Joint Institute for Nuclear Astrophysics

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# Gamow-Teller transitions from $^{56}$Ni

By measuring nuclear reactions occurring in a beam of unstable isotopes traveling nearly half of the speed of light, nuclear physicists are a large step closer to understanding how the elements heavier than iron are created. The key is understanding the chances of electrons being captured by protons in the nuclei of rare isotopes in the two most common types of supernovae.

Nuclear physicists at the National Superconducting Cyclotron Facility (NSCL) at Michigan State University (MSU) recently succeeded in using a new technique to extract information about nuclear reactions involving the unstable isotopes that are critical for creating accurate simulations of supernovae. Not only was the technique successful in this particular study that looked at nickel-56, it can be applied to many similar isotopes in order to help understand some of the most awesome astrophysical phenomena known to man.

The results were recently reported in Physical Review Letters (http://prl.aps.org/abstract/PRL/v107/i20/e202501) and commented on in a Viewpoint in the same issue written by Karlheinz Langanke of GSI, Germany's premier nuclear physics laboratory (http://physics.aps.org/articles/pdf/10.1103/Physics.4.91).

The development of this new technique opens the road to extend similar studies to regions of the nuclear chart previously unreachable and the successful experiment at NSCL leads the way for many new discoveries.

Two astronomical phenomena that are thought to be responsible for the creation of elements heavier than iron are core-collapse and thermonuclear supernovae. In the former type, a massive star collapses after it has burned its nuclear fuel through fusion and can no longer withstand the gravitational forces. Eventually, it ejects material into space after the density has increased so much that a powerful shockwave destroys the star. The latter kind is thought to involve a white dwarf star that slowly consumes matter from a nearby companion star, which can ignite and explode due the increased pressure, density and temperature in the star.

Many questions remain about how exactly these gigantic explosions take place, but they have one thing in common – a particular type of nuclear reaction called "electron-capture" plays an important part in both.

The experiment conducted at NSCL determined the probability of the Gamow-Teller transition occurring from Nickel-56 to Copper-56. In the crust of a neutron star, large numbers of electrons and a huge amount of energy makes it possible for protons to capture electrons and become neutrons, emitting neutrinos in the process. This nuclear reaction reduces the number of electrons present and lowers the star's temperature, both of which accelerate the star's collapse leading to a supernova.

In a Gamow-Teller transition, the reverse happens and a neutron in the nucleus transforms into a proton. For isotopes with nearly the same number of protons and neutrons – such as nickel-56 – the strength of both processes is nearly identical. So by studying this Gamow-Teller transition, the nuclear physicists were able to learn just as much about the reverse process that occurs in pre-supernova stars.

The new data for Nickel-56 are not only important because this isotope is abundant in supernovae stars, but also because it is key to unlocking better methods to use theory to estimate the electron-capture rates on many more unstable nuclei in the iron region.

In order to make these measurements, many things had to happen in concert. A beam of nickel-58 was sped up to 100.000 miles per second and smashed into a thin foil of beryllium. A small number of the ions hit another nucleus in the foil and fragmented into pieces. Yet a smaller number of these were the nickel-56 isotopes the nuclear physicists wanted to study.

A series of powerful magnets separated the wheat from the chaff, delivering a beam of nickel-56 isotopes that in turn were shot into a target of liquid hydrogen. Some of the isotopes interacted with the single-proton nuclei and exchanged a neutron for the proton—a Gamow-Teller transition—creating copper-56. Immediately after the reaction, the S800 Spectrograph detected the heavy fragments produced in the reaction and triggered the Low Energy Neutron Detector Array, which measured the low-energy recoiling neutrons from the interaction.

Both the liquid hydrogen target (funded through a NSF MRI to Ursinus College) and LENDA were used for the first time in an experiment.

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