Department of Physics and Astronomy
College of Arts & Sciences

Isotopic Rebels: Dancing to their Own Tune

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Every family has its rebels, and tin is no exception. There are isotopes that follow the rules to the letter, and there are isotopes that disregard the rules altogether. (Isotopes, remember, are just cousins within a given element’s tribe: they have the same atomic number but different numbers of neutrons.) University of Tennessee nuclear physicists lately have made some fascinating discoveries about the kindred nuclei of tin, which dwells within the "poor metals" neighborhood of the periodic table. Assistant Professor Kate Jones found that Tin-132 is an extreme example of the shell model (see "Magic Tin: A Cinderella Story"). But her university colleagues have found that relatives closer to Tin-100 might be more inclined to rebellion, defying the accepted wisdom of how a nucleus should behave.

Now more than half a century old, the shell model has become the blueprint for how nuclei—the heart of all atoms—are put together. If the shell of a nucleus is full, or "closed," there is little room for any additional protons or neutrons to come in and upset the balance. And if within that closed shell the existing protons and neutrons are assembled in what are called "magic" numbers—2, 8, 20, 28, 50, 82, and 126—they make the nucleus particularly strongly-bound and more stable against decay. "Doubly magic" nuclei have magic numbers of both protons and neutrons.

As Physics Professor Witold Nazarewicz explained, "In the shell model, protons and neutrons are described as moving in orbits, much like electrons in atoms, but the individual motion is modified by the tendency of nuclear forces to bind (them) into pairs, which dance around like couples at a ballroom."

Jones and her colleagues showed that Tin-132 is likely the best existing example of a doubly-magic nucleus—kind of the Fred Astaire and Ginger Rogers combination of the shell model. The team of experimentalists and theorists led by **Iain Darby** (a Postdoc at UT, now at IKS KU Leuven, Belgium) and **Associate Physics Professor Robert Grzywacz** has found, however, that the lighter isotopes of tin don’t necessarily dance in such a predictable pattern. They focused their efforts on the nuclear landscape around Tin-100, a rare, short-lived isotope with a doubly-magic nucleus of 50 protons and 50 neutrons.

Grzywacz explained that the nearby isotopes Tin-103, 105, and 107 are all structured with one, two or three pairs of neutrons, plus one odd neutron. At their lowest energy levels, or ground states, the spin of these isotopes fits the shell model. But that is not the case for Tin-101, which is essentially the core of Tin-100 with an extra valence neutron. In experiments at Oak Ridge National Laboratory’s Holifield Radioactive Ion Beam Facility, researchers found that the spin of the extra neutron in Tin-101 determines the spin of the isotope, and that in its ground state the spin is “flipped” from that of Tin-103. They attribute this reversal to the strength of the pairing force between neutrons, which changes depending on the neutrons’ orbits. This switch is unexpected because typically in territory around doubly-magic nuclei, three-particle and single-particle systems have identical spin.

"This effect is unique in the nuclear chart near closed shells," Grzywacz said. "We are lucky to see it because the single particle levels are so close in Tin-101."

He added that much the same way electrons pair up to carry current in superconductors, the presence of the Tin-100 core generates effects which enhance neutron pairing in the “odd” neutron orbital of Tin-101. This enhancement is what produces a spin flip in Tin-103.

"Clearly, Tin-100 is very special," he said. "The system’s doubly-magic nucleus plus few valence neutrons are particularly important because they are ‘simple’ and therefore can clearly and convincingly test nuclear models."

Reaching these conclusions was not simple, however. Tin-101 atoms are difficult to produce and to study, and Grzywacz said it took years of hard work to develop the necessary measurement tools.

"We have invented several experimental tricks," he said, some of which maybe be used for new superheavy element research.

The results of the work are published in *Physical Review Letters* in the paper "Orbital-dependent nucleonic superfluidity in the lightest known isotopes of tin."

In addition to Darby, Grzywacz and Nazarewicz, other UT physicists who worked on the experiment were Professor Carrol Bingham, Associate Professor Thomas Papenbrock, Sean Liddick and Jimmy Rotureau; and Graduate Students Lucia Cartegni, Stephen Padgett, and Mustafa Rajabali. The collaboration team was rounded out by Morten Hjorth-Jensen (University of Oslo), Jon Batchelder (Oak Ridge Associated Universities), Carl Gross and Krzysztof Rykaczewski (ORNL) and David Joss and Robert Page (University of Liverpool).