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Robert Street 1920–2013

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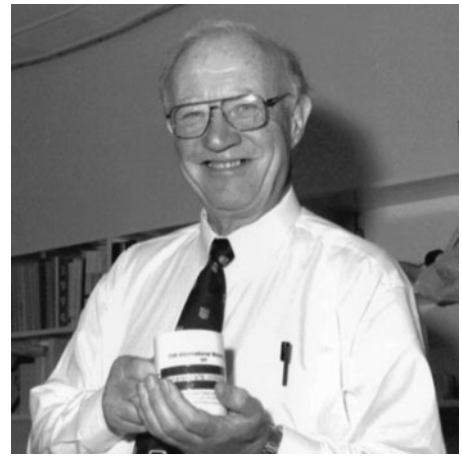
Following wartime work on radar and a University of London PhD awarded for measurement of absolute power, Bob Street developed his interest in low-temperature magnetism in solids while on the staff at Sheffield University. In 1960 he became Foundation Professor of Physics at Monash University where he built a department with strong capabilities in solid state physics. His own research continued at Monash but was put aside when he became Director of the Research School of Physical Sciences at the Australian National University (1973–7) and then Vice-Chancellor at the University of Western Australia (1978–86). Although the ANU experience was not a happy one, he flourished at UWA where his initiatives and strategic thinking laid the groundwork for advancement of the university. Street had kept up with advances in his research field and upon retirement he went back to it with notable success in publication, supervision of research students, acquisition of research grants and fruitful collaborations. He is fondly remembered as a first class physicist with a passion for cricket.

Introduction

Professor Robert Street AO, FAA, who died on 4 July 2013 at the age of 92, had a remarkable career; a career that took him from the Yorkshire coal fields, via war service in radar research, Monash University and the Australian National University (ANU) to the heights of Australian academia as Vice-Chancellor of the University of Western Australia. Following his retirement as VC he continued his scientific career in magnetism, producing over 128 papers in the next 20 years, nurturing a new generation of researchers and actively fostering several start-up companies based on his and collaborators' R&D.



Family Background and Early Life

Robert (Bob) Street was born on 16 December 1920 in Wakefield, Yorkshire, the elder of two sons to Joe and Edith Elizabeth Street (née Jones). His family had a long connection with the Yorkshire coalfields. His father, both grandfathers and many other relatives were miners. Ultimately (by the time Bob was born) his father headed the mine rescue team at the West Riding Mines Rescue Station. While his maternal grandfather (Alfred Jones) worked in the Yorkshire mines he hailed originally from Shropshire and this appears to have influenced Bob. The poetry of A. E. Housman was always a favourite, with an extract from *The Shropshire Lad* being read at his funeral.

Bob and his younger brother, Ronald, were the first generation of the family not to work in the coalfields. Ronald's destiny was aviation: commissioned in 1943 he saw combat in Burma flying Thunderbolts. He remained in the Royal Air Force after the war flying Dakotas during the Berlin Airlift before retiring in 1966 to pursue

a successful career in commercial aviation. For Bob, his destiny was science and ultimately Australia. In doing so he was the first of his family to go to university.

In his oral history[1] Bob attributes his early interest in science to encouragement by his father and several teachers. Their inspiration was so great that by age twelve he had a stated ambition to 'be a physics professor'. In particular, to his father he attributed his skills to make and look after equipment: 'When I was eight or ten I would go down with him to his workshop in the cellar … where he taught me how to use simple hand tools—planes, saws, all these things, but not chisels. More importantly, he taught me to look after them. We built all sorts of things, including crystal wireless sets and valve sets'.

At Hanley High School his emerging interest in physics flourished under the mentoring and inspiration of his headmaster, E. G. Laws (an Oxford graduate in chemistry), and his physics teacher who was very interested in the experimental side of physics, and let Bob have the run of the laboratory and an associated metal workshop. There Bob completed probably his first serious physics experiment: the observation of the Sun's Fraunhofer lines and the absorption lines of sodium and potassium using a spectrometer that he had 'cobbled up' himself in the workshop.

University Education and the Second World War

World War II indelibly affected Bob's subsequent life and career as it did most of his generation. In his case, the 'legacies' included an accelerated undergraduate degree, a long-time partner and wife and an introduction to solid-state physics. In his oral history[2] Bob describes how he was offered an Open Exhibition for admission in September 1939 but, despite considerable encouragement and several attempts, was unable to meet Oxford's mandatory Latin requirement. Thus he made a late application for King's College and enrolled in January 1940. At that time King's had been evacuated from London to Bristol to avoid the risk of bombing although Bristol became very much a target. As a result Bob's undergraduate studies were carried out in the midst of a major blitz. However, as he regaled in his oral biography, air raids were 'great unifying events… you get to talk to people, I suppose to keep your spirits up'. One of those he met in a shelter was a young woman, Joan Bere, studying history at King's. On 26 June 1943 Bob and Joan were married.[3]

Given the urgency of the war, King's had accelerated its undergraduate degrees so that in just over a year Bob completed a 'BSc Special' majoring in physics. In late 1941, after being interviewed by C. P. (later Lord) Snow of *Two Cultures* fame he joined the Department of Supply and was posted to the Air Defence Research and Development Establishment in Christchurch, Dorset.

The story of the development and deployment of radar in the late 1930s and its critical role in World War II is well known. Within a year of the first demonstration of radar by Watson-Watt in 1935 as a means to detect aircraft, construction had begun of the radar stations that were to play a vital role in the Battle of Britain in 1940. These first operational radars were low frequency radars operating in the very high frequency band on wavelengths of a metre to several metres. While such radars (based upon ground stations) were suitable for air defence, their size, power requirements and sensitivity were significant limitations. In particular, despite several attempts, development of an airborne radar system for deployment in fighter aircraft proved challenging. The breakthrough that changed the radar field dramatically was the invention in 1940 of the cavity magnetron, which allowed radars to operate on 'centimetric wavebands', corresponding to wavelengths of 3 and 10 cm.[4,5] The size of the cavity magnetron meant that it could be easily installed in an aircraft. The shorter wavelength of the radar pulses meant that the detection not only of aircraft, but also of surface objects was now possible. The cavity magnetron and the resulting radar systems it made possible were critical to the rapid deployment of radar during World War II. In addition to 'solving' the challenge of an airborne radar system for night fighters, the cavity magnetron made possible the air-to-sea and ship-borne radars that proved particularly significant in the Battle of the Atlantic against German U-boats.

By late 1941, British radar research and development was centred on two primary sites: Bawdsey Manor in Malvern and at Dorset, where Bob Street commenced in late 1941. In May

1942 the Dorset facility was moved to Malvern in response to concerns that it was vulnerable to a German seaborne raid similarly to the one that the Allies had carried out on a German radar station at Bruneval on the French coast. Malvern, now entitled the Royal Radar Establishment, was Bob's working place for the remainder of the war.

Bob's contributions to this massive R&D enterprise were of course modest, commensurate with that of a new BSc graduate. His own project[6] concerned the development of techniques to measure the power output of the signal generators used to calibrate the receivers that were incorporated in the centimetric radar sets of all kinds.

However, the ethos of this wartime facility and his experience there, not to mention the major figures he met, must have shaped his future career and approach to science in many ways. While the focus was very clearly on designing and deploying practical devices that could shorten the war, the physicists and other scientists and engineers brought together were some of the leaders of their generation. Thus the science deployed was leading edge and the practical developments in turn stimulated (if only somewhat later as peace came) basic science. It is a reasonable supposition that this mix, so clear in Bob Street's own research over the next 60 years, was stimulated and encouraged by his wartime experiences. Indeed Watson-Watt in his account[7] of the development of radar specifically commented: 'It is more important that there should be a large number of scientists free to nose around in other people's business, asking their own questions in their own way, than that there should be large establishments engaged on the production of pieces of equipment designed, however ingeniously and economically, to meet operational requirements that have already been formulated'. That 'nosing around' and asking questions became very much a hallmark of Bob's subsequent career. And, as we shall see, Watson-Watt's 'warning' about 'large establishments engaged on the production of pieces of equipment' featured strongly in one of the more turbulent periods of his career.

His fundamental curiosity about what was happening around him also seems to have come to the fore and led him, in his 'spare time', to complete an external MSc at the University of London in wave mechanics, his interest being stimulated by thinking about the materials science underpinning the carborundum crystal and its wire contact that sat at the heart of the whole radar system. In this way one suspects that his lifetime interest in material science was stimulated.

Post-war Work in the UK

Bob accepted a position as an assistant lecturer at Nottingham (then a college of the University of London, later in 1948 to become the University of Nottingham) and his academic career began to blossom. Building on his wartime work on power measurement at centimetric wavelengths he completed a PhD on the absolute measurement of power in 1948 awarded by the University of London. Perhaps more significantly for his future career, following a suggestion of Professor L. H. Bates (the Head of Department), he carried out experiments (with John Woolley) to understand the so-called ΔE effect in a technically important material, Alnico.[8] This effect arises from the variation of a material's Young's modulus by an applied magnetic field. To explain the experimental observations Bob developed a novel theory of the elastic properties of ferromagnets in terms of a thermally activated domain process. The theoretical predictions were in excellent agreement with experiment. As a result of these experiments, magnetic viscosity, or the time-dependence of magnetization, was to remain a life-long obsession.

In 1954 Bob moved to Sheffield University as a senior lecturer. There, due to the availability of a liquid hydrogen facility, he extended his interests in magnetic materials to studies at low-temperature. He also established a collaboration at the Atomic Energy Authority at Harwell, where early experiments to measure magnetic structures using neutron diffraction had commenced. In particular he investigated[9] the anti-ferromagnetism in mixed cobalt and manganese alloys realizing that these new techniques allowed a microscopic, atomic-level interpretation. Bob also used these experiments to show that measurements of magnetic viscosity permitted the study of magnetic structure of very small volumes comprising $\sim 10^6$ atoms.[10] At the time of this work (1954) this constituted a notable addition to methods of metallurgical investigation and can be seen as an interesting precursor of nanotechnology.

Relocation to Australia and Monash University

With this background and following encouragement from his Head of Department at Sheffield, Professor W. Sucksmith, (in part because there appeared to be no positions likely in the UK for some time) Bob applied for the Foundation Professor of Physics at a 'new university' (Monash) to be developed in Victoria, Australia. The advertised position called for a person with interests in the field of solid-state physics. In early 1960 the position was formally offered to Bob and he and his family relocated to Melbourne with him taking up the position in November 1960.

Monash[11] at that time was less than two years old; the inaugural Vice-Chancellor, Louis (later Sir Louis) Matheson, only having been appointed in 1959 and the first professors and staff recruited during 1959–60. Street was the 86th Monash staff member and the sixth professor to be appointed.

Once he accepted the offer of the foundation professorship in early 1960 he threw himself wholeheartedly into the planning of the new department, ordering equipment and recruiting academic and support staff. In this he was strongly encouraged by Matheson with whom he established an excellent rapport and friendship. Unlike more recent times in universities, resources did not seem to be a limiting factor. As Bob observed in his oral history[12]: 'It was a different world, completely.… Strange as it seems now, all you had to do was to ask. So I asked for all sorts of things: a helium liquefier to avoid the possibility of blowing ourselves up with hydrogen, electron microscopes, big magnets, equipment to put in the laboratories, lecture theatres, all these things – and they were there in abundance. We had it very easy'.

People were the other dimension and over 1960 he was active in recruiting the first academic and technical staff to the department. The result was that when the inaugural cohort of 350 students entered Monash in February 1961, Bob was head of a small but very viable department that over the next decade was to grow into one of the largest and most successful physics departments in Australia at the time.[13]

By any standards Bob's leadership of the Physics department at Monash from inception until 1973 must rank as one of the most spectacular in modern Australian university history. Prior to Street's arrival and the development of the Monash department, solid-state physics research in Australia was essentially non-existent in universities and very limited elsewhere. The CSIRO Division of Tribophysics (under the leadership of Dr Walter Boas, FAA) had a focus on the mechanical properties of metals and in Sydney in the Division of Applied Physics a group under Dr Guy White FAA, recently returned from a PhD at Oxford, was developing a basic research program in the low-temperature properties of solids. Street actively sought to collaborate with these groups; initiating evening research colloquia to bring together the dispersed Melbourne community and developing an active program of shared visitors with Guy White's group.[14]

Building a research culture based on active research programs with associated PhD students was an important priority for the embryonic Monash under Matheson's leadership. Indeed the first students enrolled at Monash in 1961 were PhD students, predating the first undergraduates by a few weeks. Bob enthusiastically endorsed this philosophy. An early appointee[15] recalls being summoned early in his appointment to a 'sermon' on the need to establish a research program, recruit PhD students and 'publish or perish'; a sermon that he sensed had been given to all new staff. Others[16] remember Bob as 'a mentor and very good friend (who) fostered a research and teaching environment with the hallmarks of cohesion, co-operation and camaraderie'. As we suspect he learned at Royal Radar, he actively took an interest in all the research activities in the Department, conducting a tour of the laboratories several times a week during which he would talk to all and particularly to students—PhD, honours and even undergraduates—and get them to tell him what they were doing.

While the development of the research activities of the new department was a high priority, undergraduate teaching was not neglected. Bob believed that even professors should teach and particularly first year. Michael Morgan, Monash's current (2015) Head of Department and an undergraduate in Bob's days, recalls[17] being taught by Bob and experiencing at first hand an obvious joy for physics especially experimental physics. He was 'a man who was

passionate about teaching and passionate about research and that came across very clearly to all students… (and he remains) a role model for academics today'.

Under his leadership, the department grew rapidly with new staff recruited, research students attracted and as a result research outputs soared. By 1964 the department's complement of staff was 65 and there were over 30 research students. Research publications and PhD completions rose steadily over the decade with over 450 publications, 76 PhDs and 10 MSc graduates produced during his tenure. The PhD graduates are a roll call of people who would play significant roles in Australian science and academia including Geoff Wilson, the first Monash PhD in physics and later a Vice-Chancellor of two universities, Don Price, a senior CSIRO scientist and Paul Rossiter, DVC(R) at Curtin.

Scientifically his own contribution to this output was 18 papers that included the research projects of 10 postgraduates that he supervised. The major focus of his work at Monash was on chromium to which he brought the whole arsenal of experimental techniques including neutron diffraction (through a collaboration at the newly established Lucas Heights reactor) and Mössbauer spectroscopy. These experimental observations were interpreted and explained through a detailed model based on spin-density waves.[18]

As Monash developed Bob turned part of his attention outward and began his service to the wider scientific community and the nation to which he and his family had come. He was a pioneer in science education through the development of the Victorian physics curriculum, science communication through the ABC TV science program 'Science Question Time' and professional development through the Australian Institute of Physics.

He established links with the Australian physics community through his Chairmanship of the National Standards Commission (1965) and later (1973) as Chairman of the Interim Commission on Consumer Standards. He was invited to become Chairman of the Australian Atomic Energy Commission's Advisory Committee (1965) and later was the President of the Australian Institute of Nuclear Science and Engineering, the organization which facilitated access by University researchers to the facilities available at the AAEC (later Australian Nuclear Science and Technology Organisation (ANSTO)) Research Establishment at Lucas Heights. In 1965 he became an inaugural member of the Australian Research Grants Committee (ARGC), the precursor to the Australian Research Council, and was ARGC Chairman from 1972 to 1976.

In 1973–4 there were two significant developments. The first was scientific recognition through election to the Australian Academy of Science. Bob was nominated to the Academy by Walter Boas, seconded by Sir Ernest Titterton and supported by Guy White. Boas[19] succinctly summarized his research to date as: 'Professor Street is distinguished for experimental and theoretical work in magnetism, (particularly): i) Magnetisation processes in ferromagnetic materials. Street analysed the time dependence of magnetisation particularly in high coercivity materials and verified his theoretical predictions by experiment. He developed a unified theory of elastic properties of ferromagnets in terms of fundamental domain processes and this theory accounts for a wide variety of experimental data, and ii) Magnetic interactions in solids. This work is elucidating the magnetic structures of anti-ferromagnetic metallic systems by neutron diffraction, magnetic susceptibility, magneto resistance and elastic measurements'. External referees include Nicolas Kurti, one of the mid-twentieth century pioneers in magnetism, who noted[20] 'Street's work in the field of ferromagnetism is characterised by an imaginative approach both in its experimental realisation and in its theoretical conception and interpretation'. White and other supporters also strongly commended his development of the Monash department and his wider scientific leadership. Not for the first time or indeed the last this resulted in an intense debate about whether or not scientific leadership warranted consideration in election. In the end Council voted to elect Bob and he became a Fellow in 1973; a fitting tribute at an important junction in his own career both in science and in leadership.

This change was to come with his appointment as Director, Research School of Physical Sciences at the ANU. In accepting Bob's resignation from Monash, Louis Matheson wrote[21]: 'Your appointment was without doubt one of the

most successful we made in the early days, and your membership of the University, both professionally and personally, has been tremendously valuable and appreciated'.[21]

The Australian National University

After the success at Monash, Bob's time at the ANU was a time of disappointment, frustration and some controversy. In his own words[22] the period as Director, Research School of Physical Sciences was 'not the happiest of times'. *Fire in the Belly*,[23] the official school history written in 1996, almost consigns the Street directorship to a footnote between the (turbulent) end to Titterton's term as Director and the 'calming' influence of Carver. Bob himself is characterized as 'an aloof and formal Director' and 'a fervent disciple, if not creator, of the catch cries of the seventies—accountability, resource allocation, pursuit of excellence and research planning, all thrust forward as new ideas with no evident recognition of the extent to which such concepts were already current practice'.

Foster and Vargese in their official history[24] of the ANU were more generous. From this account Bob Street appears as a man ahead of his time and certainly clashing with the complacent culture of a research school facing major change.

The 1970s were a decade of immense change in Australian higher education. The high point was the take-over from the States by the Whitlam Government in 1974 of responsibility for university funding. However, this euphoria rapidly faded amidst the financial excesses and crises of the latter years of the Whitlam Government. These crises (which led to the constitutional crisis of 1975 with the dismissal of the Whitlam Government) ultimately led to a series of Federal budgets that significantly reduced University funding and the funding of the ANU in particular. Few, if any universities and certainly not the ANU in those days had the tools or processes to deal strategically with a significant budget reduction beyond an across-the-board cut that (naturally) impacted the softer elements of budgets such as travel or simply 'froze' posts.

As detailed by Foster and Varghese,[24] Street's response was revolutionary: he convinced the Faculty Board of the Research School to commission a review of the School's research activities. While now a standard element of academic quality assurance across the system, this was a novel development not only for the ANU but for any university. The review reported in 1976 and even today its report reads much as any contemporary review. Certainly it would not be good practice to chair the review as Street did himself. However, it is probably harsh to describe this, as Foster and Vargese do, as 'a major mistake'. Without his chairmanship one suspects that the review itself would not have been as sharply focused or as strategic.

The review report expressed sentiments and criticism that would recur across the next decade or more. The review recognized: 'The School must be and be seen to be at the forefront research activity in Australia.… scope and nature of its activities should help lead the overall Australian research effort in the disciplines it encompasses, providing appropriate focal points of research activity of the highest international standard. That standard should be evident in the quality of its output or else there is little justification for continuing to support a special research establishment'. No better and more succinct statement of the purpose of the Institute at the ANU would be heard over the next twenty years. Yet the review concluded that while areas within the School demonstrated such a standard of research excellence and performed a role of research leadership, the committee concluded: 'as a whole the School lacks an overall image of excellence' again a critique that would be heard again. Perhaps most significantly the review argued strongly for a people-first view rather than a view that building infrastructure and big equipment was sufficient. As noted earlier, one senses in this a lesson Bob took from his earliest days at the Royal Radar Establishment at the feet of luminaries such as Watson-Watt.

Foster and Vargese attribute Street's failure to be able to implement the recommendations of the review to his two major errors: chairing the review and using the Faculty Board of the School to commission it: 'what the board had given it could just as easily take away: as the official initiator of the review, it could control the outcome'. Yet one has to wonder what alterative mechanism could have been used. The ANU simply did not have the processes or the culture of external review that would exist a decade later to deal with such a review. Equally, as Foster and Vargese note, the Street review's medium term impact was significant: it heralded the emergence of

a modern culture of external review and one suspects that without it the transformation that his successor, John Carver, as Director wrought, would have been that much more difficult.[25]

Another area in which Bob was undoubtedly ahead of his time at the ANU, and which troubled him, was the relationship with the undergraduate component of the ANU—the then School of General Studies to become The Faculties in 1979. In his oral history[26] Bob comments: 'I had the rather naïve idea that maybe if the researchers were involved in undergraduate teaching there could be two advantages: they could help students in the School of General Studies to see subjects from a different perspective, and an important spin-off would be to attract undergraduate students to the postgraduate work that was going on… But no one else in the research school (other than himself) followed that suggestion'. Again culture and complacency in the face of emerging transformational threats were to blame. A decade later when one of us (MNB) joined the ANU as a professor in the Faculties one of the first committees he was appointed to by the then DVC, Professor Ian Ross, was an 'Interface Committee' charged with working out how the Faculties and the Institute could work more productively together!

It is also quite likely that Bob's inability to implement the review he commissioned was because of his own character: he believed implicitly in reasonable people operating reasonably. In the Research School of Physical Sciences (RSPhysS) of his day he collided with an established bureaucracy and culture very resistant to change however cogently or logically argued. Whatever the reasons for the short-term failure of the review, its long-term ramifications bring credit on him and his term at the ANU.

During this period Bob continued his chairmanship of the ARGC until 1976 and the National Standards Commission until 1978, and became a member of the Australian Science and Technology Committee (ASTEC) that Fraser established in 1977. Despite the perception they gave of a distant Director,[27] these external interests delivered just the sort of leadership expected of senior ANU professors.

The University of Western Australia

Bob Street was appointed Vice-Chancellor (V-C) of the University of Western Australia (UWA) in late 1977. His arrival in Perth in February 1978 at the age of 58 coincided with the downturn in government funding of universities resulting from the commonwealth take-over of university funding, not the universities themselves. He thus took up his new position in a period of much financial uncertainty and turmoil and, from the beginning, lead from the front.[28]

As he later described,[29] his reception at UWA was rather different than it had been at ANU. 'I was very pleased also to be part of that university, and never regretted going over there. It was a long-established institution and the people involved took a jealous pride in its being the only free university in Australia. Everybody I met in the university and in the outside community looked upon it as a real benefit to them and cherished it. I felt that people supported it in ways which were quite unknown in other parts of Australia, and everywhere there was a warm welcome as though you were doing something worthwhile for them.'

Almost immediately on taking up his appointment Bob sent a memorandum out to all Department heads, warning of the likelihood of imminent budget cuts and instructing them to plan for a reduction in staffing levels. This caused significant angst from the staff, with the prevailing attitude that the University should not contemplate such cuts unless forced to do so by the government. Needless to say, Bob was not the most popular person on campus at that time. He subsequently oversaw an across-the-board 11% reduction in teaching and support staff in the period of 1978 to 1981 and further reductions in subsequent years. Reorganization of senior administrative staff, driven mainly by retirements was also necessary during his first years.

Bob's tenure at UWA also saw the introduction of union representation of both academic and non-academic staff, changes to study leave, a new superannuation scheme, and many other changes including ongoing decentralization of decision-making processes.

As a first step he circulated a discussion paper that proposed the creation of resource groups that would take responsibility for staffing, equipment and other expenditures in their areas. While progress was slow, significant changes were made to the internal decision-making processes in the university that improved the efficiency

and effectiveness of decision-making. This was an ongoing process, ultimately leading over a decade later under Fay Gale to the devolution of most decision-making to Department or School level. As at the ANU, Street's initiatives and strategic foresight laid the groundwork for others to plough.

In spite of the negative effect of the various economy measures that needed to be taken, Bob's tenure as V-C is considered, in hindsight, to be a remarkably creative period in the history of the University. From the day of his arrival in Perth, Bob argued that the climate of financial stringency made it more important than ever to not get bogged down in stagnation and mediocrity. Bob's efforts led to a three-year grant from the Commonwealth to fund new initiatives and, through his initiative two funding programs—the University Development Fund and the Senate Special Projects Fund—were started, which funded new teaching and research initiatives. The many new activities and ventures started from these two funds are considered to be one the major achievements of Bob's tenure as V-C. Together with significant growth of externally funded activities meant that Bob on his retirement at the end of 1986 was able to hand over to his successor a University well positioned to tackle future challenges.

His many duties as V-C included Chairmanship of the Festival of Perth (now the Perth International Arts Festival), a role he took very seriously and with much stamina. It is folklore that one year he and Joan attended 14 successive nights of performances, dedication well beyond the call of duty.

Post-retirement—Back to Magnetism

On retiring as V-C Bob Street restarted his research career. He had kept up to date with the advances in solid-state physics during his time as V-C and was keen to re-immerse himself back into mainstream research. As he later related,[30] 'During the time I was vice-chancellor, I used to read *Physical Review Letters* quickly before passing it on to people who had more pressing need for it. Consequently I kept reasonably well aware of developments, though not in detail'. He took up residence in a small office in the Physics Department as Emeritus Professor of Physics and honorary research fellow and commenced his new life as a researcher.

Bob described[31] this period as 'the most productive and rewarding period of my career'. Over the next 15 years he initiated a magnetism research program at UWA, building a well-equipped research laboratory, supervising 20 PhD and over 30 BSc Honours students and obtaining a share of research funding totalling more than $13 million. He published 128 papers between 1988 and 2003 and these papers have been cited over 2500 times.

Magnetics Research

As circumstance would have it, there was a resurgence in interest in magnetism in the mid-1980s driven by the invention of new rare-earth based permanent magnet materials and the development of magnetic storage media. Within a very short period of time these new materials enabled the miniaturization of electric motors and development of entirely new electronic devices, perhaps the most well-known at the time being the Sony Walkman. As well, new magnetic materials used in computer memories and other applications also gained significant attention.

Even before retiring, Bob Street had arranged his first post-retirement project at CSIRO Division of Applied Physics with former Monash PhD student Dr Rod Day. In his return to research Bob initially focused on the phenomena that had first captured his attention as a young researcher in the UK in 1949—magnetic viscosity—but now using more advanced instrumentation and new magnet materials based on alloys of neodymium, iron and boron (NdFeB). Bob travelled regularly to Sydney to carry out the research, working day and night in the laboratory. As he later related, 'and one night (all these things, it seemed, happened at night) there we were in the laboratory measuring, for the first time, the magnetization of a rare-earth permanent magnet when the magnetic field had been changed. We sat and marvelled as, sure enough, the pen on the chart recorder went shooting across and then gradually moved more and more slowly. That particular process is a logarithmic variation with time—it starts fast and then goes more and more slowly, but never ends. We had predicted in 1949 that it would vary according to a logarithm of time, and there it was. We just sat there watching it, over and overagain'.

The first paper[32] from this collaboration was published in 1987. Significantly, this paper

showed that the theory of time-dependent magnetic behaviour originally developed by Bob back in 1949[33] described exactly the behaviour of the new 'hard' permanent magnets.

The Magnetics Laboratory

Bob's research at CSIRO was followed by a successful ARC grant application that enabled the purchase of a vibrating sample magnetometer (VSM) vital to carrying out research on magnetic materials. This grant proved to be very important to Bob's post-retirement career that evolved over the next 15 years. In addition to equipment, the grant provided funds for a key laboratory staff member and access to technical staff. With generous financial assistance from UWA, the Magnetics Laboratory, known as HiPerm, was established in the basement of the physics building to house the new magnetometer and the many students that followed. In the ensuing years the magnetometer was joined by a second, more powerful VSM and a SQUID magnetometer, making the HiPerm laboratory the best-equipped and most active Magnetics Laboratory in Australia. As well as the many postgraduate students, over the ensuing years the magnetics laboratory hosted several international visitors for periods of a few days to several months, often at their own expense.

The Magnetics Laboratory was central to the establishment and operation of an ARC Special Research Centre at UWA in 1991. The Research Centre for Advanced Mineral and Materials Processing, RCAMMP as it came to be known, was a collaboration of materials chemists, physicists and engineers at UWA, focused on the science behind value-adding to the nation's mineral resources. A focus of RCAMMP was research aimed at improving the scientific understanding and processing of rare-earth permanent magnets.

Research Activities

Bob's work on time-dependent magnetization continued and broadened to include a wide range of topics aimed at delineating the mechanisms of reversible and irreversible magnetization. The work was a blend of experiment and theory. The role of magnetic domains and the interactions of domain-wall boundaries in determining the magnetic properties was a common thread of much of Bob's research during this period. Magnetic domains consist of small regions where all of the individual atomic magnetic moments are lined up in the same direction. To change the magnetization it is necessary for the domains to grow or shrink by domain wall motion or take on a different alignment. Strong permanent magnets require very high applied magnetic fields (high-coercivity) to move the domain boundaries and change the magnetization. Of significance is the size of the domains and the relationship between grain size and domain size. When the two are equal, each grain corresponds to a single magnetic domain and enhanced magnetic behaviour is often observed.

Of particular interest was the role of the domain structure in the new ultra-high- coercivity rare-earth permanent magnets based on NdFeB and samarium/cobalt (SmCo). Bob's group pioneered the use of Magnetic Force Microscopy (MFM), in collaboration with scientists at Digital Instruments (USA) in using soft magnetic probes to image domain structures in the new rare-earth magnets. Combining the structures obtained using MFM with conventional Kerr microscopy enabled a complete picture of magnetic domain structure in these materials, avoiding the problems associated with use of conventional probes. By understanding the role of microstructure, magnets exhibiting the highest coercivities at the time were developed through control of the grain structure of the material.

A related area of research involving the interaction of domain and grain boundaries undertaken in Bob's laboratory was remanence enhancement associated with the coupling at the grain boundaries between hard and soft magnetic phases, causing an enhancement of the remanent magnetization of the material. The study of remanence enhancement became a strong area of research in the Magnetics Laboratory, resulting in numerous publications. It was shown for the first time that alloys containing two phases, consisting of α iron and a high-coercivety, rare-earth alloy phase, exhibited greatly improved remanent magnetization, providing the soft and hard phases were magnetically coupled at grain boundaries. Significant studies were carried out that delineated the roles of magnetic coupling at the boundaries and grain size on remanent magnetization, domain-wall motion and time-dependent magnetization in these alloys.

Collaborations

In his post-retirement career Bob developed strong collaborations with several colleagues at UWA and with several overseas scientists and organizations. Soon after retiring he joined forces with Paul McCormick, Professor of Materials Engineering, whose research on mechanical alloying and mechanochemical reactions provided a novel route for manufacturing magnetic materials with a range of microstructures and enhanced properties. Their collaboration over the ensuing fifteen years formed the basis for numerous projects focused on the role of microstructure on magnetic properties, the synthesis of so-called nanomagnetic materials and the optimization of magnetic properties.

Also during this period, collaboration was initiated with Professor Yuri Estrin, a noted expert on plasticity in metals and alloys. Professor Estrin, a Gledden Visiting Fellow at UWA (later to become Professor of Materials Engineering at UWA), was visiting McCormick to collaborate on modelling rate-dependent crystal plasticity. Informal discussions between the three revealed strong similarities in the theoretical treatment of magnetization kinetics and time-dependent plasticity. A magnetic constitutive equation of state was developed, which was formally equivalent to the mechanical constitutive equation used to describe time-dependent crystal plasticity. The constitutive equation allowed a common treatment of the kinetics of magnetization and plasticity over a wide range of conditions. The constitutive theory was extended to a model describing unstable magnetization processes associated with domain wall motion.

Bob maintained an open access policy, welcoming and offering the facilities of the Magnetics laboratory to new staff and visitors to the Physics department. Two such new staff were Dr Tim St Pierre and Dr Robert Stamps, who joined UWA in the mid-1990s. St Pierrre extended the breadth of the Magnetics Laboratory to biomagnetism and magnetic resonance imaging (MRI). He and Bob developed a strong collaboration in the development of MRI techniques to quantitatively determine iron levels in the livers of patients with iron overload diseases. Stamp's field was theoretical and computational physics, and he and Bob could often be seen in the laboratory in deep discussions on topics such as exchange interactions and spin dynamics in magnetic materials.

International Workshop on Magnetic Materials

In December 1995 an International Workshop on Magnetic Materials was held at the UWA in honour of Bob Street's 75th birthday. Over forty invited guests, including fourteen from overseas attended along with twenty PhD students and researchers from Bob's group. A special guest was Dr John Woolley, with whom Bob had published his seminal research of time-dependent magnetism in 1949. Twenty-one papers were presented at the workshop, including the opening paper presented by Bob, entitled 'Magnetization Processes in Thin Films with Perpendicular Anisotropy.' Several of the papers were published in the *Journal of Physics D*.[34]

Mentoring

One of Bob's most enjoyable jobs during his retirement was acting as a research mentor at the then CRA Advanced Technical Development Centre in Perth. Bob's role was to talk to the researchers about their projects and ideas, providing sage advice on both a technical and a personal level. Out of these visits came some very interesting ideas and projects. A project of particular note was the development of a method for magnetic detection of defects along the Co.'s rail lines in the north-west of Western Australia (WA), based on the *in situ* detection of stray magnetic fields at defects in the rail, developed by a permanent magnet as it passes along the track. Another project that grew out of his mentoring was the idea of using mechanochemical reactions to destroy intractable organic toxic wastes such as PCB and DDT. This idea was conceived by CRA researcher Peter Donecker and after discussions with Bob and Paul McCormick, led to a significant project funded by CRA and Akzo Nobel that confirmed the mechanochemical destruction of DDT. Whilst the process was shown to be highly successful, leading to a letter published in *Nature*, the process was not cost competitive with alternative high temperature combustion processes.

Commercialisation of Research

Bob Street was a strong supporter of efforts to translate findings from the laboratory to the

outside world. During his post-retirement career he became involved in the successful spin-off of two of the technologies that emanated from research carried out in the Magnetics Laboratory.

Advanced Powder Technology Pty Ltd

Publicity of the research on rare-earth permanent magnets caught the attention of Carr Boyd Minerals, then the owners of the Mt Weld rare earth deposit in WA. Dr Frank Honey, a Director of Carr Boyd and noted WA scientist, was interested in whether mechanochemical processing could be used to directly manufacture high quality rare-earth permanent magnets, thus value adding to an important mineral resource. Dr Honey's interest led to a long collaboration and the formation of Advanced Powder Technology (APT) in 1997, with Street, Honey and McCormick as Directors. Major shareholders of the company were the UWA and Lynas Rare Earths, who had acquired the Mt Weld deposit from Carr Boyd.

Patents were granted for the process and a Joint Venture between APT and the Korean company, Samsung Corning, was established in 2000 to develop a manufacturing process for cerium oxide and other nanoparticles. Bob served as a Director of APT for eight years. In 2005 APT was renamed Advanced Nanotechnology Ltd (now renamed Antaria Ltd) and was floated on the Australian Stock Exchange (ASX:ANO).

Inner Vison Biometrics

Inner Vision Biometrics was established by Tim St Pierre to commercialize MRI techniques for measuring iron levels in the livers of people with iron overload diseases. Bob served on the board of the Co. and its successor, Resonance Health Ltd (ASX:RHT), during the initial commercialization period and went on to Chair the company during the period as a public company.

Recognition and Memories—Comments from those who Worked with Bob

In addition to his fellowship of the Australian Academy of Science, his service to his adopted homeland was recognized on Australia Day 1985 by being made an Officer in the Order of Australia. The citation read: 'For service to learning, particularly as Vice-Chancellor of the University of Western Australia'. In 2001 he received a Centenary Medal 'for service to Australian society and science in physics'. His contributions to UWA and to Monash are recognized by the Robert Street Building at UWA and annual Robert Street Prizes at UWA for the most outstanding PhD thesis and at Monash for the most outstanding PhD thesis in Physics. Ultimately we suspect that Bob would wish to be remembered by those with whom he worked and whom he taught or mentored.

Roy Lourens, who served Bob as his Deputy Vice Chancellor at UWA, summarized him very simply: 'He combined scholarly distinction with rare leadership qualities, and for all his eminence he remained at heart a warm, humorous and humble person. He was one of those WYSIWYG types—What You See is What You Get—no scheming, no politicking guile or disloyalty. He could be trusted to the full, and that quickly engendered a sense of loyalty in return; direct, and a proud Yorkshireman to boot'. Others even simpler: as the classical 'gentleman scholar'.[35]

In retirement he was 'a man of leisure enjoying his one true hobby, magnetism'. He loved to come into the laboratory, to talk to the students, and work on any one of several scientific questions. Although he was retired, it was not uncommon for Bob to be in the laboratory with one or more of his students after 6 p.m. at night watching the VSM collect some more data.[36]

Apart from his deep knowledge and passion for physics, Bob had many other interests. He was a keen cricket player (Fig. 1[37]) until his mid-forties though, despite being eligible by birth for selection, his ability was not at a level to play for his beloved Yorkshire County team. He was a keen but not particularly successful fly fisherman, enjoying much more productivity from his large vegetable garden, developed in the Perth Hills in his retirement. His other interests were in classical music especially opera and reading, to be replaced by audio books when he developed macular degeneration.[37]

Bob was highly respected and well loved by all his students. He challenged them. He made their research exciting and challenging, he was at his best in guiding his students. His favourite instruction to a student uncertain on how to solve a particular problem was 'just do it'. If a student obtained a sufficiently novel result, he/she was awarded one of Bob's 'mini Nobel prizes'.

Bob Street's students were in awe of his intellect. His humour and wit were legendary.

Figure 1. Bob Street batting for The Vice-Chancellor's XI against a Student XI during the first cricket match ever played at Monash University (1961).

Bob was always willing to spend time helping a student with a problem. He had a very broad knowledge of solid-state physics. The Magnetics Laboratory was a vibrant and active place. He had an engaging nature and treated everyone equally, always willing to patiently correct the most elementary of mistakes without humiliation.

Bibliography

A full bibliography of scientific publications by Robert Street is available online as Supplementary Material to this paper.

Acknowledgements

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for access to their archives and to Professor Paul Johnson who made available selected documents from UWA's archives.

Endnotes

1. *Professor Robert Street (1920–2013), physicist*, Australian Academy of Science 2005 interview of Professor Robert Street with David Salt. www.science.org.au/node/449908 (Accessed: 22 June 2015) Henceforth referred to as '*Street Oral History*'.
2. Street, as above.
3. In an intriguing coincidence Joan, who had been employed at Bletchley Park after her own foreshortened studies were completed and before she was married, worked after her marriage to Bob as a personal assistant to (Sir) Leonard Huxley who later became VC at ANU and with whom the Streets rekindled their friendship when Bob went there in 1978. (Alison Street, private communication.)
4. For a history of the cavity magnetron see for example *Engineering and Technology History Wiki*, ethw.org/Cavity_Magnetron (accessed 22 June 2015).
5. One of the people urging the development of centimetric radar was an Australian, Professor Mark (later Sir Marcus) Oliphant then at Birmingham University and who would after the war become the inaugural Director of the Research School of Physical Sciences at the ANU that Street would also later lead.
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15. J. Pilbrow, private communication, April 2015.
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25. In his oral (see www.science.org.au/node/450007#15 (accessed 15 April 2015)), Carver recounts his vision for the School and what he found on his appointment as Street's successor: 'Fundamental was the idea that the school should be seen as integral and valuable to the Australian nation…. Things were very different in '78 when I came back. It was not that any of the work was not important or that some of it was not extremely relevant, but a lot of people outside the school did not see the importance or the relevance. And a lot of people within the school didn't think it was important to make the relevance more apparent… I wanted to make the school relevant to the nation and to be accepted that way by everybody'.
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27. Ophel and Jenkin, already cited, (n. 23).
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