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Captured electrons excite nuclei to higher energy states

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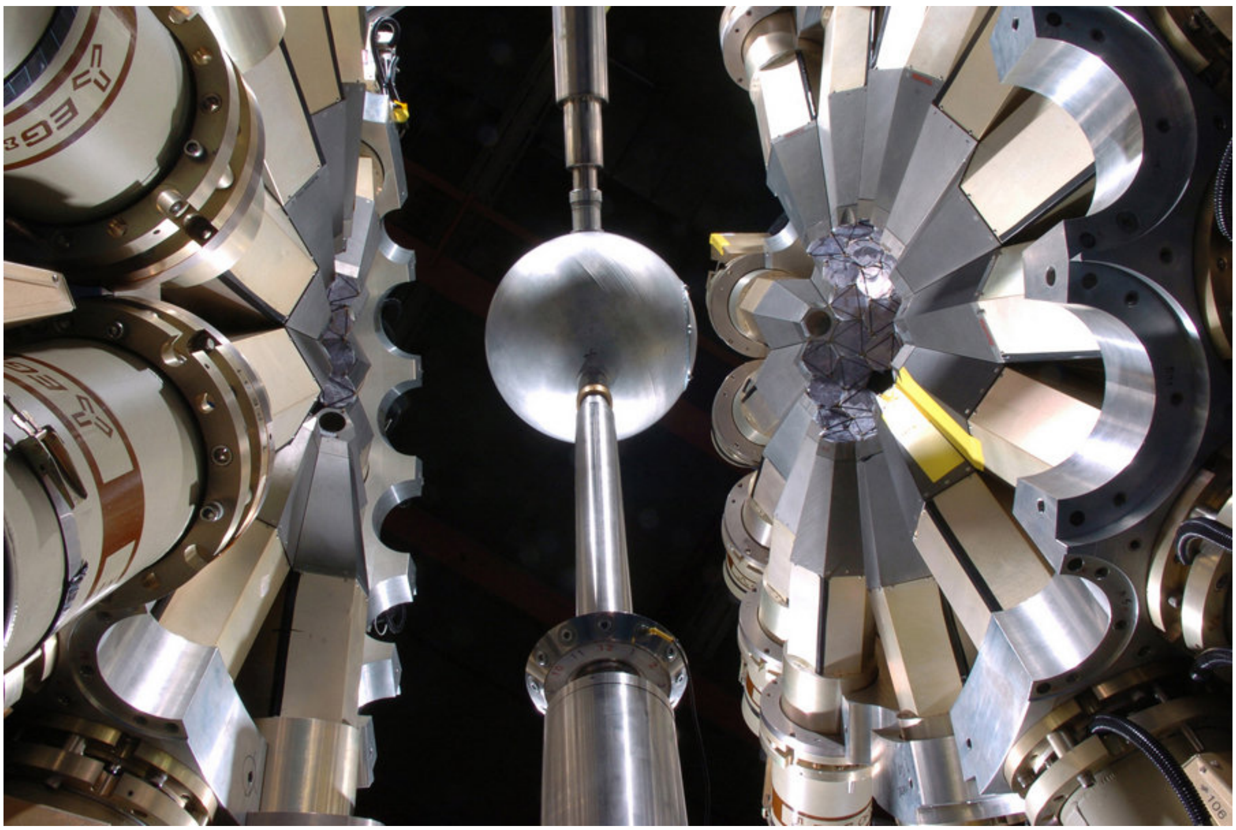


Argonne scientists and collaborators used the Gammasphere, this powerful gamma ray spectrometer, to help create the right conditions to cause and spot a long-theorized effect called nuclear excitation by electron capture. Credit: Argonne National Laboratory

For the first time, physicists from the U.S. Department of Energy's

(DOE) Argonne National Laboratory and their collaborators, led by a team from the U.S. Army Research Laboratory, demonstrated a long-theorized nuclear effect. This advance tests theoretical models that describe how nuclear and atomic realms interact and may also provide new insights into how star elements are created.

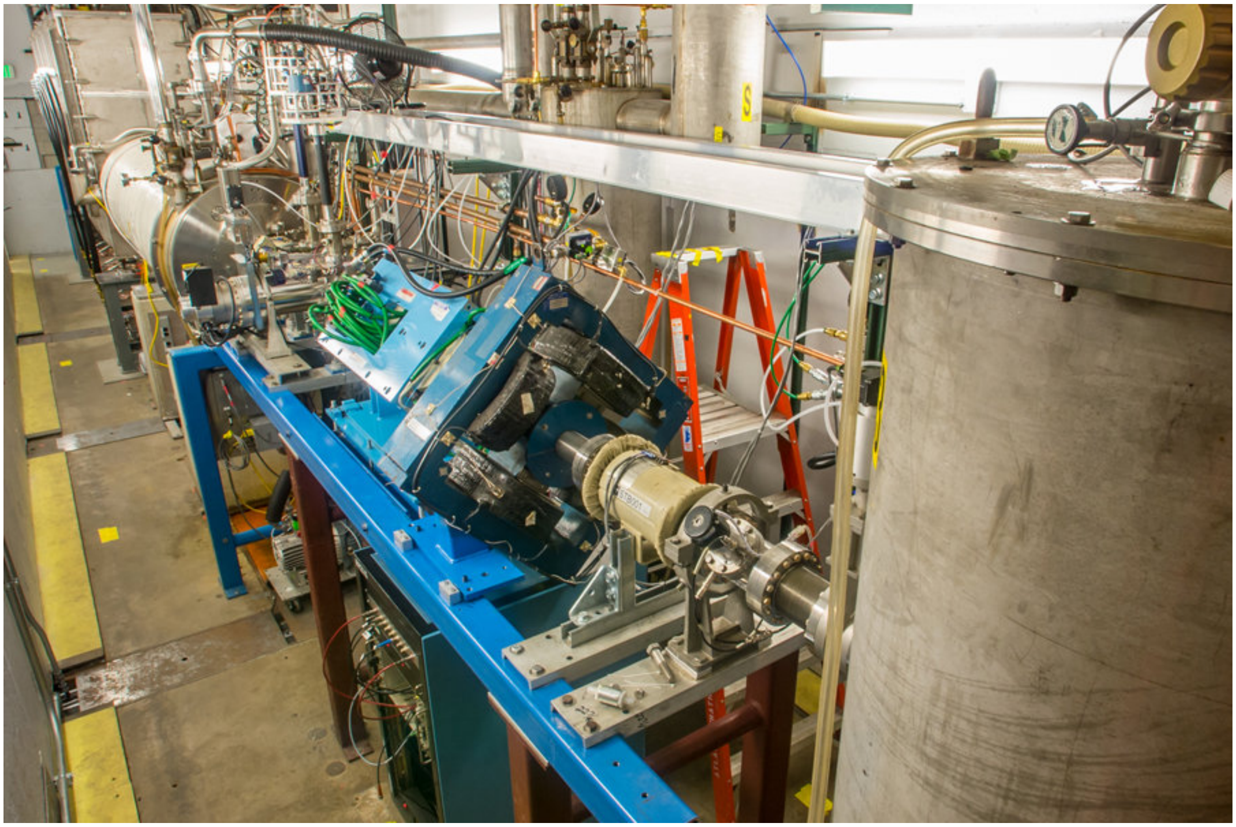
Physicists first predicted the effect, called nuclear excitation by electron capture (NEEC), over 40 years ago. But scientists had not seen it until now. Using the Argonne Tandem Linac Accelerator System (ATLAS), and Gammasphere, a powerful gamma ray spectrometer, the researchers created the right conditions to cause and spot the behavior.

The NEEC effect occurs when a charged atom captures an electron, giving the atom's nucleus enough energy to jump to a higher excited state.

An excited nucleus stays in each energy state for a while before decaying into the state below it, shedding energy in the form of gamma rays. These excited states typically last for much less than a billionth of a second, but in some rare cases, they can live far longer, even for millions of times the age of the universe.

The longer-lived energy states are called isomers, and to observe the NEEC effect, the researchers produced an isomer with a half-life of about seven hours. In other words, after seven hours of existing in the isomeric energy level, about half of the nuclei of this type will decay.

The scientists chose to produce this nucleus, called ^{93}Mo, an isotope of molybdenum, because of its unique arrangement of energy levels. "There is an allowed energy level not far above the isomer state," said the Army Research Laboratory's Chris Chiara, the study's lead scientist. "Under normal circumstances, the isomer will decay naturally after about seven hours, but if NEEC occurs, the nucleus is excited out of the isomer to the slightly higher state. That state then quickly decays to a state below the isomer, emitting gamma rays that have distinct energies that we can look for."



Argonne scientists and collaborators used the Argonne Tandem Linac Accelerator System to help create the right conditions to cause and spot a long-theorized effect called nuclear excitation by electron capture. Credit: Argonne National Laboratory

To make ^{93}Mo, the researchers used ATLAS, a DOE Office of Science User Facility, to accelerate a beam of ions towards the atoms in a target foil where the nuclei of the two fused together. These reactions formed ^{93}Mo in a highly excited state at the center of Gammasphere, which waited to detect evidence of the effect in the form of gamma rays.

As the ^{93}Mo atoms move through the target material, they bump into atoms that slow them down and strip them of electrons, putting them in a high-charge state. Electrons from the target atoms then fill those vacancies in the ^{93}Mo, and if the electrons have the right energy before the capture, they may excite the nucleus into the next highest state. When this state decays, the nucleus releases a gamma ray that can be traced back to the NEEC reaction.

The target, made by ATLAS's in-house target maker, John Greene, played a crucial role in the detection of NEEC. Greene was able to work on the fly, tweaking the target as the scientists learned more about the ^{93}Mo nucleus. With everything in place, the team began to gather data.

"We detected gamma rays from these reactions over the course of the three-day experiment, and we accumulated around eight billion events in total," said Mike Carpenter, a group leader at Argonne in charge of Gammasphere. "From these events, we were able to identify around 500 gamma rays that were emitted during the decay of ^{93}Mo that wouldn't have been released if it weren't for NEEC."

The power and sensitivity of Gammasphere was vital to the experiment's success. "We made use of a new digital Gammasphere mode, which allowed us to run at a rate about five times higher than would have been possible with the older analog system," said Chiara. But it was not only the hardware at ATLAS that was important. "As experts in the field of gamma-ray spectroscopy, the Argonne staff provided invaluable scientific and technical support," he added.

The team's success may lead to advances in astronomy and cosmology as it could improve the accuracy of models scientists use to gauge how stars form. The quantities of elements in a star depend largely on the structure and behavior of nuclei. Over long periods, and with vast numbers of atoms interacting, the survival—or destruction—of specific isomers can have a cumulative influence. Taking the NEEC effect into account could improve our understanding of what stars are made of and how they evolve.

Scientists at the Army Research Laboratory are also interested in possible future applications for the controlled release of nuclear energy from isomers via the NEEC effect. If scientists and engineers could harness this energy, it might help develop power sources with 100,000 times greater energy per unit mass than chemical batteries.

The results of the experiment were published in a paper titled "Isomer depletion as experimental evidence of nuclear excitation by electron capture," on February 8 in *Nature*.

More information: C. J. Chiara et al, Isomer depletion as experimental evidence of nuclear excitation by electron capture, *Nature* (2018). DOI: 10.1038/nature25483

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