Department of Physics and Astronomy
College of Arts & Sciences

Fighting for Subatomic Independence

Mechanism behind correlations of protons in neutron-rich nuclei revealed

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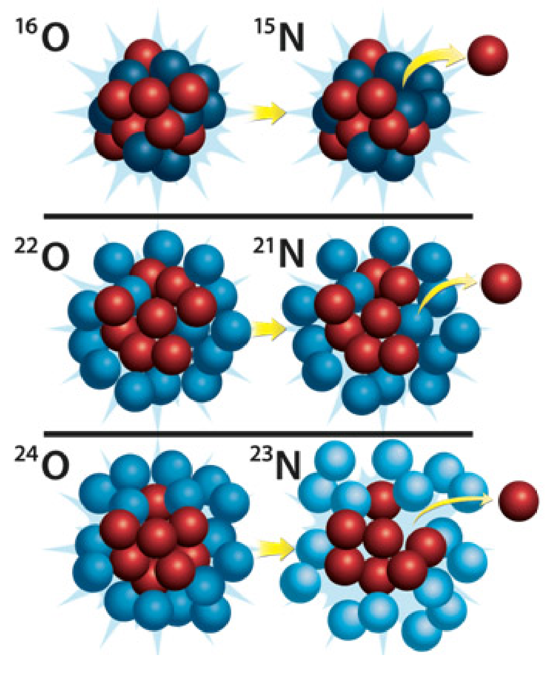
Protons and neutrons typically enjoy a peaceful coexistence, bound together in the nuclei of all matter. In the nuclear shell model, which has been very successful in explaining how nuclei are structured, there is an assumption that this peace comes with a certain level of detachment: each proton or neutron is an independent spirit, moving on its own within the collective force (or mean) field they generate as a whole. Deviations from an independent motion may reveal important features of how nucleons communicate under both normal and more extreme conditions. In a very recent article "Quenching of Spectroscopic Factors for Proton Removal in Oxygen Isotopes" that appeared in *Physical Review Letters*, Dr. Gaute Hagen and his colleagues attempt at understanding the role of correlations in very neutron rich nuclei, particularly in terms of the underlying nuclear forces, so that they can probe the limits of stability of matter.

Correlations play a crucial role in physics, and science in general. A proper understanding of correlations conveys important information about the underlying laws of motion. In quantum mechanical systems, the concept of independent particle motion has played, and continues to play, a fundamental role in studies of complex many-particle systems. Within such a picture, the various constituents in a complicated many-particle system are assumed (as in the nuclear shell model) to move in an average mean field set up by the other interacting particles. When scientists observe any kind of deviation from that model, they expect those observations to reveal important features of both the structure and the dynamics of a many-particle system. Unfortunately, traditionally there have been rather few such "observables" from which they can extract clear information. The consequences of correlations in many-particle systems are very difficult to measure experimentally and to interpret theoretically.



Proton knockout from Oxygen-16, Oxygen-22 and Oxygen-24. The thickness of the arrow showing the removed proton reflects the spectroscopic factor for this process, or in other words how "free" the protons can be considered in neutron rich oxygen isotopes.

Illustration by Andy Sproles, Oak Ridge National Laboratory.

Working with Øyvind Jensen and Morten Hjorth-Jensen from the University of Oslo and B. Alex Brown and Alexandra Gade of Michigan State University, Gaute (an adjunct assistant professor of physics and member of the Oak Ridge National Laboratory Physics Division), studied the chain of oxygen isotopes in a sophisticated numerical simulation, made possible by state-of-the-art high performance computing facilities at both the National Center for Computational Sciences at ORNL and the Notur project in Norway. This work also enjoyed support from the UNEDF SciDAC project.

As nuclear physicists, the group is keenly interested in understanding the role of correlations, particularly in terms of the underlying nuclear forces, so that they can probe the limits of stability of matter. This takes their studies into the territory of nuclei at high densities and temperatures, as well as into the realm of nuclei rich in neutrons or protons, the so-called "driplines," where adding just one more nucleon robs a nucleus of the stability it needs to stay intact. For years, nuclear theorists and experimentalists have worked together to understand the strongly correlated behavior of protons in the neutron-rich nuclei at the limit of the nuclear chart. For these nuclei, experiments suggest that the deeply-bound protons behave less independently as more neutrons are added to the system.

In a typical quantum mechanical fashion, the research team's simulation of oxygen isotopes allows selected neutrons to leave the nucleus as free particles and at the same time stay inside to occupy bound orbitals. The results demonstrate a surprising, intimate relationship between the enhanced correlations of the outnumbered protons and the freedom of the abundant neutrons to partly escape from the nucleus: if the neutrons are forbidden to enter the free continuum, the protons will fight harder for their own independence. In Figure 1 the proton knockout of the various oxygen isotopes are shown together with the influence of the continuum on the neutrons in the nitrogen nuclei.

While further studies will be necessary, this work provides researchers with new insight into the dynamics of many-particle systems.