Magic Tin: A Cinderella Story

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See the related cover article in *Physics Today*'s August 2010 issue!

Tin might easily be considered a kind of Cinderella of the periodic table. It's relegated to the "poor metals" territory of the famous chart and is often put to work protecting other metals, like steel, or teaming up with copper to make bronze. But with a little magic, tin shines all on its own, a point illuminated by Dr. Kate Jones' work, as highlighted in a recent *Nature* paper.

Jones is an assistant professor of physics, specializing in nuclear structure. The nucleus makes up 99 percent of the visible matter in the universe and comprises protons and neutrons held together by the strong (nuclear) force. In the 1950s, physicists Maria Goeppert-Mayer and J. Hens Daniel Jensen discovered that nuclear architecture arranges those particles (known collectively as nucleons) into shells, akin to the orbits of electrons. Further, the structure of the shells mandates how the protons and neutrons move. Their work culminated in a 1963 Nobel Prize for Physics.

Now, nearly 50 years later, Jones and her colleagues have shown an excellent example of this blueprint in action. Their experimental results are explained in "The magic nature of ^{132}Sn explored through the single particle states of ^{133}Sn," published in the May 27 issue of *Nature*.

Once the shell of a nucleus is full, or "closed," it becomes much more difficult to add or subtract a proton or neutron. There are certain "magic" numbers of nucleons in closed shells—2, 8, 20, 28, 50, 82, and 126—that render a nucleus particularly strongly-bound and hence more stable against decay. "Doubly magic" nuclei have magic numbers of both protons and neutrons. This is the case of Tin-132, which has 50 protons and 82 neutrons and is one of only 10 doubly-magic nuclei observed to date. These nuclei are of particular interest to scientists because they can provide a standard by which to assess nuclear structure. Such a model can help predict the properties of more exotic nuclei, like those created in laboratories, which are much less-tightly bound and so live fleeting lives, swiftly falling victim to decay. An understanding of the nuclear shell model is also crucial to understanding the r- (rapid) process, in which a nucleus captures a large number of neutrons in rapid succession. This occurs, for example, in a supernova explosion, and is responsible for the formation of elements heavier than iron, such as gold and platinum.

"All the precious metals in your jewelry box: gold, silver, and platinum; are produced in the r-process," Jones said.

To get a clearer picture of the shell model, Jones and her colleagues designed an experiment to add a single nucleon to a Tin-132 nucleus, outside its doubly-closed shells. Working at Oak Ridge National Laboratory's Holifield Radioactive Ion Beam Facility, they collided Tin-132 with a deuteron: a deuterium nucleus composed of one neutron and one proton. The neutron was added to the Tin-132 nucleus, creating Tin-133. The proton emerged from the reaction, where the researchers measured its energy and angle to determine *how* the neutron was incorporated into the new Tin-133 nucleus. The investigations revealed that Tin-133 had even purer states than those in Lead-209, outside the doubly-magic nucleus Lead-208—the previous benchmark. The team concluded that Tin-132 is therefore most likely the best existing example of a doubly-magic nucleus, providing a new standard to infer the properties of less-easily-measured nuclei, particularly those responsible for the synthesis of the heaviest elements. That standard, interestingly enough, lasts under a minute.

"When Maria Goeppert-Mayer and Hans Jensen did their Nobel Prize work over 60 years ago, could they have anticipated that the best example of their work would be Tin-132, a nucleus that has a half-life of only 40 seconds?," Jones mused.

Jones' co-authors on the paper are K.Y. Chae, R. Kapler, Z. Ma, and B.H. Moazen of UTK; J.A. Cizewski, R. Hatarik, S.D. Pain, and T.P. Swan of Rutgers University; A.S. Adekola of Ohio University; D.W. Bardayan, J.C. Blackmon, D. Shapira, J.F. Liang, C.D. Nesaraja, and M.S. Smith of ORNL; K.A. Chipps, L. Erikson, and R. Livesay of Colorado School of Mines; C. Harlin, N.P. Patterson, and J.S. Thomas of the University of Surrey; R.L. Kozub and J.F. Shriner, Jr., of Tennessee Technological University; and F.M. Nunes of the National Superconducting Cyclotron Laboratory and the Department of Physics and Astronomy at Michigan State University.

Jones joined the physics faculty at UTK in 2006. She earned the Ph.D. in experimental nuclear physics at the University of Surrey, England, in 2000. In 2009 she was one of three nuclear physicists to receive a prestigious Outstanding Junior Investigator (OJI) Award from the U.S. Department of Energy. The Office of Nuclear Physics OJI program recognizes exceptional scientists early in their careers by supporting development of their individual research programs. The honor brought with it a total of $300,000 for three years to support her research.