Argonne NATIONAL LABORATORY

Physics

Helium-8 study gives insight into nuclear theory, neutron stars

The most neutron-rich matter that can be made on Earth—the nucleus of the helium-8 atom—has been created, trapped and characterized by researchers at the U.S. Department of Energy's Argonne National Laboratory. This new measurement gives rise to several significant consequences in nuclear theory and the study of neutron stars.

"This result will help us test the best nuclear structure theories that are out there right now, including work from the Physics Division's own theory group," said Argonne physicist Peter Mueller, who, along with Ph.D. student Ibrahim Sulai and other Physics Division colleagues, used an innovative laser trap to confine individual helium-8 atoms long enough to precisely determine their nuclear charge distribution, a quantity that indicates how the atom's two protons and six neutrons arrange themselves to form the nucleus.

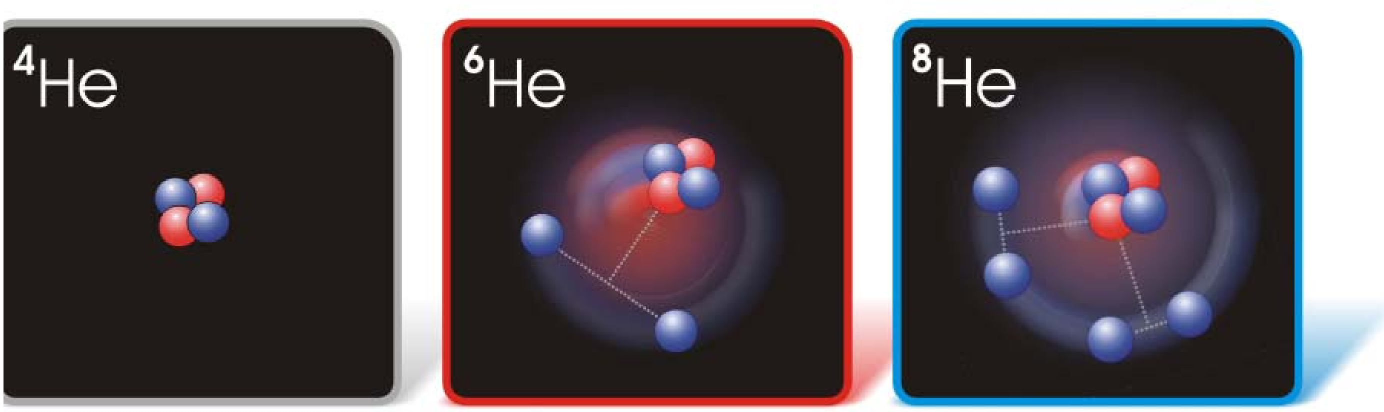
Unlike stable helium, which usually has two and occasionally one neutron that pack closely and symmetrically with two protons, the element's unstable isotopes—helium-6 and helium-8—have additional neutrons that form "halos" around the compact central core. In 2004, the Argonne team had determined that the two extra neutrons in helium-6 arrange themselves asymmetrically on one side of the nucleus, a few trillionths of a millimeter away from the core.

In their recent study, however, the researchers discovered that helium-8's four extra neutrons group themselves differently from helium-6's. The four helium-8 neutrons in the halo arrange themselves in a less lopsided way around the core, altering the dynamics of the nucleus.

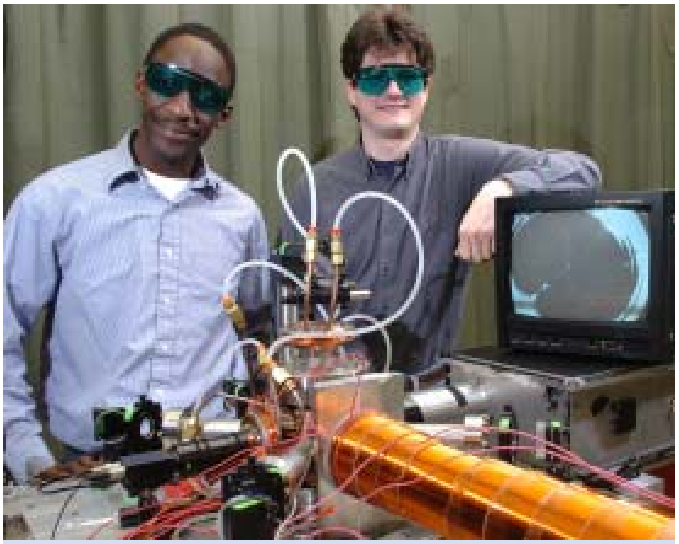
Helium-6 and helium-8 are both radioactive and decay quickly, complicating efforts to measure their properties. Helium-8 has a half-life of only a tenth of a second, meaning that samples of the atom have to be measured "on-line," or immediately after they are produced, which is not easy in the first place. Scientists require high-power accelerators to create even a tiny quantity of these atoms.

In this experiment, the Argonne scientists teamed up with Antonio Villari and his colleagues from the GANIL cyclotron facility in northern France, one of a handful of facilities that could generate a sufficient quantity of helium-8. Still, helium-8 represents only a small fraction of all the atoms that the cyclotron produces, so scientists needed a way to separate the target atoms from the rest of the atom stream and to observe each helium-8 atom long enough for an accurate study.

In order to do so, the scientists created an "atom trap" using six laser beams to restrain the helium-8 atoms. While other particles in the beam would fly right past the trap, about once every two minutes one helium-8 atom would fall into it. The laser beams functioned as the bars of a small cage—if the atom moved too much



Diagrams illustrate the nuclear structure of three forms of helium.



University of Chicago graduate student Ibrahim Sulai (left) and Argonne physicist Peter Mueller stand by one of their atom traps, similar to one that they used in France to identify the structure of the helium-8 atom.

to one side, then one of the beams would push it back towards the middle.

Once the atom was trapped, the scientists shined another pair of laser beams onto it. By tuning this laser's frequency, they matched the atom's resonant frequency, causing it to glow bright enough so that Mueller and his colleagues could tell they had collected it.

Because the atom's resonant frequency depends on its nuclear structure, each helium isotope glows at a slightly different frequency. With the help of precision atomic theory calculations provided by collaborator Gordon Drake from the University of Windsor, Ontario, the researchers were able to use the measured frequency data to reveal helium-8's nuclear structure.

While the team carried out the experiment at an accelerator in France, Argonne will soon submit a bid for a new facility that could produce far greater quantities of helium-8 and other rare isotopes, attracting students and scientists from all over the world to Illinois.

The proposed Facility for Rare Isotope Beams (FRIB), for which Argonne will submit a bid, could, for example, generate more than 1,000 times the number of unstable helium nuclei that researchers are now able to produce in the same time. "Having access to a facility like FRIB would open up many new possibilities for research into types of matter nearly impossible to examine otherwise," Mueller said. "This result shows that we have reached a scientific frontier, and FRIB would enable us to expand it even further."

A scientific paper on this work, "Nuclear Charge Radius of ^{8}He," was published in the December 21 edition of Physical Review Letters, and was selected as an "Editors' Suggestion" to promote reading across fields.
— *Jared Sagoff*

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