

ANTHONY MILNER LANE

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Tony Lane came from humble beginnings to become one of the world's leading theoretical nuclear physicists. His career in the Theoretical Physics Division at the Atomic Energy Research Establishment (AERE) at Harwell was characterized by his outstanding successes in explaining experimental nuclear data. He pioneered the understanding of the important nucleon capture reactions by introducing new mechanisms of direct and semi-direct capture and, together with colleagues, he greatly advanced knowledge of nuclear analogue states, and the role of isospin in nuclear physics. With R. G. Thomas, he wrote a comprehensive review of R-matrix theory, applied to analyse resonances in nuclear reactions, which became one of the most cited papers in physics. His book *Nuclear theory* gave a good account of the use of pairing force theory in nuclear physics, and its application to nuclear collective motion.

## EARLY LIFE

Anthony Milner Lane (Tony) was born in Trowbridge, Wiltshire on 27 July 1928. His father, Herbert William Lane, had been a dispatch rider in World War I, and worked as a clerk. His mother, Doris Ruby Milner, worked as a cleaner. Tony's younger brother Bryan arrived in 1930, and his sister, Marcia, in 1933. After the Margaret Stancomb Infants School, Tony attended the Parochial Junior School in Trowbridge from ages six to 11. He benefited from the kindness and attention of the unmarried lady teachers there, particularly Miss Jones and Miss White whom he continued to see after he left the school. His intellectual ability was early apparent, and he gained a place at Trowbridge Boys High School.

There, he came to attain first position in academic subjects, though he remained average in art, gymnastics and sports. By the end of the fifth form, he had won three books as prizes.

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Given his obvious talents, a striking aspect of his early life was his lack of reading (in later life he was a great reader!). There were no books in his house, apart from two reference works, and Tony said that, even in his last three years of school, he never read anything except school work!

When he started High School in 1939 he acquired a new bike which greatly expanded his horizons. An enthusiastic trainspotter (as many boys were), he could easily ride the four miles to Westbury where one could view several rail lines including the main line to Cornwall. This place became a mecca to him and he spoke of the 'intense happiness' he gained from spotting a new locomotive (in later birdwatching years, this joy was matched when spotting a new species). His hobby took him to the main Great Western line in Swindon, and went too far when he was allowed by a crew to ride on an engine footplate. This was illegal, and he was caught and prosecuted for it, a case reported in the *News of the World*.

Cycling also enabled Tony to visit relatives in the area, especially his aunt Millie and uncle Bill Bailey in Bradford-on-Avon. Bill's white-collar work and their middle-class life gave Tony a glimpse of a way of life he could aspire to. In the late 1930s they took Tony to the seaside (his first holiday) in their MG car. He cited their support as crucial for opening his horizons and breaking down the class barrier; as a boy, Tony found the middle class very forbidding.

According to Tony, the High School had 'a great bunch of staff'. In his second year he was put into the Latin stream rather than the science stream. This may have eased his admission to Cambridge, where Latin was still a requirement, and obviously proved no impediment to his becoming a great scientist. In the sixth form, he was prepared for the Cambridge scholarship exam by the headmaster, L. G. Smith, and more importantly by maths teacher H. J. 'Tubby' Downing, receiving tutorials twice a week for several months. Tony won an Exhibition to Selwyn College, Cambridge, in 1946. This was such a rare achievement that pupils were given a half-day holiday to celebrate.

Tony's academic success at school was demonstrated by his Higher School Certificate in which he gained distinctions in all categories. Tony attributed his success to his ability for intense concentration; he often did four hours of homework and worked until midnight. He was not able to stop until he had answered and understood problems. This obsessiveness and ability to focus on problem-solving no doubt led to his later success in making discoveries in nuclear physics, but there was a downside. Following intense study, he found the return to 'real life' difficult, and believed it led to his mental breakdown in 1960. In the sixth form, having abandoned trainspotting, he took to film-going with friends, and took up cross-country running and long cycle rides to keep himself physically and mentally fit. He developed an interest in flowers and birds. However, as previously mentioned, no book reading distracted him from his studies.

Looking back, Tony thought himself lucky to have had such a superb teacher as the kindly and benign Mr Downing whose expositions were characterized by 'beautifully precise and clear speaking and writing'. After leaving for Cambridge, Tony continued to visit him during vacations. Tony always felt the love his parents had for him, even as he entered a different world to theirs (they frequented the pub whilst he stayed home to study). Tony began going on country walks with girls from the Trowbridge Girls High School, and in 1945–6 acquired his first serious girlfriend in Audrey Earl. With his gentle, loving nature, Tony always enjoyed the company of women. He was a good talker, and developed a fund of stories, often about his own failings, which endeared him to the opposite sex.

## CAMBRIDGE

In 1946 Selwyn was a relatively new and small college with about 300 students, many taking theology because of its strong Anglican ties. About 90% of the new intake were demobbed servicemen from a broad section of society who were friendly and easy-going but serious students. Although Tony had initial problems with his Wiltshire accent and a lack of wide-ranging knowledge, he soon began to fit in and make friends. He had a room in the college for all three of his years as an undergraduate, and his natural curiosity and great energy enabled him to work out a successful routine. His room had only a coal fire and no ensuite bathroom; a gyp (college servant) brought him hot water in the morning. For a bath once or twice a week, he had to go beyond his staircase. At the time, these were the normal Spartan conditions in Cambridge colleges.

In the mornings, he attended lectures in mathematics, and found the standard of lecturing to be 'often poor and sometimes atrocious', something I also found in Cambridge seven years later. The standard of problems was higher than he had expected; public-school entrants had been 'crammed' to a higher level than he'd reached. However, he was helped by his kindly college tutor, Dr Durrant, and by excellent supervisors (whom he shared with the maths scholarship winner, Paul Mattock). His main supervisor, whom Tony described as a helpful, modest and charming man, was R. A. Lyttleton of St John's College, who later became an eminent FRS in his area of theoretical astronomy. For one term, Tony and Paul had to go to Peterhouse to be supervised by J. C. Burkill, whom Tony found authoritative, kindly and approachable. Tony was certainly taught well because after three years he achieved Wrangler status with Firsts in Parts I and II of the Mathematics Tripos and a First-Class Honours Degree.

At school, Tony had taken little part in team games, and had little inclination or talent for ball games, partly due to short-sightedness (figure 1). He only acquired glasses at college, but didn't wear them often then despite moderate astigmatism. At Selwyn, however, he seriously took up rowing, finding it the perfect way to keep fit and keep his mind off maths problems for a few hours. Despite being a little underweight, he had some talent for it, and his Selwyn 3rd boat won its oars twice and rocketed up the league of boats. In his second year he was trialled for the first boat, but a torn back muscle prevented further progress and in his fourth year at Cambridge, he had to settle for coaching. The camaraderie of rowing was wonderful in giving him a special set of friends, including Brian Jenkins, Jim Bland, Douglas Carter and John Forbes. These all became lifelong friends, together with their wives. Jim gave a fine tribute to Tony at his funeral in 2011, recalling how rowing dominated their Cambridge lives: 'Winning [was] everything . . . We rowed together, talked rowing together, and ate dinners in Hall together: we almost slept together.' Tony's passion for rowing was exceeded in the 1950 May races by another passion when, to the horror of the rest of the crew, he abandoned his boat (in its final race to gain promotion) to make a reserved journey to the South of France to meet Nani (Nanette), his future wife!

Rowing took up his afternoons, but at 5 p.m. Tony often attended open lecture courses which must have considerably broadened his mind. They included 'Philosophy' by Bertrand Russell, and 'Architecture' by Nicholas Pevsner. College dinner was at 7.30 p.m. followed by coffee with a group in someone's room, and finally studies until 11 p.m. or midnight.

In the vacations, Tony hitchhiked home via Oxford; this was customary for students after the war, lasting well into the 1950s, and gave Tony some good stories to tell. In the summers of the late 1940s, he attended various farming camps, and in 1947 he met Blanche Edwards,



Figure 1. Curling during a trip to North America in around 1960. Photograph provided by the family.

a teacher-training student at Weymouth. They did some hitchhiking together to local places such as Exeter and Lincoln cathedrals, and he often visited her parents, but, although he was fond of her, their future studies in different directions pre-empted thoughts of matrimony. He began travelling abroad in June 1948 with a week's hitchhiking around Ireland with John Forbes, including a tour of the Guinness factory in Dublin. Half the lifts were from priests, and a priest led them to a place where they could sample the illegal 'potcheen', a drink they found awful. In 1949 Tony succeeded in obtaining a travel grant following an interview at King's College by a panel headed by the great historian, G. M. Trevelyan, on condition that

he wrote an account of his journey. He used it on a heavily loaded cycle and train trip to the continent: he stopped in Paris, took a train to Lyons, cycled down the Rhone valley, took a train to Nice, cycled along the coast through Monaco to Genoa in Italy, and finally took a train back to England. He had a wonderful, ridiculously cheap two weeks (by today's standards) on mostly empty roads with an amazing absence of other tourists.

Following his maths degree in the summer of 1949, Tony had to decide what to do next. The decision to move towards physics was made in a casual chat with his tutor, Dr Durrant. The move could either take the form of a further year taking Part III of the Maths Tripos with theoretical physics as an option (incidentally, my choice) or a degree in Natural Sciences Part II, Physics Speciality. Tony chose the latter, which essentially meant doing a physics degree in just one year, including laboratory work. He had to move out of college into digs four miles away in Trumpington and commute by bike. The owners of his digs, Mr and Mrs Clark, provided a real second home, with an excellent dinner every evening. He had to study 10 hours a day with practically no time for other activities—just a little coaching for rowing. He achieved only a 2.2 rating for his physics degree, but the year's deviation from theoretical physics probably had a beneficial effect on his future career. Tony had closer relations with experimental nuclear physicists, and more interest in their results, than theorists who had remained in the 'ivory tower' of mathematics. In the late 1950s, theorists in high-energy fundamental-particle physics in Cambridge moved out of the Cavendish Laboratory away from experiment into the Department of Applied Mathematics and Theoretical Physics (DAMTP), and major new discoveries in this area ceased to be made in Cambridge.

During his time in Trumpington, Tony made friends with a neighbour, Francis Macfarland, and his wife Andrée, an Egyptian Jewess whom Francis had met while on National Service in Alexandria. They regularly invited him to Sunday lunch and, in June 1950, Andrée asked him to coach her niece, Nani Zissman, who was arriving from Israel to embark on the 'PCB' (physics, chemistry, biology) Baccalauréat at the Sorbonne in Paris. He agreed, and found her to be 'fascinating, exotic and challenging', like, he thought later, Garbo in *Ninotchka*. In July they all travelled abroad by train to a small village near Marseille to stay with Andrée's sister, Gaby Ferrat. Here tuition soon gave way to romance, and Tony had a lovely time.

Whilst in France, he heard from the famous atomic physicist, Prof. D. R. Hartree, that he had been accepted to do theoretical physics research for a PhD in Cambridge. On his return in September, he was told it was to be in nuclear physics under the supervision of Mr J. M. C. Scott. He found Mr Scott to be painfully shy and other-worldly, and not a very good physicist or supervisor. My own recollections of him were of his unique lecturing technique; facing the blackboard, he wrote equations with his right hand and erased them with a duster in his left hand before his students had much opportunity of seeing them! Tony was the only PhD student in low-energy nuclear physics; particle physics students included the future Nobel prize winner Abdus Salam. In his first year, Tony familiarized himself with recent nuclear physics literature and attended the quantum mechanics lectures of the great Paul Dirac. The expertise he gained in quantum mechanics would be essential for understanding and achieving the objectives of nuclear theory (see Box 1 for the nature of nuclear physics and the areas in which Tony specialized). He also made fruitful contacts with experimentalist students, including Douglas Colvin, and their supervisors, Denys Wilkinson and Tony French, who guided him into interesting areas of nuclear physics. As a result, he made a crucial decision

for his future successful career. Rather than work on abstract theory, he would examine, and try to interpret, experimental results such as peaks in energy spectra, indicating resonances and possibly new types of nuclear states.

**Box 1: Definitions***Nuclear physics and quantum mechanics*

The theoretical basis of low-energy nuclear physics is non-relativistic quantum mechanics, with the following essential features. Nucleons (protons and neutrons) are fermions with spin  $\frac{1}{2}$  and obey Fermi–Dirac statistics; two identical particles cannot occupy the same state. The quantum mechanical phenomenon of the penetration of potential energy barriers plays a major role, particularly in nuclear reactions, and in nuclear decay probabilities.

*Objectives of nuclear theory*

Characterization and calculation of nuclear states and their properties (energy, angular momentum). These include states bound against particle emission which can decay by electrodynamic photon emission, and unbound states, particularly resonances which have a long lifetime.

Characterization and calculations of cross-sections of nuclear reactions which describe the results of collisions between incident particles,  $\gamma$ -rays, and nuclei. The main types of reactions are:

*Elastic or inelastic scattering and direct reactions.* These are characterized by no time delay so that the incident particle, or one produced in a single major collision, emerges immediately.

*Compound nucleus reactions.* These are characterized by a time delay in which the energy of the incident particle is shared out in many collisions to form a nuclear state which finally decays when a particle acquires enough energy to escape from the attractive potential well of the nucleus. Such reactions are particularly important at very low energies, such as in nuclear reactors, where long-lived resonances occur.

*The nuclear shell model*

In the nuclear shell model, initiated by Mayer and Jensen, nucleons behave like electrons in an atom; they occupy orbits, bound by a central attractive potential, this time arising from the combination of attractive forces from the other nucleons. Residual forces between nucleons and the way in which the nucleon spin is coupled to its angular momentum determine the spectrum of energies of the nuclear states containing a set of nucleons in specified orbits. The lowest shells consist of four nucleons in the 1s shell ( $\alpha$ -particle or He nucleus) with zero angular momentum, and 12 nucleons in the 1p shell with angular momentum 1, which, in different combinations, make most of the states of light nuclei up to  $^{16}\text{O}$ .

*R-matrix theory*

This theory, applied to compound nucleus reactions, is based on a spherical boundary surrounding the nucleus at which internal quantum mechanical wave functions are linked to external ones for channels which describe free particles entering or leaving a well-defined nuclear state. For a single resonant internal state, its energy width is determined by the sum of partial widths which represent the probabilities of decay into the various possible channels.

*Isotopic spin*

Isospin in low-energy nuclear physics,  $t$  or  $T$ , is a quantum number, analogous to intrinsic spin  $\frac{1}{2}$ , used to distinguish neutrons, with  $t_3 = -\frac{1}{2}$ , from protons with  $t_3 = +\frac{1}{2}$ . Nucleons in a shell model orbit with angular momentum  $j$  are then characterized by  $j$  and  $t_3$ . Isobaric analogue states are those in neighbouring nuclei which have nucleons in the same  $j$  orbits with the same total angular momentum coupling, but with neutrons exchanged with protons, i.e. different  $T_3$ . Differences in their energies arise from small differences in the strong nuclear forces between nucleons, but also from the Coulomb force acting only on protons which strongly affects heavy nuclei.

In Easter 1951, he went to stay with Nani in Paris. The following July she came to Cambridge and they went on a two-week hitchhiking tour to Inverness via York and Edinburgh, returning via Fort William, the Lake District and Cardiff. Their final stop was Trowbridge where Nani had a warm welcome from Tony's parents and Millie. The following summer, Tony arrived in Israel by boat for an extended stay in which he met Nani's parents, Thérèse and Issia, and many friends. Nani delighted in showing him Israel, and at the end of the visit, they were married in a very rare civil ceremony performed in Haifa by the British Consul, Mr Rabbett (who, luckily, was a Cambridge graduate).

During his second research year, Tony had thought of a thesis research topic, 'The application of the shell model to nuclear reactions', but was dissatisfied with his supervision. Possibly following a suggestion by Denys Wilkinson, he approached the great physicist Rudolf Peierls, who, impressed by his thesis choice, agreed that he should spend his third year, 1952–3, with him in Birmingham. In September 1952 Tony arrived in Birmingham, initially sharing a prefab whilst he sought married digs where Nani could join him. They made friends with several young couples, including Gerry Field, a staff member of Peierls' department, and his wife Lela. Together with Rudy and Genia Peierls, they helped Nani adjust to the big change in climate, language and culture.

At the time, Peierls was possibly the finest supervisor of theoretical physics research in the country, and had attracted a dozen brilliant research students to join him and his staff in a warm, family atmosphere. Two or three visitors a week came from Britain and the USA, and a slew of new experimental results were being examined. The one other nuclear physics student was Luigi Radicati, with whom Tony got on well and they collaborated on one problem. Whilst Tony could not match the speed of thought or technical mathematical ability of the other students, he could immerse himself in a problem so as to find unexpected connections, especially in data, and discover new results. He had the tenacity to persevere until he reached a thorough understanding. In guiding his work, Peierls was as successful as Mr Downing had been at school. At the end of the year, he was asked to organize an international conference on Nuclear Physics to be held in Birmingham in June 1953. In this capacity, he wrote to Mr Scott in Cambridge inviting him to come 'with any students who might be interested'. Scott replied that he would like to come 'along with a student, A. M. Lane', whom he 'hadn't seen lately!' He had forgotten about Tony's leaving Cambridge eight months earlier, a story that became a favourite of Peierls'.

Tony's work for his thesis, finally entitled 'Nuclear resonance reactions and their use in the determination of nuclear structure', involved successful analyses of data on states seen in light nuclei, in terms of nucleons in the  $1p$  configuration of the Nuclear Shell Model obtained

theoretically by intermediate coupling, described by him in several subsequent papers, the first (1)\* dealing with  $^{13}\text{C}$  and  $^{13}\text{N}$ . The general application to nuclear reactions was described separately (2).

### THEORETICAL PHYSICS DIVISION

In May 1953, Tony went to the AERE at Harwell to be interviewed for a job by Brian Flowers, then head of the Theoretical Physics Division (TPD), later Lord Flowers and author of many government reports. Tony joined TPD in September, initially staying in a hostel in Abingdon. Nani joined him in November and initially they were housed in Buckland House, a stately home with no central heating, before being assigned a prefab on the Harwell site. The head of the Nuclear Physics group in TPD was the brilliant physicist Tony Skyrme, author of a soluble field theory; ‘skyrmions’ now abound in several areas of physics.

At Harwell, TPD had rooms at the end of Hanger 8 (the site had been a wartime airfield) which contained GLEEP, the first reactor outside the USA as well as a Van de Graaf machine, a Cockroft–Walton set, and associated offices belonging to the Nuclear Physics Division (NPD). Tony thus had easy access to members of NPD and their experimental results. The talented personnel of about 18 included John Bell, the originator of ‘Bell’s Theorem’, which tests the validity of quantum mechanics, and John Tait, who worked on neutron transport and collaborated with Bethe to prove that reactors could not turn themselves into large nuclear explosives. Another member was an easy-going Canadian, Bill Thompson who, with his Jewish wife, Trudi, had met the Lanes at Buckland House and became good friends. Tony found the atmosphere at Harwell friendly and informal with people on first-name terms, quite un-British compared to university physics departments at the time where surnames were the norm. Conditions for research were ideal for Tony as technical assistance in typing papers and computing were available with very little bureaucratic distraction. For the next 30 years, he was largely free to pursue his own lines of research and respond to invitations to travel abroad and collaborate with others. He did not have to write proposals for future work and answer to a bureaucracy as to the significance of his work. The value of his work was rapidly appreciated by the worldwide scientific community working on nuclear physics and he was in great demand to visit institutions in many countries.

At this point it is worthwhile explaining why nuclear physics was at the time so important for governments around the world. To be able to construct reactors to produce nuclear power, a vast amount of data was needed on nuclear reactions and their cross-sections. This particularly applied to reactions, including fission, produced by neutrons following their production by fission and their slowing down by moderators. As large amounts of fission products would be formed in nuclear fuel, neutron cross-sections on a wide variety of elements were needed. A particularly important type of reaction is a capture reaction in which a  $\gamma$ -ray is produced by neutron capture, an example being by the fission product, xenon, which produces so-called ‘poisoning’ of reactivity in a reactor. Ignorance of this led the operators of the Chernobyl reactor to pull out control rods too far to produce a reactivity excursion, and the subsequent explosion was produced by molten fuel being ejected into the coolant water. Tony was the lead author in many papers on the examination of experiments in capture reactions, particularly in

\* Numbers in this form refer to the bibliography at the end of the text.

collaboration with Eric Lynn of NPD. Their first work (6) studied neutron capture on  $^{238}\text{U}$  and  $^{232}\text{Th}$ , the former being very important as, with the subsequent rapid  $\beta$ -decay of  $^{239}\text{U}$ , it leads to the formation of the long-lived, but fissionable, plutonium isotope  $^{239}\text{Pu}$ . This reaction is the main way to make the dominant uranium isotope,  $^{238}\text{U}$ , into a possible reactor fuel in a 'breeder' reactor as well as enabling the military application of plutonium. In subsequent work on neutron capture (8, 9) the collaboration found it necessary to introduce additional direct capture to explain cross-sections in the resonant region. For higher incident neutron energies, when I arrived in TPD in the early 1960s, Tony led me to construct a 'semi-direct' theory of capture by a neutron initially exciting a collective dipole state which subsequently decayed by radiation (16). The mechanisms of direct and semi-direct capture explained why experimental capture cross-sections were often much larger than those expected in compound nucleus theory. Tony became undoubtedly the world's leading expert on the theory of capture reactions.

In his first years at Harwell, Tony collaborated with the theorist, J. P. (Phil) Elliott in TPD and the experimentalists, Joan Freeman (later Jelly) in NPD and Denys Wilkinson at Oxford University. Possibly a recommendation by the latter led to a surprise invitation for Tony in May 1954 from Prof. Victor (Viki) Weisskopf to spend a year at MIT. In September, he and Nani travelled to New York on the *Queen Elizabeth* for what was to be the most exciting year of his life. They were welcomed by Norman Austern from Brookhaven National Laboratory who drove them to Boston where they received an overwhelming welcome and Nani was given a job in scanning particle tracks. Among the physicists there he met Herman Feshbach, and Carl Wandel from Denmark, with whom he wrote a well-received paper (4) on the imaginary part of the nuclear optical model potential which is responsible for absorption of an incident nucleon into a compound nucleus. He also interacted with the nuclear experimentalist Fay Ajzenberg and made friends with Sidney Drell, an elementary particle theorist. In addition to frequent visits to nearby Harvard, Tony used the ample travel funds to make scientific exchanges and give lectures all over the USA, Canada and Mexico. Scientifically, his most important visits were to Princeton, where, in addition to briefly meeting Einstein and Oppenheimer, he met Eugene Wigner and R. G. (Bob) Thomas, the latter visiting from Los Alamos National Laboratory. Wigner was one of the giants of nuclear theory, having introduced R-matrix theory to describe resonances in nuclear reactions (see Box 1). The three of them wrote a joint paper (3), and Tony and Bob, who had similar interests, began writing a review of this theory. A visit to Los Alamos was arranged for January 1955, and Bob drove Tony and Nani there from Boston in a newly acquired Willys station wagon. They met Bob's wife, Ainslee, and children, who showed Nani the area's attractions while Bob and Tony worked together. Their joint work on the review continued with several meetings and hundreds of letters exchanged up to 1957, when, while Tony was visiting Oak Ridge National Laboratory, news arrived of Bob's suicide. Their monumental review article (7), which remains a classic to this day, was finally published in *Reviews of Modern Physics* in 1958, and became one of the most cited publications in physics literature. Tony later wrote a review of reduced widths (10) which are essential ingredients of R-matrix theory.

On leaving Los Alamos in 1955, Tony and Nani headed for Pasadena and Caltech, stopping at the Grand Canyon on the way. There, Tony descended the 5000 ft to the canyon floor, from snow at the top to 75°F at the bottom. On the way back up, 1500 ft from the top, he became exhausted and stopped at a refuge where he used the emergency phone to call the top. He

reached Nani who was having cocktails; she called the rescue service and a sheriff arrived on horseback with a spare horse saying, 'That'll cost you 25 dollars!'

The rest of 1955 involved visits to the American Physical Society meeting in Washington in April and a meeting in Mexico City in June. Among others, he met Alex Zucker and Charlie Moak from Oak Ridge, and Georges Temmer in Washington, and Gerry Phillips in Houston, all of whom became good friends. He was working like a horse and developed a nervous condition about which he consulted medical staff at MIT. In September he and Nani left the USA on a slow Italian boat and travelled via Tangier, Naples and a holiday in Israel before returning to Harwell in October.

The result of Tony's collaboration with Phil Elliott was an extensive article (5) on the Nuclear Shell Model in 1958 which contains many comparisons with nuclear data. In addition to his conversations with experimentalists, Tony was unusual for a theorist in that he examined experimental literature, noting in a 'little black book' unusual features of observations that he couldn't understand from existing theory. This enabled him to develop new theories and identify new types of nuclear states including those reached by collective excitations of ground states, for example octupole vibrations (11), and ones prominently produced by nuclear reactions. Working with John Soper, a new arrival in TPD in 1958, and based on experimental data, he initiated several studies of isobaric analogue states produced by  $(p, n)$  reactions (12, 14), and their implications for the isospin dependence of the nuclear optical model potential (13). Tony produced several subsequent papers on the role of isotopic spin in nuclear physics, becoming a major expert on this topic and contributing an article to a book on the subject (21). The years 1955–8 were golden years for Tony; he and Nani were settled in their prefab, and, by producing original works and the two major review articles, he became established as one of the world's leading nuclear physicists. He was in great demand to work and give lectures abroad and visited Los Alamos in 1956 and Oak Ridge in 1957. Invited by Prof. Yenicaï to give lectures, he had a colourful visit to Istanbul in 1958 and again in 1959.

G. S. Mani from India joined the nuclear theory group in TPD in 1957, and urged Tony to accept an invitation to go to the Tata Institute in Mumbai for six months to give a series of lectures on nuclear physics. Nani was keen to go, and they arrived in October 1959. Tony made the mistake of trying to include in the lectures work on collective motion of nucleons in nuclei which he had not had time to study properly, and this led to panic before lectures and ultimately a nervous breakdown. He got through the first term, and they had a Christmas break visiting Madras and a hill-station. Further lectures in Madras made matters worse, and, after returning to Mumbai in January, they decided to curtail the visit by two months and returned by plane to Israel via Tehran. An Indian friend that he made, S. Jha, was a great help during his stay; Tony said he would have collapsed earlier without him. After recuperating in Israel for over a month with Nani's parents, they returned to Harwell.

Tony was still anxious about keeping up with advances in nuclear physics, but fortunately his GP, Gordon Lennox, proved a great help, advising him and Nani to create a more normal life in a proper house. After numerous miscarriages, Nani finally had a normal pregnancy, and their daughter, Galina, arrived in June 1961. They found a house, Naylesbridge Cottage, in the lovely village of Blewbury, which needed a great deal of work to make it habitable. In December 1962 they moved in just before the big freeze, when Tony showed that his brilliance in physics did not extend to everyday life. In a desperate attempt to start his car, he put a small oil lamp under the engine which unfortunately set it on fire and burnt out the car (he persuaded

the insurance company to cough up by saying he was insured, amongst other things, against 'his own stupidity').

By 1962, Tony had overcome his anxieties and showed that he had mastered new nuclear physics theories by giving a series of 30 lectures to nuclear physicists, including experimentalists at Harwell. These lectures on pairing force theory and description of collective motion of nucleons in nuclei form the basis of his book *Nuclear theory* (15) published in 1964. David Rowe, who spent two years in TPD in the 1960s before pursuing a career at the University of Toronto, found it incredibly useful, especially in explaining the relevance of the Bohm–Pines random phase approximation to nuclear physics. It also explained the relevance of the Bardeen–Cooper–Schrieffer theory of superconductivity to nuclear structure, and the manner in which it competed with standard mean-field theories to maintain the spherical symmetry in many cases where the mean field would have predicted nuclei to be deformed and rotational. Much later, in 1980, Tony and J. Martorell explained in detail how the random phase approximation restored symmetries lacking in Hartree–Fock mean field theory (24).

In late February 1963, Tony went to Florida State University in Tallahassee for two weeks to give lectures. He interacted with Georges Temmer and his wife, Odette, who introduced him to a coastal nature reserve with great birdwatching, always a calming influence. He must also have met the Australian nuclear physicist Don Robson there. Collaboration with Don in the 1960s led to three useful and informative published papers (17–19) on a 'Comprehensive formalism for nuclear reaction problems'. Later in 1963, Tony and Nani went to the Weizmann Institute in Israel for six months, where Tony interacted with local physicists Igal Talmi, Amos de Shalit, and Harry Lipkin, and also Carl Levinson, a visitor from the USA. The great event of the visit was the arrival of Tony's son Michael in a hospital in Haifa, which delighted grandparents Issia and Thérèse. Later in 1964, daughter Galina had the first of three very serious asthma attacks (others occurred in 1971 and 1973). These entailed rushing her to hospital for immediate treatment to save her life, experiences which left her parents completely drained. I remember Tony arriving at Harwell ashen-faced after one event.

Tony had his own health challenge late in 1966 when he contracted tuberculosis. His treatment involved two months in hospital and a year of injections and pills. However, his and Galina's health problems did not stop Tony and Nani from travelling, helped by Galina's asthma never occurring abroad. They spent a year at the Rice Institute in Houston, Texas, from October 1965, invited by Gerry Phillips who had spent a year at Harwell around 1960, and were in Boulder, Colorado in 1967–8, where Brian Ridley, a nuclear experimentalist from Harwell, had moved. This US visit also included a stay at Oak Ridge and interaction with Alex Zucker. He and wife Joan-Ellen, together with Charlie Moak and wife Billie, and Joe Fowler and wife Ruthie, became good friends. In addition, Tony made a brief trip to Canberra in January 1967 where he met Greg Clark, then in his final PhD year. Greg and wife Pammie became close friends.

In 1969, Tony's visits abroad continued with one to Witwatersrand University in Johannesburg to interact with Friedel Sellschop who had previously visited Harwell. Later that year, he presented a paper on 'The present theory of capture' (20) at an International Atomic Energy Agency conference in Vienna, most of which originated with him. In the 1970s long overseas visits eased off although he spent three months at the Weizmann Institute in 1970 and six months in Canberra, Australia in 1972–3. Working with A. Z. Mekjian, he investigated sum rules for collective excitations which provided evidence of two-body correlations in nuclei,

and they wrote a review article on 'Coulomb mixing effects in nuclei' (22) based on sum rule evaluations. With O. Bohigas and J. Martorell, he produced a review article on 'Sum rules for nuclear collective excitations' (23). In 1975 Tony was elected FRS, and in the following year he was promoted at Harwell to the rank of deputy chief scientific officer, a post which in his case did not entail any administrative responsibilities. This individual merit promotion was the highest that could be made in the Civil Service for a scientist solely engaged in research.

## LATER YEARS

At home in Blewbury, Tony and Nani adopted a second son, James, in January 1971, a bright child who became a stimulating maverick, working in IT. Unfortunately, Nani developed breast cancer in 1973 which, though initially removed, returned with many metastases in 1978. She died in February 1980, a great loss for Tony. With great resilience, Tony attended cookery classes and reached Cordon Bleu standard for special occasions. Galina fell in love with a medical student from Israel, Arik, and moved there, eventually having three children. Tony found solace in his friends, country walks and his hobby of carving duck decoys. In 1981 he met Jill Parvin, a talented teacher, writer and theatre director with wide-ranging interests (including Tagore, Korczak, Indian dance, China). She was attracted by Tony's gentle manner and intelligent enquiring mind, and he by her colourful, often exotic world, which included five lively daughters—Victoria, Cleo, Freya, Alexandra and Beatrice. Michael left home to study film (he became an editor for the BBC), and Tony and Jill moved into a tall house in Walton Street in Oxford, marrying in October 1983.

Further disaster struck when Galina was severely injured in a bomb explosion on a bus in Israel in December 1983. Tony and Michael went out to be with her as she began her long recovery. Tony's natural optimism and resilience were needed yet again to survive the subsequent tragedy of Jill's terrible illness and death from motor neurone disease. She was diagnosed in March 2000 and told she had 14 months to live. To help cope with her increasing lack of mobility, they moved to a house in Squitchey Lane in north Oxford with a downstairs bedroom. Following her death on 7 June 2002, Tony was rescued by his college friend Brian Jenkins and wife Catherine, who had him to stay in their house in Devon.

In the early 1980s, to contribute to research programmes at Harwell, Tony turned his attention away from nuclear theory towards atomic and molecular theory. In the context of the separation of isotopes by laser light, possibly applicable to  $^{235}\text{U}$  and  $^{238}\text{U}$ , he made several contributions to the theory of photoionization. In collaboration with the atomic and molecular physicist, J. P. Connerade, he wrote several papers, including a review of interactive resonances in atomic spectroscopy (29). A by-product of this work, and a fundamental contribution to atomic physics, was his proof (25) that the multi-channel quantum defect theory could be straightforwardly derived from Wigner's R-matrix theory.

In the later 1980s Tony went on to produce theory and calculations regarding the feasibility of muon-catalysed fusion. This process, in which mu-mesons produced by high energy reactions initially form compact meso-molecules with hydrogen or deuterium nuclei, brings the nuclei much closer together and could possibly facilitate fusion. Tony contributed two articles on the formation and decay of meso-molecules to a book on the subject (27, 28). Tony



Figure 2. Birdwatching at Minsmere, Suffolk, 2004. Photograph provided by the author. (Online version in colour.)

also wrote several papers of general interest in quantum mechanics, including one with P. T. Greenland of TPD, on how the decay of a state could be affected by external influences such as collisions (26).

By the time Tony retired from Harwell in 1989, he had held over 20 visiting professorships at universities and research institutions around the world. He was greatly admired and respected by all those who worked with him for his depth of knowledge and his kind words. He never made harsh comments about other people's work, although he did regret the attitude of Professor Rosenfeld who, when editor of *Nuclear Physics*, rejected papers by nuclear experimentalists who used R-matrix theory to analyse nuclear resonances instead of his own rival theory. In his retirement, he continued his interest in physics at the Clarendon Laboratory in Oxford, and revelled in the wealth of stimulating lectures and courses available in other subjects in Oxford. He enjoyed reading, theatre and films, and walking holidays in Britain, especially the Lake District, to which he introduced many of his expanded family (eight children, spouses and twelve grandchildren!). It is testament to his loving nature that he got on so well with his step-children and their partners and offspring. Country walks and birdwatching remained some of his favourite pastimes; I had the pleasure of taking him on trips to birdwatching sites in East Anglia where we more than once saw a merlin on migration (figure 2).

During Jill's illness, she was helped by Soňa Petkova from Slovakia. After Jill's death, Soňa continued to live at Squitchey Lane, while improving her English and learning massage



Figure 3. Tony in his garden, around 2000. Photograph provided by the family. (Online version in colour.)

therapy. She became yet another daughter to Tony and was a huge help to him in his last years when he was recovering from a heart attack and receiving cancer therapy. A final tragedy for Tony was the death of James from a diabetic coma in 2006. He had great comfort from watching the birds in his garden (figure 3), for whom he devised a brilliant feeder (large birds and squirrels couldn't use it!). He never lost his intellect and, in his last months, tried to find alternative proofs of Fermat's last theorem. In this he failed, but he left behind a valuable scientific legacy and a large number of family members and friends, all of whom greatly miss this lovely man.

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## AUTHOR PROFILE

*Charles F. Clement*



Following a degree in Mathematics at Cambridge, Charles Clement studied for a PhD in theoretical nuclear physics under Richard Eden and, for a year at Harwell, Tony Skyrme. After two years as an Instructor at Princeton University, in 1962 he joined the Theoretical Physics Division of the Atomic Energy Research Establishment of the UKAEA at Harwell where his final appointment was as a Senior Principal Scientific Officer. During this period he spent two years in Visiting Positions teaching graduate nuclear physics at Florida State University and University of Minnesota. After leaving AEA Technology (the successor to UKAEA at Harwell) in 1993, he has acted as a Consultant with an Associate Position at the Physics and Astronomy Department of University College, London. He has nearly 60 years of research experience in both quantum and classical areas of theory related to nuclear physics, heat and mass transfer, nuclear fuel modelling, nuclear safety, and finally mainly to the physics of aerosols. He has been very active in the aerosol research community and was President of the Aerosol Society (UK and Ireland) from 2002 to 2006, and received an International Aerosol Fellow Award in 2008 from the International Aerosol Research Assembly (the first UK recipient of this award). He is a long-term member of The American Physical Society and a Fellow of the Institute of Physics, and author of more than 200 papers, book chapters and reports.

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