End of the magic: Shell model for beryllium isotopes invalidated

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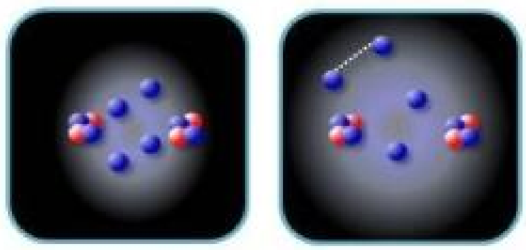

Dance of the nucleons: Theoretically, the beryllium-12 nucleus can be seen as a con-glomeration of two helium-4 nuclei with four additional neutrons. Assuming a magic neutron number of N=8, the shell model predicts that, in the beryllium-12 nucleus, all four of these neutrons should be located between the helium-4 nuclei (left). However, the research findings contradict this hypothesis and indicate that two of the neutrons are located outside the helium-4 nuclei. This structure, which more closely resembles the combination of a helium-8 nucleus and a helium-4 nucleus, means that the beryllium nucleus is significantly larger and indicates that the shell-model prediction of N=8 being magic is incorrect for the beryllium-12 nucleus. Credit: Andreas Krieger, Institute of Nuclear Chemistry, JGU

A research group led by Professor Dr. Wilfried Nortershäuser has, for the first time, managed to measure the size of the charge distribution in the atomic nucleus of the highly exotic beryllium-12 isotope. The researchers were surprised to find that the so-called charge radius increases in comparison with that of the beryllium-11 isotope, while the radius of the matter distribution was significantly smaller. These findings contradict the famous shell-model in nuclear physics regarding the structure of atomic nuclei as it was expected that the nuclear charge radius would also be smaller.

"Our result contradicts the shell model prediction and is a clear indication that the number of 8 neutrons is not magic in the case of beryllium isotopes," says Andreas Krieger of the Institute of Nuclear Chemistry at Johannes Gutenberg University Mainz (JGU). The magic numbers specify how many neutrons or protons can fit onto the shells of the nucleus of an atom.

Atomic nuclei are made up of nucleons, which are positively charged protons and uncharged neutrons. The number of protons determines the element, so that if there are four protons, this means that the nucleus must be that of an atom of beryllium. The number of neutrons may vary, and this is what leads to the existence of different isotopes of an element. In the case of beryllium, a light metal, only the beryllium-9 isotope is stable with its 9 nucleons (i.e. 4 protons and 5 neutrons). All other beryllium isotopes decay after a certain amount of time. Our planet is made up of about 500 stable or very long-lived isotopes; some 2,500 additional radioactive isotopes have to date been created and analyzed in various "isotope factories" around the world. The systematic study of atomic nuclei led to the discovery that nuclei that contain a certain number of protons and neutrons are particularly stable. These so-called magic numbers of protons or neutrons are 2, 8, 20, 28, 50, 82, and 126.

In 2008, the group led by Wilfried Nörtershäuser precisely measured the nuclear charge radius - the radius of an imaginary sphere around the region where the protons of the nucleus are concentrated - of the isotope beryllium-11 using a laser technique. The scientists were able to demonstrate that the seventh neutron in beryllium-11, which has a very small binding energy, is found at a considerable distance from the residual beryllium-10 core, and surrounds it like a halo. According to the mechanical model, the nuclear core is forced into a circular motion so that its charge is "spread" over a larger area, thus increasing its charge radius.

The researchers then shifted their focus to the nucleus of the beryllium-12 isotope. For this purpose, the sensitivity of the laser spectroscopic technique had to be enhanced by a factor of 1,000 because the isotope can only be generated with a low production rate at the ISOLDE/CERN isotope factory. In addition, the relevant particle only exists for less than the blink of an eye; after a mere 20 thousandth of a second, half of all the beryllium-12 nuclei produced will have decayed.

Using a high precision laser system, Nörtershäuser's young investigator group, in collaboration with colleagues from the Max Planck Institute of Nuclear Physics in Heidelberg and the KU Leuven, were able to measure the nuclear charge radius of this very exotic isotope. The researchers were surprised to find that the nuclear charge radius increases in comparison to that of the halo nucleus of beryllium-11, although the neutrons are more tightly bound in beryllium-12. This clearly contradicts the shell model prediction, in terms of which the charge radius should have decreased. "To explain the result, we have to assume that shells are not occupied in sequence, so that the third shell may already have neutrons before the second shell is completely full," says Nörtershäuser. This means that the number of eight neutrons in beryllium isotopes is no longer a magic number.

In its issue dated April 6, 2012, the professional journal Physical Review Letters reported on this experiment and the comparison with theoretical modeling calculations undertaken at the GSI Helmholtz Center for Heavy Ion Research. The calculations are clearly able to reproduce the evolution of the measured charge radii along the isotopic chain. Other investigations of nuclear structure designed to lead to a better understanding of the form of atomic nuclei are currently in the course of preparation at both ISOLDE at CERN and the TRIGA research reactor at the Institute of Nuclear Chemistry of JGU.

More information: A. Krieger et al., Nuclear Charge Radius of 12Be, *Physical Review Letters*, 108:14, 6 April 2012. doi:10.1103/PhysRevLett.108.142501

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