Researchers Perform Quite a Magic Trick: Making Nickel-48 Materialize

^{48}Ni has so many more protons than neutrons that it ought to fall apart, but it is stabilized by having just the right number of both nucleons to form closed shells.

Chalk up another one for the shell model . . . maybe its last one for a while. The model has had a long run in predicting which nuclei would have special stability compared to their neighboring isotopes because they had the right numbers of protons and neutrons—magic numbers—to completely fill the available shells, or energy levels. By now, experimenters have found about ten doubly magic nuclei (in which the numbers of protons and neutrons are both magic) but still sought one elusive holdout: ^{48}Ni. A group of researchers working at the Grande Accélérateur National d'Ions Lourds (GANIL) in France has now produced this lightest of nickel's isotopes.[1] (Two other isotopes of nickel are also doubly magic.)

Existing accelerator facilities are not expected to yield any more bound isotopes with doubly magic configurations; the remaining candidates among the lighter nuclei have such high excesses of protons over neutrons or vice versa that they would be unbound. In the region of superheavy elements, magic numbers are not known very accurately. Even for the lighter nuclei, comments Richard Casten of Yale University, the concept of magic numbers might be somewhat fragile: Magnesium-32, for example, has 20 neutrons—normally a magic number—but still does not exhibit closed-shell behavior. The robustness of magic numbers will be further explored by advanced radioactive beam facilities now being planned, which are expected to come on line during the next ten years.

Had it not been for the stability conferred by its doubly magic numbers, ^{48}Ni might never have been seen at all. The nucleus holds eight more protons than neutrons, so that its strong Coulomb forces compete with the nuclear forces that hold the nucleus together. When one plots the atomic number Z against the neutron number N for all the known nuclides, ^{48}Ni lies on the edge of the populated territory, at the drip line beyond which nuclei simply cannot hold together. Whereas the role of magic numbers is well established among the stable nuclei, the observation of ^{48}Ni extends the applicability of magic numbers to a far more extreme case: ^{48}Ni is the most proton-rich nucleus ever seen.

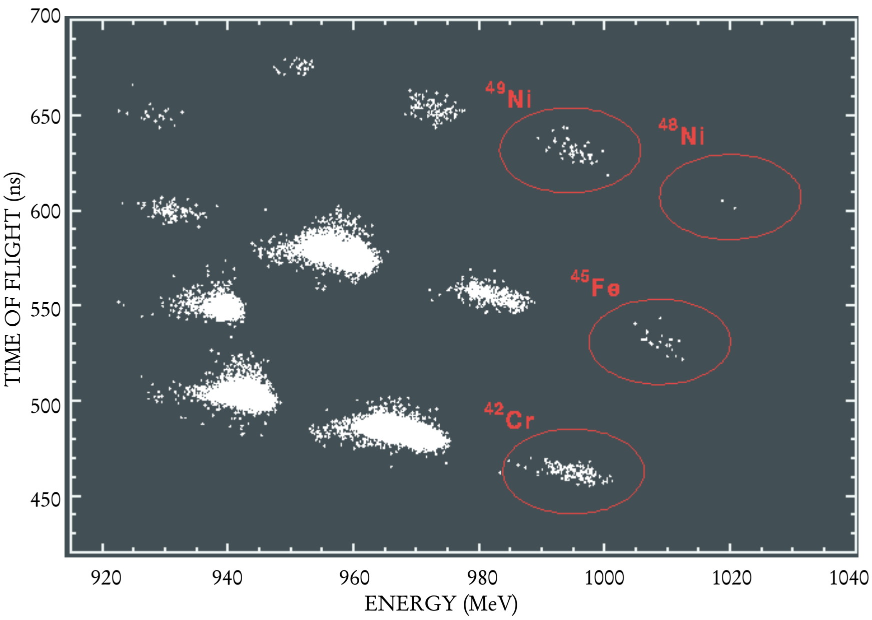
The synthesis of ^{48}Ni was performed by researchers from the Centre d'Etudes Nucléaires (CEN) de Bordeaux-Gradignan, from GANIL, from the Institute of Atomic Physics in Bucharest-Magurele, Romania, and from the University of Warsaw; their spokesman is Bertram Blank of CEN. In their experiment, the team bombarded a natural nickel target with a beam of highly charged ^{58}Ni ions over a ten-day period. Within the multitude of nuclei generated by this collision, the group culled at least two, and possibly four, nuclei of ^{48}Ni. The atoms lived for more than 0.5 μs.

Now that they have identified ^{48}Ni, Blank and his colleagues want to study its decay mode, which may offer insight into a central question of nuclear structure: whether nucleons are correlated by pairs within the nucleus. ^{48}Ni is expected to decay by emission of two protons because single proton decay is energetically forbidden. (Iron-45 is another candidate for two-proton decay.)

Experimenters want to study the angular correlations and energy distributions of the two protons to determine whether they are correlated as they emerge from the nucleus. "We have already tried to see the ^{48}Ni decay, but the experiment was optimized to identify the nucleus rather than to detect its decay," Blank told us. "We have proposed a new experiment to look for the decay and we should run it before next summer."

Low-probability events

It was no easy feat to form proton-rich ^{48}Ni. The French-Rumanian-Polish collaboration had made a stab at it in two experiments at the Laboratory for Heavy Ion Research (GSI) in Darmstadt, Germany, in 1993 and 1996. Those experiments[2,3] produced a few nuclei each of ^{50}Ni and ^{49}Ni, but the calculated cross section for forming ^{48}Ni, with one fewer neutron, is lower than that for ^{49}Ni by a factor of 30–35. (On average, the drop in cross section from one mass to the next is a factor of 20 in this mass region.) Compared with the beam at GSI, a newly

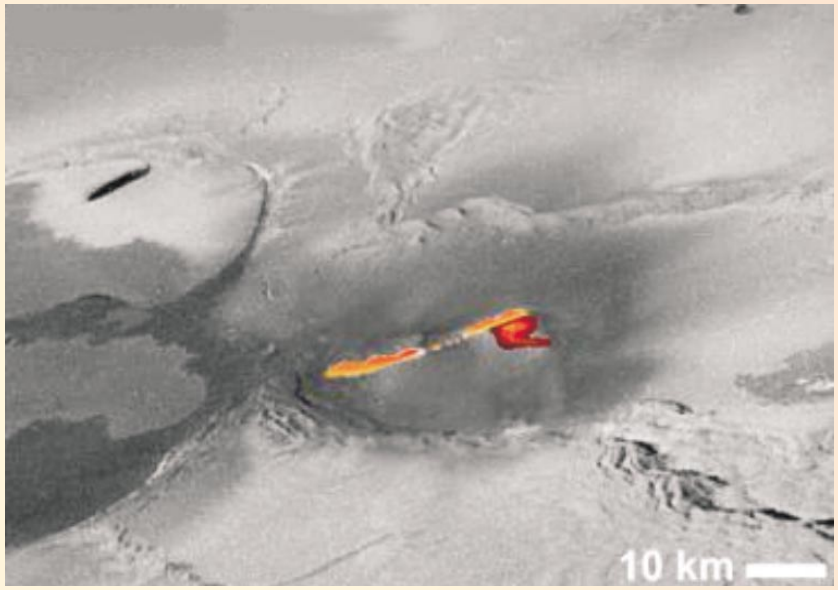


Two atoms of ^{48}Ni are identified by their values of energy and time of flight (rightmost circle). The atoms are among the products of the collisions of high-energy nickel-58 atoms with a natural nickel target in an experiment run at GANIL in Caen, France. The reaction products also include other proton-rich isotopes: ^{49}Ni, ^{45}Fe, and ^{42}Cr. (Adapted from ref. 1.)

Galileo Flyby Discovers Immense Lava Fountain on a Jovian Moon

By an improbable stroke of good fortune, the north-polar region of Io, the innermost of Jupiter's four Galilean moons, was putting on an extraordinary volcanic display just as NASA's Galileo spacecraft flew by to take pictures on Thanksgiving Day last year. Because its proximity to Jupiter and its orbital resonance with two neighboring moons subject it to severe tidal flexing, Io turns out to be the most volcanically active body in the Solar System. (See the cover of this issue.)

But the Thanksgiving outburst captured by Galileo's Solid State Imaging Camera (SSI) and shown at right was no run-of-the-mill Ionian volcanic outburst. It appears to be a "lava fountain," not unlike—but much larger than—similar displays occasionally seen in volcanically active terrestrial sites like Hawaii. No such event had ever been clearly observed on Io. Early in December, the newly discovered lava fountain was named Tvashtar, after the Hindu sun god who forged the thunderbolts of Indra. In the same vein, Loki, Io's biggest volcano, is named after a Norse blacksmith deity.



The Io fountain was a curtain of very hot lava shooting up more than a kilometer from a 25 km long linear fissure in the moon's crust. The Galileo team was able to estimate the spectacular height of the curtain because the SSI imaging angle, in this polar region, was very oblique, and because—by another stroke of luck—the fountain was captured independently, just three hours later, by the Infrared Telescope Facility (ITF) on Mauna Kea in Hawaii, which recorded it as a bright prominence very close to Io's limb.

Information on the fountain's temperature was derived from an infrared spectrum taken by Galileo's Near-Infrared Mapping Spectrometer and from the intensity of the SSI image itself. The lava was, in fact, so incandescently hot that photon saturation effects on both instruments yielded only a lower limit on the temperature—namely, 1250 K. The actual temperature is probably closer to 1600 K.

"Tvashtar dramatically illustrates our new view of Io as a world of high-temperature molten silicate rock vulcanism," says John Spencer (Lowell Observatory), a member of the ITF team. "It is clearly not the much calmer world of relatively cool sulfur eruptions and glorified geysers imagined by some of us after the Voyager flybys 20 years ago."

The image shown here has been modified by the Galileo team to remove "bleeding" artifacts caused by the glowing lava's overload of SSI camera pixels, and the team has added colors to indicate how the lava fountain would look to the eye. The pool of lava shown at the right-hand end of the fissure is a bit of artistic license based on pixel-overloading thermal emission from that region; but it might, in fact, be another fountain. The original SSI image was black and white. The picture, whose spatial resolution is an impressive 185 m, was taken from a distance of 17 000 km..

Torrence Johnson of Caltech's Jet Propulsion Laboratory is Galileo's project scientist. The spacecraft was launched in 1989 and arrived at Jupiter six years later. Until recently, Galileo has spent most of its time in the safe outer reaches of the Jovian system, far away from the dangerously intense radiation belt near Io's orbit. The discovery of Tvashtar was announced at the December 1999 meeting of the American Geophysical Union in San Francisco.

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developed ion source at GANIL produced a beam of nickel ions with lower energy (74.5 MeV/nucleon) but the higher current (7.2×10^{11} particles/s) more than compensated for the lower energy in terms of the numbers of ^{48}Ni nuclei that could be formed. Blank said that his team initially wondered whether GANIL's increased beam intensity would be sufficient to produce ^{48}Ni. Apparently it was.

The experimenters used the technique of projectile fragmentation, which involves the breakup of the beam particles—in this case ^{58}Ni ions with charges of +26—as they slam into a metal target. In such an experiment, "everything happens, from stripping off a single neutron to breaking up the entire nucleus," said Michael Thoennessen, who does similar experiments at Michigan State University. "Among the myriad possibilities are a very few events in which exactly ten neutrons and no protons have been stripped off the beam particles."

To sort out these very few events from several hundred other fragment isotopes, Blank and his coworkers passed the stream of particles emerging from the target through a series of selectors and detectors collectively known as the LISE3 separator. The separator filters out those events not likely to correspond to the ^{48}Ni nuclei being sought. The remaining nuclei fall onto a series of five silicon detectors. With the data collected by the silicon detectors as well as by sensors placed within the LISE3 separator, the experimenters characterize every candidate nucleus by a total of ten parameters, such as energy loss, residual energy, position, and time of flight. To be identified as a particular isotope, every one of the ten parameters must fall within a specified range of the expected value.

The figure on page 19 is a plot of two of the measured parameters:

energy loss in the first silicon detector and time of flight between a point in the LISE3 separator and the first silicon detector. The data points fall into groups corresponding to the scatter around the various nuclei that have been produced in the collision. Two data points lie in the expected range for ^{48}Ni. Also circled are points corresponding to three other proton-rich nuclei.

The researchers believe that they actually saw four nuclei of ^{48}Ni. The additional two events simply were missed by the instrument registering the time that particles passed a point upstream. The efficiency of that instrument was only 70%, because it had to withstand a fairly high counting rate. When Blank and his colleagues dropped the time-of-flight criterion from their 10 required parameter values, four atoms made the cut.

From their data, the French-Rumanian-Polish collaboration was able to set a lower limit on the halflife for the decay of ^{48}Ni. From that lower limit, in turn, they deduce a maximum value expected for the Q value, or energy release, for two-proton decay. If the two-proton decay can be seen, the measured Q value may place some constraints on nuclear theory. Additional interest may be generated by comparing properties of ^{48}Ni with those of its mirror nucleus, calcium-48. Calcium-48 is the only mirror nucleus of a doubly magic isotope that is stable against particle emission.

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References

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