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Exotic nuclei held together by another kind of 'magic'

Experiments show how massive nucleus gains stability.

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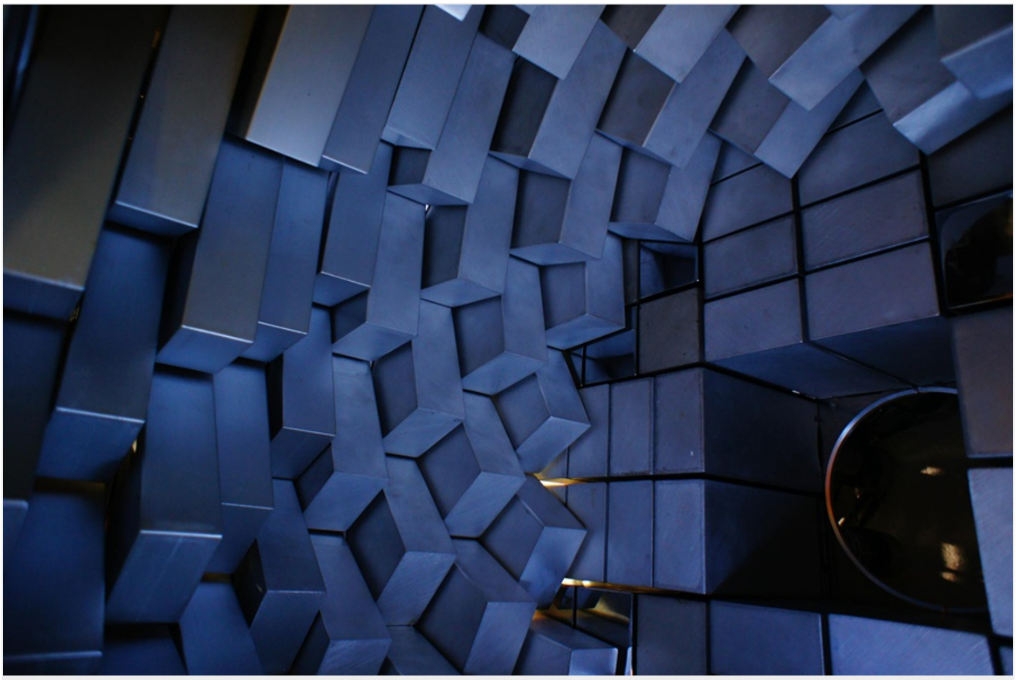

Satoshi Takeuchi

A gamma-ray detector at the Radioactive Isotope Beam Factory in Japan was used to study properties of exotic nuclei.

Researchers in Japan have provided experimental evidence for a 'magic number' of neutrons that stabilizes 'fat' atomic nuclei overstuffed with these particles. The results, reported in *Nature* today[1], refine the understanding of how nuclear forces hold nuclei together, and should inform theories of how elements form in stars.

Protons and neutrons in atomic nuclei are organized into a shell-like structure analogous to that of electrons orbiting the nucleus. Just as the filling of successive electron shells creates highly stable atoms — the inert gases — so the filling of shells with the 'magic numbers' of 2, 8, 20, 28, 50, 82 and 126 protons or neutrons produces particularly stable nuclei.

However, it has been known since the 1970s that the magic numbers of neutrons can be different for exotic nuclei, which have an unusually large imbalance of protons or neutrons. Determining which numbers are 'magic' can test current theories of the nuclear forces that bind protons and neutrons, and aid predictions of whether new, artificial superheavy elements can be stabilized.

For exotic nuclei, 28 is not a magic number of neutrons[2]. In 2001, a Japanese team suggested that there might instead be a magic number at 34 neutrons[3]. This would make atoms of the exotic calcium isotope ^{54}Ca (which has 20 protons and 34 neutrons) 'doubly magic', because of its closed shells of protons and neutrons. But this proposal has gone unresolved for more than a decade because it is hard to make ^{54}Ca.

'Doubly magic' stability

David Steppenbeck, a nuclear physicist at the University of Tokyo, and his colleagues were able to make ^{54}Ca atoms by firing high-energy beams of the scandium and titanium isotopes ^{55}Sc and ^{56}Ti (which are already neutron-rich 'exotics') at a target made of beryllium, using the particle accelerator at the Radioactive Isotope Beam Factory at the University of Tokyo. "No other facilities in the world can produce ^{55}Sc and ^{56}Ti beams with sufficient intensities to successfully measure excited states in ^{54}Ca," says Steppenbeck.

These collisions occassionally produce an ‘excited’ ^{54}Ca nucleus, which has excess energy that it sheds by releasing a gamma ray. The energy of the gamma ray indicates how much energy the excited ^{54}Ca nucleus has, relative to the unexcited (ground-state) version. The larger the energy difference, the more stable the ground state.

Steppenbeck and his colleagues found that the ground state of ^{54}Ca is relatively stable compared to other exotic isotopes, confirming the idea that it gains stability by being doubly magic.

Why is the magic number of neutrons in exotic nuclei different from that of ordinary nuclei? One possibility is that in very neutron-rich nuclei, nuclear forces are not based on merely the sum of all the interactions between pairs of protons and neutrons. Three-way interactions among triplets of particles, or ‘three-body forces', must also be taken into account.

“I think this new work confirms the crucial importance of three-body forces in the nuclear interaction,” says Stéphane Grévy, a nuclear physicist at the Bordeaux Gradignan Centre for Nuclear Studies in France.

The work will help researchers seeking to improve theories of how heavy elements are formed from lighter ones inside stars and supernovae, a process called nucleosynthesis. A key step in the process involves the rapid capture of neutrons by nuclei that are already neutron-rich. However, quite what the current findings imply for this process remains to be explored.

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References

1. Steppenbeck, D. *et al*. *Nature* **502**, 207–210 (2013).
2. Bastin, B. *et al*. *Phys. Rev. Lett.* **99**, 022503 (2007).
3. Otsuka, T. *et al*. *Phys. Rev. Lett.* **87**, 082502 (2001).