BIOGRAPHICAL
MEMOIRS

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Roger Cowley

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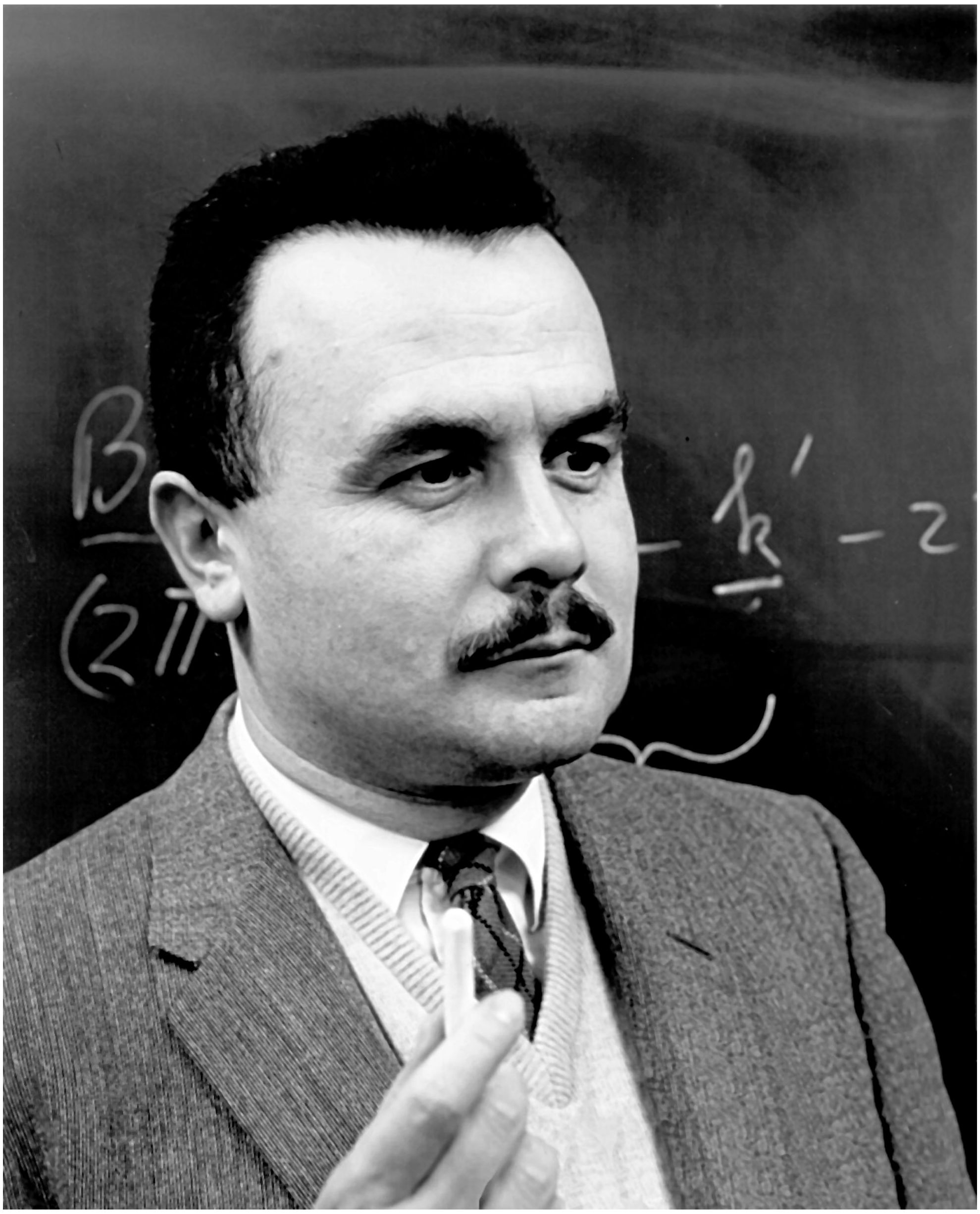

B. N. Brockhouse

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Elected FRS 1965

By Roger Cowley FRS

*University of Oxford, Department of Physics, Clarendon Laboratory,
Parks Road, Oxford OX1 3PU, UK*

The early years

Bertram Neville Brockhouse was born on 15 July 1918 in Lethbridge, Alberta, Canada. His grandfather was a miner who emigrated to North America from England. He became active in a strike to unionize the mines and to protest against the poor working conditions; as a result he had to leave mining. He then, with his son, Israel Bertram Brockhouse, went homesteading in Southern Alberta with a small farm and domestic animals, where his son married Mabel Emily Brockhouse (*née* Neville), who had grown up in Illinois and belonged to a family of English Americans. They had a family of four, the eldest of whom was Bertram Neville, known to his friends and family as Bert. He had a sister, Alice, and two younger brothers, Robert, who died in infancy, and Gordon, who became a civil engineer for the railroad. The homestead was on the Milk River close to the Canada–USA border and the local school was a one-room elementary school a couple of miles from the farm. Bert was a nominal attendee at this school but did not remember learning to read or to do simple arithmetic there.

In the winter of 1926–27, the farm failed and the family moved to the city of Vancouver. Bert attended the Central School and then the Lord Roberts Elementary School and King George High School and considered the basic education he received to be good, except for the social aspects. He found school work to be easy and was younger than most of his classmates. The family finances continued to be precarious and Bert helped by delivering papers throughout most of his teens. The depression made the situation worse and in 1935 the family moved by train to Chicago in the hope that their circumstances would improve. Bert became interested in the technical aspects of radios and learnt to repair, design and build them. He set up a small business as a radio repairman while his parents ran a small grocery store.

Unfortunately neither business was a success. For part of the time in Chicago he also worked for the Aubert Controls Corporation as a laboratory assistant. However, the company became bankrupt in 1937 and the whole family decided in 1938 to return to Vancouver by car and greatly enjoyed the journey.

In Vancouver, Bert began to take an active part in politics and joined the left-wing NDP party. He was profoundly anti-totalitarian and anti-communist so that when World War II began he enlisted in the Royal Canadian Navy with the hope of becoming a radio telegrapher. He spent some months at sea but most of his war years were spent on land, servicing ASDIC (Anti-Submarine Detection Investigation Committee) equipment. In 1944, he enrolled in a six-month course in Electrical Engineering at the Nova Scotia Technical College. On graduating, he became a Sub-Lieutenant and was assigned to the test facilities of the National Research Council of Canada in Ottawa. While in Ottawa, Bert met Doris Miller, who later became his wife.

When the war ended in 1945 Bert was drafted home to Vancouver and was discharged from the Navy. The Canadian Government provided some financial support for veterans wishing to undertake further education, and Bert took up his studies at the University of British Columbia. He enrolled in the physics and mathematics course and did well in the first year, winning another scholarship. Additional financial support came from the small business that he ran at this time, while his transportation was provided by a motorcycle. In the summer of 1946, he travelled on the motorcycle to Chicago and then to Ottawa, a distance of about 3000 miles, so that he could see Doris again. Bert's father died in the winter of 1946 and his sister was married, so the home arrangements altered. Bert completed his BA degree in 1947 and was offered a summer position at the National Research Council of Canada back in Ottawa. While there, Doris and Bert became engaged.

Bert then enrolled in the MSc programme of the University of Toronto, which at the time was one of only two Canadian universities to offer a PhD programme, the other being McGill. He worked with Professor Hugh Grayson-Smith and Professor James Reekie on the effects of stress and temperature on ferromagnetism and finished his Masters degree within 8 months. In May 1948 Doris and Bert were married in her mother's home village of Kirkfield. After another spell as a summer student at the National Research Council in Ottawa, Bert returned to the University of Toronto to begin his PhD studies. Unfortunately both his supervisors left Toronto for other posts so that he was left essentially unsupervised. Happily, E. C. (later Sir Edward) Bullard FRS arrived as Head of the laboratory and assumed the direction of Bert's thesis. However, Bullard left Toronto to return to the UK and Bert was left to finish his thesis with very little supervision. His PhD was completed in the autumn of 1950 and described further researches in the area of ferromagnetism.

The education that Bert received was rather disorganized, partly because of the war and partly because of his unfortunate experience with PhD supervisors. Nevertheless, he remembered most of his teachers with fondness. He did not become comfortable with quantum mechanics and much of his research work was essentially classical in nature, with quantum mechanics thrown in when needed. He learnt thermodynamics, statistical physics and nuclear physics from lectures but the solid state physics was learnt from reading the formidable textbooks of F. Seitz and N. F. (later Sir Nevill) Mott FRS and H. Jones.

Bert was appointed a lecturer in the Physics Department in Toronto in 1949 and the natural progression for his career was to stay in the academic world. Very significantly Bert did not do this but was recruited by Don Hurst to join his group at the Atomic Energy Project of the National Research Council, which was later to become Atomic Energy of Canada Limited (AECL) at the Chalk River laboratories, about 250 miles north of Toronto on the Ottawa River. As Head of the Neutron Spectrometer Section of the General Physics Division, Don Hurst was looking for additional staff to develop neutron scattering experiments, a field that was then almost untouched and was important both for reactor designers and for its basic physics. Bert had been spotted as an excellent student at Toronto University and was invited to apply for a permanent position as a Research Officer. Bert moved to Deep River, the town associated with the laboratories, in the summer of 1950, in a van bringing his family's belongings, while Doris stayed at Balsam Lake near Kirkland with her parents and their young daughter, Ann. Don and Margaret Hurst then drove them to Deep River later that summer. One wonders if the Brockhouses appreciated how cold Chalk River could be in the winter or how isolated it must have been in 1950.

The Chalk River years, 1950–62

It was during his 12 years at Chalk River that Bert made the tremendous developments in neutron scattering techniques for which he was awarded the Nobel Prize. He worked extremely hard and successfully and together with a few colleagues left his competitors far behind in other international laboratories: Brookhaven, Saclay and Harwell. In the early 1950s it was known from the work of Placzeck and others that the scattering of slow neutrons in solids was governed by the laws of conservation of energy and of wavevector, but there had been very few attempts to make experimental measurements of the effects. The energy exchanged to the crystal was the energy of the phonon (quantized lattice vibration) or magnon (quantized spin wave), whereas the wavevector difference between the incident and scattered neutrons gave the wavevector of the phonon or magnon modulo the wavevector of a reciprocal lattice vector. The dependence of the energy of the phonon or magnon on the wavevector is known as the dispersion relation but the only measurements of any aspect of these dispersion relations were the specific heat and optical properties. As a result, in the early 1950s there was very little experimental information about these dispersion relations and even a controversy about whether the phonons and magnons existed.

In principle, the dispersion relations could be determined in detail with neutron scattering techniques. This is because the dispersion relations have typical energies of about 10 meV so that a good description of these energies requires the neutron energies to be determined with an accuracy somewhat better than 1 meV. However, neutrons are produced with an energy of nearly 1 MeV and have to be moderated before they have the necessary low energies, that were then difficult to determine accurately.

The first method that Bert used in experiments with Don Hurst and Myer Bloom made use of a resonant scattering technique in which the neutron is absorbed in materials, such as samarium or cadmium, that have very low nuclear energy levels and absorb neutrons of low energy. The sample was surrounded with one of these materials and then irradiated with a range of neutron energies from a single-arm spectrometer that had already been built by Don Hurst. The experiment was successful and these experiments continued to be performed and improved throughout the 1950s. Bert and Don Hurst measured the phonon frequency distribution of the phonons in aluminium, lead, graphite and diamond, and showed that the results could distinguish between the predictions of an ideal gas model and an Einstein model for the phonons (1, 2)*. However, the energy resolution was too poor to determine the dispersion relations because the energies of the neutrons were typically about 10 eV and the energies of the phonons very much smaller. This method has, in recent years, been revived for the eVS spectrometer at ISIS, near Oxford, which was designed to operate with neutrons of energy in excess of 10 eV.

It was in 1950 that a meeting of Don Hurst, Bert, Neville Pope and Trudi Goudschmit decided that the resolution of the instrument could be improved only if the energy of the incident and scattered neutrons was reduced and that such experiments should be possible with the NRX reactor at Chalk River, which at the time had the highest neutron flux in the world. Nevertheless, these experiments would require, in addition to this high flux, considerable advances in the experimental techniques. There were two possible methods of determining the energies of the neutron with an accuracy of about 1 meV. A neutron of energy of 10 meV has a velocity of 1.4 $km\,s^{-1}$ so that if there is a flight path of 5 m the neutron energy can be determined to 1% by timing to an accuracy of 30 μs. Timing to this accuracy was achievable in 1950. The alternative method uses Bragg reflection from single crystals, as demonstrated previously by Cliff Shull in his diffraction experiments for which he shared the Nobel Prize with Bert in 1994. The typical angles of scattering are 50°, so that 1% accuracy is achieved with an angular accuracy of about 0.5°. The difficulty here lies in the fact that monochromators available in 1950 were very inefficient and so the count rates were very low.

Bert decided to develop his large aperture double spectrometer, now known as a triple-axis-crystal spectrometer, using diffraction to determine both the incident and scattered neutron energies. He began a substantial programme of instrument development and, as described in the Chalk River progress reports, he designed shielding to reduce the backgrounds, persuaded David Henshaw to grow mosaic single crystals of aluminium and lead to improve the monochromators, developed the neutron detectors to improve the counting efficiency, reduced the background by improving the shielding and improved the efficiency of the counting chain. Despite all this activity, progress was not easy and at the end of 1952 the spectrometer was still unsuccessful. It is worth noting that it now takes considerably more than two years to design and build a triple-axis-crystal spectrometer.

At the end of 1952 the NRX reactor suffered an accident and the Brockhouses spent the best part of the next year at Brookhaven National Laboratory on Long Island in the USA. Bert worked with Lester Corliss and Julius Hastings at the Brookhaven graphite reactor and benefited considerably from their expertise in elastic neutron scattering. He studied the multiple scattering and magnetic structure of zinc ferrite (6), the magnetic structure of chromous oxide (3) and, with George Vineyard, the neutron scattering from liquid aluminium and made an 'inconclusive attempt to study the energy distribution of scattered neutrons by absorption measurements'.

After returning to Chalk River, Bert concentrated his attention on inelastic neutron scattering. He was convinced that his triple-axis-crystal spectrometer was the correct approach even though his colleagues in other laboratories considered that the time-of-flight technique was the most promising approach. He therefore set up his crude triple-axis-crystal spectrometer at the NRX reactor and continued to make improvements. The monochromator was a single crystal of aluminium grown by David Henshaw and with a fixed angle of scattering. There was a makeshift sample table and an analysing spectrometer mounted on rails so that the scattering

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

angle could be adjusted. This equipment was used to measure the frequency distribution of the phonon modes in vanadium, which, because it was an incoherent scatterer, did not require the sample table to rotate (5). Measurements were also made of the scattering from liquid lead and from heavy and light water and all these measurements were reported at the American Physical Society Meeting in 1955.

Early in 1955, Bert and Alec Stewart performed the first successful measurement of the phonon dispersion relations in a single crystal of aluminium. They determined the energy distribution of the scattered neutrons for a fixed angle of scattering and sample orientation. Usually they made two scans each day, using different choices for the angles of scattering and sample orientation. They were then able to map out the dispersion relations by choosing just those peaks in the neutron scattering that happened to have wavevectors that were close to a high symmetry direction. It was a lengthy and tedious process. Nevertheless, this classic experiment was reported at the end of 1955; it showed that phonon dispersion relations did exist and that they could be measured with neutron scattering techniques (4, 8).

Bert then set about showing that similar measurements could be made of the magnon dispersion relations in magnetic materials. Magnetite was chosen, a ferrimagnet that, with hindsight, was more difficult to study than many simple antiferromagnets such as MnF_2. This choice was made because Bert wished to be able to rotate the direction of magnetization to distinguish the magnetic scattering, by the change in intensity with magnetization direction, from the phonon scattering and because large single crystals were readily available. The measurements were performed for 12 different sample orientations and at a constant scattering angle; the results showed that the peaks in the neutron scattering came from magnetic scattering and that the magnon dispersion relations could be obtained (7).

Collaborating with a visitor from India, P. K. Iyengar, Bert's next project was the determination of the phonon dispersion relations in a single crystal of germanium. They used the same equipment as for the aluminium measurements but employed a method of successive approximations to obtain the energies of the phonons having wavevectors on or close to the high symmetry directions. This approach was successful but was also very labour intensive (9).

Although Bert concentrated on the triple crystal spectrometer, he also built pioneering examples of time-of-flight spectrometers. These instruments have rotating choppers that produce monochromatic pulsed beams of neutrons. In 1955 it was difficult to spin the choppers reliably and quite impossible to spin four choppers exactly phased with one another for many hours, as done in many of these instruments nowadays. It was known that powdered beryllium scattered all the neutrons with energies above 4 meV out of the incident beam, whereas lower-energy neutrons are largely transmitted. Bert and Alec Stewart in 1955 constructed a time-of-flight instrument with a beryllium filter and a single chopper that was similar to the instruments built at Brookhaven, Harwell and other laboratories. The instrument produced pulses of all the neutrons with energies less than 4 meV. Bert and Alec improved the resolution by constructing a novel difference filter but the instrument still had poor resolution and was closed down in 1957.

In its place, Bert built a rotating-crystal spectrometer in which a rotating single crystal, made of aluminium, produced both a monochromatic and a pulsed beam of neutrons. This instrument was steadily improved by building a variable-angle counter bank containing six counters and allowing the incident angle and hence the neutron energy to be varied. The spectrometer was initially built at the NRX reactor but was later moved to the N5 beam tube of the new and more powerful NRU reactor, where it was used for experiments on liquid lead (10), water (11), liquid helium and argon.

Figure 1. Bert crouching near the spectrometer at the C5 hole of NRU some time in 1960.

By 1957 it was clear that one of the main problems in the determination of the dispersion relations comes from the lack of the ability to control the various angles of the triple-axis-crystal spectrometer, so a new instrument was built at the NRU reactor (figure 1). The monochromator and its associated shielding drum was designed by Bill McAlpin and this allowed the incident neutron energy to be varied by controlling the monochromator angle. The sample table and the secondary spectrometer were mounted on rails, and the four different angles controlling sample orientation, scattering angle, monochromator angle and analyser angle were all motorized. Somewhat before these developments, the elegant theoretical papers by Louis Van Hove described neutron scattering and, in particular, emphasized that the physical quantities in the scattering process were the energy transfer and the wavevector transfer, $\boldsymbol{Q}$. Just before this the Chalk River Nuclear Laboratories had invested in a mainframe computer, the Datatron, and this was programmed to calculate the angles so that the energy transfer could be varied in a predetermined way while $\boldsymbol{Q}$ was held constant. Initially the angles were printed out and set on switches next to the spectrometer. Later the computer produced punched paper tape that controlled the spectrometer and this, coupled to the electronic control equipment built by Ed Glaser, made an enormous difference to neutron scattering. First, it enabled the triple-axis-crystal spectrometer to determine the energy of a particular desired wavevector for the phonon without the need for any complex successive approximations and, second, the technique enabled a whole series of scans to be made without any further inter-

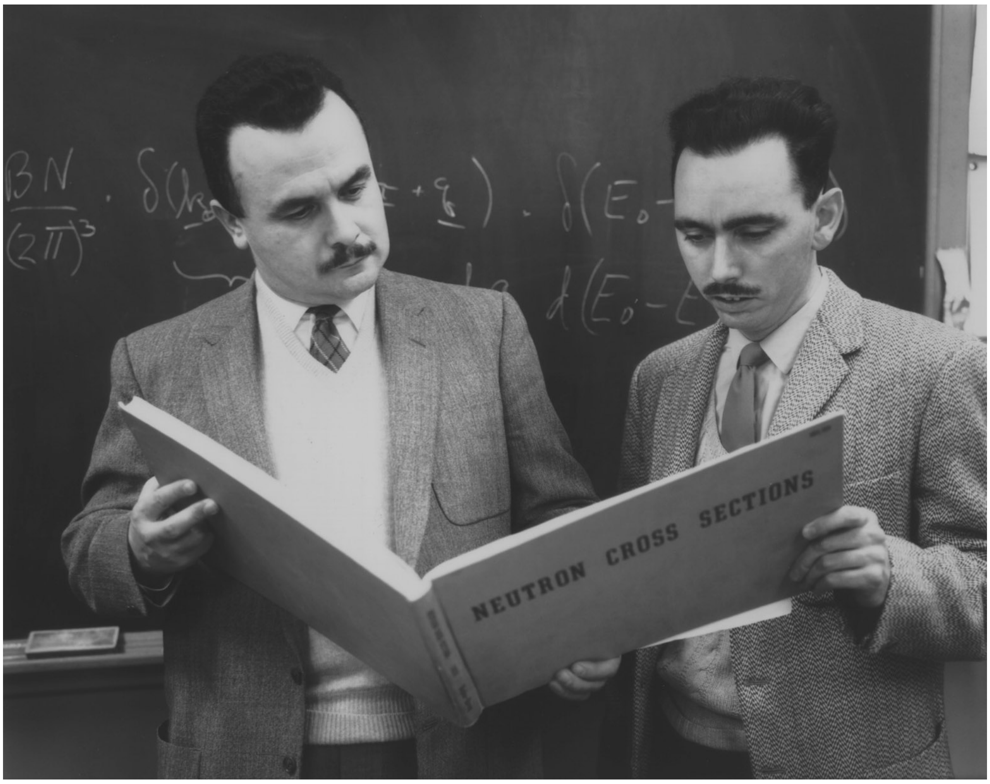

Figure 2. Bert and Dave Woods discussing neutron cross-sections.

vention. As a result an experiment could be done much more easily and much more quickly than before.

There has not been a similar development for time-of-flight instruments and even now, after 50 years of progress of computers, very few experiments have been performed successfully to measure the dispersion relations in three-dimensional crystals with time-of-flight techniques. Time-of-flight techniques can clearly be made highly productive if the wavevector transfer is either unimportant or a scalar; however, if $\boldsymbol{Q}$ is three-dimensional, experiments are usually best performed with a triple-axis-crystal instrument almost identical to that built by Bert except that the control is now obtained from a dedicated personal computer.

The late 1950s and early 1960s were a time of exploitation of the new techniques. Bert became the Head of a new Branch at Chalk River in 1960. The staff employed in the branch increased with some new permanent appointments and by an influx of visitors from Japan, India, Italy, Argentina and the UK as well as a few Canadians. Dave Woods (figure 2) joined the branch as a research officer. Bill Cochran (FRS 1962) came from Cambridge for a sabbatical year in 1958–59. Together they and Bert measured the phonons in sodium iodide. The results led directly to the development of the shell model that had been proposed by R. Dick and A. Overhauser but had previously been applied only to the dielectric properties. The new data, available for the whole of the dispersion relation for NaI, enabled the shell model to be thoroughly tested and shown to give a very satisfactory description of the interatomic forces

(12). Bill Cochran then went on to show that the model was also successful in describing the dispersion curves of germanium where, in particular, the low-frequency acoustic mode did not need to be explained by long-range forces but could be more satisfactorily explained by the polarizable shells of the atoms. Gerald Dolling joined the group in 1961 and measured the phonon dispersion relations in silicon, which showed similar effects to those in germanium, while Dave Woods, Bill Cochran and Bert extended the work on alkali halides to KBr and obtained similar results to those in NaI (20).

As a direct consequence of this development, Bill Cochran developed the shell model further and produced his soft mode theory of structural phase transitions in which, at the phase transition, the crystal becomes unstable against a particular phonon (normal mode of vibration). This concept was shown to provide a reasonable description of results from strontium titanate and is now used throughout physics.

The phonon dispersion relations in metals were studied for a relatively simple free-electron metal, sodium, and for a more complex metal, lead, by Bert, Dave Woods and the visitors T. Arase, Guiseppe Caglioti, K. Rao, Bob March and Alec Stewart. It is difficult now to realize the impact of these experiments because at the time there was even a question as to whether well-defined phonons would exist in simple metals or whether the short-wavelength phonons would be completely scattered by the conduction electrons. The results clearly showed that there were well-defined phonons and that the phonons had very little damping, indicating the correctness of the Born–Oppenheimer approximation. The results for sodium strongly supported the new pseudopotential theories of interatomic forces (19), and those on lead showed that the dispersion relations had singularities in the derivates as predicted by Walter Kohn (15, 18). The singularities were related to the Fermi surface and provided a new way of measuring the Fermi surface in metallic systems. Taken together, these two experiments showed that the basic concepts of describing the interatomic interactions in metals in terms of the pseudopotential were largely correct for these metals.

Fewer experiments were performed on magnetic systems. The experiments on magnetite were extended with Hiroshi Watanabe to include the optical branches of the spin wave dispersion relations (17). Measurements were made together with Roger Sinclair of the acoustic spin waves in a face-centred-cubic cobalt alloy containing a little iron (13). The crystal field spectra of the rare earth oxides were measured together with Leo Becka, K. Rao, Roger Sinclair and Dave Woods by replacing the analyser of the C5 spectrometer with powdered beryllium and a large counter. This greatly increased the count rate at the expense of the resolution but has been a very useful technique for measuring the frequencies of branches that have little change with wavevector (16). It is surprising that Bert did not attempt to measure the dispersion relations in any antiferromagnets that, with hindsight, are easier measurements to make than those he actually performed; possibly it was the lack of suitable samples or because he was wary of systems that were not ferromagnets and for which he might have difficulty in deciding whether the scattering came from phonons or spin waves.

Although the results were possibly less striking, Bert continued to use his rotating-crystal spectrometer particularly for experiments on liquids. He measured the scattering from liquid lead, water, heavy water and argon. The results were analysed particularly by Neville Pope and showed features such as the diffusion at long wavelengths and the narrowing of the spectra at larger wavevectors as predicted by P. de Gennes (FRS 1984). He was clearly the leader in this field as well but it was more difficult to make an enormous impact than for the experiments on solids. One of the last experiments Bert attempted while employed at Chalk River was to try to determine whether well-defined vibrational modes existed in liquids for long wavelengths. This experiment did not have a conclusive result but it was not until the 1990s that experiments were performed which clearly showed that well-defined modes in some liquids could be measured with neutron scattering techniques but not in other materials.

In addition to these measurements, Bert continued to develop the neutron scattering techniques and devised a method for determining the eigenvectors of the dispersion relation by measuring the scattered intensities. He, together with Leo Becka, K. Rao and Dave Woods, demonstrated this for some special phonons in germanium (21). He wrote several excellent reviews such as 'Methods for neutron spectrometry' (14), in which he explained in detail the instruments he had built and the way in which they should be used. They became standard reference works for all new neutron scatterers for many years.

At the end of Bert's time at Chalk River, the third International Conference on Inelastic Neutron Scattering was held in Chalk River and sponsored by the International Atomic Energy Agency. The conference had 64 participants from 13 different countries, presenting 67 papers, and represented a very large fraction of all those who were then active in the field of inelastic scattering of neutrons. The conference was completely dominated by Bert. He was the person who was most knowledgeable about all the techniques and had performed the best experiments. Today there are well over 10 000 participants in neutron scattering worldwide and their numbers are limited more by the lack of neutron beams than by the lack of problems.

Although, as we have seen, Bert was exceptionally busy and productive during his 12 years at Chalk River, he did also find the time for his family. Five children were born in the hospital in Deep River. One of them, Jamie, was autistic and was placed in a special school over 100 miles away. Bert and Doris made many friends in Deep River and Bert had the energy to take part in a number of amateur dramatic productions including three Gilbert and Sullivan operas and Shaw's 'The Arms and the Man'. He enjoyed his music greatly and there are many accounts of him singing both at home and while working at one of his spectrometers.

McMaster University, 1962–84

Bert left Chalk River Nuclear Laboratories in 1962 to become a Professor at McMaster University, which was new, and had an active physics department. The university also operated a nuclear reactor, which had a somewhat lower neutron flux than that provided by the Chalk River NRX and NRU reactors. Bert, together with his students Sow-Hsin Chen, Eric Svensson and Mike Rowe, designed and built a novel triple-axis-crystal spectrometer. The instrument had a double monochromator so that the monochromatic beam went in the same direction no matter what the incident neutron energy was. The analyser consisted of several small and largely unshielded analysers mounted in a common analyser shield that was fixed in position. The spectrometer was then much cheaper to build than the spectrometers at Chalk River and it was hoped that the multiple analysers would compensate for the lower flux. Unfortunately, the spectrometer never operated effectively, in part because the double monochromator decreased the flux even further and in part because within the analyser shielding there were lots of beams of neutrons giving much crosstalk between the analysers. After considerable work and effort, the spectrometer was abandoned and Bert and his students performed their experiments at Chalk River both on Bert's original spectrometers and on a new one they built using a simplified form of the C5 spectrometer.

The science studied by Bert and his students was more restricted in range than it had been at Chalk River. The experiments were concerned with the lattice dynamics of three-dimensional solids and nearly all of them concerned either metals or alloys. With one or more of his 11 doctoral students he studied the phonon dispersion relations of tungsten (22), tin (23), copper (25) and gold-doped copper (24) to determine the effect of impurity modes on the dispersion relations. Later, his students studied the phonon dispersion curves of bismuth–lead and thallium alloys (26), iron (27), nickel (28), silver (30), palladium (29), platinum (31) and rubidium (32). This was all very good work and was important for providing the phonon dispersion relations for a wide range of different metals. Bert was a conscientious supervisor and provided excellent training for his 11 research students; many of them have since had prestigious positions in physics. He taught them his four rules on how to become a successful research student.

1. An experimentalist has to ensure that his data are correct.
2. He should use his intuition, especially if it is good.
3. Work takes precedence over coffee breaks and reading newspapers.
4. A research student does not have a nine-to-five job.

Bert's research in this period, while making a substantial contribution to the subject, began to lack the originality and insight of his work at Chalk River, and his research using neutron scattering techniques stopped in 1973.

Throughout his career he was concerned about the price of energy, as were many of those involved with the early days of nuclear power. At about the time he left Chalk River, he calculated how much neutron scattering had cost every person in the world and said he thought the progress just about justified the expense. The figure would be much higher today, now that there are a good number of purpose-built facilities for neutron scattering. After 1973, he continued with his concerns about energy production and the world's waste of energy. He considered that the price of energy is a key issue and that energy should not be priced as cheaply as it is today. He insisted that half of the world's energy is wasted without any benefit to anyone and that half of the rest of the energy is used in self-defeating ways that are detrimental to the whole planet. Bert was a serious conservationist and, as shown by his house and by the cars that he drove, he believed in putting his ideas into practice.

Bert also became interested in philosophy. In his earlier years at McMaster University Bert studied first the Anglican faith and then Roman Catholicism and eventually joined Doris in the local Roman Catholic church. He also became interested in the philosophy of science and tried to understand and appreciate the larger picture of the universe and how his science fitted into this picture. He gave lectures on his philosophy but it never reached the point at which he wrote a coherent account of his thoughts.

Bert took an active part in the teaching at McMaster University, and was very successful at communicating his enthusiasm for physics to some of both the undergraduate and research students. He was Chairman of the Physics Department from 1967 to 1970 when he argued that the undergraduate course should include a wider range of topics including astronomy, philosophy and energy conservation. The course on astronomy was very successful; there is now a research group at McMaster working on astronomy and the department is called the Department of Physics and Astronomy. He was influential in building up the department and won the respect and admiration of colleagues throughout the university. He became an Emeritus Professor on his retirement in 1984.

Bert received many honours for his neutron scattering experiments. In 1962 he was awarded the Oliver E. Buckley Award of the American Physical Society. This is the premier award of the American Society for Solid State Physics. It is interesting that he was honoured by the American Physical Society before receiving any honours from a Canadian society. He was elected to the Royal Society of Canada in 1962. In the following year he was awarded the Duddell Medal and Prize of the Institute of Physics and the Physical Society in the UK, in 1965 he was elected to Fellowship of the Royal Society, and in 1967 he was awarded a Canadian Centennial Medal and the Gold Medal of the Canadian Association of Physicists. The University of Waterloo granted him an honorary doctorate in 1969, and McMaster University in 1984. The Royal Society of Canada awarded him the Henry Marshall Tory medal for his outstanding contributions to science in 1973 and he became a Companion of the Order of Canada in 1984. He was exceptionally pleased to be awarded the Nobel Prize in 1994 even though it was 35 years since he had performed his seminal research on neutron scattering. He was awarded the prize jointly with Cliff Shull, who performed experiments on neutron diffraction and the determination of structures in the late 1940s and early 1950s. He was the first Canadian to have been born in Canada, educated in Canada and awarded the Nobel Prize for original work done in Canada. A river-front street in Deep River, near to where Bert lived while working at Chalk River, was renamed Brockhouse Way in his honour.

Those of us who had the privilege of knowing Bert personally owe him a tremendous debt of gratitude. He inspired many of us to take up the challenge of neutron inelastic scattering, and to work long and hard to improve the methods and techniques so that we could do the experiments correctly and convincingly. Throughout his career he demonstrated an honesty, thoroughness and passion for his work that are an example to us all. There are many 'absent-minded professor' stories about Bert, but the unique and important results showed his courage to persevere with the triple-axis-crystal spectrometer when most others were using the time-of-flight technique, his care in performing the experiments and his concern for the welfare and happiness of his fellow scientists, students and other human beings. After he was awarded the Nobel Prize, Bert made himself available for media interviews and speaking engagements not just to major publications and large audiences but also to schools and small-town newspapers. He was concerned that the Canadian people had supported him to do his research and that he now had an obligation to explain to them how their taxes had been spent. Bert and Doris always welcomed his colleagues and their families into their home and showed their affection for one another as well as for their six children and eight grandchildren. Bert considered that 'the most important thing a person could do for the world is to raise their children well'. His own political views steadily changed with time from the left-wing NDP philosophy of his youth to being strongly right-wing and a Canadian patriot. In his last few years Bert had serious health problems, including difficulty in seeing and in retaining his mobility. He sought out technical aids to help him overcome his difficulties but his greatest aid was the support he received from Doris and he accepted her care with grace. Bert died on 13 October 2003 and is survived by Doris.

Acknowledgements

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