to the John Curtin School of Medical Research.

In his push for the University to embrace commercialization much more aggressively than it formerly had—pointing to successes within his School as evidence of the benefits of this approach—Carver was ahead of his time, or ahead of the University's readiness to accept such a culture change. With the passage of time, Carver's view of commercialization is now well and truly part of the ANU psyche.

The Academies

Carver was elected in 1986 to Fellowship of two academies, the Australian Academy of Science and the Australian Academy of Technological Sciences and Engineering. He was also a member of the International Academy of Astronautics.

Prior to his election to the Australian Academy of Science, he played a leading role on two of the Academy's National Committees, the Committee for Space Research and the one into which this was later incorporated, the Committee for Solar, Terrestrial and Space Physics. He chaired the former from 1968 to 1978, almost half the life of that committee, and the latter from 1985 to 1988. During this period he was Australia's delegate to the International Council for Science's Committee on Space Research (COSPAR), serving both as a Bureau Member and a member of its Finance Committee.

Figure 3. Chairing the opening session of the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space in New York, February 1978.

Service to International Science

Space Science—United Nations Committee on the Peaceful Uses of Outer Space

In the period 1970–95, Carver was chairman of the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, succeeding another Australian, D. F. Martyn. The main committee and its two sub-committees, one concerned with scientific matters, the other with space law, provide international forums for pursuing the peaceful use of space flight and technology. More than thirty countries attended the annual meetings of the scientific sub-committee that took place for two weeks, initially in New York, and subsequently in Geneva and Vienna (Figure 3).

During Carver's chairmanship, the sub-committee dealt with a substantial number of important matters that impinged on the national interests of many countries in the world. Four such matters were: (1) the right of a nation to operate a remote sensing satellite over another country; (2) access to the geostationary orbit for 'direct broadcasting' satellites that would be heard in other nations; (3) procedures to avoid biological contamination of the Earth and the other planets as a result of space flight; and (4) the use of nuclear power sources to provide the electricity needed to power satellites, an important requirement for missions that were being flown in the 1970s to explore the outer reaches of the solar system. The sub-committee operated by consensus and arriving at a consensus view frequently took many years.

Notwithstanding the generally co-operative atmosphere of these meetings, there were moments of excitement and high drama. During Carver's chairmanship, the Soviet Union was flying radar satellites in low orbits that used nuclear power sources to operate their powerful radar transmitters. The theory was that a satellite would be injected into a higher orbit at the end of its operational life to avoid contamination of Earth upon re-entry. On two separate occasions the procedure failed, coincidentally the week before the scientific sub-committee met. On the first occasion it resulted in a 3,000-km trail of radioactive material across northern Canada, resulting in world-wide concern and a long debate in the scientific sub-committee. Carver later recalled that the Soviet delegate argued that the discussion should not be recorded in the minutes as the accidental re-entry was not on the agenda for the meeting. Carver showed the skills gained in numerous meetings of university boards and committees by ruling that it should be included under 'other business'. When another radar satellite re-entered the atmosphere several years later, the chief Soviet delegate was heard by one of us (KGMcC) to say to Carver: 'Next time, John, I will arrange personally that the Sputnik lands on your office in Canberra!'

Throughout his record twenty-five years as chairman, Carver oversaw the careful achievement of consensus on this and other difficult matters where development of space technology had the potential to impinge on national jurisdictions with adverse consequences. For his long and distinguished service he was awarded the COSPAR International Cooperation Medal at a meeting of that organization in Warsaw in 2000. An illuminated address signed by the then Secretary-General of the United Nations, Boutros Boutros-Ghali, presented to him on that occasion, reads, in part:

> Your tenure as Chairman has seen dramatic progress in the field of space science, technology and applications and equally dramatic changes in the international political situation. You presided over a period of growth in the work of the Subcommittee. You were instrumental in many of the Subcommittee's most significant accomplishments during this period, most notably the complex discussions and

negotiations that culminated in the adoption by the General Assembly, in December 1992, of the Set of Principles Relevant to the Use of Nuclear Power Sources in Outer Space.

On behalf of the United Nations, I would like to join the Member States of the Committee on the Peaceful Uses of Outer Space in expressing gratitude for your many years of dedicated service.

Anglo-Australian Telescope Board

The Anglo-Australian Telescope had a stormy gestation, mainly due to difficult political negotiations in both countries and some opposition from competing scientific interests. Both countries finally agreed in 1967 to fund the construction of the telescope, but discussions as to how it would be administered were not finally resolved until 1971, when it was decided to establish the AAT Board (Gascoigne *et al.* 1990). However, by 1978, when Carver succeeded R. Street as Director of the ANU's Research School of Physical Sciences and also succeeded him on the AAT Board, these events were well in the past.

Carver's membership of the Board was long and distinguished. In 1982, he was appointed Deputy Chairman and one year later Chairman, a position he held until 1986. He retired from the Board in 1989. In a personal letter to F. W. G. White, that is held by the Australian Academy of Science, written early in Carver's fifteen-year membership of the Board, J. P. Wild wrote: 'Perhaps his main contribution to the Board [has been] to continue the good work of Bob Street rebuilding the bridges between the Board and the ANU which had earlier been in an appalling state of disrepair.' That was clearly a further example of Carver the diplomat.

Service to the Australian Government and the Broader Scientific Community

Australian Science and Technology Council (ASTEC) (1980–86)

Carver was one of the early appointees to the Australian Science and Technology Council. After a long gestation, ASTEC finally became a statutory authority in 1979 reporting directly to the Prime Minister. Its first Chair was G. M. Badger (Fenner 2005).

Carver was appointed to ASTEC in April 1980. He and Badger knew each other well; they were friends as well as colleagues. Initially they served as heads of their respective departments of Physics and Chemistry at the University of Adelaide; their interaction was closer still when Badger became Vice-Chancellor and Carver chairman of the Education Committee and a member of the University Council. In 1981, two years into his service on ASTEC, Carver was appointed Deputy Chair, the position he held until the end of his term. He served under Badger's chairmanship until the latter retired at the end of 1982, then under R. O. Slatyer as Chair.

In Carver's time, ASTEC played an influential role in framing Australia's science policy, having direct access to the Prime Minister and then to Cabinet. One of its most important standing committees was the Standing Committee of Inquiry into Technological Change in Australia (TCC), formed in 1981. In the previous year, the Australian Government had received a report from its Committee of Inquiry into Technological Change in Australia, which recommended that

> ASTEC be asked to establish a Standing Committee to monitor technological change at the national level: specifically, to review on a continuing basis the processes and trends in technological change in Australia and elsewhere; and to evaluate and report on the direct and indirect effects of technological change at the national level.

The Council's response to this recommendation was the formation of the twelve-member TCC with Badger as the Chair, three other members from ASTEC, and eight outside members. Carver was one of the ASTEC members; he became Acting Chair in 1982 for a short period on Badger's retirement, before the appointment of a permanent Chair.

Membership of ASTEC's enquiry into Australia's involvement in the nuclear industry was one of the more challenging and controversial of Carver's responsibilities. The enquiry was agreed to by the Government only when it was pushed through the Labor Caucus by Prime Minister Hawke against considerable opposition. Then Deputy-Chair of the Council, Carver headed a three-man, twelve-day visit to Washington, Ottawa, Paris, Bonn, and London as part of this investigation. It must have been a gruelling schedule.

Another important matter referred to the Council for advice was the funding of the Australia Telescope. This came up in a year that, according to Carver, was 'particularly tight', so that

> it was pretty hard to fund something as exotic and extravagant as a large expansion of the country's radioastronomy work. Nevertheless ASTEC, very wisely in my view, took the decision to put the funding of the Australia Telescope right up to the top of the list, at the expense of all other recommendations that were put in. And it was granted. It's like having work done round your house: sometimes you remember the job long after you forget the costs. That instrument has proved to be marvellous and has attracted back into Australia some very good scientists such as Ron Ekers, who was associated with us in Adelaide early on. Combined with other major instruments in this country it has kept Australia right at the forefront of astronomy.

As convener or member of other ASTEC working parties, Carver was involved in the preparation of a number of reports to Government, including those on microelectronics, robotics, and basic research. The reports on 'Technological Change and Employment' and 'Technology and Handicapped People' were produced during his term as Acting Chair of the TCC, while towards the end of his term on that committee he chaired the working party on 'Higher Education Research Funding'.

The Council's Annual Report for 1983–84 shows that no fewer than eight reports were tabled in Parliament in that reporting year, and Carver would have been directly involved in most of them. The report 'Australia's Role in the Nuclear Fuel Cycle' was tabled in Parliament by the Prime Minister on 31 May 1984. In his speech, in which he referred to the Government's request for a scientific assessment of the adequacy of ways in which countries managed and disposed of radioactive waste, he said that:

> ASTEC, *as the pre-eminent Council providing independent advice to the Government on science and technology questions*, [our italics], was judged best-qualified to perform [the role of making this assessment] under the personal direction of Professor Slatyer.

This assignment was an indication of the importance of the Council in that period, and the reason for its high level of activity at the height of its influence.

Carver's long service on the Council concluded in August 1986. In his introduction to the Annual Report for 1986–87, Slatyer, noting the retirement of Carver and others, wrote: 'In particular, I would like to acknowledge the major role played in all aspects of ASTEC's work over the last six years by my Deputy Chairman, Professor John Carver.' The Prime Minister of the day, R. J. Hawke, wrote in equally appreciative terms:

> I am writing to thank you for your services as Deputy Chairman of ASTEC. The Government values greatly the advice it receives from ASTEC, and has appreciated your contribution to the Council's reports on Australia's role in the nuclear fuel cycle, microelectronics, and telecommunication's research and development in Australia.
>
> Your acting chairmanship of ASTEC's Technological Change Committee in 1983 also contributed substantially, I am sure, to the work of that committee. Thank you very much for your very considerable contribution to the work of ASTEC. [personal letter to JHC dated 15 September 1986]

ASTEC was to continue for another twelve years, but the six years during which Carver was a member had seen some of its most important contributions.

Radio Research Board (RRB)

Carver was appointed to the Radio Research Board in 1964 and served on it for eighteen years, chairing it from 1977 to 1982. Although it is doubtful that he himself had been a beneficiary of the Board's bounty up until the time he joined it—nuclear physics not being part of its remit—his appointment was highly appropriate. At the time he took up his appointment in Adelaide, several members of the department there had been, or were, recipients of RRB grants, radio and atmospheric physics being two of the department's major research interests.

The Board had a long history of supporting research in the universities. In 1926, the Council for Scientific and Industrial Research (CSIR, later CSIRO) at only its second meeting accepted Sir John Madsen's proposal that such a body be established. The Board's initial charter was to study the ionosphere and radio transmission. Thus, in the early years it drew its funds from a number of sources besides CSIR: the Post Office, the Overseas Telecommunications Commission and the Australian Broadcasting Commission.

Later, there were contributions from the Departments of Defence and Communications.

By the time Carver joined the Board, its function had changed from earlier days, when it had had its own laboratories, to that of providing financial support for individuals and research groups in many of the universities. Nevertheless, it still adhered closely to its founder's aim, namely

> to encourage and support research in the universities and provide a link between 'freewheeling' academic research and the more industrially oriented research of CSIR. Although this policy inevitably came under attack by those advocating the central control of research, Madsen persisted in his view that independent research in the universities was an essential component of the national effort. His energy and diplomatic acumen won his point and the independence of the RRB (Myers 1986).

It is not easy to trace exactly what were the main preoccupations of the Board during the years of Carver's membership. While the Board's Annual Reports up to 1939 can be found in the *Journal of the Council for Scientific and Industrial Research*, they are no longer to be found in that journal after that year, even though the journal itself continued for a number of years. The work of the Board was classified during the war years, but an account of the work in this period can be found in W. F. Evans's book *History of the Radio Research Board, 1926–1945* (Evans 1973). Surprisingly, after the war, publication of the Reports did not resume in the *Journal*, nor are they held as publications in their own right in library collections. Moreover, the present authors have not been able to find copies of them in personal collections, although some data can be gleaned from papers held by the National Archives of Australia. What one account of more recent times shows, however, is that in 1979 ASTEC recommended that the Board should support an expanded range of activities beyond its initial focus on studies of the ionosphere and the propagation of radio waves. The move to support communications research more broadly was one that Carver supported. The expanded coverage is illustrated by the titles of projects that were subsequently supported, which included:

Charge Trapping and Charge Transfer in FEP/Teflon Foils and their Influence on the Performance of FEP/Teflon Foil Electret Microphones

GaAs Transistors and their Use in UHF Amplifiers

Computer-Aided Design

Development of a New Photovoltaic Solar Energy Conversion Device.

The Board's budget had expanded correspondingly to support this wider range of research. In the final year of Carver's chairmanship, the Board's total expenditure, almost entirely on individual grants, was over $300,000, disbursed to more than fifty projects in some sixteen universities (RRB 1993).

Three years after Carver's term as chairman ended, the Board ceased as an entity. In 1985, it merged with the Electrical Research Board to become the Australian Telecommunications and Electronics Research Board. Nevertheless, Carver would no doubt have been proud to have chaired a board that, even to the last days of its existence, maintained that 'independent research in the universities was an essential component of the national effort'.

Australian Space Board

The Australian Department of Industry, Technology and Science established the Australian Space Board in 1986 to stimulate participation in the space industry by Australian companies. Carver was one of the five inaugural members and remained on the Board until it was disbanded in 1993. His interest in the utilization of science for practical purposes provided an important and insightful input to the deliberations of the Board, and to its advice to the government of the day. The Board provided strong support for the development and applications of 'Satellite Remote Sensing' in Australia, and for the local development of global positioning and satellite communications technologies.

Epilogue

John Carver faced a serious illness over the last years of his life with courage and equanimity, and he and his wife Mary together coped with his illness with dignity and patience. So well did they keep knowledge of it to themselves that few, if any, of his colleagues in the School knew he was ill, although some may have suspected it.

He never lost his sense of humour, or his mental acuity.

Carver will be remembered as an able leader with a warm and friendly personality; with a smile that one could easily kindle; and with a knack of getting his own way through logic, patience and tact. As a distinguished scientist and academic administrator, and as an extremely able international scientific diplomat, he made an outstanding contribution to his country for which he was appointed a member of the Order of Australia in 1986. He died on Christmas Day 2004 in the peaceful surroundings of Clare Holland House, a hospice on the shores of Lake Burley Griffin in Canberra, surrounded by his family. He is survived by his wife, Dr Mary Carver, two sons and two daughters, John, Robert, Jane and Mary Ann, and sixteen grandchildren.

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