NUCLEAR PHYSICS

Flood of New Isotopes Offers Keys to Stellar Evolution

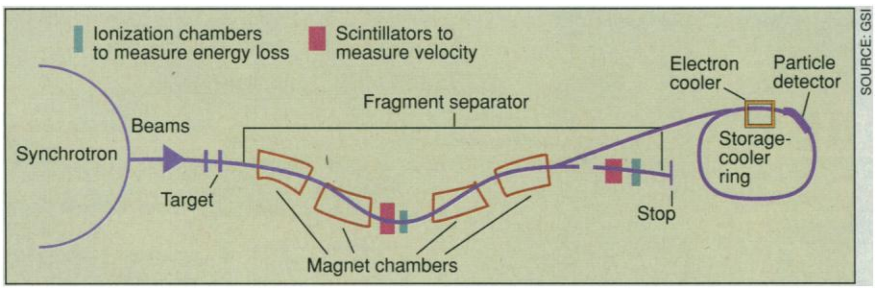
OMIYA, JAPAN—Germany's heavy-ion accelerator laboratory, GSI, in Darmstadt, is renowned for giving researchers the tools needed to create the six heaviest elements in the periodic table. But the facility is also helping scientists to fill gaps, at an unprecedented rate, in another important atomic listing—a chart of unstable isotopes. Measuring the mass and lifetimes of those isotopes, in turn, could help scientists confirm theories about how supernovae produce heavy elements and distribute them throughout the universe.

Some of the most exciting findings are coming from Monique Bernas, a nuclear physicist at the Institut de Physique Nucléaire in Orsay, France, and a team of researchers including Bernas's colleagues from Orsay, GSI, and the Centre de Recherche Nucléaire in Strasbourg. Drawing on data from two runs over 2 years, the team has identified more than 100 new isotopes produced by smashing uranium-238 ions into lead and beryllium targets. The new particles are primarily neutron-rich isotopes of medium mass. GSI's synchrotron is the only accelerator in the world capable of bringing uranium ions to the required speed of 750A MeV.

The shower of new isotopes has been a pleasant surprise to scientists. "It's really extraordinary," says Isao Tanihata, a nuclear physicist at Japan's Institute of Physical and Chemical Research (RIKEN). "Usually if you find just one isotope, you can make a paper out of it." Hans Geissel, a GSI nuclear physicist who collaborated with Bernas on the experiment, says that a half-century of work on fission had led many researchers to assume that future experiments would yield only familiar faces. "This was not the case," he says. "It is astonishing that we were able in two runs to find more than 100 new [nuclei]."

Speaking here last month at the Fourth International Conference on Radioactive Nuclear Beams, Bernas gave credit to GSI's synchrotron and to a 5-year-old piece of equipment called a fragment separator. The team uses a technique called projectile fragmentation, in which a stream of accelerated ions is directed at a thin target. Peripheral collisions between the projectile ions and target particles produce radioactive nuclei, which continue traveling in the direction of the original beam. Although this process normally produces proton-rich nuclei by shedding the more loosely bound neutrons, Bernas's group theorized that uranium-238 might trigger fission reactions that would produce neutron-rich nuclei. They were right.

The fragment separator is essentially a series of devices that pull the mixed stream of fragments emerging from the back of the target into separate beams based on their magnetic and atomic energy-loss characteristics. In effect, each isotope is sorted and placed on a unique path, making identification easier. Furthermore, any particular stream of fragments can be directed into other devices for further investigation. The high energy of the collision also strips away most electrons, making it easier for scientists to determine the mass of the nucleus. "It is a truly profound experimental facility," says physicist-astronomer Richard Boyd of Ohio State University.



Road to discovery. Particle beams are extracted from GSI's synchrotron and routed through the fragment separator and sometimes also the storage-cooler ring.

Aside from the sheer number of new isotopes, Bernas also recorded the first sighting of an isotope, nickel-78, with an unusual subatomic configuration. Protons and neutrons are believed to occupy a series of spherical "shells." A nucleus containing a full shell of either protons or neutrons is more stable than its neighbors on the periodic chart, and nuclei with full shells of both are more stable still. Nickel-78 fills that bill, making it an ideal subject for investigating theories about nuclear structure and properties.

Nickel-78 might also be a key to understanding the rapid neutron capture process, or r-process, which supernovae use to synthesize heavy elements. The r-process is thought to trace a path through the chart of elements, and nickel-78 is believed to occupy one of the key points along this path. Determining its properties is expected to help pin down the r-process path. "It's really important," says RIKEN's Tanihata. "None of the [heavy] nuclei along this r-process path have been observed before." Tanihata, Bernas, and Boyd are planning ways to identify even heavier isotopes along the r-process path.

Other groups at GSI are using the fragment separator in combination with the storage-cooler ring. The fragment separator sorts the isotopes, putting each isotope on its own trajectory. One or several isotopes can then be selected and injected into the storage-cooler ring, where they are "cooled" to the same velocity. The fragments are randomly spaced out around the ring, with the pattern of distribution providing a way to determine the frequency, and then mass, of the individual fragments. The lifetimes of isotopes can be observed through a change in their trajectory resulting from a shift in their magnetic properties as they decay. Such mass and lifetime measurements are expected to provide important clues about the distribution of mass in the universe, stellar processes, and the age of the universe itself.

Researchers also welcome the separator's ability to produce nuclei that are stripped of most, if not all, electrons, because that is the condition in which they are believed to exist in supernovae. That quality has taken on added meaning in the wake of the recent discovery at GSI that bare nuclei and the same isotopes carrying electrons have different half-lives. "It was always assumed that an isotope had a certain lifetime, and you could relate it to the age of the universe," GSI's Geissel says. The knowledge that lifetime depends on the charge state, he says, will have to be considered when using elements such as rhenium and osmium as nuclear clocks to time stellar processes.

The one drawback to the GSI apparatus is the low intensity—number of isotopes per unit of time—for some of the observed nuclei. But modifications planned over the next few years are expected to boost the intensity of the primary beam and capture more of the generated fragments. Such steps should raise the observed rate of secondary products such as iron-70 from four events per hour to four events per second. That profusion of particles should help researchers to fill in the blanks on their isotope charts—and in their theories of stellar evolution.

–Dennis Normile