CSIRO PUBLISHING

Historical Records of Australian Science, 2012, **23**, 176–186
http://dx.doi.org/10.1071/HR12012

Kenneth James Le Couteur 1920–2011

B. A. Robson

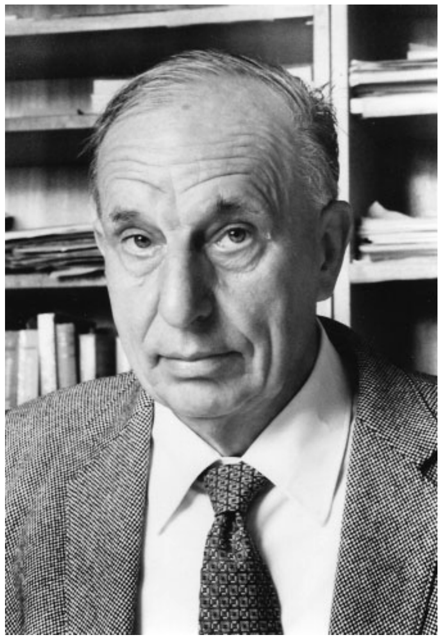
Department of Theoretical Physics, Research School of Physics and Engineering,
Australian National University, Canberra, ACT 0200, Australia. Email: brian.robson@anu.edu.au

Kenneth James Le Couteur was born in St Helier, Jersey, on 16 September 1920 and died in Canberra on 18 April 2011. He had a distinguished career as a theoretical physicist in the United Kingdom and in Australia as the Foundation Professor of Theoretical Physics in the Research School of Physical Sciences of the Australian National University. He was internationally recognized for his significant contributions to the statistical model of excited nuclei and the extraction of beams from proton synchrocyclotron accelerators.

Jersey

The island of Jersey, officially the Bailiwick of Jersey, is a British Crown Dependency off the coast of Normandy, France (Syvret and Stevens 1981). Jersey is the largest of the Channel Islands with an area of $\sim 120\,km^2$ and is a self-governing parliamentary democracy under a constitutional monarchy, with its own financial, legal and judicial systems. Until the 19th century, indigenous Jerriais, a variety of Norman, was the language of the island, although French was used for official business. During the 20th century an intense language shift took place and Jersey became predominantly English-speaking. Until the 1960s, the population of Jersey had been relatively stable for decades at around 60,000 but is now $\sim$98,000. The capital of Jersey is St Helier, the island's only town, with a population of $\sim$36,000. More than 50% of the island's area has been agricultural land and fisheries are also important uses of Jersey's marine resources.

The Le Couteur family has lived in Jersey for many generations. Kenneth's father was Philippe Le Couteur, who had a carpentry business. He was a good tradesman who ran an excellent business with a very high standard of workmanship and seven qualified tradesmen. Philippe was a very able man who had to leave school early because his father died of pneumonia, caught bringing in his cows during bad weather. Kenneth's mother was Eva Gartrell, who came to Jersey from Looe in Cornwall. She worked as a housewife. They lived at 6 Rouge Bouillon in St Helier.



Philippe and Eva Le Couteur had three children: Phyllis, Philip and Kenneth. The eldest, Phyllis, became a teacher and a member of the Council, the local parliament in Jersey. Philip, the second child, became a lawyer and later the Registrar in Jersey. Philip had access to all the register records on Jersey and confirmed that although the Le Couteurs had lived in Jersey for many years, it is likely that the family originated from Caen in Normandy. Kenneth was the youngest child and was born on 16 September 1920 in St Helier. During the time that he grew up in Jersey, Kenneth used to go sailing and fishing with his family in the English Channel in an eleven foot sailing dinghy. He made his own

fishing lines from the hairs from horses' tails and Kenneth and his elder brother would cast their own lead sinkers in the kitchen fireplace. Sailing and fishing became his lifelong hobbies.

Kenneth's parents arranged that he had the opportunity to receive a good education. He attended both Victoria College Preparatory School and Victoria College (founded on Queen Victoria's birthday on 24 May 1850), which was consciously patterned after the English public schools. The medium of instruction was English from the beginning and was therefore one of the causes for the decline of French as the island's élite sent their sons to the Victoria College. Kenneth, aged sixteen, was a member of Form 6 in 1937 at the College and was inspired by his mathematics teacher, Mr Kennett, who had been a 17th wrangler in the Cambridge Mathematical Tripos, to become an applied mathematician. Victoria College was an excellent school that enabled several students, including Kenneth, to obtain an open scholarship to the University of Cambridge, in competition with students from all over the United Kingdom.

Academic Career

University of Cambridge 1938–41

Kenneth commenced as an undergraduate at St John's College, Cambridge, in September 1938. His main subject was mathematics, his tutor being Ebenezer Cunningham, a lecturer in mathematics, who had graduated Senior Wrangler in 1902, won the Smith's Prize in 1904 and written a book, *The Principle of Relativity*, published in 1914, one of the first treatises in English about special relativity. One year later, the Second World War started and Kenneth found himself marooned in the UK, being unable to visit his family following the occupation of Jersey by the German Army in mid-1940. If he had remained with his family it is possible that he would have been sent to war as a German soldier. He completed his undergraduate degree course in 1941 and was the joint winner in 1941 of the Mayhew Prize for distinction in applied mathematics.

Bletchley Park 1941–5

Following the award of the BA degree Kenneth was recruited to work at Bletchley Park, the site of the United Kingdom's main decryption establishment, the Government Code and Cypher School (GC&CS), where ciphers and codes of several Axis countries were decrypted, especially the ciphers generated by the German Enigma and Lorenz machines (Hinsley and Stripp 1993). The high-level intelligence produced at Bletchley Park provided crucial assistance to the Allied war effort and probably shortened the war by two to four years.

On the day that Britain declared war on Germany, the operational head of GC&CS wrote to the Foreign Office about recruiting 'men of the professor type'. Personal networking was employed for the initial recruitment, particularly from the universities of Cambridge, Oxford and Aberdeen. Cryptanalysts were selected for various intellectual achievements, whether they were linguists, chess champions, crossword experts or good mathematicians. The most influential and best known in later years was Alan Turing, who is widely credited with being 'The Father of Computer Science'.

Having been recruited in 1942 as a Go champion and an excellent applied mathematician, Kenneth worked initially on codebreaking involving the Enigma machine, which had been invented by the German engineer Arthur Scherbius at the end of the First World War. The early models were used commercially from the early 1920s and were adopted by the military and government services of several countries, especially by Nazi Germany before the Second World War. During the war the British codebreakers, assisted by Enigma decryption techniques and equipment received from the Polish Cipher Bureau in July 1939, were able to decrypt a vast number of messages that had been enciphered using an Enigma machine.

This codebreaking activity was very demanding work involving shift work. The Germans changed their codes at midnight, which was a time when there was not much traffic, and they had a new code each day. The codebreakers commenced at $\sim$2.00 a.m., because they needed a few messages to start on, and they hoped to finish by breakfast time. It was very hard and tiring work.

The German Army High Command also employed the Lorenz cipher machine, which was a high security teleprinter cipher machine intended to enable them to communicate by radio in complete secrecy. Unfortunately, the codebreakers working to decipher the messages transmitted by a Lorenz machine were taking four to six weeks to do this, by which time the information in them was generally not operationally useful.

In 1942 Maxwell Newman, a lecturer in mathematics and a Fellow of St John's College at Cambridge, proposed to the GS&CS that the codebreaking process for deciphering the messages transmitted by a Lorenz machine could be mechanized. He was assigned the task of developing a suitable machine in December 1942. Construction started in January 1943 and the first prototype was delivered in June 1943. It was operated in Newman's new section, termed the 'Newmanry', and the prototype machine was nicknamed the 'Heath Robinson' after the cartoonist of the same name who drew humorous drawings of absurd mechanical devices.

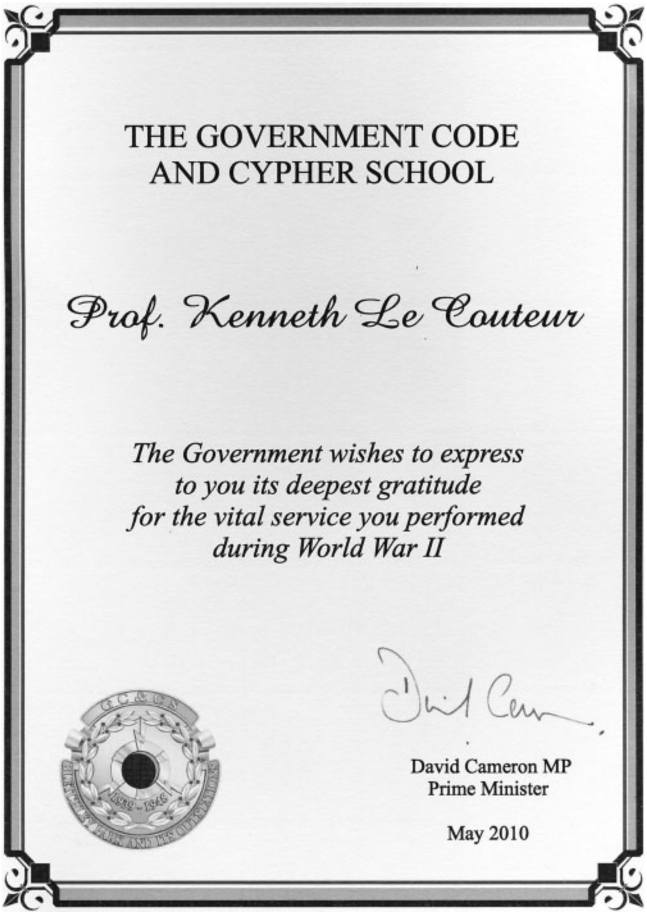
The Robinson machines, which used electromechanical switches, were limited in speed and reliability. In February 1943 Thomas Flowers, an English engineer, proposed a totally electronic system using over 1,800 valves. Flowers' dedicated team built the first machine in eleven months. It was immediately called 'Colossus' by the Bletchley Park staff for its immense proportions. It operated five times faster and was more flexible than the Heath Robinson machine and was installed in the Newmanry. This proved to be very successful and ten Colossus machines were in use by the end of the war. The second Colossus, using 2,400 valves, was put into service on 1 June 1944 and immediately produced vital information for the imminent D-Day landings planned for Monday 5 June: a courier handed Eisenhower a note summarizing a Colossus decrypt that confirmed that Hitler wanted no additional troops moved to Normandy, as he was still convinced that the preparations for the Normandy landings were a diversionary feint. Handing back the decrypt, Eisenhower announced to his staff, 'We go tomorrow.' Kenneth was a member of the Newmanry personnel from 1943 to 1945 and became acquainted with the Colossus computer, which was later recognised as the world's first electronic, digital and partially programmable computer. (The first fully programmable digital electronic computer was the ENIAC, which was completed in 1946 in the USA.)

The use to which the Colossus computers were put was of the highest secrecy, and the Colossus itself was highly secret and remained so for many years after the war. Thus, Colossus could not be included in the history of computing hardware for many years, and Flowers and his associates also were deprived of the recognition they were due. However, the technology of Colossus, and the knowledge that reliable high-speed electronic digital computing devices were feasible, had a significant influence on the development of early computers in Britain and probably in the USA. The nature of Bletchley Park was not revealed to the general public until 1974 and before this date, Kenneth would say that during the War he had worked at the British Radar Establishment at Malvern. Indeed (see Fig. 1) it took until 2010 for the British Government to thank Kenneth for his vital service at GC&CS during the Second World War.

Universities of Cambridge and Manchester 1945–9

In 1945, following the end of the Second World War, Kenneth returned to the University of Cambridge as a Fellow of St John's College and registered for a PhD degree. His initial supervisor at Cambridge was Maurice Pryce, who suggested investigating some theory of Homi Bhabha concerning 'Relativistic Wave Equations for the Elementary Particles' published in *Reviews of Modern Physics* in 1945. However, in 1946 Pryce was appointed Wykeham Professor of Physics at the University of Oxford and Nicholas Kemmer, who was also interested in relativistic wave equations for elementary particles beyond the electron, became Kenneth's supervisor.

Kenneth's PhD thesis, entitled 'Meson Theory', investigates in detail the properties of the most general linear relativistic equations and is developed from Bhabha's 1945 review paper. His thesis research work was carried out alone without collaboration. In 1947 Kenneth was awarded a Turner and Newall Fellowship at the University of Manchester and continued his PhD work there during 1948–9. While at Manchester he was supervised by Léon Rosenfeld who had become Professor of Theoretical Physics there, succeeding Douglas Hartree who was famous for his work on atomic structure calculations. Kenneth was awarded a PhD degree for his



THE GOVERNMENT CODE
AND CYPHER SCHOOL

Prof. Kenneth Le Couteur

*The Government wishes to express
to you its deepest gratitude
for the vital service you performed
during World War II*

David Cameron MP
Prime Minister

May 2010

Figure 1. The Government Certificate sent to Kenneth Le Couteur by the British Prime Minister, David Cameron, in 2010.

thesis submitted to the University of Cambridge in 1949.

While at the University of Manchester, Kenneth commenced work on the evaporation theory of nuclear disintegrations, involving the statistical model of excited nuclei. Nuclear disintegrations, initiated by cosmic rays of high energy, were being studied extensively by photographic emulsion techniques and the available experimental results provided sufficient statistical evidence to test the evaporation theory. Kenneth proceeded to develop the evaporation theory for several years and became a world authority on the statistical model of excited nuclei (see later).

At the University of Manchester Kenneth frequently visited the library and it was there that he met his wife, then Enid Margaret Domville, who was a librarian. Her father was Sydney Domville, born 31 May 1895, a tax assessor for the British Government in Manchester and Dublin, and her mother was Margaret Trafford. Kenneth claimed that the library appeared to lose his book ‘charge slips’ because they were not sure whether to file them under L or C, and that he met Enid in a discussion over these delicate matters. They married (see Fig. 2) on 14 July 1950 following Kenneth’s move to the University of Liverpool.

University of Liverpool 1949–56

When in 1949 Kenneth moved to the University of Liverpool, initially as a Senior Lecturer

Figure 2. Kenneth Le Couteur and Enid Domville on their wedding day, 14 July 1950.

and later as a Reader, Herbert Froehlich occupied the Chair of Theoretical Physics and Herbert Skinner occupied the Lyon-Jones Chair of Experimental Physics and Mathematics, previously occupied by James Chadwick. Kenneth continued his research on both relativistic wave equations and the evaporation theory of excited nuclear disintegrations, and also collaborated with other theoretical physicists at Liverpool on both nuclear and atomic problems.

Chadwick had developed a 37-inch cyclotron at Liverpool. Before he left to return to Cambridge in 1948 to become Master of Gonville and Caius College, Chadwick made plans to produce a 156-inch 400 MeV synchrocyclotron so that Liverpool was destined to have one of the most powerful accelerators outside the USA in the early 1950s.

Skinner, who in 1949 was now responsible for construction of the Liverpool synchrocyclotron, had received reports by James Tuck and Lee Teng from the Chicago synchrocyclotron laboratory, which had been initiated by Enrico Fermi several years earlier. Their third, 1950 report considered alternative methods of extracting the internal beam because the then conventional method by scattering spread the beam in an undirected way so that most was wasted without reaching the external experimental area. In order to overcome this problem, Tuck and Teng proposed to extract the proton beam from a synchrocyclotron by modifying the normal magnetic field in such a way as to build up the amplitude of radial oscillations until protons could escape from the magnet. This method of extraction became known as the peeler-regenerative method. In 1950 Skinner asked Kenneth if he would check out this alternative method. Kenneth, trained initially as an applied mathematician, considered that he could achieve this by analytical techniques, and in this way he was able to show that a suitable peeler-regenerative method extraction system could be developed for the Liverpool accelerator (see later).

Kenneth's theoretical work on the peeler-regenerative extraction method was put into practice by a very able experimentalist, Albert Crewe, to whom Skinner had given the responsibility for extracting the proton beam.

Australian National University 1956–89

While working at Britain's Atomic Energy Establishment at Harwell, 1947–51, Ernest Titterton was a member of the General Physics Division under Herbert Skinner and was put in charge of a research group that was to carry out work with nuclear emulsions and cloud chambers. One of the areas of his research was the study of multi-particle disintegrations ('stars') produced in nuclear emulsions by very fast (150 MeV) neutrons from a beryllium target. Although these events were of qualitative interest, Titterton was unable to obtain quantitative information from them. Consequently he sought help from Kenneth at Liverpool in interpreting the data, in view of his theoretical work on the evaporation theory of excited nuclear disintegrations. Titterton was impressed with Kenneth's abilities and this association led him later, after he moved to a chair at the new Australian National University (ANU) in Canberra, strongly to encourage the appointment of Kenneth as the Foundation Professor of Theoretical Physics there.

In addition, Kenneth's theoretical work on the peeler-regenerative method for the extraction of the beam from a synchrocyclotron and its spectacular success when put into practice on the Liverpool machine made his appointment very attractive to Marcus Oliphant, the Foundation Director of the Research School of Physical Sciences at the ANU, who was intending to build a large, 2 GeV proton synchrocyclotron to carry out experiments in particle physics. Kenneth was appointed Foundation Professor of Theoretical Physics in the ANU's Research School of Physical Sciences from 1 April 1956. He held this position until his retirement in December 1985, when the title of Emeritus Professor was conferred upon him.

Kenneth arrived in Canberra in May 1956 with his wife Enid and two young daughters, Caroline and Penelope (born in 1952 and 1953, respectively). A third daughter Mary (now called Avinashi) was born in Canberra in 1957 and a foster daughter Marion Chesher, who stayed with them during the holidays but otherwise lived in nearby Goulburn, New South Wales, was adopted into the family. The Le Couteur family lived at 12 Hutt Street, Yarralumla, conveniently situated near the planned Lake Burley Griffin, which was filled in 1964. Kenneth built a sailing boat in his garage so that he could take his family sailing on the lake. When the family holidayed on the south coast of New South Wales, he would enjoy his other hobby, fishing off the rocks. These hobbies and boatbuilding skills he inherited from his childhood in Jersey.

When Kenneth arrived in 1956 as the Head of the new Department of Theoretical Physics in the Research School of Physical Sciences, one of only four small research schools comprising the ANU, the Department had only one other member, Frederick Barker, and the Research School had five other departments: Particle Physics, Nuclear Physics, Astronomy, Geophysics and Radiochemistry, led by Marcus Oliphant, Ernest Titterton, Richard Woolley, John Jaeger and Frank Scarf, respectively. The predominant direction of the Research School of Physical Sciences was associated with nuclear physics and the construction of the 2 GeV synchrocyclotron to undertake research in particle physics, although the School had absorbed, as its Department of Astronomy, the Commonwealth Observatory located at Mt Stromlo, and established a Department of Geophysics in recognition of the economic importance of the Australian mining industry.

From his arrival in Canberra, Kenneth played a very active role in the development of both the Department of Theoretical Physics and the Research School of Physical Sciences. Always gracious and courteous, he was respected and liked by his colleagues. He was one of the first members of the Australian Mathematical Society at its foundation and was elected a Fellow of the Australian Academy of Science in 1960. Kenneth regarded his main achievement as the building up of his Department to its later size, breadth and international reputation. From 1959 to 1968 the Department grew in size by the addition of researchers, many of whom worked mainly on nuclear, particle and plasma physics. Later the Department expanded its interests into statistical and condensed matter physics. By 1974 the Department had nine tenured staff members (Kenneth Le Couteur, Frederick Barker, David Peaslee, Brian Robson, Kailash Kumar, William Woolcock, Lindsay Tassie, Rodney Baxter and Jagadishwar Mahanty) together with a steady stream of people coming through the Department as students, research fellows and visitors, many of them from overseas. Kenneth believed that theoretical physics was a discipline in its own right and members of the Department were not constrained to pursue narrow areas of research but were free to work on any interesting ideas, often with excellent results. The Department, under Kenneth's leadership and with the encouragement of the early Directors of the Research School, undoubtedly helped to cement the ANU's role as a leader of Australian research and postgraduate education.

Kenneth also developed a strong collegial atmosphere within the Department. Every new arrival in the Department would be entertained by Enid and Kenneth so that they and their family were made to feel at home in Canberra, which was often far removed from their place of origin. In particular, each year Enid and Kenneth gave a Christmas party (complete with homemade mince pies, Father Christmas, individual gifts and lawn croquet) for the entire department and their families.

Kenneth always encouraged strong interactions with experimental departments of the School, and he himself at times worked closely with the nuclear, particle and plasma groups.

His own research work at ANU covered a wide variety of topics, ranging from purely fundamental mathematical investigations on a conjecture of Bessis concerning the partition function for quantum statistical mechanical systems and the structure of a non-relativistic S-matrix, through linear relativistic wave equations, the statistical model of the nucleus and fluctuations in nuclear cross sections to the more practical considerations of the focusing and guiding of charged particles by magnetic fields. Many of these research areas he had commenced in his earlier career at Cambridge, Manchester and Liverpool. In the years 1958–69 he supervised eight PhD students, who worked mostly in the areas of nuclear, plasma or particle physics.

Another of Kenneth's earlier experiences that he brought with him to Canberra was computing and he was instrumental in pioneering the development of computing within the ANU. Kenneth obtained for the Department the first computer—that is, a machine that could store a program as well as do specified computations—to be installed at the ANU, an IBM1620, in order to perform large-scale numerical calculations. This computer, which arrived on 2 January 1962, employed a high-level programming language (FORTRAN), which was compiled to obtain a basic machine-language program. The machine was controlled and operated by the Department of Theoretical Physics within the Research School of Physical Sciences, 1962–5. Kenneth placed Brian Robson of the Department in charge of the computer.

From the beginning, the IBM1620 was made available as a University resource, so that members of the ANU outside the Department were actively encouraged and taught to use it. In the first few months, the IBM1620 was used in connection with research into nuclear scattering, nuclear stability, stellar atmospheres, rock magnetism, seismology and microbiology and for work of the National Time Service. In the first year, the teaching of statistics to third-year undergraduates was supplemented by including some practical computer experience in their course.

In 1964 the ANU received a grant to upgrade its computing facilities, and it was decided to establish a Computer Centre, initially within the Research School, to provide a computing service to the University and to undertake teaching and research in computing science. This took place in late 1965, when the IBM1620 became the basis of the Computer Centre and six of the seven associated staff members formed the nucleus of the new centre.

Kenneth made other major contributions to the development of the Research School of Physical Sciences. During 1962 a new building was designed to house the 'mathematical sciences' associated with the Research School of Physical Sciences, that is, the new Department of Mathematics led by Bernhard Neumann and the Department of Theoretical Physics. The initial building was completed in 1963 and was subsequently extended on two occasions. Kenneth played a significant role in both the design and planning of this building, which eventually housed not only the two departments mentioned but also the Department of Statistics from the Research School of Social Sciences and the Physical Sciences Library.

In addition, Kenneth acted as Director of the Research School of Physical Sciences on many occasions. In particular, he was Acting Director for two extended periods, September 1973–September 1974 and February–December 1978, between the appointments as Director of Ernest Titterton and Robert Street and Robert Street and John Carver, respectively. On both occasions he brought a strong sense of unity to the Research School after periods of considerable tension.

Following Kenneth's retirement in December 1985, he continued as a member of the Department of Theoretical Physics as an Emeritus Professor and Visiting Fellow until 1989. His contribution to the Research School of Physical Sciences and to the ANU was recognized in 1996 with the naming of the former Mathematical Sciences Building as the Le Couteur Building.

For several years during his retirement Kenneth spent more time enjoying the south coast of New South Wales, where the family had acquired a house at Maloney's Beach. However, in 1988 Enid had a major stroke and life changed for both her and Kenneth. They continued, however, to live in Hutt Street until 1997 when they moved to Ginninderra Gardens Aged Care Facility in the Canberra suburb of Page. Kenneth died on 18 April 2011, basically of old age, and is survived by Enid, his daughters Caroline, Penelope and Mary (Avinashi), his foster-daughter Marion, his grand-children Ruth (Abipsa) and Jon-George, and his great-grand-children Isabella and Leny.

Significant Research Achievements

Kenneth achieved international fame for his significant contributions to both the statistical model of excited nuclei and the peeler-regenerative beam extraction method for synchrocyclotron accelerators.

The Statistical Model of Excited Nuclei

In 1949 one of the main areas of nuclear research was the disintegration of nuclei by high-energy cosmic rays using the photographic emulsion technique. While still at the University of Manchester, Kenneth was generously supplied with recent emulsion data of such disintegrations of silver and bromine nuclei, by both a local colleague, N. Page, and Donald Perkins of the Imperial College of Science and Technology, London, and he noted that these data contained sufficient statistical evidence to provide an effective test of some theories of the disintegration process. Kenneth continued analysis of these data following his move to the University of Liverpool.

Earlier experimental results indicated that the emitted particles from a high-energy cosmic ray 'star' could be divided roughly into two groups, namely (i) a few particles of high energy, and (ii) a greater number of slow particles with an energy spectrum typical of nuclear evaporation. Qualitatively, it was clear that the fast particles must consist of nucleons that had come into direct collision with the primary particle, often a fast neutron, initiating the star, and of mesons created as the bremsstrahlung of these collisions. The theory of such processes was not yet in a satisfactory state. Before finally escaping, these fast particles must lose energy to the nucleus and so leave it in a highly excited state. Further particles are emitted until the final nucleus is stable; it is these secondary particles which one may examine by nuclear evaporation theory.

The statistical treatment of nuclear disintegrations can be applied to this secondary process. However, the excitation energies involved in large stars are very much higher than those envisaged by the theory, which assumes that the excited nucleus is always in approximate thermodynamic equilibrium. This requires that the interval between the emission of successive particles is longer than the time required for the convection of energy across the nucleus. Kenneth realized that this condition is probably satisfied since, for all but the largest stars, the mean kinetic energy of the evaporated particles (perhaps 13 MeV) is much less than the kinetic energy ($\sim$22 MeV) of the nucleons at the top of the zero-point Fermi distribution, which is mainly responsible for the convection of energy.

Kenneth's development of the evaporation theory of nuclear disintegrations (10) and its application to cosmic ray stars created in silver and bromine nuclei was one of the earlier significant papers in this field and was very highly cited. Kenneth demonstrated that theory provided good agreement with experiment for the energy distribution of the evaporated particles and for the ratio of emission of singly and doubly charged particles, provided that the Coulomb potential is assumed to be reduced at high excitation energies. He showed (11) that the mean energy of the protons evaporated from disintegration stars increases with star size in agreement with experimental results, and considered (18) the effect of statistical fluctuations in nuclear evaporation, which is important for the interpretation of data concerning small stars such as those produced by π-meson capture or by artificially accelerated particles. He also determined that the Fermi gas law provides the most satisfactory energy-temperature relationship between the high-energy star data and the observed level density at low energies.

At the University of Liverpool, Kenneth collaborated with another theoretical physicist, J. M. B. Lang, on the statistics of nuclear energy levels (20). They found that the simplest relation between the excitation energy U and the nuclear temperature t that gave a good fit of the then available experimental data, is given by $U = At^2/11 - t + A^{2/3}t^{7/3}$ MeV. This work was continued with a student, Donald Lang, at the ANU in the late 1950s (25). They derived a theory of cascade neutron evaporation processes and analysed in detail the energy spectra of neutrons produced by 190 MeV bombardment of six elements. This paper was also very highly cited. Following this work, Kenneth was asked to write a review article entitled 'The Statistical Model' for a book on nuclear reactions (27) and two articles on 'Nuclear Evaporation' (29) and 'Nuclear Reactions at High Energy' (30) for the *Encyclopaedic Dictionary of Physics*.

The Peeler-Regenerative Beam Extraction Method

The value of a synchrocyclotron is much increased if the beam can be extracted from the machine and allowed to pass through a screening wall into a separate experimental room. However, simple methods of beam extraction, such as scattering, only yield $\sim 10^{-5}$ of the internal circulating beam. This is about the same fraction of the beam that spirals out naturally from the magnet into a reasonable solid angle.

Liverpool had the benefit of progress reports from the Chicago synchrocyclotron, which had been started by Fermi several years before (Le Couteur 1993). The 1950 report III by James Tuck and Lee Teng considered alternative methods of extracting the internal beam because the then conventional method by scattering spread the beam in an undirected way so that most was wasted without reaching the external experimental area. They suggested the peeler-regenerative method and Skinner asked Kenneth to check it out. At Chicago, Tuck and Teng had found a way to produce the required radial motion by magnetic deflection and showed that the necessary fields could be produced by blocks of iron, called the peeler and the regenerator, fixed between the poles of the synchrocyclotron.

Kenneth noted that Tuck and Teng had traced some particles through the system by a laborious graphical method but realised that this did not prove the stability of the beam for which all particle motions, radially and vertically, must be considered.

Kenneth had graduated at Cambridge as an applied mathematician and saw that an analytical solution was possible if the magnetic fields were assumed to vary linearly with radius. This allowed a complete survey of the problem by the method of transfer matrices described in paper (15) and the results are shown in Fig. 4 of that paper. The stability region has peeler strength S less than regenerative strength T. In contrast, Tuck and Teng's chosen configurations had S > T, leading to vertical instability of the beam. Skinner informed Chicago of Kenneth's analytic solution but this information was ignored and in 1952 when the Chicago cyclotron was completed the apparatus failed as expected.

In hindsight it is surprising that paper (15) had some difficulty with referees (Le Couteur 1993). The referees may have been unfamiliar with the mathematical method used but since then transfer matrices have become a standard technique in accelerator design: the mathematics of alternating-gradient accelerators is similar to that of a peeler-regenerative system.

To achieve the maximum possible energy from the synchrocyclotron it was necessary to continue the acceleration to large radii, where the variation of magnetic field with radius becomes non-linear. These non-linear effects were examined in paper (19), to determine how far out it was safe to go.

In 1953–4, when the synchrocyclotron magnet was complete, Crewe, who had just completed his PhD, was assigned the task of measuring the magnetic field and smoothing it by shimming the pole pieces (Le Couteur, 1993). With the field information and the theory of papers (15) and (19), the peeler-regenerative system was designed as described in paper (21). Next Crewe constructed the peeler-regenerator system and magnetic channel.

During the next year the rest of the cyclotron, vacuum system, radiofrequency supply and so on was completed and finally the system could be tested (Le Couteur 1993). At the first try a photographic paper at the mouth of the channel showed the required beam shape. George Holt determined the flux of particles into the channel from the irradiation of carbon blocks placed there. The flux was optimized by slight movements of peeler and regenerator. This was tedious, since each movement meant opening the vacuum tank, which had to be re-pumped for another try next day. After some adjustment of the magnet current, it was seen that the system had realised its theoretical expectations. As had been anticipated, the external beam had a very small energy spread and so could be focused by an external magnet into a small spot. Indeed, Kenneth's exact analytical solution of the linearized problem (15) led to the extraction of 3% of the internal proton beam from the Liverpool synchrocyclotron into the experimental room as a well collimated beam, some 3,000 times the intensity obtainable by a scattering technique. A brief report was published in paper (22).

The Liverpool design had been cautious, the demand for cyclotron time was so keen that there would have been no second chances if it failed (Le Couteur 1993). However, with the successful outcome, Kenneth realised that it might be possible to design a simpler system with a regenerator but no peeler, relying instead on the natural decrease of the magnetic field at the edge of the cyclotron magnet. However, this involved solution of strongly non-linear coupled differential equations. Kenneth found an approximate solution (paper (23)). The first electronic computers were being installed in England and Kenneth managed to get access to one at Rothamsted to check the calculations, which were found to be reasonably accurate. Meanwhile Crewe, who had been enticed to Chicago, had used Kenneth's approximate solution, as in Fig. 7 of paper (23), to build a successful extractor in the Chicago cyclotron.

Other laboratories followed the Liverpool example: Berkeley, Uppsala, Orsay, Harvard, Rochester and CERN. Kenneth was a consultant on the CERN project, which was outstandingly successful because of the precision of the field measurements there, the amount of computing available and the quality of the engineering (Le Couteur 1993).

Legacy

Kenneth considered that his legacy was his contributions to the Research School of Physical Sciences (now the Research School of Physics and Engineering) and the ANU through his building up of the Department of Theoretical Physics so that it had a significant breadth of activities and enjoyed an international reputation in theoretical physics. Indeed, during Kenneth's headship of the Department, five members of staff were able to publish books on a wide variety of physics topics: Kumar (1962), Tassie (1973), Robson (1974), Mahanty and Ninham (1976) and Baxter (1982). These publications contributed significantly to raising the international profile of both the Department and the Research School of Physical Sciences.

Acknowledgements

The author thanks Professors R. J. Baxter, R.W. Crompton and N. H. Fletcher and the Le Couteur family for their assistance.

References

Baxter, R. J. (1982). *Exactly Solved Models in Statistical Mechanics*, Academic Press, London, New York.

Hinsley, F. H. and Stripp, A. (eds) (1993). *Codebreakers: The Inside Story of Bletchley Park*, Oxford University Press, Oxford.

Kumar, K. (1962). *Perturbation Theory and the Nuclear Many Body Problem*, North-Holland Pub. Co., Amsterdam.

Le Couteur, K. J. (1993) *Correspondence to David King*, Department of Physics, University of Liverpool. Le Couteur Family Archives, Canberra.

Mahanty, J. and Ninham, B. W. (1976). *Dispersion Forces*, Academic Press, London, New York.

Robson, B. A. (1974). *The Theory of Polarization Phenomena*, Clarendon Press, Oxford.

Syvret, M. and Stevens, J. (1981). *Balleine's History of Jersey*, Phillimore, Chichester.

Tassie, L. J. (1973). *The Physics of Elementary Particles*, Longman, London and Wiley, New York.

Bibliography

1. Le Couteur, K. J., 'A Geometrical Minimum Problem', *The Mathematical Gazette* **31** (1947) 261–265.
2. Le Couteur, K. J., 'Particles of Half-Odd Integral Spin', *Proc. Camb. Phil. Soc.* **44** (1948) 63–75.
3. Le Couteur, K. J., 'The Theory of Neutral Particles', *Proc. Camb. Phil. Soc.* **44** (1948) 229–241.
4. Le Couteur, K. J., 'Gauge Invariance and Rest Mass', *Nature* **164** (1949) 106–106.
5. Le Couteur, K. J., 'The Indefinite Metric in Relativistic Quantum Mechanics', *Proc. Roy. Soc. London A* **196** (1949) 251–272.
6. Le Couteur, K. J., and Rosenfeld, L., 'Canonical Transformations of the Hamiltonian in Meson Field Theory', *Phil. Mag.* **40** (1949) 151–157.
7. Le Couteur, K. J., 'The Interaction of Point Particles with Charged Fields', *Proc. Camb. Phil. Soc.* **45** (1949) 429–440.
8. Le Couteur, K. J., 'The Structure of Linear Relativistic Wave Equations 1', *Proc. Roy. Soc. London A* **202** (1950) 284–300.
9. Le Couteur, K. J., 'The Structure of Linear Relativistic Wave Equations 2: Representations', *Proc. Roy. Soc. London A* **202** (1950) 394–407.
10. Le Couteur, K. J., 'The Evaporation Theory of Nuclear Disintegrations', *Proc. Phys. Soc. London A* **63** (1950) 259–282.
11. Le Couteur, K. J., 'The Relationship between the Size of Nuclear Disintegration Stars and the Mean Energy of the Emitted Particles', *Proc. Phys. Soc. London A* **63** (1950) 498–501.
12. Le Couteur, K. J., 'The Relationship between the Size of Nuclear Disintegration Stars and the Mean

Energy of the Emitted Particles', *Proc. Phys. Soc. London B* **63** (1950) 375–375.

13. Hughes, J., and Le Couteur, K. J., 'Spin Orbit Coupling in the Nuclear Shell Model', *Proc. Phys. Soc. London A* **63** (1950) 1219–1222.
14. Le Couteur, K. J., and Zienau, S., 'Coherent Scattering of Light by an Atom and Negative Energy States', *Proc. Phys. Soc. London A* **63** (1950) 1223–1226.
15. Le Couteur, K. J., 'The Regenerative Deflector for Synchrocyclotrons', *Proc. Phys. Soc. London B* **64** (1951) 1073–1084.
16. Le Couteur, K. J., 'Factorization of the Algebra of Particles of Half-Odd Spin', *Proc. Camb. Phil. Soc.* **48** (1952) 110–117.
17. Le Couteur, K. J., 'Dirac New Electrodynamics', *Nature* **169** (1952) 146–147.
18. Le Couteur, K. J., 'Statistical Fluctuations in Nuclear Evaporation', *Proc. Phys. Soc. London A* **65** (1952) 718–737.
19. Le Couteur, K. J., 'Perturbations in the Magnetic Deflector for Synchrocyclotrons', *Proc. Phys. Soc. London B* **66** (1953) 25–32.
20. Lang, J. M. B., and Le Couteur, K. J., 'Statistics of Nuclear Levels', *Proc. Phys. Soc. London A* **67** (1954) 586–600.
21. Le Couteur, K. J., 'The Extraction of the Beam from the Liverpool Synchrocyclotron 1: Theoretical', *Proc. Roy. Soc. London A* **232** (1955) 236–241.
22. Crewe, A. V., and Le Couteur, K. J., 'Extracted Proton Beam of Liverpool 156-Inch Cyclotron', *Rev. Sci. Instr.* **26** (1955) 725–725.
23. Le Couteur, K. J., and Lipton, S., 'Non-Linear Regenerative Extraction of Synchrocyclotron Beams', *Phil. Mag.* **46** (1955) 1265–1280.
24. Le Couteur, K.J., 'The Vertical Motion of Particles through the Regenerative Beam Extractor of a Synchrocyclotron', *Nuclear Instruments* **1** (1957) 343–344.
25. Le Couteur, K. J., and Lang, D. W., 'Neutron Evaporation and Level Densities in Excited Nuclei', *Nuclear Physics* **13** (1959) 32–52.
26. Lang, D. W., and Le Couteur, K. J., 'Pairing Energy Effects in Excited Nuclei', *Nuclear Physics* **14** (1959) 21–32.
27. Le Couteur, K. J., 'The Statistical Model' in *Nuclear Reactions*, Vol 1 Eds. Endt, P. and Demeur, M. (North Holland, Amsterdam, 1959), 318–355.
28. Le Couteur, K. J., 'Integral Representation of a Double Commutator', *Nuovo Cimento* **16** (1960) 227–229.
29. Le Couteur, K. J., 'Nuclear Evaporation' in *Encyclopaedic Dictionary of Physics*, (Pergamon Press, Oxford, London, New York, Paris, 1960) L16, 1–1.
30. Le Couteur, K. J., 'Nuclear Reactions at High Energy' in *Encyclopaedic Dictionary of Physics*, (Pergamon Press, Oxford, London, New York, Paris, 1960) L16, 1–4.
31. Le Couteur, K. J., 'Supra-Thermal Particles' in *Proceedings of the Fourth International Conference on Ionization Phenomena in Gases* (*Uppsala*), Ed. Nilsson, N. R. (North Holland, Amsterdam, 1960) IIIB 637–639.
32. Le Couteur, K. J., 'The Structure of a Non-Relativistic S-Matrix', *Proc. Roy. Soc. London A* **256** (1960) 115–127.
33. Kumar, K., Le Couteur, K. J., and Roy, M. K., 'A Fermi-Thomas Type K-Matrix Method for Nuclei', *Nuclear Physics* **42** (1963) 529–550.
34. Kumar, K., Le Couteur, K. J., and Roy, M. K., 'Nuclear Potential Energy and the Single-Particle Density Matrix', *Nuclear Physics* **60** (1964) 634–640.
35. Le Couteur, K. J., 'Fluctuations in Nuclear Cross Sections', *Physics Letters* **11** (1964) 53–54.
36. Le Couteur, K. J., and Roy, M. K., 'Approximations to the Dirac Density Matrix', *Physics Letters* **8** (1964) 37–38.
37. Le Couteur, K. J., 'Dirac Density Matrix', *Proc. Phys. Soc. London* **84** (1964) 837–843.
38. Le Couteur, K. J., 'Particle Guiding by Heli- cal Multipole Fields', *Plasma Physics* **9** (1967) 457–470.
39. Dallimore, P., Davidson, W., Hellstrom, J., and Le Couteur, K.J., 'Intermediate Structure in ^{23}Na' in *Proceedings of the International Conference on Properties of Nuclear States (Montreal)* Eds. Harvey, M., Cusson, R.Y., Geiger, J.S. and Pearson, J.M. (Les Presses de L'Universite de Montreal, 1969) 783–783.
40. Le Couteur, K. J., 'Comments on Statistical Model and Collective Modes of Nuclei' in *Cooperative Phenomena*, Eds. Haken, H. and Wagner, M. (Springer-Verlag, Berlin, Heidelberg, New York, 1973) 298–302.
41. Le Couteur, K. J., 'Some Problems of Statistical Mechanics and Exponential Operators' in *Proceedings of the International Conference and Winter School of Frontiers of Theoretical Physics*, Eds. Auluck, F. C., Kothari, L. S. and Nanda, V. S. (MacMillan Company of India, 1978) 209–235.
42. Le Couteur, K. J., 'Representation of the Function Tr(exp(A-λB)) as a Laplace Transform with Positive Weight and Some Matrix Inequalities', *Journal of Physics A* **13** (1980) 3147–3159.
43. Le Couteur, K. J., 'Nonlocality and Gauge Invariance in Relativistic Wave Equations', *Czechoslovak Journal of Physics B* **32** (1982) 403–407.