Obituary

Bertram N. Brockhouse (1918–2003)

Father of neutron spectroscopy

Advances in science often start with abstract and difficult ideas — Mendel's gene or Dalton's atom come to mind. Only much later, through defining experiments, do they become such concrete objects that one wonders what all the fuss was about. Genes have become sequences of nucleic acids, and atoms are now real things that can be manipulated one at a time with scanning probe microscopes. So it is, too, in condensed-matter physics: the phonon and the magnon were postulated as elementary quantum excitations of matter but acquired a real existence only through a brilliant set of experiments with thermal neutrons in the late 1950s. Those experiments were performed by Bertram Brockhouse and marked the beginning of a new field of spectroscopy, inelastic neutron scattering. Brockhouse — who shared the 1994 Nobel Prize in Physics with Clifford Shull — died on 13 October 2003.

In the 50 years since Brockhouse's invention, neutron spectroscopy has become a standard tool of physics. The neutron, an electrically neutral particle, is able to penetrate deep in the interior of matter; it possesses a magnetic moment and has, at room temperature, a wavelength that nicely matches the distance between atoms in solids and liquids. Dozens of reactors, and more recently accelerators, have been built for neutron spectroscopy: the new Spallation Neutron Source in Oak Ridge, Tennessee, will provide the most intense pulsed neutron beams ever used in research, and, at a total cost of US$1.4 billion, is one of the largest scientific projects in the world.

Brockhouse was raised on a farm in Alberta but showed an early interest in electronics, running a small radio repair business before joining the Canadian Navy at the start of the Second World War. After physics degrees from the Universities of British Columbia and Toronto, in 1950 Brockhouse joined the Chalk River Nuclear Laboratory in Toronto. Encouraged by Don Hurst there, who had already built a prototype neutron spectrometer, he started building a series of increasingly sophisticated neutron spectrometers to study excitations in solids. Unlike Shull, who worked on the static positions of atoms and spins, Brockhouse focused on their movements. For this, he needed to measure the neutrons' energy change as they scattered from his sample, tying down the incoming and outgoing neutron energies, as well as the momentum transfer ('Q') from the neutron to an excitation in the sample.

By 1957 his famous triple-axis spectrometer, operating in the 'constant Q' mode, was complete. The first axis held a crystal used to select the incoming neutron energy; the second, the sample under study; and the third axis analysed the scattered neutron energy. The choice of angles of the axes was determined by simple energy- and momentum-conservation rules: set all the angles in such a way as to keep Q (the momentum transferred to the crystal) constant while varying the energy change of the neutron. Taking advantage of the high neutron flux of the new National Research Universal nuclear reactor at Chalk River, then the world's most powerful source of neutrons, Brockhouse wasted no time in applying his new invention to a series of fundamental experiments. In rapid succession, he and his co-workers produced ground-breaking papers on phonons in metals, semiconductors and insulators; on magnons in magnetic materials; and on diffusive molecular and atomic motions in liquids.

The phenomenon of superconductivity offers a good example of the impact that neutron spectroscopy had on physics. About the same time that the detailed phonon spectra of metals were emerging from Chalk River, Bardeen, Cooper and Schrieffer had announced their theory of superconductivity. The star actor in the theory was the phonon; it was the glue that bound the electrons into pairs to form the superconducting state at low temperatures. It is fair to say that it was the exquisite agreement between neutron spectroscopy and superconducting tunnelling experiments on the self-energies of the electrons that convinced the last sceptics that the problem of low-temperature superconductivity had finally been solved. The same debate is currently raging in the context of high-temperature superconductivity, where neutron spectroscopy is again a central player in determining the nature of the force that binds the superconducting electrons. Magnon and phonon spectra have been measured with neutrons and are being correlated with spectra directly related to the forces between the charge carriers.

In 1962 Brockhouse moved to McMaster University in Hamilton, Ontario — a good choice, as it had an on-campus nuclear reactor with a fairly substantial neutron flux. Brockhouse quickly gathered an enthusiastic group of graduate students and faculty interested in the new spectroscopy. He built a triple-axis spectrometer at the reactor to give his graduate students hands-on training, although for serious research they still had to travel to one of the large national laboratories. At McMaster, Brockhouse's interest shifted gradually away from neutrons towards broader issues. As chair of the Department of Physics he introduced several new programmes, one of which, astronomy, has blossomed over the years so much that the department's name has been changed to Physics and Astronomy. However, the Brockhouse neutron legacy remains. The nuclear reactor is still running, and Bruce Gaulin, holder of the Brockhouse Chair in Physics of Materials, is leading the efforts to build a Canadian beamline at the Spallation Neutron Source in Oak Ridge.

Today, the phonon and the magnon are seen as fundamental elements of matter almost on the level of atoms or molecules. But Brockhouse himself had trouble fully accepting the reality of the objects that he had brought to life. In his Nobel prize lecture, he talked of the "grand atlas of the physical world", in which atoms and their positions have a place. But he was not sure that the phonon and the magnon belonged in it. This scepticism may have been grounded in a general mistrust of quantum phenomena that was still common in the 1940s, when Brockhouse received his graduate education. A more likely cause for his reserve rests deeper — Bertram Brockhouse was a very modest man. But perhaps he was ready to accept the phonon and magnon, after all. Addressing a group of undergraduate students after winning his Nobel prize, he said: "I used to think that my work was not important, but recently I have had to change my mind."

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