BIOGRAPHICAL MEMOIRS

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Sir Peter Hirsch


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DAVID JOHN HUGH COCKAYNE

19 March 1942 — 22 December 2010

Elected FRS 1999

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David Cockayne had a wide-ranging and lasting impact on electron microscopy in materials science. He had dual UK and Australian nationality, and his professional career was divided between the two countries. His research was exceptional. His most important scientific contribution was the development (with I. L. F. Ray and M. J. Whelan in Oxford) of the dark-field ‘weak-beam’ technique of transmission electron microscopy, which improved by an order of magnitude (to 1.5 nm) the resolution at which complex crystal lattice defect geometries could be studied. The technique had a significant impact on advancing our understanding of the structure and properties of lattice defects in many materials, and became established as a routine tool in laboratories all over the world; it is still widely used today.

With D. R. McKenzie in Sydney he developed a powerful high-precision electron diffraction technique within an electron microscope to study small volumes of amorphous material, orders of magnitude smaller than is possible with X-rays or neutrons, giving nearest-neighbour distances accurate to 0.001 nm. As Director of the University of Sydney Electron Microscope Unit from 1974 to 1999, he led the development of the Unit to provide a first-class centralized service of electron microscopy for the university as a whole. This stimulated other Australian universities to follow his example.

He provided exemplary leadership nationally and internationally for the electron microscopy community. He was President of the International Federation of Societies for Electron Microscopy (IFSEM) from 2003 to 2007. He promoted numerous conferences, courses and workshops on different aspects of electron microscopy and was an inspiring teacher and lecturer. He was passionate about enabling the young to discover the secrets and beauty of the hidden microscopic world.

His character, values, and actions reflected a deep-rooted humanity.
1. THE EARLY YEARS

David John Hugh Cockayne was born on 19 March 1942 in London, the middle of three children of John Henry Cockayne and Ivy (née Hatton). The eldest was his sister, Diana; the youngest was his brother, Michael. His father, who had been a scholarship boy at Wellingborough Grammar School, was a policeman in London during World War II. His mother worked for the Post Office, and had been a champion swimmer. His paternal grandfather had worked in his family’s shoe factory, and his paternal grandmother had been in service as a young woman. David’s maternal grandfather had been a postman. Little is known about his maternal grandmother, except that she was born in the Union Workhouse at Billericay in Essex.

Although David’s father enjoyed his job, he realized that in England he was not going to be able to give his children the opportunities, and particularly the education, that they deserved. So the family emigrated to the Geelong area of Victoria in Australia when David was eight years old and already at primary school in London (Bedfont Primary School). They were sponsored by an uncle, Frank Cockayne, who died before they arrived. Their first accommodation was a semi-permanent ‘van’ in a caravan park near Ocean Grove, some 15 miles from Geelong. They soon moved to a house nearby, close to a 16-acre farm that belonged to Frank’s widow Trix and her sister Bruce. The three children greatly enjoyed exploring the farm. His father found employment in Geelong as an accountant.

David enjoyed the country life to which he was introduced at this young age, and his love of nature and the outside remained with him throughout his life. The beach at Ocean Grove was not far away, and David used it as a running track. As he grew up he became a keen distance and cross-country runner. David’s primary school education was first at a nearby school in Wallington, and then at Ocean Grove. On one occasion at that school his mouth was washed out with soap. This incident is mentioned in Helen Garner’s novel *Joe Cinque’s consolation*. She was at the school at the same time and witnessed the incident, and when they met again many years later, when David was already a professor, they laughed about their recollection. But in the novel she claims, quite wrongly, that at their meeting he denied it ever happened. The reason for this fictional account in Garner’s novel was to illustrate the fallibility of people’s memories. This is discussed in David’s book *Memories* (36)*, which he published in 2009 (see §8). David also wrote some charming pieces about his early life in Australia, specifically for his children, providing a colourful impression of what life had been like.

The family moved to a newly built house in an area of new migrants in Geelong in 1952, and David moved to Tate Street School in Geelong. David did well at this school and in 1953 was entered for a scholarship to Geelong Church of England Grammar School, which he was awarded. However, the scholarship only paid two-thirds of the fees, and David’s parents could not afford to pay the rest or for the school uniform and other costs. Fortunately the headmaster of Geelong Grammar at the time, Dr James Darling, was an enlightened educationalist, and he ensured that these costs were covered, as well as the boarding fees at the Timbertop outpost of the school in David’s ‘intermediate’ year (year 10, 1957).

David loved his period at Geelong Grammar (1954–60). He was greatly influenced by Darling, an Englishman who had become headmaster at a relatively early age in 1930 and remained there until his retirement in 1961, when he became chairman of the Australian Broadcasting Commission. Darling was a natural leader and innovator among educationalists in Australia.

* Numbers in this form refer to the bibliography at the end of the text.
David John Hugh Cockayne

Darling’s educational aim was to produce well-rounded civilized personalities, who, while specializing in some aspects of the arts or science, should also be sensitive to other branches of human endeavour. He also believed in the importance of fostering physical courage and stamina by providing opportunities for adventure. His vision and outlook impressed David enormously, as did his personality. In the boys’ senior years Darling took some of the classes and led discussions ranging way outside the normal curriculum, including philosophy and theology. As David put it, he believed in educating the whole person, and he was one of David’s heroes. David’s cultivated personality owed much to the school’s ethos.

Darling was also responsible for establishing the school’s outpost at Timbertop on the slopes of a mountain of that name. The location was remote and rugged, set in heavily timbered alpine country. The whole of David’s ‘intermediate’ school year took place there. The boys were responsible for all the chores around the settlement in addition to the regular schoolwork and outdoor projects, and for challenges aimed at developing self reliance and practical skills. The boys were allowed to set their own challenges and stretch themselves as much as they liked. David adored it, and he learned to love the Australian bush, a love that stayed with him for the rest of his life. One of the science teachers at the time was John Landy, an old boy of the school fresh from holding the world mile record (1954–57). He eventually served as Governor of Victoria (2001–06). He was an outdoor naturalist, and, inter alia, taught David how to trap and mount butterflies. For several years after he left school, David went back to Timbertop for a week or two at the start of the new school year to help the new intake of students to settle in and learn unfamiliar tasks. His year at Timbertop remained very important to him all his life.

According to the curator of the school, Michael Collins Persse, David was an outstanding member of his generation there. In 1959 he obtained first-class honours in chemistry in the Matriculation examinations and second-class in two mathematics papers and in physics. In 1960 he reversed those results. His interest in the physical sciences was probably engendered by the excellent teaching by the chemistry teacher, Ken Mappin, and the physics teacher, Lex Spear. David wrote to both of them on his election to the Royal Society, telling them that this honour reflected their excellent groundwork. According to Alec (now Lord) Broers (FRS 1986), who attended the same school and left in 1955, there was also an outstanding mathematics teacher at the school at that time, who is likely to have had an influence on David, who was very keen on and able at mathematics. There were four Geelong Grammarians from the later years of James Darling’s headmastership who became Fellows of the Royal Society, the other three being Broers, Ted Ringwood (1972) and Jeremy Pickett-Heaps (1995).

David won the Old Geelong Grammarians’ Prize as dux of the School in 1960, a prize that was awarded at the headmaster’s discretion, an indication of Darling’s high regard for him. Darling made him a School Prefect and Captain of the Geelong House (for dayboys) in 1960. David won several other prizes and was a sub-lieutenant in the Cadet Corps.

2. University of Melbourne, 1961–66

In 1961 David enrolled in Melbourne University to read physics. He was the first member of his family to go to university, and he was very aware of the changes in family fortune over two generations. At Melbourne University he was a member of Trinity College and lived in the Jeopardy Wing of the college, as did his future brother-in-law, Anthony Kerr. His future wife,
Jean Kerr, enrolled at Melbourne University in 1962, reading French and English honours. She was resident at James Clarke Hall, next to Trinity College; she and David got to know each other early in 1962 and became close friends in 1964. Her parents were Cecil and Stella Kerr. Cecil read electrical engineering at Queensland University and in 1930 was Rhodes Scholar at Wadham College in Oxford, where he read physics.

David graduated in 1964 with first-class honours in physics. The fourth year was an honours year and it is likely that a course by John Cowley (FRS 1979) on electron diffraction stimulated him to choose the diffraction group for his MSc. In his MSc thesis David acknowledged ‘the guidance and incentive offered by Professor J. M. Cowley for his introduction to and elucidation of the field of electron diffraction’. The alternatives at Melbourne then were nuclear physics and atmospheric physics. At the time Cowley and Alex Moodie had developed the multi-slice theory of electron diffraction which included \( n \)-beam dynamical interactions (Cowley & Moodie 1957). The first experimental tests of this theory, by Peter Goodman and Gunter Lehmpfuhl, suggested that a specialized convergent beam diffraction camera was needed to obtain high-quality quantitative beam electron diffraction data to compare with the multiple-slice calculations. The camera was built at the Commonwealth Scientific and Industrial Research Organisation by Peter Goodman and Alex Moodie with an expert workshop technician, Jock Mills. David’s involvement in this work is best described in his own words (personal communication to P.B.H. in about 2009):

My own involvement with the multi-slice came about in 1965, when John Cowley sent me to work with Alex Moodie and Peter Goodman, to ‘give them a hand’, I was told, on account of Peter’s heart problems. Give them a hand! The aim was to build a diffraction camera for the purpose of obtaining quantitative convergent beam electron diffraction data to compare with some of the first multiple slice calculations, as they were then called. This was throwing one in at the deep end. Things happened that couldn’t happen now. This wonderful electron diffraction camera was built by Peter and Alex, with the expert workshop hands of Jock Mills, from the ground up. It was a magnificent instrument, Alex and Peter and I spent from early morning until very late in the evening—often going out to collect a cooked chicken to continue eating through the evening experiments. I remember returning to the lab on one occasion to see this stark shadow of Peter, cast on the wall, from the intense light emitted from the screen, his hair standing bolt upright from the electric charge on the gun! But we survived, and we published a very nice paper. It was one of the first shewing quantitative agreement between multi-slice calculations and experiment. The fitting parameter was the sample thickness, which the results shewed could be determined to within one unit cell.

Alex Moodie considered David to be very impressive in all he undertook. He showed outstanding aptitude in helping to optimize the operation of the instrument. A relatively rudimentary computer program had been devised by Moodie and Goodman for the multi-slice calculations, but David developed this and applied it to the observed intensity distribution as a function of angle of incidence for reflections from a crystal of MoS\(_2\) under conditions of excitation of systematic reflections. Unfortunately it turned out that Cowley and Moodie had used the wrong sign in their original derivation and had unwittingly produced a theory of positron diffraction. This is acknowledged in John Cowley’s book (Cowley 1975). The error delayed the work by some months but when it was sorted out the agreement was excellent, as indicated by the fact that the sample thickness (the fitting parameter) could be determined to within one unit cell. The work is described in a classic paper by Cockayne, Goodman, Mills and Moodie (3)*, which had a lasting impact. This was David’s first full publication and he was justly proud of it.
The title of David’s MSc thesis (2) was ‘Numerical calculations of the $n$-beam solution in electron diffraction with experimental verification using convergent beam diffraction’. In it he discussed in impressive detail the development of the $n$-beam dynamical theory of electron diffraction in a form suitable for computation, and demonstrated the high accuracy that could be obtained by the good agreement with experiment. He then used this to assess the accuracy and applicability of various approximations widely used, in particular the ‘phase grating approximation’. He had already collaborated with Peter Turner on the subject in his 1964 honours year (1). An appendix of the thesis dealt in detail with the sign of the propagation factor in the $n$-beam dynamical theory, and concluded that the sign of the propagation function as given in the Cowley and Moodie papers needed to be changed.

David obtained first-class honours for his MSc thesis at the University of Melbourne and was awarded the Competitive Professor Kernot Scholarship for MSc Theses. He was also awarded a Commonwealth Scholarship to read for a DPhil at Magdalen College, Oxford. Shortly before he left for Oxford in September 1966, David proposed to Jean and they announced their engagement.

3. Marriage and family

Jean travelled to England in January 1967, and they were married in Shilton, Oxfordshire, on 28 July 1967. Their marriage was warmly welcomed by both families. Just before David’s father died, he said to him that ‘Jean was the best thing that ever happened to our family’, and Jean’s parents Cecil and Stella also fully approved the match. David had passed with flying colours!

Their was a very happy marriage. They were blessed with three children.

Sophie, born in Oxford in 1973, worked as a corporate lawyer in Sydney and London before buying a vineyard south of Sydney, which she runs with her husband, Rajarshi Ray. They have two daughters, Zoe (born in 2009) and Zahra (born in 2011). David much enjoyed Zoe, and was happy to know before he died that Zahra was on the way.

Tamsin, born in Sydney (1975), studied medicine at Sydney University and specialized initially in remote general practice, in the Northern Territory, but then worked in various positions in the UK, Ireland and Indonesia, and served as a ship’s doctor on a trip to Antarctica, as well as studying for diplomas in palliative care and tropical medicine. She now works in Darwin in postgraduate medical education, a move she believes was influenced by David’s keen interest in postgraduate education. She married Matthew Pinter and they had a baby boy, Sebastian, in 2014.

James was born in Sydney in 1977. He is an international lawyer and has worked in several senior positions on transnational crime and counter-terrorism. He married Rachel Davis in 2012. Her maternal grandfather, C. J. (Kit) Milner, was a physicist from Sheffield who was Professor of Applied Physics of the University of New South Wales in Sydney. He worked for a year on the Manhattan Project during World War II. His father, S. R. (Ross) Milner FRS, was Professor of Physics at Sheffield University.

The Cockaynes are a very close family. Jean and David were a delightful couple, who brought warmth, long-lasting friendship and thoughtful kindness to all those privileged to have met them.
4. The First Oxford Period, 1966–74

David joined the Department of Metallurgy in Oxford in September 1966 as a graduate student to conduct research under the supervision of Dr M. J. Whelan (FRS 1976). His subject of research was electron microscope images of defects in crystal lattices. At that time the electron microscopes were housed in a hut next to the house at 10 Parks Road, which served as the Metallurgy Annex, and most of the electron microscopists had their offices in the house. The building had previously been the Mathematical Institute and during the war the hut had served as a Maternity Hospital. The researchers in 10 Parks Road were referred to by the metallurgists in the main Metallurgy (Hume-Rothery) building as ‘unfrocked physicists and chemists’. There was a close community spirit among the occupants of the Annex, but David and Jean fostered the departmental community spirit as a whole by organizing walks in the Oxford countryside at the weekends, to which everyone was invited.

By the time that David started his research, the diffraction contrast technique for the study of dislocations had been established (see Bollmann 1956; Hirsch et al. 1956) and the theory of image contrast was well developed (see Hirsch et al. 1965), so that generally the nature of the dislocation images could be understood and the dislocation parameters, such as the Burgers vector, derived with confidence from the images. There were exceptions; for example, when elastic anisotropy was involved, extra care was needed. Bright-field or dark-field images were usually obtained by excitation of one Bragg reflection and interpreted by the so-called two-beam dynamical theory. However, to obtain strong images, these were taken with the incident beam at or relatively close to the Bragg angle for the particular reflection selected. This meant that the image contrast arose from the atomic displacements due to the elastic strain field over distances typically of the order of 10 nm. This method gave no information about the strains close to a dislocation or about the nature of the core of a dislocation. It also put a lower limit on the partial dislocation separation for a dissociated dislocation. The object of David’s research was essentially to develop methods to probe the high strains close to the dislocation cores.

David first investigated theoretically the images produced by the interference of two or more beams reaching the image. (This differs from the diffraction contrast technique, in which the image is formed by one bright-field or dark-field beam.) J. W. (later Sir James) Menter FRS was the first to show (see Menter 1956) that by using this technique, images of fringes could be produced in a crystal of platinum phthalocyanine that had the same spacing as the lattice planes. The lattice spacing in this structure (1.2 nm) was large enough to be resolved with the microscopes available at that time. In particular Menter showed a classic image of a terminating fringe, which was interpreted as a terminating lattice plane at an edge dislocation. When David started this project, high-quality images of lattice fringes had been produced in different structures by other workers (see, for example, Parsons & Hoelke 1969) from regions of crystal containing dislocations. The interpretation of these images usually assumed a direct correspondence between the fringes and the lattice planes, thereby apparently offering a powerful method of probing the distortions close to the core of the dislocation through the local bending of the planes close to a terminating fringe, assumed to indicate a dislocation, in the image. David showed, through his $n$-beam calculations for systematic reflections, that neither the terminating fringe nor the fringe bending necessarily bears a one-to-one relationship to the distribution of the lattice planes. Furthermore, changes in the diffraction geometry would produce changes in the number of terminating fringes and changes to the fringe bending not related to the lattice plane geometry in any simple way. The analysis
David John Hugh Cockayne was applied to crystals containing screw dislocations, and was verified by experiments on deformed Ge in a collaboration with J. R. Parsons and C. W. Hoelke, with whom David spent part of 1970 at Chalk River Nuclear Laboratories in Canada. This led to an important joint paper, which was very influential (6).

The calculation of fringe images was performed by taking into account the weakly excited systematic reflections as well as those strongly excited. David noticed that sometimes weak beams that had low intensities in regions of perfect crystal, because of their large deviation from the Bragg angle, could attain high intensities in small regions close to a dislocation. This occurred essentially when part of the column near the dislocation was bent so that locally the reflecting planes were at the Bragg angle. Analysis showed that these strong peaks could occur for any column in the crystal within which \( s^g + \beta^1 = 0 \), at a turning point of \( \beta^1 \), where \( s^g \) is the distance in reciprocal space of the Ewald sphere from the reciprocal lattice point for the reflection, and \( \beta^1 = g.(dR/dz) \), where \( g \) is the distance in reciprocal space to the reciprocal lattice point for the reflection, \( R \) is the displacement of an atom in a column along the beam direction and \( z \) is the coordinate in the beam direction. David verified this result by many-beam computed images of various dislocations using the many-beam Bloch wave formulation of Howie and Whelan (see Hirsch et al. 1965). This means that if \( s^g \) is made sufficiently large, the peak of the weak beam can lie very close to the dislocation; its half-width is typically about 1.5 nm, and the position of the dislocation can be determined to within about ±1 nm. This represents an order of magnitude improvement over the conventional strong beam method, in which typically the dislocation image widths are of the order of 10 nm. The result was the development of the dark-field ‘weak-beam’ technique, which has become the standard method for investigating complex lattice defect geometries. The experimental procedures were developed with Ian Ray, and the original paper, published in 1969, was by Cockayne, Ray and Whelan (4). The technique has had an important impact in advancing the understanding of the structure and properties of lattice defects in many materials; it became a routine tool used in laboratories all over the world and is still widely used today.

David himself, together with Ian Ray and others, performed some of the initial investigations. One of the important early applications of the weak-beam technique, arising from the small dislocation width, was to the determination of stacking fault energy \( (\gamma) \) by measuring the separation of partial dislocations bounding a stacking fault in a dissociated dislocation. The usefulness of this technique was demonstrated initially for dislocations in Cu 10% Al (4). In this paper the relationship between the observed image peak separation \( \Delta_{\text{obs}} \) and the actual partial separation \( \Delta \) was derived. Somewhat later, Cockayne and Ray (5) showed that the dislocations in Si were dissociated (an example taken from (7) is shown in figure 1), contrary to some results obtained with the conventional strong-beam method by previous workers, and \( \gamma \) for an intrinsic stacking fault was found be to be 51 mJ mm\(^{-2}\) (5, 7). Analysis of nodes in the dislocation networks showed that \( \gamma \) values for intrinsic and extrinsic faults were comparable. This was followed by measurements of \( \gamma \) in Ag and Cu (8), and with R. C. Crawford the antiphase boundary energies in a series of ordered Fe–Al alloys were measured (10). An important observation was the fourfold dissociation of DO\(_3\)-type superlattice dislocations (13); segments of these dislocations lying in orientations predicted to be unstable on energetic grounds were found to be composed of zig-zag elements, each of which was outside the range of unstable orientations. Another important application of the weak-beam technique has been to the study of the nature and geometry of small dislocation loops in quenched or irradiated materials (12).
David's research did much to elucidate the nature of the dislocations in semiconductors. Apart from the classic work on Si (7), referred to above, with P. Pirouz and others he revealed the dissociation of dislocations in diamond (16). The observations on dislocations in semiconductors were generally made with the dislocations stationary. It was generally assumed that when the dislocations are dissociated, they lie on the so-called `glide planes'. There was a question at that time whether the dissociated dislocations would also move in the dissociated form on the `glide planes', or whether they would move as undissociated dislocations on the so-called `shuffle planes'. In a classic paper with A. Hons and J. C. H. Spence (14), David observed the movement of basal dislocations in the Group II–VI compound CdS with the wurtzite structure in situ in the electron microscope. The dislocations were found to be dissociated and moved as dissociated dislocations, under thermal stresses in the electron microscope. These experiments were performed in Sydney, after David had moved there in 1974.

The development of the weak-beam technique is an example of the rigorous approach and the deep physical insight in diffraction phenomena that characterized David's research. He was familiar with the n-beam dynamical theory using the multi-slice method from his MSc studies in Melbourne. But now he was using the n-beam Bloch wave formulation of Howie and Whelan for imperfect crystals (see Hirsch et al. 1965). He used these computations to show that the positions of the weak-beam peaks were relatively insensitive to foil thickness.

Figure 1. A weak-beam 220 dark-field image of a 30° dislocation in silicon showing the dissociation into Shockley partial dislocations. The peak separation in this image is 5 nm. The inset shows the diffracting conditions used to form the image peaks. Note the narrow width of the image peaks. (Reprint of Fig. 4 from (7); copyright © The Royal Society).
or the depth of the dislocation in the foil. In an important paper he performed a theoretical analysis of the weak-beam method (9), established the conditions under which strong images would be obtained by the weak-beam method, and assessed when the kinematical theory would be applicable (see Hirsch et al. 1960). He derived expressions for the peak widths and peak positions and established the conditions for obtaining good weak-beam images both theoretically and experimentally (9, 11). The development of the weak-beam technique established David’s outstanding reputation in this field.

5. Sydney University, 1974–2000

5.1. Development of the Electron Microscopy Unit

David took up the post of director of the University of Sydney Electron Microscope Unit (EMU) in June 1974, at the age of 32 years. The Unit was set up in 1958 to provide a centralized service of electron microscopy for the university as a whole, and David was its second director. At a time of escalating costs of the instruments, and their increasing sophistication and variety of modes of operation, which required a high level of expertise and skilled maintenance, a central facility was deemed to be an efficient way to meet the demands of the departments that used electron microscopy. David’s contribution to the EMU is described by Kyle Ratinac (Ratinac 2008). On arrival at the EMU, David noted the extremely cramped conditions. He commented, ‘had I seen the squalid housing of the Unit at that time, or had the Unit seen me before appointment, neither side would have signed the contract’ (34). He immediately pressed the university for increases in suitable space not only to alleviate the then existing shortfall but also to cater for the inevitable growth in demand. David’s relentless crusade was successful, and in 1981 the EMU moved into a building (the Madsen Building) suitable for electron microscopy, with space for expansion. David also campaigned vigorously on the need for strategic planning for equipment acquisition and succeeded in getting institutional support for the provision of funds by departments and the university towards bids for instruments from infrastructure schemes on a regular basis. In this way the EMU was able to acquire state-of-the-art instruments for microscopy and microanalysis on a continuing basis. Figure 2 shows David operating one of these electron microscopes, a JEOL JEM 100 CX.

David had clear views about the modus operandi of the Unit. Users should do their own work, with the Unit’s staff providing assistance and advice when needed. To make this possible he made the EMU internal training programmes ‘more structured and focussed with emphasis on the training of users to become skilled and independent practitioners. This approach made it possible for the EMU to support more users, because they were less reliant upon the availability of support’ (27). But he also believed strongly that the EMU academic staff should conduct their own research. On arrival David was rather surprised about the lack of interest from the physical sciences to use the EMU facilities. He rectified this by building up his own research within the EMU, the highlights of which are described in the next section. Other academics in the EMU were also attracting research grants, building up substantial momentum. At the same time there was increasing interest from industry for access to the EMU facilities, and for industrial projects. The EMU resources were increasingly stretched.

The solution came through the Australian Research Councils’ call for bids for Key Centres for Teaching and Research intended to undertake industry related research and promote postgraduate teaching, and professional upgrading courses for industry relevant to national...
Key centres typically received substantial funding for six years. The brief for these centres matched the interests and activities of the EMU well. David, together with colleagues from the EMU and the School of Physics, made a successful bid to set up the Australian Key Centre for Microscopy and Microanalysis at the University of Sydney (35) (see also Ratinac 2008). David became director of the Key Centre from 1995 as well as continuing to be director of the EMU. The functions of the two units were coordinated. The Key Centre took over the management of the training and industry programmes as well as the schools programmes and some of the research activities of the EMU.

David was very keen to encourage children’s interest in science through microscopy. There were many school visits to the EMU, and in-house training programmes for school teachers and technicians were set up (see O’Connor 2008a). The emphasis on education and outreach activities of the Key Centre provided the opportunity to develop the schools programme further. During this period David and his colleagues conceived the idea of having a travelling scanning electron microscope (SEM) to take to schools (35) (see O’Connor 2008b). A tabletop SEM from JEOL was converted into a robust and safe instrument suitable for use by schoolchildren. The instrument was mounted on large rubber tyres for wheeling across bumpy schoolyards. A customized Ford Transit van was used for transport. Initially it was used in
short-term placements at high schools, but later it was used in the centre’s ‘Microscopes on the Move’ programme launched in 2000. During that year alone (alas, as David was leaving for Oxford) this microscope was presented to more than 20000 students and members of the public.

David’s leadership and development of the EMU and the centre were an outstanding success. Other Australian universities began to recognize the value of centralized electron microscope facilities and to follow the University of Sydney’s example.

When David was first appointed Director of the EMU in 1974 he was also given the position of associate professor. The university recognized his outstanding leadership by promoting him to full professor in 1986, and then to a personal chair (Professor in Physics (Electron Microscopy and Microanalysis)) in 1992.

When David left the University of Sydney to go to Oxford, the then Vice-Chancellor, Professor Gavin Brown, readily agreed to continue David’s strategy providing both the service and research functions of the EMU. There was broad consensus across users in all disciplines serviced by the EMU that the services provided for them were world class, and that this was partly due to the EMU’s research function (see Ratinac 2008), vindicating David’s policy. Before his departure, University of Sydney News in 1999 commented: ‘since David arrived, the Unit has been developed into what has been described as ‘a jewel’ of the University’ (see Ratinac 2008).

5.2. Research at Sydney University

Much of the first few years at the EMU was taken up with the development of the Unit, but in due course David built up a substantial research group. His publications demonstrate a broad range of interests. Topics investigated included the spinodal decomposition of alloys, the structure of thin films and high-temperature superconductors and analyses of image contrast from stacking faults, fullerenes, minerals and soils; he was even a co-investigator on a project supported by the National Health and Medical Research Committee analysing elemental profiles across kidney cell membranes. But the main thrust of his research was in two areas: (i) semiconductors, in particular the study of strain relief by misfit dislocations in semiconductor heterostructures, and (ii) the study of amorphous materials by electron diffraction.

Before discussing these, a study with Gronsky (15) of lattice fringe imaging with tilted illumination of modulated structures, in particular in spinodally decomposed alloys, should be noted. At the time this method was popular in investigations of slowly varying changes in interplanar spacings. With his experience in the shortcomings of this method in regions of rapidly varying interplanar spacings occurring close to dislocations (6), David considered that there was a need to establish the accuracy with which images could be interpreted for slowly varying interplanar spacings. An important problem that arises is due to the phase shift introduced by the lens transfer function, which depends on defocus and the spherical aberration coefficient; the function varies with scattering angle and has different values for each of the two Bragg beams, and possible satellite peaks in modulated structures, entering the aperture and producing the interference fringes in the image. There is therefore the possibility of mismatch between the image fringe spacings and the underlying interplanar spacings. The effects on fringe spacings of various cases of variations in interplanar spacings with distance, with and without segregation of atomic species, were considered theoretically. The study concluded that the variation of the lens function across the distribution of elastic scattering must be considered when determining the closeness of the match between fringe
and interplanar spacings, and identified situations when severe distortions between fringe and interplanar spacings could occur, and possibly even terminating fringes that do not correspond to dislocations. As with the work with Parsons and Hoelke (6), this was a warning not to make simplistic assumptions about the relationship between fringe and interplanar spacings.

**Semiconductors**

One of the early studies was the observation on gliding dissociated dislocations in hexagonal CdS, already referred to in §4. However, the main thrust was in the study of strain relief by misfit dislocations at interfaces in semiconductor heterostructures. This was a ‘hot’ topic at the time, and several groups worldwide were addressing the technologically important problem. David’s group contributed more than 20 journal publications on this topic in the 1990s. It is difficult to do justice to this large body of work. A particular feature of his contribution was that careful experimental observations were nearly always accompanied by detailed theoretical modelling using elasticity theory. He considered, *inter alia*, the effect of dislocation dissociation on misfit dislocations and strain relief, a topic only addressed briefly by others. In an elegant study with J. Zou (20), David considered the equilibrium dissociation configuration in low-strained In$_{0.1}$Ga$_{0.9}$As/GaAs single heterostructures, using high-resolution electron microscopy (HREM). To identify the interface, a thin layer (two unit cells thick) of AlAs was grown between the GaAs substrate and the strained InGaAs layer. The HREM contrast of the AlAs layer was sufficiently different for the interface to be identified. It was found that for a 60° misfit dislocation, the 90° partial is located just above the interface, whereas the 30° partial lies in the substrate, the separation between the two being the same as for the bulk GaAs. The equilibrium geometry was explained by elasticity theory.

Zou and Cockayne (21) went on to consider the misfit dislocation generation by dissociated 60° threading dislocations in quantum-well heterostructures. This is a modification of the original Matthews & Blakeslee (1974) model for undissociated dislocations. The study showed that the two partial dislocations experience different misfit stresses, resulting in the critical thickness for the two partials being different from each other and also from that for an undissociated dislocation. Various dislocation configurations were predicted, including the possibility of stacking faults extending over the width of the specimen, when the leading partial moves but the trailing partial cannot. The analysis explained experimental results in the literature.

In another paper with Zou in 1996 (22), it was shown that in epitaxial layers with large misfits, when nucleation of dislocation loops from the surface was a possible mechanism for strain relaxation, the accepted condition for critical thickness suggested by Matthews et al. (1976), which considered a semicircular loop expanding in a semi-infinite layer, needed modification when an epilayer/substrate interface was intercepted during nucleation of the expanding loop before the critical radius $R$ for spontaneous expansion was reached. In principle the loop could then act as two threading dislocations of opposite sign, which, by moving apart, generated misfit dislocations at the interface. Using a simplified elastic model that neglected the attraction between the threading dislocations, it was shown that the critical thickness for generating misfit dislocation by this mechanism could, in some cases, be smaller than for a free-standing strained film in the classical model (22).

In 1997, together with S. C. Anderson, C. R. Birkeland and G. R. Anstis, David published a paper entitled ‘An approach to quantitative compositional profiling at near-atomic resolution using high-angle annular dark field imaging’ (24). This was a typically careful study of
the composition profile at a heterostructure (GaAs/Al\textsubscript{0.6}Ga\textsubscript{0.4}As) interface (at monolayer resolution) using a then new method of image simulation for high-angle annular dark-field (HAADF) images in scanning transmission electron microscopy (STEM), which included thermal diffuse scattering, responsible for the atomic-number-sensitive image contrast in HAADF images, and a comparison with the so-called chemical mapping approach of Ourmazd and colleagues, which depended on detailed image simulation of images produced in a high-resolution transmission electron microscope (see Ourmazd \textit{et al.} 1989). The results were in good agreement with each other and with the expectations from the known growth conditions. The width of the interface was found to be $4 \pm 1$ monolayers. This new computational technique extended the power of the HAADF \(Z\)-contrast technique significantly and is more generally applicable than the Ourmazd technique, which is specific to particular structures.

With Chou, David also studied, under weak-beam conditions, the rod-like \{311\} defects in irradiated Si. These defects, formed by self-interstitials, were important because of their relation to a transient enhanced diffusion phenomenon, which restricts the miniaturization of Si devices. They found that the so-called \{311\} defects are more complex in character than previously thought, with different structures. A subsequent molecular dynamics calculation suggested that several different structures may coexist and that the observed images might arise from this possibility (23, 25).

In the late 1990s David also started a research programme on quantum dots (QDs), using transmission electron microscopy (TEM) under zone axis multi-beam imaging conditions, to obtain information on the composition, shape and size of the QDs, which was important in determining their optoelectronic properties. Figure 3 shows an example of the work of his group on coherent InGaAs QDs grown on a (001) GaAs substrate (26). The experimentally observed images, shown at the top right of the composite diagram, consist of crosses with arms that spread out towards the periphery. The simulated images \((a), (b)\) and \((c)\), shown below the experimental images, are for lattice mismatches of 4\%, 6\% and 7\%, respectively. The strain-field distribution was calculated with three-dimensional anisotropic finite element analysis.
The TEM image simulations were performed by using multi-beam dynamical theory with the column approximation (see Hirsch et al. 1965). The arms of the cross in all three simulations have constant width. Simulation image \((d)\) was calculated by assuming a gradual increase in the mismatch from 4\% at the bottom of the QD to 6\% at the top. The arms of the cross now increase slowly towards the periphery of the image, suggesting that the more pronounced effects in the experiments indicated segregation of In towards the surface of the QD.

Study of amorphous materials by electron diffraction

In addition to the intensive programme on semiconductors, David also branched out into a rather different area: the study of amorphous materials by electron diffraction. With D. R. McKenzie he developed a powerful electron diffraction technique within an electron microscope to determine accurate radial distribution functions (giving the average distributions of atoms around a central atom) from small volumes of amorphous material, orders of magnitude smaller than possible with X-rays or neutrons because of their small scattering cross-sections (17). By collecting highly calibrated energy-selected electron diffraction patterns to high scattering angles, he created a precision tool giving nearest-neighbour distances accurate to 0.001 nm.

An early application was the first proof of the existence of thin-film amorphous carbon in diamond form (18). The thin amorphous carbon films were produced by deposition on a NaCl substrate from a plasma stream of a cathodic vacuum arc with a curved magnetic filter. Figure 4 shows the diffracted intensity as a function of \(q\), the smooth curve \(f^2\) fitted to it at high scattering angles, the corresponding diffraction pattern (with the dashed lines showing the relevant parts of the diffraction pattern contributing to the low-angle and high-angle parts of the diffracted intensity curve), the reduced density function, and a model of two linked tetrahedra of carbon atoms. See the text for details. (Image created by D. J. H. Cockayne; reprint of Fig. 7 from Hirsch (2010), with permission from Taylor & Francis.) (Online version in colour.)

![Figure 4. Analysis of a diffraction pattern of amorphous carbon (18). Shown are diffracted intensity as a function of \(q\), the smooth curve \(f^2\) fitted to it at high scattering angles, the corresponding diffraction pattern (with the dashed lines showing the relevant parts of the diffraction pattern contributing to the low-angle and high-angle parts of the diffracted intensity curve), the reduced density function, and a model of two linked tetrahedra of carbon atoms. See the text for details. (Image created by D. J. H. Cockayne; reprint of Fig. 7 from Hirsch (2010), with permission from Taylor & Francis.) (Online version in colour.)](image-url)
in crystalline diamond. The two peaks corresponding to interatomic distances between first and second nearest neighbours are well reproduced in the amorphous carbon, whereas the peak of the third nearest neighbour is absent, corresponding to a random rotation of the two tetrahedra about the 2–5 bond linking them. Another example was the refinement of the structure of the C\textsubscript{70} molecule, which was obtained from the \(G(r)\) data for a powder sample with a simulated annealing technique, which assumed that the atoms interacted through a potential equal to \(-G(r)\). The relaxed minimum-energy structure is shown in figure 5; it is an ellipsoidal molecule, slightly pinched at the waist, consisting of hexagons and pentagons of carbon atoms. The various interatomic distances within the molecule were determined to an accuracy of 0.001 nm.

### 5.3. Sydney University administration

The university appreciated David’s leadership qualities in research, his breadth of knowledge, his judgement, and his negotiating and people skills. In the 1990s he was appointed to several university committees. In particular, in 1990 he joined the University of Sydney Research Committee, becoming its chairman in 1994, a post that he held until his departure to Oxford in 2000. During this period the committee discussed many difficult and contentious issues on the nature of research and training in several subject areas and disciplines. To quote from a statement by Professor J. R. Lawrence to the University of Sydney Academic Board after David’s death:

> Professor Cockayne carefully steered the discussion on these topics through an appreciation of the relationships between research and traditional academic disciplines and creative scholarly work across the whole spectrum of new studies now available. This resulted in a much broader and more satisfactory basis being formed for research policy and development in the University.

David was also one of the deputy chairs of the Academic Boards from 1993 to 2000. He served as Acting Pro-Vice-Chancellor (Research) for three months in 1996. During this period the federal government proposed a 12% cut in university funding. David painted a bleak picture of the potentially devastating consequences in an article in *University of Sydney News* (see Ratinac 2008), saying, *inter alia*, ‘Research is not like a supermarket; you can’t close it one day and hope to open it the next. Most research programmes take five or ten years to develop,'
and yet they could be killed off in a day simply by losing staff.’ And he exhorted the university community to explore every avenue to alert the government to the seriousness of the situation for the country’s future. David’s contribution to the Academic Board was summed up by Professor Lawrence:

David was an informed cultured enthusiastic key member of the team of deputy chairs of the Board created by John Mack. His lucid analysis and exposition were based firmly on his dedication to the highest academic intellectual principles and standards. He really cared and thought about academic research and teaching administration and its importance. He made a major contribution to the interpersonal cohesion of the group and hence the effectiveness of the Academic Board and ultimately the whole University.


David and Jean moved back to Oxford in 2000, when David took up the post of Professor in the Physical Examination of Materials, at the Department of Materials. He also became Professorial Fellow at Linacre College. David and Jean bought a house in North Oxford, renewed long-standing friendships and made new ones. To quote David on the return to Oxford, ‘Jean and I came for an adventure.’

In the department he reorganized the electron microscope facilities and provided an environment in which research based on the electron microscope flourished. He attracted outstanding academic and postdoctoral staff, and graduate students. He acted as mentor and advisor to many in the group.

He again built up a powerful research group. An important advance was the extension of the electron diffraction technique to obtain high-precision data from nanosized volumes of amorphous materials. To obtain such a small probe size, it must be highly convergent, resulting in its being highly coherent. With W. McBride and D. Nguyen-Manh, David examined the effect of coherent convergent illumination on electron diffraction data taken from nanovolumes of amorphous material (29). Electron diffraction patterns from an amorphous silicon model were simulated for coherent convergent illumination for different probe sizes and corresponding convergent angles, and compared with an experimental diffraction pattern taken from a thin film of amorphous silicon with a probe size of 1.2 nm. The results showed that for amorphous volumes as small as 1.2 nm in diameter, the interference effects induced in the diffraction data by the use of coherent convergent illumination were largely suppressed by the lack of order in amorphous materials. This meant that the methods to derive the radial distribution function (or the related reduced density function) from the diffraction data developed for incoherent illumination could also be used for coherent illumination for nanosized volumes of amorphous materials.

Having established the soundness of the technique, David, together with C. Lang, S. A. Song and Nguyen-Manh (33), applied it to studying the structure of the amorphous phase in the rapid-phase-change material Ge₂Sb₂Te₅, which had potential use in the active layer of high-density storage devices. In these devices, information is encoded by creating amorphous spots in a polycrystalline matrix by heating and quenching with a laser pulse. The amorphous phase has different reflectivity and resistivity from those of the crystalline matrix, which can be read. The amorphous phase can be erased by using a pulse of different energy to recrystallize the material. In their paper the authors used density functional theory to derive a
new model for the building blocks of amorphous Ge$_2$Sb$_2$Te$_5$ and tested it against the reduced density function derived from experimental electron diffraction patterns of the amorphous phase. The proposed building block structure was used in an amorphous-structure model to calculate the reduced density function, and it was then refined against the experimental data. In the model the amorphous structure was based on distorted and misaligned rings of Ge$_2$Sb$_4$Te$_4$, the misalignment being introduced by the heating during amorphization due to weak inter-ring bonds. During the phase change the rings essentially remained as rings, as a result of the stronger intra-ring bonds. This study was an excellent early example of how the electron diffraction technique could be used, together with \textit{ab initio} calculations, to derive a polyatomic structure of a nanoscale volume of material.

The work on QDs started in Sydney was also continued. After the TEM evidence of elemental segregation in the case of In(Ga)As/GaAs(001) islands (26), David became interested in segregation within QDs as a strain-relieving mechanism. Together with Lang and Nguyen-Manh, he used atomistic modelling techniques to predict the alloying profile in pyramid and dome-shaped Ge(Si)/Si(001) islands (30). The results showed that the composition profile was dominated by the surface segregation of Ge and Si to the substrate island interface. The shape transformation from the pyramid to the dome shape observed experimentally was predicted accurately by the modelling. Before David’s work in Sydney and Oxford, the generally accepted view of modes of strain relief in QDs was changes in surface shape, alloying and the introduction of misfit dislocations. The work by David’s group in Sydney and Oxford established that segregation of elements within the QDs was an important additional strain-relieving mechanism.

A joint and rather elegant study by David’s group and that of Frances Ross at IBM led to exciting observations by \textit{in situ} time-resolved TEM of the processes occurring during Si capping of coherent dome-shaped Ge/Si(001) islands (32). During the initial stages of Si deposition, the dome-shaped islands flattened to a pyramid shape and also shrank in volume. This shrinkage was explained by intermixing of the deposited Si with the wetting layer, and a consequent diffusion of Ge from the islands into the wetting layer. A simple semi-quantitative model was developed that explained the experimentally observed shape and size evolution during capping. All the processes involved were surface processes and did not require bulk diffusion, which would have been too slow at the temperatures of the experiments. The results provided valuable insight into atomic processes that control QD size, and consequently the electronic and optical properties.

Another highlight of the research of David’s group, in collaboration with a group in the University of Karlsruhe, was the determination of the positions of rare-earth doping atoms at the interface between crystalline Si$_3$N$_4$ and the amorphous intergranular films in this polycrystalline ceramic. The rare-earth atoms La and Lu promote the growth of needle-like grains that enhance toughness. Using the HAADF STEM technique, David and his collaborators determined the three-dimensional coordinates of the specific sites of the La and Lu atoms relative to the adjacent Si$_3$N$_4$ crystal structure (31). Figure 6 shows the arrangements of the La and Lu atoms in the HAADF STEM images. The atoms at the corners of the hexagons are Si. The regular arrangement of the rare-earth atoms within an otherwise amorphous layer is remarkable. It is clear that the structural arrangements of the La and Lu atoms at the interface are different. This raised the possibility that these structural differences may be important for understanding the attachment kinetics during grain growth, which are known to be different for different rare-earth sintering aids, and which determine the grain anisotropy and bulk mechanical properties of Si$_3$N$_4$-based ceramics.
7. PROMOTION, DISSEMINATION, TEACHING AND LEADERSHIP OF ELECTRON MICROSCOPY

David made outstanding contributions to the promotion, dissemination and teaching of electron microscopy, both nationally and internationally. During his Sydney period he organized and promoted many courses on different aspects of electron microscopy and analysis, and was much respected for inspiring the younger microscopists and for stimulating interest in electron microscopy in schools. In Oxford, with Angus Kirkland, David transferred the ‘Microscopes on the move’ programme already referred to in §5 into a cyber-SEM technique, enabling schools to access and drive an SEM in Oxford. Many schools took part in this programme. These educational activities demonstrate David’s enthusiasm for electron microscopy and the microscopic world, and his passion to enable the young and old to discover the secrets and beauty of this hidden world.

David was a member of a number of editorial boards and was joint Editor-in-Chief of Micron from 1991 to 2009. He would not publish any papers containing significant text produced by cut-and-paste from previous publications. He would not tolerate this type of self-plagiarism.

In the 1980s David assumed major roles in national and international activities of the electron microscope community. He was member of the National Committee for Electron Microscopy of the Australian Academy of Science from 1978 to 1986, and its chairman from 1986 to 1994. He was a co-founder of the Australian Society for Electron Microscopy, and its Foundation President from 1986 to 1988. With Professor H. Hashimoto he promoted the Asia Pacific Conferences and Workshops in Electron Microscopy and acted as General Secretary of the Committee of the Asia Pacific Societies of Electron Microscopy from 1984 to 1996. His work within Asia through this committee fostered mutual contacts in the region. He was very interested in helping to develop and promote electron microscopy in China. In 1988 he was a visiting professor at the University of Science and Technology in Beijing and was appointed an honorary professor in 2005. He was also made an honorary professor at Lanzhou University of Technology (2006–07). In a letter to Jean Cockayne after David’s death, the President of the Chinese Electron Microscope Society, Professor Ze Zhang, and its Secretary General,
Professor Xiaodong Han, noted that David had made a remarkable contribution to the society and to the development of Chinese electron microscope activities. In 1987 he was elected to the Executive Committee of IFSEM and was its General Secretary from 1995 to 2002. From 2003 to 2008 he served as President of IFSEM, and was then Vice-President until 2010. This demonstrates the high esteem in which he was held internationally by the electron microscopy community, which he served selflessly, and for which he provided outstanding leadership.

8. Musings and memories

David was a deep-thinking person, sensitive to the problems confronting others, in particular the younger members of the research community. He felt sufficiently strongly about these issues to record his views in writing. In 2009 he published a novella entitled Memories that addressed the problems affecting researchers, particularly (but not exclusively) scientists, in a university environment (36). The topics discussed include the pressures on scientists to publish papers—for established researchers to remain ahead of the game, and for the up-and-coming postdoctoral workers to establish a good track record, bolster their CVs and improve their chances for a permanent appointment. These pressures can result in various consequences, and in the book this is illustrated with an extreme case in which the postdoctoral researcher who could not cope with the conflicting pressures invented some experimental results to fill a gap in support of a model proposed by the senior academic leading the research, in time for presentation at a conference. The excuse was that they had done these experiments before and knew what the results would be. This and other themes in the book are discussed through fictional characters in a collegiate university. This particular episode reflects what happened with a publication in the USA involving electron microscopy, which caused a considerable stir at the time. But many other issues are discussed in the novella that were of concern to David, for example the need for scientists to present their results clearly in any written publication, leaving no room for ambiguity of interpretation. He also refers to the difficulties arising from differences in culture; thus, Chinese students have been brought up to defer to the views of their elders and find it difficult to question what they are taught. These are all issues that David encountered with his students. An important theme in the book is the nature of ‘memory’, and its unreliability. A diary is a permanent record of a memory, but an aboriginal cave painting needs refreshing from time to time, with the possibility that the memory might be changed although its basic message might remain intact. The relevance of this to the restoring and refreshing of old masters is also alluded to. And there is reference to Helen Garner’s novel mentioned in §1, which misuses an incident with David to demonstrate the unreliability of memory.

After David moved to Oxford in 2000, he contributed regularly to the Australian Microscopy Society Newsletter, with essays entitled ‘Goaday from the UK’ (28). These were reflections on issues that had arisen at the time and had stimulated his musings, often at conferences that he had attended. There are some 30 articles over a period of almost a decade (issue 74 (2002) to issue 106 (2010)). They include his views on the costs and benefits of research, the role of scientific conferences, the problems facing young scientists in getting academic posts, nanotechnology, research funding, and ethics in scientific publications, as well as various topics more specific to electron microscopy.
The articles, like the novella, are beautifully crafted, usually in a humorous style, and are well worth reading. There are some real gems among them, for example issue 84 (2004), which deals with the teaching of crystallography. In issue 90 (2006) he describes what happened when a plenary lecturer at the Royal Society had his PowerPoint presentation fail catastrophically, with no chance of recovery. The lecturer was in fact David himself (although he does not say so in the article), and he gave his talk on microscopy(!) without slides. The lecture was nevertheless a great success, and the session ended with a request to the organizers that for future meetings the plenary lecturers be asked to perform without slides! In issue 78 (2003) he reports that while attending a conference on amorphous materials in Bonn, he visited Cologne Cathedral and wrote, ‘When looking at the stained glass windows in the nearby Cathedral of Cologne, I realised that they were the poster presentations of the day—panel after panel giving the story in glorious technicolour.’

The last few letters were written while he was already very ill with lung cancer (he had never smoked), and his last (issue 106, dated June 2010), written about six months before he died, ends with a rather poigniant paragraph:

There are many examples where the success of good things is used to argue for their continuance. But there are examples of good things (and no doubt bad things also) which should come to an end, because they have run their course, and this column is one such. So with thanks to the forbearance of editors over a decade and to any readers who regularly reach so far on the page over the years, I sign off with the variant of the usual call sign—Goodbye from the UK.

9. EPILOGUE: A CIVILIZED MAN

David retired from his Oxford chair in September 2009. He was already ill but bore his increasingly painful illness stoically. He continued his research, writings, and service to the electron microscope community. He and his wife, Jean, also managed to do some travelling around this period. Figure 7 shows David and Jean in front of (to quote David) ‘The giant SiO$_2$ QD’, in the Louvre, taken during a trip to Paris in 2008.

He had an illustrious career in research in electron microscopy, in the management and development of university electron microscopy facilities, in the promotion of the field through his inspired teaching and dissemination of the subject, and in providing exemplary leadership to the electron microscopy community on the national and international stage.

None of this affected his innate modesty. He was generous with his time in giving help, advice and stimulation to students, staff and colleagues alike. He was a brilliant lecturer, and a very popular keynote or invited speaker at conferences.

His research was outstanding, characterized by a profound insight into the complexities of electron diffraction and microscopy, the development and application of high-precision techniques, and a rigorous analysis and deep understanding of experimental observations. Anyone who was privileged to work with him, as I was, knows that nothing but complete understanding would satisfy him. One of his referees for a medal commented that David ‘made the impossible possible’. He was elected to the Royal Society in 1999, and was awarded the Massey Medal of the Australian and UK Institutes of Physics in 2009.

His novella and the Newsletters to the Australian Microscopy Society reflect David’s broad intellectual and cultural interests, which extended beyond the specialized science perspective, and they demonstrate his powers of lateral thinking, his humour, his concern for others and
their problems, and his deep insight into many issues. In a lecture (the George Adlington Syme Ovation 1960) entitled ‘The education of a civilized man’ to the Royal Australasian College of Surgeons in 1960, J. R. Darling, who was David’s headmaster at Geelong Grammar School, defined a civilized man as ‘sensitive, wide in his interest, tolerant and yet courageous, intellectual and strong in principle’ (Darling 1960). This describes David perfectly.

In September 2009 a conference was held in Oxford to mark his retirement from the chair (see Hirsch et al. 2010). Some hundred or so delegates attended, many from overseas. They came not only because they admired him as an outstanding scientist and to celebrate his achievements, but also because they had a great affection for him.

His death in 2010, so soon after his retirement, was a tragic blow to Jean, who, lovingly, had supported him throughout his career and cared for him during his illness, and to his three children and his extended family, but also to his many friends and colleagues all over the world.

His humour outlived him. At his funeral his son, James, read out a eulogy that David had prepared for the occasion, typically to ‘save someone some trouble’ (see (37)).
Honours and distinctions

1985–87  Vice-President, Australian Institute of Science and Technology
1986–88  Foundation President, Australian Society for Electron Microscopy
1986–94  Chairman, National Committee for Electron Microscopy, Australian Academy of Science
1999    Fellow of the Royal Society
2000–09  Professorial Fellow of Linacre College, University of Oxford
           Honorary professor, School of Physics, University of Sydney
2002–06  President, International Federation of Societies for Microscopy
2003–08  Honorary research associate, Australian Key Centre for Microscopy and Microanalysis, University of Sydney
2005–10  Honorary professor, University of Science and Technology, Beijing (China)
2006–07  Honorary professor, Lanzhou University of Technology (China)
2007–10  Vice-President, International Federation of Societies for Microscopy
2009    Massey Medal of UK and Australian Institute of Physics

Acknowledgements

I am very grateful to the many people who have given me information and advice about David’s life and career. In particular I am greatly indebted to the Cockayne family for their help, and especially to Jean Cockayne, who has given me, inter alia, detailed information about the family history, David Cockayne’s early days, and the Melbourne period. She also gave me copies of letters she received after his election to the Royal Society, after his retirement and after his death. The last included a statement by Professor J. R. Lawrence to the Sydney University Academic Board, parts of which I have quoted. Michael Cockayne, David’s brother, and Anthony Kerr, Jean’s brother, have given me information about David’s schooldays and the Melbourne University period. I have also had very helpful letters about David’s schooldays from Michael Perse, the Curator of Geelong Grammar School, Lord Alec Broers FRS and Professor Jeremy Pickett-Heaps FRS, who attended the same school and overlapped with David.

Alex Moodie and Peter Turner gave me valuable information about David and his scientific contribution, particularly during his Melbourne period.

The section on David’s contribution to the development and management of the Sydney University Electron Microscopy Unit has made much use of information from various papers in the book 50 great moments (2008), published on the occasion of the 50th Jubilee of the Unit and in particular of the article ‘Great moment 11’ (Ratinac 2008).

I have also benefited greatly from advice and discussions with my Oxford colleagues Professor M. J. Whelan FRS, Professor Peter Nellist and Professor A. Kirkland, and with others who knew David well, in particular Professor A. Howie FRS and Professor C. J. Humphreys FRS.

I have also made use of the obituaries published in the Australian Microscopy Society Newsletter issue 110 (2011), which include those by Guy Cox, Peter Turner and Alex Moodie, and in particular that by David’s son, James Cockayne, which he read out at David’s funeral and which includes David’s own contribution (37).

Finally, I would like to thank Katherine Hartwell for her invaluable help and hard work in providing me with copies of papers and other information, and for typing and preparing this manuscript.

The frontispiece photograph was taken in 1999; copyright © The Royal Society.

References to other authors


**Bibliography**

The following publications are those referred to directly in the text. A full bibliography is available as electronic supplementary material at http://dx.doi.org/10.1098/rsbm.2014.0025 or via http://rsbm.royalsocietypublishing.org.


Biographical Memoirs


(20) 1993 (With J. Zou) Equilibrium dissociation configuration of misfit dislocations in low strained In0.5Ga0.5As/GaAs single heterostructures. *Appl. Phys. Lett.* 63, 2222–2224.


(23) 1999 (With C. T. Chou & N. A. Marks) Modelling of \{311\} defects in silicon. In *Proc. 6APEM, Hong Kong*.


(35)  
