Experiments and calculations allow examination of boron's complicated dance

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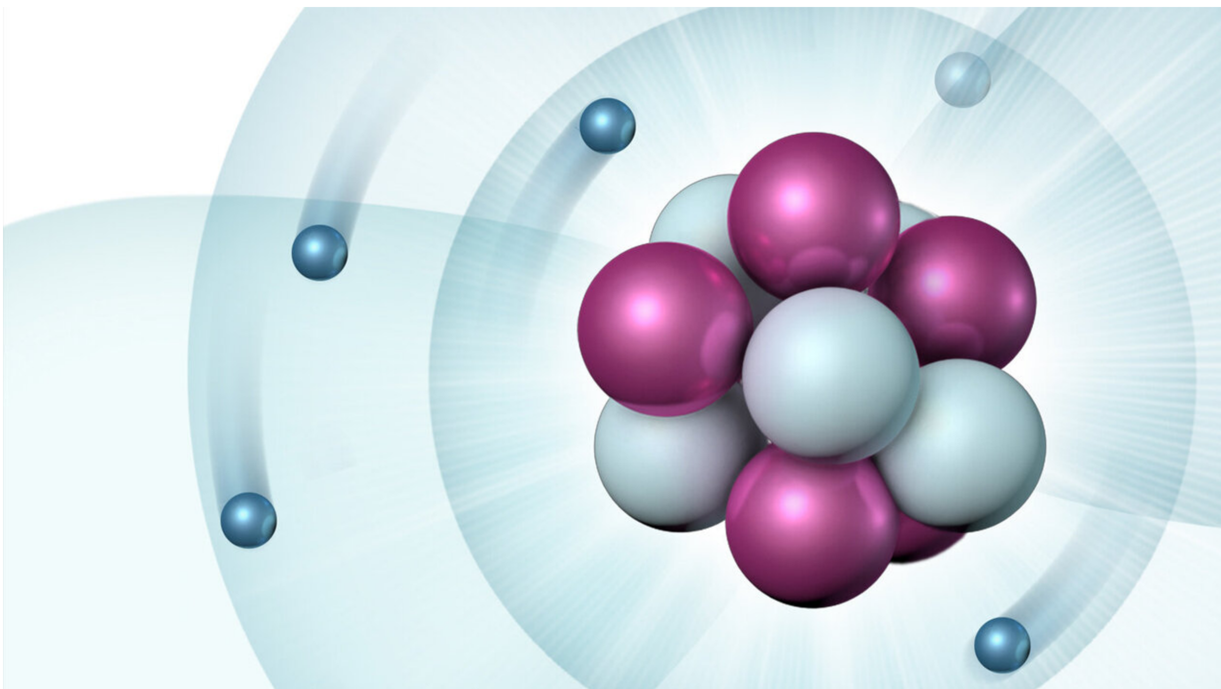

Schematic of a boron atom. Credit: Ellen Weiss/Argonne National Laboratory

Work opens a path to precise calculations of the structure of other nuclei.

In a study that combines experimental work and theoretical calculations made possible by supercomputers, scientists have determined the nuclear geometry of two isotopes of boron. The result could help open a path to precise calculations of the structure of other nuclei that scientists could experimentally validate.

Researchers at the U.S. Department of Energy's (DOE) Argonne National Laboratory, in collaboration with scientists in Germany and Poland, determined the difference in a quantity known as the nuclear charge radius between boron-10 and boron-11. The nuclear charge radius indicates the size of an atomic nucleus—which often has relatively indistinct edges.

Nuclear charge radii are difficult to compute with high precision for atoms much larger than boron because of the sheer number of neutrons and protons whose properties and interactions must be derived from quantum mechanics.

Nuclear theory builds from quantum chromodynamics (QCD), a set of physical rules that apply to quarks and gluons that compose the protons and neutrons within the nucleus. But trying to solve the nuclear dynamics using QCD alone would be an almost impossible task due to its complexity, and researchers have to rely on at least some simplifying assumptions.

Because boron is relatively light—with only five protons and a handful of neutrons—the team was able to successfully model the two boron isotopes on the Mira supercomputer and study them experimentally using laser spectroscopy. Mira is part of the Argonne Leadership Computing Facility (ALCF), a DOE Office of Science User Facility.

"This is one of the most complicated atomic nuclei for which it is possible to arrive at these precise measurements experimentally and derive them theoretically," said Argonne nuclear physicist Peter Mueller, who helped lead the study.

Looking at how the nuclear configurations of boron-11 (^{11}B) and boron-10 (^{10}B) differed involved making determinations at extraordinarily small length scales: less than a femtometer—one-quadrillionth of a meter. In a counterintuitive finding, the researchers determined that the 11 nucleons in boron-11 actually occupy a smaller volume than the 10 nucleons in boron-10.

To look experimentally at the boron isotopes, scientists at the University of Darmstadt performed laser spectroscopy on samples of the isotopes, which fluoresce at different frequencies. While most of the difference in the fluorescence patterns is caused by the difference in the mass between the isotopes, there is a component in the measurement that reflects the size of the nucleus, explained Argonne physicist Robert Wiringa.

To separate these components, collaborators from the University of Warsaw and Adam Mickiewicz University in Poznan carried out state-of-the-art atomic theory calculations that precisely describe the complicated dance of the five electrons around the nucleus in the boron atom.

"Earlier electron scattering experiments couldn't really say for sure which was bigger," Wiringa said. "By using this laser spectroscopy technique, we're able to see for certain how the extra neutron binds boron-11 more closely."

The good agreement between experiment and theory for the dimensions of the nucleus allows researchers to determine other properties of an isotope, such as its beta decay rate, with higher confidence. "The ability to perform calculations and do experiments go hand-in-hand to validate and reinforce our findings," Mueller said.

The next stage of the research will likely involve the study of boron-8, which is unstable and only has a half-life of about a second before it decays. Because there are fewer neutrons in the nucleus, it is much less tightly bound than its stable neighbors and is believed to have an extended charge radius, Mueller said. "There is a prediction, but only experiment will tell us how well it actually models this loosely bound system," he explained.

An article based on the research, "Nuclear Charge Radii of 10,11B," appears in the May 10 issue of *Physical Review Letters*.

More information: Bernhard Maaß et al, Nuclear Charge Radii of B10,11, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.122.182501

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