

Andrew (Andy) Howard Reginald Cole 1924–2024

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ABSTRACT

Andy Cole (1924–2024) was a world leader in the infrared spectroscopy of small gas molecules, a field in which he had international collaborators in the UK, Europe, Japan, Canada, and the United States. After studying and working overseas, he spent his career at the University of Western Australia, rising from senior lecturer (1955–7) to have a personal chair in 1969 and serve as Professor of Physical and Inorganic Chemistry and Head of Department from 1971 to 1989). He was interested in science education at all levels, and together with Don Watts and Bob Bucat published a textbook for high school students—*Chemical Properties and Reactions*. He received multiple awards and honours including the Leighton Medal of the Royal Australian Chemical Institute in 1984. Andy was a prominent member of the Physical Chemistry Division of the International Union of Pure and Applied Chemistry. He was elected a Fellow of Australian Academy of Science in 1974. A talented cricketer and hockey player in his youth, in retirement, he enjoyed golf, travelling and looking after his ten grandchildren with his wife Ursula.

Keywords: Andy Cole, cricket, golf, infrared spectroscopy, IUPAC, school chemistry education.

Family background

Andrew (Andy) Reginald Howard Cole was born in Midland Junction, Western Australia (WA), then a small town east of Perth, on 21 April 1924, and died in Perth on 5 February 2024 just two months before his one hundredth birthday. His father, James (Jimmy) Howard Cole who left school at fifteen, was a wheelwright and fitter and turner who served his apprenticeship at the Western Australian Government Railways Workshop in Midland Junction. He worked as a fitter and turner on the Kalgoorlie goldfields before enlisting as an Air Mechanic Second Class in the Australian Flying Corps in the World War 1 in September 1917. Jimmy married Anness Jean Hyatt in 1920 soon after his return from active duty and resumed his career at the railway workshops in Midland Junction, a town where he was active in local government and was the mayor from 1947 to 1955. Andy was the second of three sons. Their parents read widely, and were determined that their sons would have every educational opportunity (Figs 1 and 2).

The inclusion of Andy's own words, preserved in the autobiographical notes he composed for his family, adds a truly personal dimension to this memoir.¹

Secondary education

Completing his primary education at the Midland Junction Central School, Andy sat the Secondary School Scholarships examination in 1936. Successful children were offered a place at Perth Modern School (PMS), or an annual prize to fund their expenses at a country high school. His name was not in the list of 'successful children' published in the *West Australian* newspaper on 24 November 1936,² but he was offered a scholarship after some on the original list chose instead to go to a private school or a country high school. The

¹Unpublished biographical notes by A.R.H. Cole.

²Anonymous (1936).



Fig. 1. Andy Cole (Cole family collection).

headmaster of his school was informed of Andy's success and suggested that Andy run home to tell his mother the news, but Andy's friend Don Aitken³ lent him his bicycle to make the 2 km journey and so deliver the good news more promptly.

Andy accepted his scholarship and entered PMS in 1937. He commented that the opportunity to go to there was the most important stepping stone of his life. He certainly made the most of this opportunity. The school had both excellent teachers and first-class sporting opportunities. In his final year Andy was a school prefect and the captain of both the cricket and hockey teams. At the end of his third year, he had to choose which subjects he would study in his final two years, and thinking of becoming a teacher he thought it might be an advantage to enrol in the class that included a foreign language and not chemistry, which was to become his love. He recalls⁴ that 'on the very last day of third-year high school, the form master, one of our mathematics teachers, Mr "Pips" Piper, asked me which class I had chosen and I told him, whereupon he was somewhat aghast and told me in words of rather strong emphasis not to be so stupid but to change and nominate the main science class that took chemistry. I did that and have never forgotten; I have never failed to thank him, because I spent the whole of the rest of my life in chemistry'.

At the end of his final year, he sat the Leaving Certificate Examination and won a Science Teachers Exhibition Award, the acceptance of which involved signing a bond agreeing to become a science teacher in the Western Australian

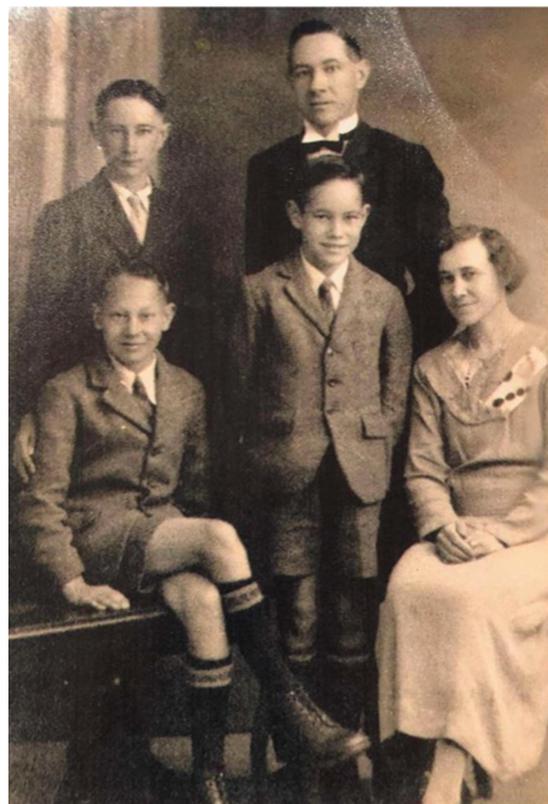


Fig. 2. Andy Seated with parents Jim and Jean and brothers Alf and Des (Cole family collection).

Department of Education for three years after graduation from the University of Western Australia (UWA), the only free university in the country at the time and the first free university in the (then) British Empire.⁵

Undergraduate education at University of Western Australia

Andy commenced studies for his BSc degree at UWA in 1942. The course followed one of the standard options—chemistry, physics, mathematics and biology in first year; chemistry, physics and mathematics in second year; chemistry and mathematical statistics in third year. He was the fortunate recipient of a St. George's College scholarship to cover his living expenses on campus, obviating the need for him daily to make the long journey to Midland Junction. In his final year he was senior student at St George's.

In his second year Andy decided that he would major in Chemistry. He graduated with a BSc and was awarded a Hackett Scholarship. He was granted a year's leave from his bond which enabled him to enrol for Honours in 1945. His honours research

³Fitzhardinge (2019).

⁴Watts (2010).

⁵Anonymous (2013).

project was based on a study of solubilities and double-salt formation in the four-component system $\text{Na}_2\text{SO}_4\text{-K}_2\text{SO}_4\text{-MgSO}_4\text{-H}_2\text{O}$ at 35°C as part of the Alunite Project (see below), and he was awarded first class honours for his research.

The Alunite Project

The Western Australian Alunite Project 1940–54 was the major research activity of the university's chemistry department during World War 2,⁶ and it was very successful in building the research capacity of the Chemistry Department. N. S. (later Sir Noel) Bayliss (1906–96) had come in 1938 to a department that had little research money or equipment, and only three staff members. The alunite project was well-funded and allowed him to build a research culture and to train a generation of chemists in thermodynamics, phase rule studies, inorganic chemistry and pilot plant design and operation. The project⁷ was a response to the possible wartime shortages of potash and alumina, and it sought to exploit the Lake Champion (a lake near Nungarin in Western Australia) deposit of alunite. The project was partly successful. Potash was produced on a commercial scale at a plant near the lake from 1944 to 1949, but no alumina was produced. Andy came to the project towards its end, and was involved in the potash fertiliser aspect of the project. Glasserite ($\text{K}_3\text{Na}(\text{SO}_4)_2$) was the primary product of crystallisation from the leach liquor and was sold as a fertiliser, but a long-term business needed to produce a purer grade of potassium sulfate. Determining the phase data for the mixture of sodium, potassium and magnesium sulfates with water, as described above, was important to the success of the project.⁸

Research assistant

Andy's success as a researcher led him to consider undertaking study for the PhD degree. Although in the mid-1940s this degree was unavailable at UWA, he took a step that allowed him to consider pursuing such a research career by resigning from his bond with the WA Education Department and repaying the money he had received under the Exhibition (\$192). He was fortunate in 1946 to be able to take up a research assistant position under Professor Bayliss, using arc-emission spectroscopy to search for trace-metals in the ash of various samples of clover as part of wider research on trace element deficiency in cropping animals. This position enabled him to pay off his debt to the Education Department and, not having to take on extra work, to continue with his sporting



Fig. 3. Cole family collection.

activities in hockey and cricket. He was named in the all-Australian hockey team and tried out for the Sheffield Shield cricket team for WA (Fig. 3).

At the end of 1946 UWA awarded him a Hackett Studentship for overseas study. At about that time, Lloyd Rees⁹ (1916–89), head of the Chemical Physics Section of CSIR's Division of Industrial Chemistry in Melbourne and a prominent spectroscopist, was visiting Perth and suggested to Andy that he should join an international research group to study molecular (infrared) spectroscopy for his doctorate. Andy duly applied for and was accepted by St John's College, Oxford University to study under Professor H. W. 'Tommy' Thompson,¹⁰ who had built up an active infrared group in the physical chemistry laboratory at Oxford.

University of Oxford

He started experimental work on his Doctor of Philosophy (DPhil, as the doctorate is known at Oxford) research project

⁶Bayliss (1980).

⁷Anonymous (2000) Lake Champion.

⁸Bayliss and others (1947).

⁹Walsh and Willis (1992).

¹⁰Richards (1985).

in September 1947. His thesis project involved measurement of infrared absorption intensities and analysis of molecular vibrations by normal coordinate calculations; some moderately high-resolution measurements of rotational fine structure of vibration bands of some small molecules, among them glyoxal¹¹ (the simplest coloured organic compound); and the first use of the reflecting microscope¹² for infrared studies of extremely small amounts (a few micrograms) of material. The equipment available at Oxford in those early days for infrared spectroscopy, although somewhat crude, allowed researchers to make reasonable measurements. Electronic recorders were only just coming into use; researchers' first measurements were made using a photographic recorder with a spot of light reflected from a galvanometer moving across photographic paper.

During this time in England, Andy maintained his love of cricket and was wicket keeper and batsman for his Oxford team.

National Research Council of Canada

Because of his previous research experience in his Honours year and the period before leaving for Oxford in 1947, the DPhil was completed in two years. Towards the end of 1949 Andy applied for a post-doctoral fellowship at the National Research Council of Canada (NRC) in Ottawa, which was just beginning a post-war expansion, based predominately on the appointment of post-doctoral fellows to the NRC Divisions of Chemistry and Physics.¹³ He was successful and obtained an NRC fellowship to work with Dr R. Norman Jones¹⁴ and he moved to Ottawa to take up the post in November. Jones was originally an organic chemist interested in the structure and properties of steroids. In Ottawa, his group's aim was to use infrared spectroscopy as an aid in determining the details of the structure of steroids and,¹⁵ in collaboration with another group, relate this to medical properties. The infrared spectra of steroids are complicated, consisting of bands in a number of important regions. Part of the spectrum is produced by the vibrations of the hydroxyl ($-\text{OH}$) or carbonyl ($>\text{C}=\text{O}$) functional groups and C-H groups that are distinguished by their environments in the molecule. There is also a region of the absorption spectrum produced by molecular vibrations spread over the whole steroid molecule. Andy was given the task of relating the different C-H group absorptions to the position of the C-H in the molecule and of relating the stereochemical configuration of the 3-hydroxy steroids to

their infrared absorption spectra.¹⁶ Andy commented, 'although the work (of the Jones group) was empirical rather than theoretical much of it contributed greatly to the establishment of infrared spectroscopy as a major tool in organic chemistry laboratories around the world. Infrared spectroscopy maintained this role for about two decades, before being superseded, firstly by nuclear magnetic resonance, then by X-ray crystallography'.

A significant development from Andy's DPhil was the construction and testing of a reflecting microscope. Infrared radiation, unlike visible light, would not pass through a lens but could be focussed by reflection by mirrors. Being involved in instrument development and construction was to be a focus of much of Andy's future work. In Ottawa he continued what he had done at Oxford, and was involved in designing and having built a new reflecting microscope. The new design used spherical mirrors which were much easier to make than the aspherical mirrors used in the Oxford instrument.¹⁷ Andy recalls, 'we could get spectra on one or two micrograms of material which were the equivalent in quality of the spectra that we could obtain on a very much larger few milligrams of material in a normal infrared spectrometer'. The work in Ottawa was published in the year Andy returned to Australia.¹⁸

Time at the NRC in Ottawa also enabled Andy to interact with Gerhard Herzberg and Don Ramsay, both of whom were to be important in his future work.

Because of the large number of English migrants in Canada, Andy found it was possible for him to continue to play cricket there. In 1950 he played in Ontario's winning team at the inter-provincial tournament played in Winnipeg. His photograph remains in the Ottawa cricket club for having scored a thousand runs in a season.

Return to England on a Nuffield fellowship

Meanwhile in Australia, Professor Bayliss had applied for a Nuffield Foundation grant to set up an infrared laboratory at UWA. Part of the grant was for equipment, and the rest for a fellowship for someone to set up the laboratory. While the grant approval was pending, Bayliss, on study leave in Chicago,¹⁹ came to Ottawa to see Andy and asked if he would be interested in returning to WA to set up an infrared laboratory. As Andy had thought it was about time to return to Australia, and he was particularly interested in applying

¹¹Cole and Thompson (1949).

¹²Barer and others (1949).

¹³King (1984).

¹⁴Gridgeman (2008).

¹⁵Watts (2010).

¹⁶Cole and others (1952).

¹⁷Cole and Jones (1952).

¹⁸Cole and Jones (1952).

¹⁹Cole (1996).

infrared techniques to chemical problems, the proposal was a welcome one. The grant was obtained. It had a restriction that equipment had to be purchased in England using sterling, and so an order was made for a Grubb Parsons spectrometer. Because the order could not be filled for six months, an arrangement with Bayliss permitted Andy to take up the appointment on 1 January 1952, and spend time in London until UWA could take delivery of the spectrometer and he could move to Perth and set up the laboratory. It was a very propitious arrangement. In London, S. F. D. Orr,²⁰ who had been with him in Thompson's laboratory, arranged access to an infrared spectrometer for Andy to use.

He was also able to follow up a project that had been suggested to him in Ottawa by visiting English organic chemist Derek Barton FRS. Andy remembered²¹ that, 'He kindly gave me samples of a large number of triterpenoids²² and introduced me to Sir John Simonsen²³ who made available many samples of simpler terpenes. So, I returned to UWA with a ready-made project, which was particularly appropriate because at that time D. (Doug) E. White had begun an extensive investigation of triterpenoids in Western Australian plants.' During the time in London, he also went to the National Physical Laboratory at Teddington to learn about diffraction gratings. Gratings would eventually replace prisms—typically crystals of sodium chloride or bromide, calcium fluoride (fluorite) or lithium fluoride with good infrared transmittance—to improve the resolution of the Grubb-Parsons spectrometer. The six months in London were very productive, resulting in five papers. A complete list of Cole's publications is contained in the Bibliography in Supplementary Material to the biographical memoir.

Back to Perth

Nuffield research fellow and contribution to infrared spectroscopy

In mid-1952 Andy returned to UWA and set up an infrared laboratory with the Grubb-Parsons spectrometer using only prisms to disperse the light. It did not take long for him to display his interest in designing and making changes to equipment. He used his single beam instrument to experimentally produce a double beam double pass instrument.²⁴

The details of turning a single beam instrument into a double beam instrument are technically difficult to describe in a memoir. The essence is that rather than two beams, one beam of light is sent alternately through sample and blank cells by a rotating mirror system. This is difficult to combine with a double-pass system as designed by Walsh.²⁵ But Andy realised it was possible using the changed design made by Rochester and Martin,²⁶ and he experimented with his Grubb Parsons to produce the desired result. Andy made further experimental changes to his Grubb Parsons spectrometer. About this time developments in making gratings meant they could be made cheaply and in good numbers. Consequently, Andy using a grating supplied by L. A. Sayce from the National Physical Laboratory, devised a method for incorporating a grating into his spectrometer, and published his method²⁷ so that others could use it to modify prism instruments. But neither of the above instrumental developments were permanently added to the spectrometer. Andy did the experiments to show his design worked. Incorporation of a grating gave the higher resolution that was later needed to look at rotational structure when he began working on small molecules in the gas phase. While on the fellowship Andy worked for two and a half years, as intended, with Doug White's group on triterpenoids. The collaboration with White produced ten joint papers all solving structural problems. While doing this he must have been involved with running routine infrared spectra for organic chemistry students, since his spectrometer was the only available instrument. At the same time, he also produced a series of eleven papers on the infrared spectra of natural products, besides the publications with White. The thrust of what he was doing is conveyed by the following extract from an abstract:²⁸ 'The correlation of infrared absorption frequency with equatorial or axial orientation of hydroxyl and acetoxyl groups in steroids and simpler cyclic compounds was extended to the tetracyclic and pentacyclic triterpenoids, with special attention to the stretching frequency of hydroxyl groups.' The research on steroids that he had begun in Ottawa continued in London with triterpenes and continued in the same vein in Perth.

At the same time Andy wrote reviews about the infrared spectra of steroids and natural products,²⁹ but he felt he had been away from areas of more fundamental spectroscopy in which he had been involved overseas. When Robin Stokes³⁰ left UWA to become foundation professor of chemistry at the

²⁰S. F. D. Orr was at the Chester Beatty Research Institute, The Royal Cancer Hospital, Fulham Road, London.

²¹Unpublished biographical notes by A.R.H. Cole.

²²Barnes and others (1953).

²³Robinson (1960).

²⁴Cole (1953).

²⁵Walsh (1951).

²⁶Rochester and Martin (1951).

²⁷Cole (1954).

²⁸Allsop and others (1956).

²⁹Cole, 1956.

³⁰Spurling and Noller (2018).

University of New England in Armadale in 1955, a position became available at UWA and Andy was able to move from the fellowship to a senior lectureship.

Senior lectureship

Andy's appointment gave him the independence to move away from using infrared on organic structures as a service to organic chemists with whom he collaborated, and to set up his own research group to study rotational fine structure in the spectra of small molecules in the gas phase. He also accrued the privileges of a continuing appointment, including the right to study leave, and Bayliss, as head of department, permitted the three years of the Nuffield Fellowship to be counted towards his study leave in 1959. With the aid of a Senior Fulbright Award, Andy went on study leave with R. (Dick) C. Lord at the Massachusetts Institute of Technology (MIT) in Boston. In his year at MIT, he learned techniques developed there for working in the far infrared (long wavelength) region, and he was stimulated to continue his research in this direction. Back in Perth, Andy only had the Grubb Parsons spectrometer fitted with prisms for dispersing light. He had already experimented with fitting diffraction gratings into this instrument. He solved his current problem by making a more permanent incorporation of gratings loaned from a number of sources, thus displaying his ability to maintain good relations with all the people he met during his scientific career. This enabled him to record spectra in the far infrared, and to complete a publication on the length of the central C–C bond in butadiene.

Important though the 1959 study leave was, Andy reports that his next study leave in 1966, with Ramsay in Ottawa influenced the direction of his research for the next twenty years. Ramsay then had just begun a large project on the visible absorption spectrum of glyoxal. It was a molecule whose spectrum was introduced to Andy during his Oxford years. He had already analysed, with a student,³¹ one of the fundamental vibrations from a spectrum supplied by Thompson. In the following years, under the general supervision of Ramsay, Andy and a large group of other researchers analysed many bands of glyoxal and its isotopically substituted analogues. Andy's contribution to this work is contained in seven publications. These studies gave very precise rotational constants and consequently precise molecular structures.

During that sabbatical leave in 1966 Andy spent four months at the National Bureau of Standards, Washington, with Dr Walt Lafferty, who had been a PhD student in Dick Lord's laboratory at MIT in 1959. Lafferty recorded the C–H

stretching infrared bands of ethane and glyoxal for him at a resolution of about 0.030 cm^{-1} . Andy completed the analysis of the ethane band, and George Osborne analysed the glyoxal band as part of his PhD project back in Perth. Shortly after that study leave, the team in Perth built a vacuum far-infrared grating spectrometer that, as Andy has reported,³² 'formed the basis of much of their research from 1967 to 1975'.

One revelation from working with Lord at MIT was that the amount of energy from infrared sources is low at long wavelengths, and so absorption of water in these regions is a problem. Absorption in the far infrared is from rotational transitions. Water has a complex of strongly absorbing, overlapping bands in this region making compensation for these bands complex. Because of the low energy from far infrared sources absorption by water can significantly reduce the exciting radiation. Therefore, it is necessary to remove water vapour to make satisfactory measurements. Andy's solution for this problem was to design a spectrometer of moderate resolution completely enclosed in a steel case that could be evacuated,³³ thus greatly reducing the concentrations of water vapour and CO_2 (Fig. 4). It was designed to record the rotational fine structure of molecules in which there were low frequency torsion and bending vibrations. This construction was possible at UWA because the Chemistry School had an excellent workshop with talented machinists, a luxury that is no longer available in chemistry schools in Australia. Thus Andy, equipped with some gratings from Lloyd Rees and the CSIRO Division of Chemical Physics in Melbourne that he was allowed to keep, and with the vacuum case, was set up for detailed studies of small gas molecules. It is not clear when the new spectrometer was ready for use, but as reported above, Andy has said,³⁴ 'it was used for research between 1967 and 1975'. With the new moderate resolution instrument studies were made on, HCl, NO, acrolein, butadiene, acrylonitrile, acetylene, CH_4 and DBr.³⁵ For the rest of his career, Andy continued in this area of far infrared spectroscopy. In the late 1970s another, vacuum-enclosed high resolution near infrared spectrometer was built. This high-resolution instrument was used for a number of studies on low frequency vibrations and rotations of glyoxal, ethane and various deuterated ethane molecules conducted by a series of post-doctoral fellows (R. E. Pulfrey, J. A. Cugley, H. M. Heise) appointed under Australian Research Council (ARC) grants.

The study leave in 1959 had further important consequences. Because of continuing interaction with colleagues like Dick Lord, Norman Jones (his first post-doctoral supervisor) and Tommy Thompson (DPhil supervisor), Andy was introduced to the work of the Commission on Molecular

³¹Cole and Osborne (1964).

³²Cole Unpublished biographical notes by A.R.H. Cole.

³³Cole and others (1970).

³⁴Cole Unpublished biographical notes by A.R.H. Cole.

³⁵Cole and Honey (1975).



Fig. 4. The high resolution near infrared spectrometer built in the Chemistry Department, UWA (Cole family collection).

Structure and Spectroscopy of the International Union of Pure and Applied Chemistry (IUPAC) and he became a Titular Member of the Commission. This involvement led to appointments to the Physical Chemistry Divisional Committee and the top management committee of IUPAC. These appointments enabled him to travel to Europe and/or North America in most years from the mid-1960s to the mid-1980s, and was influential in maintaining collaborative work with Ramsay in Ottawa, Lafferty and others in Washington, and Guelachvili in Paris. These annual visits allowed Andy to measure a new band of one of the isotopically substituted glyoxals and take the data back to Perth for detailed analysis by a series of PhD students—a way of enabling Andy and his students to study very high-resolution spectra without having to set up extremely expensive equipment in Perth.

Because of his deep involvement with IUPAC, he was asked by the Commission to produce a new edition of the *Tables of Wavenumbers for the Calibration of Infrared Spectrometers* and spent the first half of his sabbatical leave in 1974 on this task. The second half was spent with Dr. Jim Durig at the University of South Carolina, where Andy extended the spectroscopic study of glyoxal and its deuterated analogues to include the information from the Raman spectra of the *s-trans* forms, and the microwave spectra of the deuterated *s-cis* isomers.

On his last major study leave (1985) Andy returned to NRC Ottawa to study the C–H stretching band of glyoxal under very high resolution on a Bomem interferometer. This was highly successful, and on his sixty fifth birthday, the day

on which he retired in 1989, he was able to send Don Ramsey the complete analysis.³⁶

Andy Cole, educator, highly effective leader and administrator

Andy was promoted to Reader in Chemistry in 1958 and was given a personal chair in 1969, the first such appointment at UWA. He was Professor of Physical and Inorganic Chemistry and Head of Department 1971–89. He served as Dean of the Faculty of Science from 1975 to 1977. When Andy first became the Head of Department, Bayliss said to him that he had left a box of headache tablets in the drawer of the desk in case they were needed. They never were!

Undergraduate education

Andy made important contributions to chemical education. Firstly, his lectures to undergraduate students—from first year to Honours levels—were masterly. Without gimmicks, Andy's lectures were renowned for their clarity of conceptual and mathematical development. He had an innate sense of where his students were 'at' and was able to match the level of his presentations to the ever-developing student level. Perhaps he had learned from Professor Sir Noel Bayliss, his mentor and colleague, who was a renowned lecturer during Andy's undergraduate days. And perhaps he consciously worked on his skills, given his high regard for the importance of the teaching role of academics. In an

³⁶Braund and Cole (2001).

interview with Don Watts in 2010,³⁷ Andy said: 'I think teaching is a very important part of university life and I always enjoyed teaching. I was always a little worried throughout my career that nearly all promotions within the university, particularly in science, were based on research rather than on teaching. We had some very fine lecturers in the university who deserved more promotion, just as much as the fine researchers did. I think some universities now are looking at teaching prowess a little more closely than they used to, and I think that's most important'.

He valued lecture demonstrations—not at all for any entertainment value, but solely for the purpose of providing a reality to, and clarification of, the subject matter of lectures. Such was his regard for their importance that under his headship, the UWA Department of Chemistry employed three technical assistants for the purpose of maintenance of equipment used in lecture demonstrations, the setting-up of equipment before lectures, and the removal, cleaning and storage of the equipment after lectures. They helped to maintain a comprehensive card catalogue of lecture demonstrations that could be used to clarify various chemistry concepts and relationship.

Contributions to the wider education enterprise

In the 1950s, 1960s, and 1970s, the Western Australian Junior examination (taken after three years at secondary school) and the Leaving examination (taken after five years of secondary education and constituting a tertiary entrance examination) were regarded as conduits into chemistry enrolment in the only Western Australian university at that time, the University of Western Australia.

UWA had a vested interest in maintaining the standards of these school-level examinations because they served as preparation for enrolment in the first-year tertiary chemistry course. Indeed, a pass in the leaving chemistry examination was a strict pre-requisite for enrolment. Consequently, the controlling board was essentially solely responsible to UWA. Given his interest in education, and his recognised empathy toward students, it was only natural that Andy would be asked to be chairman of the board, chair of the school syllabus committee, and chief examiner—roles he undertook from 1955 to 1975. He usually marked some of the examination papers himself, along with several others employed for the purpose. He regarded these activities as an integral part of his academic duties and undertook them happily.

In the mid-1970s, Andy received an invitation/request from UNESCO headquarters in Paris to organise an international conference on the role of laboratory teaching in university chemistry education, to be held at UWA. These were the days when most academic conferences were organised

'in-house', using university facilities and usually involving university student accommodation for the delegates. In this way, registration fees for delegates were minimised (with the help of university subsidies), although the demands on the organisers were immense. UWA committed their support, and Andy agreed to hold the conference, taking on the role of Conference Chairman. Don Watts was secretary of the organising committee. The conference took place in 1978 and attracted the biggest names in chemistry education from all over the world. It was a great success, and a compilation of papers presented was published. An important part of its success was that it widened membership of the international chemistry education community to those in the southern hemisphere.

Andy and Don Watts were the natural media links between the chemistry enterprise often in the form of the Royal Australian Chemical Institute (RACI) and the public. If chemistry-related issues became topical (for example, how carbon dioxide might be a cause of global warming, whether fluorides should be added to water supplies, whether radioactive wastes might be stored in Australia, or the nature of school chemistry curricula), journalists would go straight to Andy or Don for professional information.

Involvement in curriculum materials design and production

Prior to the 1960s, chemical curricula at the school and undergraduate levels were often described as compilations of the 'preparations, properties and reactions' (preps, props and reactions) of substances.³⁸ For example, school students were required to learn how chlorine, sodium carbonate and acetic acid were made, their physical properties, some of their typical reactions, and their consequent industrial, commercial and household uses. This involved considerable rote learning.

The world of science education changed forever in October 1957 when the Soviet Union put an artificial satellite called *Sputnik* into orbit—a triumph over the American technological juggernaut. The US science enterprise went into shock. One of the outcomes of their consequent deliberations was to cast blame on the nature of the chemistry and physics curricula in schools and colleges, and an intense re-think was called for. Newly designed materials were published in response to recommendations of a committee of the American Chemical Society that attempted to capture the new objectives.

The new curriculum objectives were based on the philosophy that students should understand explanatory frameworks for the physical and chemical properties of substances. So, the new materials focussed on theories of the electronic structure of atoms, of bonding, and of reaction mechanisms, for example.

³⁷Watts (2010).

³⁸Webb (1978).

Many curriculum projects, some supported by grants of the US National Science Foundation, came to fruition in the form of classroom instructional materials and were used far and wide across the western world, including in Australia. The most popular of these, published in 1959, was the Chemical Education Materials Study, labelled *ChemStudy*, led by legendary researcher and educator George C. Pimental of the University of California Berkeley.

Despite the theoretical nature of Andy's own research (in infrared spectroscopy, as was that of Pimental), he very quickly pushed back against this curriculum revolution. He presented at many international conferences his favourite cartoon showing a cart positioned in front of horse—the message, of course, being that we had put ‘the cart before the horse’ as the old adage went. Pimental declared that the old ‘facts’ of preparations, properties and reactions had been completely replaced by the explanatory models. In Andy's view, students were being asked to explain structures and phenomena with which they were unfamiliar—being required to explain the unknown! He was among the first to recommend that a sensible curriculum should present an integrated mix of important structures and phenomena, along with theories (at appropriate levels) to make sense of them.

With Australian schools adopting the new theory-based curriculum materials enthusiastically, Andy could see that production of competing instructional materials was far too ambitious. As a stop-gap measure, he and colleagues Don Watts and Bob Bucat wrote and published a mini-encyclopedia, entitled *Chemical Properties and Reactions*, intended to be used in the classroom as a complement to the *ChemStudy* materials—a compilation of important ‘preps props and reactions’, with a strong Australian context—that might be used as an information resource for the theory-based curriculum materials.³⁹

In the Preface, the authors write:

Students who complete a high school chemistry course should have a broad appreciation of the properties of the common substances which they will handle throughout their lives—which substances are poisonous, which are flammable, which are soluble in appropriate solvents, which are corrosive, which are volatile, and so on. They should also gain some appreciation of the economic importance of common commercial materials, which can be related to the availability of ores, and the ease of extraction or manufacture. Those who go on to tertiary studies in Chemistry require, in addition, an introduction the simple theory of the subject. Therefore, we have compiled this book, not as a textbook in its own right, but as an adjunct to a principles-based course such as *ChemStudy*. ... [The students] must know what happens before facing the question “Why does it happen?”

This publication became a required resource for students at years 11 and 12 in Western Australia for about twenty years. It was also a recommended text in several other states, and was translated into Indonesian and Mandarin.

Unfortunately, the authors became aware that *Chemical Properties and Reactions* was sometimes used as a source of ‘prep, props and reactions’ to be learned by rote—perhaps reflecting the education experiences of many of the teachers—rather than as an occasional reference to materials whose properties were ‘explained’ in the *ChemStudy* materials.

Nevertheless, this attempt for a balance between phenomena and theoretical explanations preceded the realisation of the weaknesses of the *ChemStudy* materials that Andy had identified. Journals like the *Journal of Chemical Education* began to publish articles pointing out that students were learning about, for example, (i) models of bonding in chlorine molecules without knowing anything about chlorine the substance, (ii) the use of Valence Shell Electron Pair Repulsion (VSEPR) theory to predict the shapes of small molecules, with almost no reference to the significance of the molecular shape with regard to the physical and chemical properties of specific substances.

During the 1960s the Australian Academy of Science drew on the very best human resources in Australia, from schools, academia and industry, to design, write and publish materials for a high school course in Biology: *Biological Science—The Web of Life*. These materials achieved monopoly status as the recommended text in the prescribed biology curricula of all states of Australia.

With this in mind, the Academy began to consider the possibility of a corresponding project in Chemistry. The first stage in this process was a study tour to all Australian states by Professors Bayliss and Don Watts to survey and assess each of their secondary school chemistry syllabuses. The outcome was a comprehensive document.⁴⁰ In this booklet, Bayliss and Watts proposed in detail a national course of study, discussing the underlying philosophy, as well as general and specific aims, and providing a detailed list of course content and characteristics.

The recommendation was convincing. The Academy established the School Chemistry Project Committee under the chairmanship of Andy Cole. Andy appointed an advisory Project Committee consisting of those that Andy considered could make the most significant contributions to the nature of the curriculum and the produced materials: Peter Fensham (Monash University, and an internationally recognised authority in science education), Charles Fogliani (Mitchell College of Advanced Education (C. A. E.)), B. N. Kleinschmidt (Church of England Grammar School, Brisbane), John McKellar (Mitchell C.A.E, and President Royal Australian Chemical Institute), David Morgan (Editor, *Biology—A Web of Life*), Noel Norman (Australian

³⁹Cole and others (1977).

⁴⁰Watts and Bayliss (1979).

Paper Manufacturers), Alan Sargeson (Chemistry, Australian National University), David Solomon (Division of Applied Organic Chemistry, CSIRO), and Don Watts (President, W.A. Institute of Technology). It is evident from the composition of this committee that Andy wanted to broaden the inputs well beyond the teaching profession at the secondary and tertiary levels. He wanted the curriculum to show Chemistry in worldly contexts, and so it did.

Don Watts was appointed the Project Director, chairing the project from the coalface, and Bob Bucat the Assistant Director and Supervising Editor responsible for every detail of the materials.

The two-volume publication *Elements of Chemistry: Earth, Air, Fire and Water*⁴¹ integrated familiarity with phenomena (practical activities) and explanatory theories, and the relationships between classroom curricula and relevant world issues of industry and technology, mining, environment, and sustainability—always building from the concrete toward the abstract. There was a strong emphasis on visualisation of the invisible level of atoms, ions and molecules. The materials were developed with a very strong inquiry emphasis, expecting students to develop their understanding by responding to embedded questions.

Elements of Chemistry was revolutionary and well ahead of its time. It was taken up as the text of choice for the prescribed syllabuses in Western Australia (largely due to the status of Andy Cole in the education system), South Australia (where the syllabus had a very strong emphasis on presenting chemistry beyond the test-tube observations and chemical equations of the classroom, as well as in Queensland, Tasmania, and the Australian Capital Territory).

Academic plan for University of Western Australia. 1970–80

In 1970, Andy was asked by the then Vice-Chancellor, Sir Stanley Prescott, to undertake the preparation of an Academic Plan for UWA and was given a year's leave from his formal academic duties to prepare the plan. He agreed but was allowed to reserve part of his time to continue his IR spectroscopic research and supervise his PhD students. The preparation of the Plan was important at that time, since it was intended to indicate possible ways in which UWA could develop in the light of the imminent establishment of the State's second university (Murdoch University).

He worked with the UWA administrators and visited most of the forty-odd departments, had discussions with Heads of Departments and Deans of the Faculties, and gathered many

general conclusions about the potential future development of UWA with a group of academic staff, their work, hopes, and aspirations. Andy reflected on his experience.

To a certain extent I enjoyed the experience of working with the University's administrators and visiting nearly all of UWA Departments. However, at the end of the project I resolved mentally not to become further involved with university administration and university politics.⁴²

The process of planning, according to Andy, involved (i) the collection and assessment of information (ii) the making of policy decisions, and (iii) detailed planning. He decided to concentrate his efforts on (i) and, over many weeks, wrote a massive, very detailed, 132-page report, the *Academic Plan for UWA 1970–80*⁴³ which he submitted to the Planning and Staffing Committee of the Professorial Board.

Andy was the first UWA academic to produce an Academic Plan for the future development of UWA, a notable event in the history of the university. In November 1972 another UWA academic staff member, Dr H. P. Schapper, read the Cole Academic Plan and wrote a critique that identified what he said were failings in the Cole report and that became, effectively, another Academic Plan. In the critique he wrote: 'Prof Cole has not presented a plan so much as a report in which he pinpoints many deficiencies in the organisation and operation of UWA, and gives suggestions for remedying them, but did not raise the great issues which face most Universities, including UWA'.⁴⁴

Among the many other developments that were put into practice shortly after Cole submitted his report, two of his major recommendations attracted attention. Firstly, that the Professorial Board, which had become too large and unwieldy, should cease being the major academic governing body of the University and should be replaced by a smaller elected Academic Council, and secondly, that the budget should be devolved via Executive Deans to Heads of Department, thus reducing the power of the central administration. Neither of these suggestions was greeted with enthusiasm; the second was adopted about twenty years later, and the first was only partially adopted twenty-five years later!

Recognition

In 1982 Oxford University awarded Andy the degree of DSc for his combined publications under the title 'Molecular

⁴¹Bucat (1983).

⁴²Unpublished biographical notes by A.R.H. Cole.

⁴³Academic Plan for UWA, 1970–80, ARH Cole, UWA Reid Library, Special Collections Archive, Z0648, Q 378.941, 1970-2c.

⁴⁴Towards a University for WA being also a Critique of ARH Cole Academic Plan 1970–80, HP Schapper, UWA Reid Library, Special Collections Archive, Z08041, Q 378.941, 1972-2a.

Spectra and Molecular Structure'. His roles in a number of professional societies also led to recognition in the form of appointments and awards.

Royal Australian Chemical Institute (RACI)

In 1956 Andy was elected a Fellow of the RACI. He was President of the WA branch of the Institute from 1959 to 1961, and National President in 1981 and 1982. Andy was awarded the Archibald D. Olle Prize in 1978 for his 'Tables of Wavenumbers' and the Institute's highest honour, the Leighton Memorial Medal, in 1983.

Australian Academy of Science (AAS)

In 1974 Andy was elected a Fellow of the Academy, where he served as a member of Council 1979–82 and Vice-President 1981–2. He was very active in the academy, serving on eight of its committees, many as chair of the committee, and of particular interest he was a member of the Chemical Education sub-committee.

International Union of Pure and Applied Chemistry (IUPAC)

Andy made a distinguished contribution to the work of IUPAC, in common with many other Australian chemists.⁴⁵ The Union was founded in 1919 from similar pre-World War 1 organisations, and is the world authority on chemical nomenclature and standards. Its organisational structure has varied over the years but in 1975 the main administrative body was the Bureau, and much of the work of the Union was carried out by the Divisions. Each Division had a number of Commissions. The Physical Chemistry Division had a Commission on Molecular Structure and Spectroscopy. Andy was an elected member of the Bureau from 1973 to 1981, and was vice-president of the Commission from 1969 to 1973. His major contribution to the Commission was to produce a new edition of the *Tables of Wavenumbers for the Calibration of Infrared Spectrometers*. The first edition had been published in 1961 by Andy's post-doctoral supervisor R. N. Jones, with R. C. Lord and E. K. Plyler. Andy's edition took into consideration the latest high-resolution results and integrated the far infrared data with the higher frequency values. Andy commenced the task of writing this book during his study leave in 1974 in Japan at the University of Tokyo (with Hiko Shimanouchi) and Tohoku University, Sendai (with Ichiro Nakagawa who had been a post-doctoral fellow in Dick Lord's laboratory in 1959), and the next three months in Oxford. The manuscript was completed the following year and published by IUPAC with Pergamon Press in 1977,⁴⁶ and is still available.

⁴⁵Spurling and Webb (2018).

⁴⁶Cole (1977).

⁴⁷Anonymous (1968).

His work on wavenumber standards led to his appointment as an IUPAC representative on the Inter-Union Commission on Spectroscopy. This was an International Council for Science (ICSU) commission with representatives from IUPAC, the International Union of Pure and Applied Physics and the International Astronomy Union. This commission made recommendations of standards to ICSU. It also lamented that the introduction of SI units saw the departure of the Angstrom unit for wavelength and the cm^{-1} unit for wavenumber.⁴⁷ Their protest was in vain!

Andy retained his connection with the IUPAC Commission via its Sub-Commission on Infrared and Raman Spectroscopy and was pleased to be associated in 1995 with the production of the third edition of the *Tables of Wavenumbers*, that he considered a vastly improved compilation under the senior authorship of Dr. Guy Guelachvili of CNRS at the University of Paris Sud, Orsay.

Life after the University of WA

For some years after retirement, Andy maintained close contact with the University, running the Year 10 Science Summer School for high school students. After successfully directing four such summer schools and arranging for the WA contribution to be expanded by the addition of further summer schools at Curtin University and Edith Cowan University, Andy was awarded a Paul Harris Fellowship by the Rotary Foundation of Rotary International. In 1992 UWA gave Andy an Honorary DSc for his 'General Services to Chemistry and to the University of Western Australia'. He continued to attend the annual Professorial Board dinner.

Andy also stayed in touch with many of his international colleagues who had become close friends. Indeed, a great talent of his was maintaining these friendships and introducing various colleagues to each other. In an interview with Don Watts, he said: 'I don't think forming enemies ever arose in my career; but I certainly formed friendships, and those friendships were extremely profitable in scientific work, and I certainly tried to foster them'.

In 1994 he was appointed by the Government of WA to the Estuarine Research Foundation, charged with distributing funds for research into environmental aspects of the Swan River and other estuaries on the WA coast. Also in 1994, Andy and fellow golfer Doug Paterson (retired engineer) were awarded an Australian Patent for a Detachable Drive for Motorising a Golf Buggy, a lighter and more efficient battery-driven vehicle than was available on the market. These he maintained from the garage at home. Andy also wrote a statistical computer program for determining the best Par (or Stroke) Index for a golf course.



Andy Cole: 21.04.1924 – 05.02.2024

Husband of Ursula. Father of Judy, Cathy and Andrew. Grandfather of Ben, Emily, Christine, Grace, Sarah, Maddy, Rebecca, Olivia, Charlie and Isobel. Great grandfather of Elena and Beatrix and Father in-law to Andrew, Tim and Katy.

Fig. 5. Cole family collection.

With his wife, Ursula Eileen née Hagan, whom Andy had married in 1955 when she was the secretary in the Chemistry Department, Andy had two daughters and a son. The eldest child, Judith, is a Fellow of the Australasian College of Dermatologists, the middle daughter Catherine, a Fellow of the Royal Australasian College of Physicians (Paediatric Oncology) and the Royal College of Pathologists of Australasia (Haematology) and the youngest, Andrew, a Senior Vice President at Worley, the international engineering company.

Along with their shared love of golf, Andy and Ursula enjoyed gardening and travelling in their campervan throughout WA. Over a span of ten years, they welcomed ten grandchildren, who brought great happiness into their lives. Andy tutored them all in high school chemistry (Fig. 5). Towards the end of his life two great granddaughters were born. At the celebratory wake for Andy's life, son Andrew commented:

I am sorry that he did not get to meet his great grandchildren Elena and Beatrix, who have arrived in just the past month or so ... yet I did invoke him the other day when holding my granddaughter Beatrix and soothed her to sleep with dad's verbal mantras used on his children all those years ago, namely "hydrogen, helium, lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, neon, sodium, magnesium..."...They are always asleep by magnesium.

Supplementary material

Supplementary material is available online.

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