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SIR PAUL TERENCE CALLAGHAN FRS PCNZM

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Elected FRS 2001

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Paul Callaghan will be remembered internationally for many seminal contributions to the foundations of magnetic resonance imaging as applied to the rheological analysis of a series of real world materials – paints, gels, polymer solutions – and at home in New Zealand as the leading physical scientist of his day, who became a familiar science communicator through popular books, a radio programme and the promotion of high technology as a part of the New Zealand economy. Apart from his time as a research student in Oxford (1970–75) and short stays abroad, Paul undertook all his research in New Zealand, and was a passionate and effective advocate for New Zealand science. His direct and continuing legacy for condensed matter science in New Zealand was his leadership in the foundation in 2002 of the multi-university MacDiarmid Institute devoted to research in advanced materials and nanotechnology, which he led through its first five years and into its second phase. In later life he was the founder of Magritek, a company manufacturing the specialist magnets needed for resonance imaging and spectroscopy.

EARLY YEARS

Paul Callaghan was born 19 August 1947, the son of Mavis and Ernest Callaghan. The family lived in Wanganui East, a suburb of Wanganui where most men were employed at the local...
railway workshops. However, Ernest (Cally) was a shopkeeper, owning a dress fabric shop in partnership in the city. Paul was the third of four children: he had an older brother, Jim, and two sisters, Jeanine and Mary (Figure 1). His paternal grandfather, Alexander, was the son of a British soldier, stationed in New Plymouth at the time of the New Zealand land wars in the mid-nineteenth century. Both maternal grandparents, Agnes and Francis Hogg, were of Scottish origin, their parents having emigrated from Aberdeen and Edinburgh in the 1850s.

Mavis was one of nine girls in her family and they were very close. Holidays were almost always spent with relations. Paul’s cousins were an important part of his life and in later years he made time to attend numerous family reunions. When Mavis was ill for two extended periods, Paul was sent to live with an aunt and uncle and his cousins in Tauranga, where he attended school for several months before returning to Wanganui.

Ernest Callaghan had limited education, having not progressed beyond primary school, but he was an avid reader and collector of books: New Zealand history and polar exploration were his interests. Paul’s work in the Antarctic and his passion for New Zealand undoubtedly had their origins in the books that surrounded him in his youth and the conversations with his father. His older brother, Jim, left home at the age of 17 to follow his interest in physics at Victoria University in Wellington. Over the next few years, the reports from Jim about his studies had their influence, and another Callaghan son developed an interest in physics.

Paul had some influential teachers at Wanganui Boys College, and he always gave credit to his teachers of maths (Dixon), physics (Kerr) and English (Ives) for his academic success. This success could no doubt also be credited to the enthusiastic manner in which he approached all
aspects of his life. Whether stroking in the school rowing eight, playing the tenor horn, running cross-country or behaving badly, he always gave his all. This enthusiastic approach continued throughout his life and showed through in later years, when he practically became the public face of science in New Zealand.

Paul’s interests outside his work and family were quite varied. He enjoyed getting out in the New Zealand bush and back country (Figure 2). When he was younger it was tramping in the Ruahine Ranges near Palmerston North; later he made more adventurous trips on the tracks in the Southern Alps. He played the horn in the Palmerston North City Wind Band and was always ready to give a rendition of ‘Danny Boy’ at family occasions. He enjoyed trout fishing at Lake Taupo, where the family had the use of a holiday home at Omori, a quiet spot at the south of the lake. He had a small dinghy with a tiny outboard motor and would spend
hours trolling up and down the lake; or he could be found casting a fly in one of the streams that flow into the lake: a very peaceful exercise in a busy life.

Paul wrote a series of biographical essays, edited after his death by his daughter, Catherine, and published as *Luminous moments* (51). About his early life he wrote:

By the time I went to secondary school I had done a lot. I had already seen satellites passing over the sky. And I had built model planes, though never, like some of my friends, proper ones with a propeller and glow plug motor. I had also built a crystal set. We used diagrams and bits and pieces provided by other kids or bought in model shops.

Later on he described how

By the time I was seventeen years old, I had measured both the charge and the mass of an electron, using our teacher’s brilliant but rudimentary school equipment, incorporating coils of wire similar to that of my crystal set. Ernest Rutherford once said, when asked if the electron existed, ‘Why, I can see it as plain as that spoon in front of me.’ I think I grasped Rutherford’s way of ‘seeing’ way back then. The reality was in the measurement, in the self-consistency of the ideas behind the interpretation.’

He also wrote that science ‘had become a way of seeing the unseeable, or reaching a world of imagination founded in both measurement and mathematics’.

**University research**

*Victoria University of Wellington, 1966–70*

Paul entered Victoria University of Wellington in 1966 to study physics, with a University National Scholarship that he had won the previous year. In a Radio New Zealand interview, he described himself as not being an assiduous student in his school days, but he excelled at University. His transcript shows him as a straight-A scholar in mathematics and the sciences. He took two attempts at ‘Science French’, a requirement for anyone wanting to follow the honours programme (as in the Scottish system). It was taught by a formidable Mrs Frankie (Frances) Huntingdon, a true bohemian contrasting to the otherwise staid scientists. Honours were achieved on the basis of a further year after the completion of an ordinary degree. I was a year behind Paul, and met him regularly in the laboratories and at meetings of the then very active Mathematics and Physics Society. He quickly became a role model for me. His older brother was a junior lecturer working on a PhD in the nuclear physics group at the time; Jim returned to his home town soon after and had a distinguished career teaching physics. Paul completed his BSc in physics in 1970 with first-class honours, having been awarded a University Senior Scholarship in 1969. Following his graduation, he was awarded a Commonwealth scholarship to study for a DPhil in Oxford.

*University of Oxford, 1970–75*

Nuclear magnetic resonance (NMR) in matter was discovered in 1945, being used first to examine nuclear magnetic moments of all the isotopes, with the early discovery of the chemical shift caused by screening by s-electrons outside the nucleus (Freeman, 1995). It took the development of magnetic fields of uniformity one part per million in the 1950s to

* Numbers in this form refer to the bibliography at the end of the text.
resolve a single line for the proton. In the early 1960s a series of techniques were developed to exploit NMR in chemistry applications, but it was really the pulse echo technique (Pines et al., 1973) reported in 1974 that has the increased resolution and discrimination that made possible detailed studies of real solids.

On arriving in Oxford in 1970, Paul began DPhil research under the supervision of Professor Nicholas Stone. He measured hyperfine interactions using magnetic resonance, detected via gamma rays emitted from oriented nuclei (NMR/ON). He investigated antimony-124 in iron and cobalt-55. He carried out the first combined lattice-location/hyperfine-interaction experiments for both interstitial and substitutional impurities implanted in a crystalline environment (selenium in iron and cobalt). Using NMR/ON he also measured magnetic moments of the odd–odd isotopes of antimony and developed a theoretical model to explain the systematics of the $g_{\frac{11}{2}}$ shell. In his postdoctoral research he was co-responsible for developing the theory of the modulated adiabatic passage technique (MAPON), which permitted the measurement of previously hidden quadrupole interactions of nuclei in ferromagnetic lattices (1). It was an active period for him: over the period 1972–76, he published eleven papers with his supervisor, one on his own and three with a colleague, R. B. Alexander. Most were experimental papers, but there were two that advanced the theoretical understanding, a hint of the all-rounder that he was to become. Paul completed his DPhil in 1974 and stayed on for a year as a postdoctoral research fellow, following up on his research.

**Massey University, 1975–2001**

Paul returned to New Zealand in 1975 as a founding lecturer in the Department of Chemistry, Biochemistry and Biophysics at Massey University in Palmerston North, 100 km north of Wellington. Massey Agricultural College was founded in 1927, and Massey University, as we know it now, in 1964. Paul’s first three papers there used NMR techniques to analyse the molecular motion in the lipid tristearin and in the triglyceride and methyl ester of stearic acid. He had recognized the need to improve on the then new pulsed-gradient-spin-echo (PGSE) NMR method to minimize artefacts and improve the precision, accuracy and range of applications of this important experiment. His 1980 paper ‘A pulsed field gradient system for a Fourier transform NMR spectrometer’, published with a student and senior colleague, was where he described the first of his many innovations in the NMR technique (2). While he had a commercial Fourier Transform NMR instrument, he designed and built the pulse control system, the current control system and the NMR probe from scratch: it makes fascinating reading, as the contemporary electronic subsystems were so primitive by today’s standards. He used his adapted instrument to measure the diffusivity of 0.5% (w/v) polystyrene ($M_r = 110,000$) in carbon tetrachloride and equimolar benzene/butanol mixtures to calibrate the system against known results. By early 1984, this system had been proven and exploited in a wide range of applications, as summarized in Paul’s review paper at that year’s Australia–New Zealand Condensed Matter Physics Meeting, a paper which shows the detailed theoretical understanding he had of the interior motion of complex molecules in the liquid state (4).

Paul’s subsequent work using PGSE NMR was distinguished by the use of innovative approaches to the study of molecular dynamics and organization in biophysical systems, liquid crystals and micro-emulsions. He also developed the theory of this technique in anisotropic systems. A major aspect of this research was on concentrated polymer liquids (5, 7), in which he carried out a series of diffusion measurements in high polymers to clarify the influence of concentration and molar mass on their properties. He developed very large
magnetic field gradients to extend downwards the range of diffusion coefficients accessible using his techniques, and he developed methods to eliminate two problems plaguing work at that time: the movement of the samples and mismatched pulses. His special PGSE-MASSEY pulse sequence enabled the measurement of very slow diffusion with a dynamic spatial resolution well below 100 nm. With this technique he was the first to measure internal segmental motion of very high molecular weight random-coil polymers and provide a test of the fundamental scaling laws associated with the Doi–Edwards–de Gennes reptation model of polymer motion (16).

In a further major development, Paul investigated and established the method of NMR microscopy, in 1986 achieving a transverse resolution an order of magnitude better than had previously been available. He also developed the fundamental theory related to the ultimate limits to the resolution of NMR imagery (6). He was the first to observe edge-enhancement effects in NMR microscopy (18), and created a dynamic form of the microscopy in which the self-correlation function is mapped (14). This pioneering work led to the first in vivo measurements of diffusion in plants (9), enhanced analysis of flow in porous media (11) and another new technique, Rheo-NMR, for observing and quantifying rheological properties of fluids (34). In turn, this last technique was exploited to demonstrate polymer entanglement effects at high shear (15), wall slip in rigid-rod polymer solutions (28), shear banding (shear-induced phase separation into bands of different viscosities) and spurt effects in wormlike surfactants (26), molecular ordering in polymer melts (32) and the characterization of the development of electro-osmotic flow (24).

Paul was responsible for developing the scattering (q-space) formalism for PGSE NMR (12), along with some of its associated theory (19); in collaboration with Packer and co-workers, he proposed the use of diffraction theory to analyse restricted diffusion in porous materials (17). Building on this he demonstrated the first diffraction effects arising from restricted diffusion in colloidal and porous systems (12, 24). This scattering approach transformed the way in which pulsed gradient methods are now used and interpreted.

Paul then applied this diffraction approach to PGSE NMR to study electron diffusion. This was enabled by a highly original approach in which time-domain electron spin resonance was implemented at radio frequencies using the stray field of a superconducting magnet. This resulted in the first ever demonstration of PGSE ESR (electron spin resonance) (20), in which restricted electron diffusion and wall spacing geometry were studied in the quasi-one-dimensional organic conductor fluoranthene. He and colleagues also used the technique to reconstruct a three-dimensional spin density image in this organic crystal (23).

Paul’s q-space formalism, and its inherent Fourier treatment, compares with other forms of NMR spectroscopy, in particular those using two-dimensional exchange and correlation methods. From this direction, he proposed and demonstrated velocity exchange spectroscopy (VEXSY) (21), a technique that led to remarkable illustrations of correlations in velocity fields, enabling Brownian diffusion to be clearly distinguished from stationary random flow. With Stepisnik (30), he pioneered the use of generalized oscillatory gradient waveforms in order to probe the spectral density of translational motion in the frequency domain. He also developed a new formalism capable of handling the calculation of spin echo amplitudes for any gradient waveform under conditions of restricted diffusion, so broadening the range of dynamic processes which can be studied using modulated gradient spin-echo techniques.

While Paul worked in a global context, he undertook research that had advantages for New Zealand. He worked with a number of local colleagues, producing papers applying various
of his techniques to the study of water dynamics in wheat grains (8) and in wheat starch pastes (22), the trachea of rabbits (10), kraft lignins in wood pulps (13), phosphorus NMR for the pH metabolism of living insects (25), the larval midgut of *Spodoptera litura*, the leafworm moth pest (29), phloem and xylem flow in castor beans (31), seed development in the common bean (33), treated *Pinus radiata* (36) and a comparison of the temperature dependence of the rheology of ordinary butter, soft butter and margarine (during the development of today’s soft butter) (37). Most of these papers were published in the home journal of the object of the research, and Paul was careful to describe what NMR was capable of in each context.

Paul had a life-long passion for Antarctica, collecting many books about the region, and he leapt at the opportunity to visit the continent himself, by developing an innovative NMR system that used the earth’s magnetic field instead of a conventional magnet. He designed an instrument to perform resonant spin echo measurements on protons precessing in the earth’s field, using pulsed audio-frequency fields to provide the necessary spin flips (3). He took the instrument to Antarctica in the 1994, 1995 and 1997 spring seasons, and with co-workers Craig Eccles and Joe Seymour he deployed the instrument 2 km off Cape Evans, the site of Scott’s 1910–12 Hut (Figure 3). The three performed the first Antarctic NMR experiments on sea ice, measuring brine content and anomalous diffusion, as part of the New Zealand Sea-Ice Research programme, a multi-team project to relate the mechanical properties of sea ice to its formation and break-up around the continent and the consequences for global temperatures (27). Their discovery of enhanced brine motion attributed to a convective instability has important consequences for understanding the thermal conductivity of sea ice (35). Paul returned to Antarctica on three subsequent occasions, in 1999, 2002 and 2006.
In 1991 he published his first major book, *Principles of nuclear magnetic resonance microscopy*, which immediately became the standard text (12). He had been promoted to Professor in 1984 and during the period 1990–7 he was Head of Department of Physics and also of Biophysics from 1985 to 1997 (which merged with the Department of Physics in 1992). By this stage, his international career was established and he was becoming a figure of high stature in the New Zealand scientific establishment. He was elected a Fellow of the Royal Society of New Zealand in 1990; he won its E. R. Cooper Memorial Medal and Prize the same year, and its Hector Medal in 1998. The University of Otago awarded him its Michaelis Memorial Medal and Prize in 1994.

Paul was an inspirational teacher of both undergraduate and postgraduate students, and was a vital player in building a programme of innovative and engaging physics teaching at Massey. He established a multidisciplinary approach to research long before such ideas became popular, and this continues in areas such as soft condensed matter physics and biophysics. The present-day Institute of Fundamental Sciences at Massey maintains and expands this vision, with collaborations between biologists, chemists, mathematicians, physicists and statisticians.

Dr Andrew Cleland, a former colleague at Massey and now chief executive of the Royal Society of New Zealand, recalls:

> At Massey, Paul always took an active role in teaching the technology/engineering students in first year physics – he saw their role in applying physics as important, and this may also explain why he saw the benefits of getting involved with Magritek [his later start-up] – many of the students he had taught had been involved in technological innovation. The students loved his teaching which they saw as practical.

Professor Graeme Wake of Massey University taught differential equation theory to Paul as an honours student at Victoria University, overlapped as a postdoc in Oxford when Paul was a research student (where they babysat each other’s young children), and was later Head of the Mathematics Department when Paul was head of the Physics and Biophysics Departments at Massey. He remembers that ‘Paul was putting Physics on the map for Massey, exercising strong leadership in an area previously undeveloped there. The early leadership in Science at Massey, prior to his arrival along with another strong physicist, David Parry, had failed to promote Physics, but these two strong appointments planted the seeds for the strong achievements we see today.’

Victoria University of Wellington, 2001–12

The last time I visited Paul in Palmerston North was in 1999, when his time at Massey was nearing an end. He was clear that he had done all he could for Massey University and it had done all it could for him. He was contemplating a move to either Auckland or Wellington. Auckland was a bigger and more vibrant city, but the largest collection of condensed matter scientists was in Wellington and at Industrial Research Limited in Petone, across the harbour from the city. This latter was a national laboratory undertaking support for New Zealand Industry. Paul’s role as a scientific advisor was increasing and, with Wellington being the seat of government, he could do in two hours what would be a day trip from Auckland.

At the same time, the Government was seeking to ensure that science in New Zealand was more than the sum of the individual efforts and was establishing several centres of research excellence (COREs) in areas of importance to the country. Paul’s move to Wellington in 2001 as the Alan MacDiarmid Professor of Physics preceded the establishment in 2002 of the
Paul Terence Callaghan

MacDiarmid Institute for Nanotechnology and Advanced Materials, involving researchers in Wellington, Palmerston North, Christchurch and Dunedin, with Paul becoming the Director. Alan MacDiarmid (FRS 2003), an alumnus of Victoria University of Wellington, who had shared the 2000 Nobel Prize in chemistry for his work on conducting polymers, gladly lent his name to the enterprise and he was an active supporter of, and frequent visitor to, the Institute until his own death in 2007.

Paul gave an extensive interview on the formation of the MacDiarmid Institute to Professor John Spencer, the Head of the School of Physics and Chemistry of Victoria University, as a part of an oral history project. Following the Government announcement of its plan to support the creation of the COREs, Paul consulted his colleagues and led the submission of a bid for work on advanced materials. This bid had passed the first of a two-stage process when he became aware of another bid from the University of Canterbury, led by Professor Richard Blaikie, on nanotechnology, which also had a strong materials flavour. Paul took the initiative to fly to Christchurch and suggest a merged programme, and at the first meeting agreed the principle that money would follow principle investigators within the combined project, no matter where they worked. This principle was enshrined in the founding agreement at Paul’s insistence, despite reservations from the universities, and has served the institute well, especially as four universities are now participating. It has become the most successful and largest of the centres supported by the Government. At the time of writing the MacDiarmid Institute is halfway through its third six-year phase, having been through two critical review stages. Paul saw it through the first review, and handed over to Professor Richard Blaikie (now Deputy Vice-Chancellor at Otago University), who in turn passed the baton to Professor Kathryn McGrath (now Deputy Vice-Chancellor at Victoria University): another of Paul’s legacies has been the development of two new indigenous senior scientific leaders in his footsteps. The current leader is Professor Thomas Nann, whose previous role was as Associate Director of the Ian Wark Research Institute at the University of South Australia and Director of the South Australian node of the Australian National Fabrication Facility. Over time the MacDiarmid Institute has generated a national coherence to condensed matter research in New Zealand which is a model for other small countries.

Paul’s research continued with unabated intensity, with a small group that was never more than eight to ten strong, in spite of his increasing role in New Zealand science and public affairs. In his first few years in Wellington, the subject areas he covered included polymer melts, porous media, micelles, emulsions and a number of indigenous materials of commercial importance, including foodstuffs and wood. Throughout he also published papers that developed further and broadened the range of applications of the various techniques of NMR. His first paper examined the alignment of different segments of sheared polymers in a melt as a function of their molecular weight \( M^{3.4} \), as predicted by the Doi–Edwards theory. Next, in one of the first papers from the MacDiarmid Institute, he used a double pulsed gradient spin-echo NMR, with collinear and orthogonal pulses being applied and the results compared, and was able to investigate locally anisotropic diffusion in a macroscopically isotropic liquid crystal (40).

Paul continued to contribute significantly to soft matter research. He focused on complex fluids which exhibit shear banding. The particular emphasis was now on fluctuation in space and time and transient processes, including the first experimental confirmation of shear band fluctuations (42). In 2008 he published a well-cited review on Rheo-NMR and shear banding (47).
Together with researchers from SchlumbergerDoll Research, Paul led the development and use of multidimensional Laplace NMR. He bravely combined whatever NMR 1D experiments were out there like Lego bricks in order to create a wealth of new 2D and 3D experiments which were based on NMR relaxation, molecular displacements (diffusion and flow) and spectroscopy, and applied them to all sorts of materials (porous media, soft matter, biological materials). In 2002 an invited talk at the Magnetic Resonance in Porous Media Conference in Ulm prompted research on diffusion–diffusion correlation and exchange as a signature for local order and dynamics, and his conference proceedings paper (40) on the use of the second dimension in PGSE NMR studies of porous media was widely followed up. He also used the same technique to explore the local environment and dynamics in complex fluids (41). His last major technical book, on the principles of PGSE NMR, appeared in 2011 (49).

The scientific foundation of Paul’s company Magritek (see the following section) came from his work on low- and earth-field NMR and mobile forms of NMR. Low-field devices such as a mobile one-sided NMR sensor with a homogeneous magnetic field, the NMR-MOLE (mobile lateral explorer) (43) and earth field systems (44) were developed, commercialized and taken to Antarctica to measure brine diffusion in first-year sea ice.

Under the auspices of the New Zealand Royal Society, Paul and a leading poet, Bill Manhire, brought together some of New Zealand’s leading writers and physicists for an Einstein Year collaborative project. This grew out of Paul’s keen appreciation of New Zealand literature, and his long-held desire to bring the scientific and artistic cultures closer. The book Are angels OK? (45), jointly edited by Paul and Bill, was the successful outcome of this project.

In total over his life, Paul had 233 collaborators or co-authors, a sign of his wide-ranging interests and the mutual benefit that he and those with whom he worked could derive from each other.

**BUSINESS AND SCIENCE COMMUNICATION IN NEW ZEALAND, 2001–12**

Paul was acutely aware that the New Zealand Government had invested heavily in the COREs; as the capital city leader of one of the largest, he felt compelled to explain to anyone and everyone that this was money being invested wisely for the future of New Zealand. This led to two major developments in the last decade of his life: his involvement in business and his becoming a powerful science communicator.

As described above, instrument development was a key aspect of Paul’s research, and in 2004 he set up Magritek to develop specialized NMR imaging machines, with the analytic software to analyse results, for sale to the research and analytical science community. The company grew steadily, with Paul as the technical director and major salesman and advocate of its products. Mark Hunter, a former student and company colleague, writes:

Paul loved that Magritek had (and still has) the potential to become a high-technology exporter and employer of scientists based in New Zealand, this being a central part of Paul’s vision that ‘New Zealand was a place where talent wants to live’. He enjoyed taking part in solving the technical challenges and less than two months before his death he was brainstorming to try and solve a problem with one of the company’s developing products. I also believe he enjoyed knowing that Magritek had grown to a point where it had a life of its own, and had grown into a team that could function well without him.
As a result of this enterprise, Paul began a study of the New Zealand economy and its continuing reliance on primary production after 150 years of international trade. He could see that growth of more animals and trees was not sustainable in the long term, and that a high-technology sector – 100 companies with an annual turnover of $100 million – should evolve to broaden the country’s economy and aid the sustainability of the use of New Zealand land. He pointed to Fisher Healthcare (manufacturing trachea implants), Gallagher Security (evolving from electric fencing for farms to advanced security systems) and Weta Workshops (making artefacts for film and other media) as harbingers of a successful future for New Zealand. In the last major public lecture before his death – the Victoria University Chancellor’s lecture, which he delivered without notes – he spoke on this theme to a packed Wellington Town Hall and to a standing ovation. He published one book, *Wool to Weta: transforming New Zealand’s culture and economy*, on this general theme in 2009 (48). A more extensive economic analysis, *Get off the grass: kickstarting New Zealand’s innovation economy*, written with his co-worker Shaun Hendy, was published in 2013 after his death (50). Both were well received and widely debated.

The noted New Zealand domestic broadcaster Kim Hill, who runs a three-hour magazine programme on national radio on Saturday mornings, invited Paul on to explain his science. The simple and elegant explanations of his research, together with the immediate relevance of some of his results to the interest of the New Zealand economy, struck a chord. He became a regular guest, every two months, and through this his name became a household one throughout New Zealand. In 2007 they jointly published *As far as we know: conversations about science, life and the universe* (46). He also presented the television documentary *Beyond the farm and the theme park*, dealing with the broadening of the New Zealand economy.

In 2001 Paul was elected a Fellow of the Royal Society of London, which gave his audience a sense of the depth and integrity of his scientific insights. Even more so, the award of the Ampère Prize in 2004 indicated that his scientific peers thought that he was the best in the world at his work at that time, a recognition in which he and New Zealanders took great pride.

As a consequence of Paul’s standing, he was approached about a number of causes in New Zealand. One that he took seriously was the Zealandia project, the formation of a native bird sanctuary in a park within the Wellington City boundaries surrounded by a pest-resistant fence and cleared of predators. He served on the governing body for a number of years. Foreign predators, such as possums, stoats and rats, have been successfully eradicated from a number of off-shore islands. Putting the two together, he coined the phrase ‘pest-free New Zealand’ and rallied strong support for the idea which, four years after his death, has been adopted as a long-term plan by the New Zealand Government.

The Royal Society of New Zealand combines the roles played in the UK of the Royal Society and the British Association for the Advancement of Science. Paul served on the Society’s Academy Council between 1996 and 2003 and was its president from 2000 to 2003. He was instrumental in introducing the popular New Fellows’ Seminars into the annual Academy programme, based on a similar activity undertaken by the Royal Society in London.

Paul was made an Honorary Fellow of the Institution of Professional Engineers New Zealand. The category is largely used to recognize those non-engineers who have had a significant impact on engineering and technology in New Zealand.

For all his work he was well recognized in New Zealand, winning the New Zealand Prime Minister’s Science Prize in 2011. In 2006 he became a Principal Companion of the New
Zealand Order of Merit; this was followed three years later by a knighthood. And he was named New Zealander of the Year in 2011 (Figure 4). He wore these honours typically lightly.

When interviewed in 2011 in the Dominion Post (the Wellington newspaper), he described the role of being a scientist as ‘to make discoveries of permanent value, to transcend nation, race, culture and political perspectives in a truly international endeavour, to collaborate with people all over the world’.

**PAUL, THE FAMILY MAN**

Paul married Susan (Sue) Roberts in January 1969. They met in Wanganui in their late teens and continued their courtship for three years while Sue studied at Massey University for her teaching qualification and Paul studied at Victoria University. In their first year of marriage, Sue taught at Island Bay Primary School in Wellington while Paul completed his BSc. They went together to Oxford, and both of their children were born there during Paul’s DPhil studies, Catherine on 23 July 1971 and Christopher on 4 January 1974.

Paul was a devoted family man and an enthusiastic father who delighted in devising games and adventures for his children, which included building snow forts and igloos for them during his sabbatical year in Vancouver, making hot air balloons (which burst into flames over their suburban Palmerston North neighbourhood) and designing a complicated chess-like game from Lego. He took Chris hiking and hunting in the local mountain ranges, played in wind bands and orchestras with Catherine, took them both fishing on Lake Taupo during summer holidays, and was a great conversationalist, often entertaining the family with stories around the dinner table.

Paul took his family on two major sabbaticals, one to Vancouver in Canada in 1981–82 and another to Oxford in 1989, where he wrote his book *Principles of nuclear magnetic
resonance microscopy. These sabbaticals were opportunities for the family to travel around North America and Europe, and to expand the children’s education.

In part because of their childhood experiences of living abroad, Catherine and Christopher both settled in the UK, Catherine becoming a barrister specializing in public law at Blackstone Chambers in the Temple, and Christopher becoming a transplant surgeon, first at Addenbrooke’s Hospital in Cambridge and then as a consultant at Guy’s Hospital in London.

Paul and Sue separated in 2000 and later divorced. In 2006, Paul married Dr Miang Lim, a food scientist at Otago University. Miang moved to Wellington when she married Paul, and devoted herself to his care after his cancer diagnosis until his death. Together they travelled widely through Asia and North America, where they enjoyed hiking in some of the US national parks. Paul and Miang spent three months on sabbatical in Cambridge in 2011, which gave him the opportunity to bond with his grandsons, James and Thomas. He adored them both, and they loved him.

CANCER, DEATH AND LEGACY

Paul was diagnosed with colon cancer in 2008, and he fought it off with a clear scientific understanding of the symptoms and their evolution. He wrote about this in *Luminous moments*, which describes various key stages of his life: his development as a scientist, the beauty of magnetic resonance, pseudo-science, a week in his life, speaking as a cancer patient about his experience and treatment, and fatherhood. He also kept a very public blog over the months before he died which was widely followed. Once the standard procedures had been exhausted and the condition was terminal, Paul did undertake an experimental regime of treatment, as a scientist, to see if any of the alternative therapies had any merit. He spent three months in Cambridge researching and discussing economics in preparation for his book with Shaun Hendy. His son was working at Addenbrooke’s at the time (and was a valued source of technical insights and independent reassurance about the treatments he was receiving), and he had quality time with his grandchildren. He was flown back to New Zealand in the middle of this visit to deliver his Chancellor’s lecture mentioned above. One day I passed Paul cycling furiously up Trinity Lane, and I invited him to lunch at Trinity Hall with another New Zealand engineering colleague, Paul Austin, then also suffering from bowel cancer. I had forgotten they had been colleagues for several years at Massey University in the 1980s, and I sat by as they described their medical regimes with calm detachment!

Following Paul’s death on 24 March 2012, Sir Peter Gluckman (FRS 2001), chief science advisor to the country’s Prime Minister, John Key, said: ‘New Zealand has suffered a tremendous loss. Paul has been our most distinguished public scientist and in the world of molecular physics has been a giant.’

At his funeral, Dr Garth Carnaby, President of the Royal Society of New Zealand, declared that

Sir Paul was a truly ‘exceptional scientist’ whose achievements have been recognized at the highest levels both within New Zealand and internationally. Paul was undoubtedly one of New Zealand’s most inspirational scientists. His passion for science shone through in everything he did. We will remember him for the excellence of his own personal research, for his inspirational leadership of other scientists, and his ability to communicate about science to one and all.
When Sir Sam Edwards (FRS 1966) died in 2015, he was quoted in his obituary as having said ‘I might not have had the last word to say about many of these matters, but I certainly had the first word.’ He was referring to his theories of polymer motion, for which Paul provided the underpinning experimental evidence, and it was a sentiment that Paul would have echoed.

Professor Ed Samulski, a long-time collaborator from the University of North Carolina, Chapel Hill, wrote an obituary article for the *Journal of Magnetic Resonance* in 2013, entitled ‘The meaning of collaboration’ as exemplified by his many fruitful interactions with Paul. He summed up Paul as follows:

Paul studied and executed both science and administration. Unlike many scientists Paul appreciated expert administrators and the balancing act they must do in universities. He appreciated expert politicians and admired their gifts. He admired accomplished businessmen. He loved the diversity of culture in New Zealand. Through his relentless appreciation of the gifts of others, and his tireless study of the many sectors beyond science that affect its translation into positive effects for the world, he built bridges from the ivory tower of research science to all sectors of the community, and taught us all about our interconnectedness.

During the period 2008–10 there was real concern about the national innovation system in New Zealand. Paul, together with Andrew Cleland and Neville Jordan, a successful New Zealand entrepreneur, presented the Science Minister of the day, Wayne Mapp, with the idea of an agency which had the role of developing a more innovation-capable private sector that would progressively invest more heavily in R&D from its own resources. The model drew on systems in Taiwan, The Netherlands and Denmark. The reorganization of Industrial Research Limited (the one of the country’s nine Crown Research Institutes not closely tied to a single sector such as wool or meat) was ongoing at the time of Paul’s death; with the agreement of his widow, the new entity has been called Callaghan Innovation since 2013. So far its emphasis has been on shorter-term contracting research for existing New Zealand businesses, and it has shed the longer-term programmes such as those developing new technologies based on rare New Zealand natural products and advanced materials such as high-temperature superconductors. In 2017 the jury is still out on its impact.

Paul left a major international legacy to his subject of magnetic resonance imaging used to interpret complex solids and fluids. To New Zealand he left a larger legacy, including a greatly increased popular interest in science in and of itself, but also in its implication for New Zealand’s future in terms of the economy and the environment. The MacDiarmid Institute thrives, and pest-free New Zealand is on the national agenda.

**AWARDS**

2001 Fellow of the Royal Society  
2004 Ampère Prize  
2005 Rutherford Medal  
2006 Principal Companion of the New Zealand Order of Merit  
2007 Sir Peter Blake Medal  
   James Cook Research Fellowship from the Royal Society of New Zealand  
2009 Knighthood  
2010 Günther Laukien Prize for Magnetic Resonance
New Zealand Prime Minister’s Science Prize  
2011 New Zealander of the Year

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AUTHOR PROFILE

Michael Kelly

Professor Michael Kelly has been the Emeritus Prince Philip Professor of Technology at the University of Cambridge since 2016, having been the inaugural holder of the chair since 2002. He is also Emeritus Fellow at Trinity Hall, Cambridge, having been a research fellow, staff fellow, and professorial fellow at times between 1974 and 2016. He has also been a regular visitor to the MacDiarmid Institute, Victoria University of Wellington, since 2012, serving on its international advisory board since its inception. At the GEC Hirst Research Centre in 1981–92 he developed two new families of microwave devices that went in production with E2V Technologies at Lincoln. He was at the University of Surrey 1992–2002 including a term as Head of the School of Electronics and Physical Sciences; Non-executive Director of Surrey Satellite Technology Limited 1996–2002; Executive Director of the Cambridge–MIT Institute 2003–5; Chief Scientific Adviser to the Department for Communities and Local Government 2006–9, especially on energy in buildings; Non-Executive Director of Laird plc 2006–15.

REFERENCES TO OTHER AUTHORS


SHORT BIBLIOGRAPHY

The following publications are those referred to directly in the text. A full bibliography is available as electronic supplementary material via http://dx.doi.org/10.1098/rsbm.2017.0006 or via https://doi.org/10.6084/m9.figshare.c.3854749.


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