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Ben Mottelson: Codeveloper of the unified theory of the structure and dynamics of atomic nuclei

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Ben Roy Mottelson passed away on May 13 of this year at the age of 95. Ben was a giant of theoretical physics, having, with Aage Bohr (son of Niels Bohr), reshaped our understanding of the atomic nucleus in all its aspects, both static and dynamic. At the same time he had a great impact on international theoretical physics and influenced generations of nuclear physicists.

Ben was born in La Grange, Illinois, a western suburb of Chicago. Sent to Purdue University for naval officer training in World War II, he remained there after the war, receiving his Bachelor of Science degree in 1947. In 1950, after completing his doctoral thesis, “The ground states of lithium 6 and lithium 7,” at Harvard under the supervision of Julian Schwinger, he went in 1950 to 1951 to the University Institute for Theoretical Physics, now the Niels Bohr Institute (NBI), in Copenhagen, which became his base for the rest of his life. Ben became a Danish citizen in 1971, and was elected as a Foreign Member of the National Academy of Sciences in 1973.

At the time of Ben’s arrival in Copenhagen, the common picture of the atomic nucleus was that it was a liquid drop composed of a fluid of neutrons and protons, an idea originating with Niels Bohr. This picture well explained the elementary energetics of nuclei as well as dynamical properties, such as nuclear fission. However, nuclear “shell effects,” analogous to atomic shell effects (e.g., tight binding of nuclei for the “magic numbers” of neutrons or protons 20, 28, 50, 82, and so forth, which had recently been put in evidence by Maria Goeppert Mayer and Hans Jensen) seemed to be in conflict with this picture. Furthermore, as questioned by James Rainwater at Columbia University and taken up by Aage Bohr, could some nuclei be aspherical?

The challenge that Ben and Aage met was to put together a unified picture of the nucleus, to understand the interplay between collective behavior of the nucleus as a whole and the motion of individual nucleons, for which there was gathering experimental evidence. If nuclei were aspherical, one could expect them to behave as rotating tops, with bands of rotational excitations, as in molecules; such bands were investigated theoretically and found experimentally in the course of the 1950s. In addition, certain excited states of nuclei corresponded to quadrupole vibrations about a spherical equilibrium. Studies of these states opened up a particularly fruitful interplay between theory and experiment in nuclear physics.

By the mid-1950s, however, two puzzles were apparent: the first was why the measured moments of inertia of deformed nuclei were less than those of a rigid body nucleus, and—seemingly unrelated—why certain states of deformed nuclei required particularly high energies to excite. Their common solution would unexpectedly tie together nuclear and condensed matter physics. In 1958, after David Pines brought to Copenhagen the then new Bardeen, Cooper, and Schrieffer explanation of superconductivity in metals as arising from pairing of electrons, Ben, Aage, and David quickly realized that an analogous pairing of neutrons or of protons in nuclei could explain the reduced moments of inertia, in the same way that the moment of inertia of a bucket of superfluid liquid helium is less than the classic rigid body value, and that the high excitation energies were the analog of the energy gap in a
superconducting metal. Subsequent calculations of superfluid paired nucleons well explained measured excitation energies and moments of inertia, and established the idea of superfluid nucleons in both laboratory nuclei and in neutron stars.

Ben and Aage proceeded to disentangle the many facets of the behavior of atomic nuclei, developing in detail the “unified model” of the nucleus, which would well account theoretically for the experimental properties of nuclei at low energies across the range of atomic numbers. “For the discovery of the connection between collective motion and particle motion in atomic nuclei and the development of the theory of the structure of the atomic nucleus based on this connection,” Ben and Aage, together with James Rainwater, received the Nobel Prize in Physics in 1975 (1). The full theory, spelled out in the Bohr-Mottelson two-volume classic, Nuclear Structure, remains the standard of the field (2).

Thanks to Ben and Aage, the NBI in Copenhagen became a leading international center for nuclear research. After short-term appointments at NBI, Ben became a staff member of the European Organization for Nuclear Research (CERN) Theoretical Study Group that operated in Copenhagen during the years 1953 to 1957 before CERN’s long-term home in Geneva came into being, and in 1957 he became professor at the then newly established Nordic Institute for Theoretical Atomic Physics, or NORDITA, now the Nordic Institute for Theoretical Physics. He remained there for the rest of his career, apart from shorter periods at other institutions, and was NORDITA’s director from 1981 to 1983.

Following the Nobel Prize, Ben continued working in nuclear physics, especially on deformed nuclei, but his focus moved toward other small quantum systems. In 1971 Roger Balian and Claude Bloch in Paris had predicted that the density of levels in finite systems should exhibit a “supershell” structure superimposed on the shell structure familiar from atoms and atomic nuclei. To observe such effects demanded systems with 1,000 or more particles, an impossibility with nuclei, but in principle possible with metal clusters, where the relevant particles are electrons, not nucleons. In a noteworthy collaboration between Ben, other theorists, and experimentalists at NBI, supershell effects were observed, for the first time, in the distribution of the sizes of clusters formed in sodium vapor. Shortly afterward, Ben realized that shell structure would also occur in semiconductor nanostructures, or “artificial atoms,” which were in the 1990s an entirely new field. In the physics of ultracold atomic Bose gases, Ben worked intensely on the nature of vortices in rotating condensates and their connection to superfluidity.

Ben’s enthusiasm and deep knowledge of many-body and few-body physics were inspiring to people working with him and a strong driving force in shaping and guiding nuclear physics and related fields. He devoted himself to science and, with a few exceptions, avoided administrative positions. He had a key impact on international science, especially in the establishment of the ECT*, the European Centre for Theoretical Studies in Nuclear Physics and Related Areas, in Trento, Italy, of which he became founding director from 1993 to 1997. Ben received the Atoms for Peace Award in 1969, and was a member of the Board of Sponsors of the Bulletin of the Atomic Scientists.

Ben was a family person. He was married to Nancy Jane (née Reno) until her untimely death in 1975, and they had three children. In 1983 he married Britta Siegumfeldt, who died in 2014. His sense of family also encompassed physicists in Copenhagen, at the ECT* and elsewhere. Ben had a playful nature: making kites and hot-air balloons were among his delights, as well as climbing trees. Ben was fearless when expressing his views on science or politics, and when on his bike, shunning bike helmets and ignoring traffic lights. Despite personal tragedies and his own health issues in the last years, he retained his characteristic good humor to the end of his life.

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