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Can MAGIS work magic for separating stable isotopes?

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Can MAGIS work magic for separating stable isotopes?

Atomic beams, optical pumping, and magnet geometry are the crux of a fledgling method that may help meet the demand for pure isotopes.

Mark Raizen didn't set out to separate isotopes. But a few years ago the University of Texas at Austin physicist realized that the methods he was using to cool atoms to near absolute zero could be adapted to enrich isotopes, and he had a hunch his approach—magnetically activated and guided isotope separation (MAGIS)—could help satisfy the growing demand for isotopes.

Fundamental research, medicine, energy, and other markets are finding new and growing applications for isotopically enriched materials, both stable and radioactive. "Many isotopes have been expensive and rare. They're like an untapped natural resource," says Raizen. It's not unusual for enriched stable isotopes to cost $50 000 per gram, he notes.

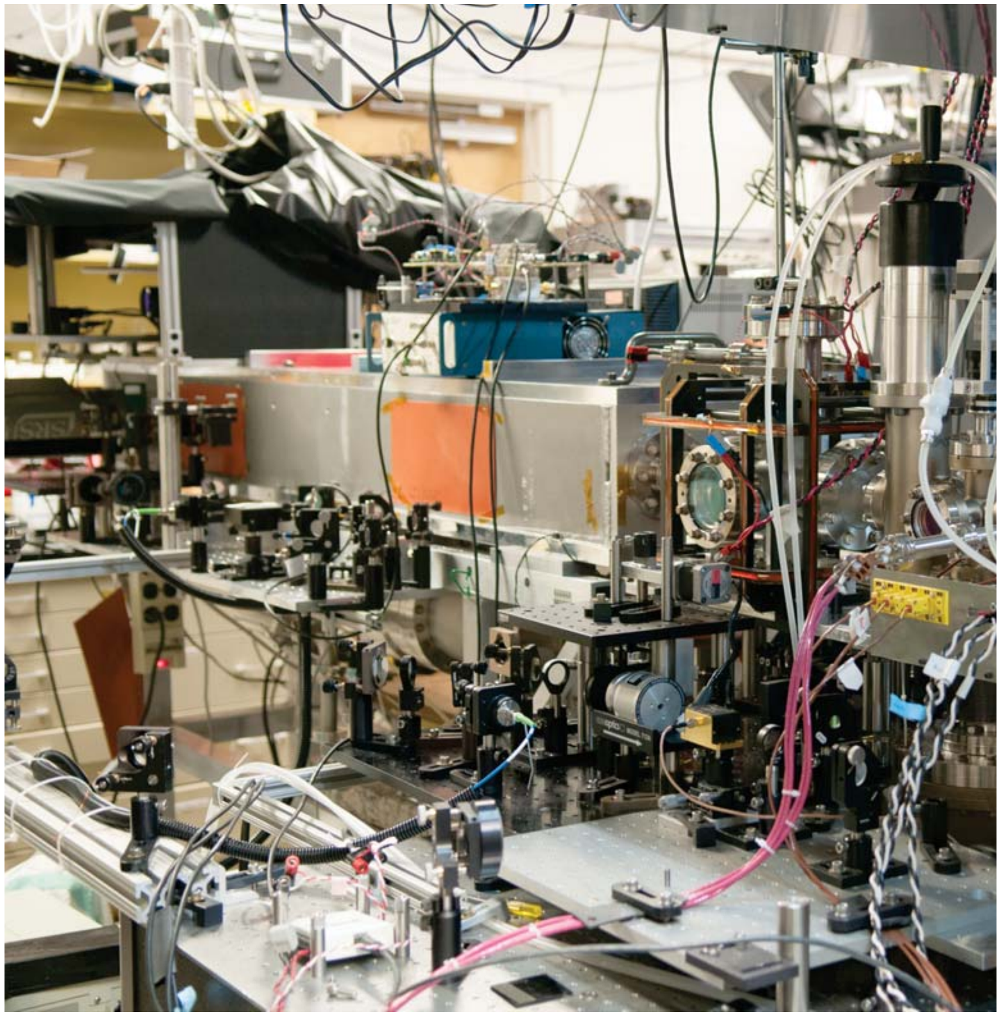
Separation anxiety

For decades, the main instrument for separating stable isotopes has been the calutron, which was first built in 1941 and separates by charge-to-mass ratio (see the article by Bill Parkins, PHYSICS TODAY, May 2005, page 45). A sample is ionized, accelerated with electric fields, and then deflected with magnetic fields. Because different isotopes of a given element have the same charge but vary in mass, they become separated in a magnetic field, with heavier isotopes deflected less. The US shuttered its last calutrons in the 1990s. Today the bulk of the world's stable isotopes come from national inventories and from decades-old calutrons in Russia. Radioisotopes are made in reactors and accelerators around the globe.

In a 2015 report for the US Department of Energy (DOE), the Nuclear Science Advisory Committee (NSAC) isotopes subcommittee highlighted the growing demand for isotopes (see PHYSICS TODAY, October 2015, page 20). High costs and uncertainty in the supply chain have limited the development of existing and new applications of isotopes, notes Raizen. The rare-earth elements are examples, he says. Another is nickel-64, which is converted to copper-64 for use in PET (positron emission tomography) scans.

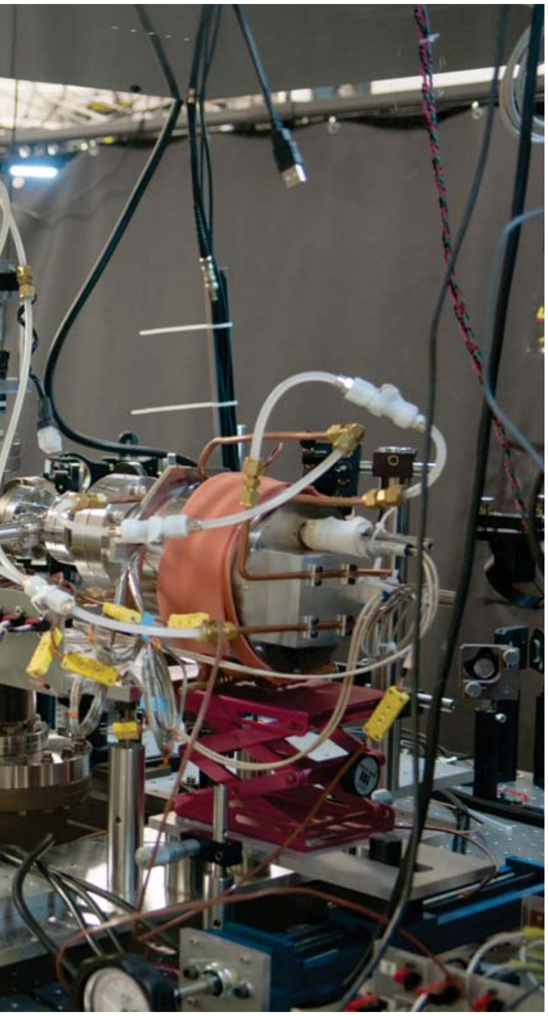
To help meet demand, various approaches are under study in the US and internationally in the private, academic, and government sectors. Centrifuge, laser ionization, chemical, electrochemical, photochemical, supersonic flow, and chromographic methods are options for separation of stable isotopes; other methods are under consideration for producing radioactive isotopes. Some methods work for light elements, others for elements with specific chemical properties, and so on.

The NSAC subcommittee report mentioned MAGIS as an emerging method for separating isotopes. "Our method is the only one that has been demonstrated so far as a possible alternative" to the calutron, says Raizen.



LITHIUM-7 AS A TEST CASE was successfully purified by magnetically activated and guided isotope separation with the lab setup shown here. The oven for heating lithium is sitting on the red lab jack to the right. Circular view ports were used for shining lasers to optically pump the isotopes. Inside the rectangular box are the magnetic guides.

THOMAS MAZUR



A new separator along the lines of a modern calutron at Oak Ridge National Laboratory will start producing small quantities of various stable isotopes this fall, and plans are in the works to increase production capability to kilograms.

As a proof of principle, Raizen and his students showed in 2014 that the MAGIS approach could enrich lithium-7 from the 92.4% in naturally occurring lithium to nearly 100%; ^{7}Li is used for pH balance in US pressurized water nuclear reactors. Now he has set up the Pointsman Foundation, a nonprofit that aims to scale up and generalize the method to produce useful quantities of other stable isotopes, especially precursors for medical radionuclides for cancer therapy and diagnostic imaging. Raizen is also involved in Atom Mines, a for-profit venture to tailor MAGIS to produce isotopes for other industrial uses. In principle, the method could separate radioisotopes, but to stay on the simple side of regulatory and safety issues, Raizen is initially sticking with stable isotopes.

Pump and part

Isotope separation with MAGIS begins with an atomic beam created by heating a sample of the element in question. After the beam is collimated, a precisely tuned laser optically pumps only one particular isotope. That changes the magnetic moment, and an applied magnetic field ushers the atoms out for collection. (See the figure on page 24.) "By scattering just a few photons per atom, you change the magnetic moment," says Raizen. "That is an efficiency that I don't think can be beat."

The optical pumping can be set to select isotopes for elimination or for collection—either by slamming them into the magnets or by guiding them out. Selected isotopes that come out at the other end of the magnet guides are pure—99.95% in the initial ^{7}Li demonstration, according to Raizen.

He expects MAGIS to work for about 80% of all stable isotopes. Excluded are the noble gases, because they can't be optically pumped with available solid-state lasers, and elements such as chlorine or oxygen that form molecular rather than atomic beams. For those elements, says Raizen, the gas centrifuge is an efficient and complementary method.

The MAGIS technique produces purer samples and is environmentally cleaner and cheaper than other approaches, he says. By contrast, chemical separation methods used for lithium and mercury create toxic compounds, mass separation methods tend to have some impurity, and calutrons are inefficient and expensive.

Nonprofit possibilities

Raizen formed the nonprofit foundation to focus on isotopes with medical and research applications. The foundation's star-studded advisory board includes Nobel laureate Steven Weinberg, Nobel laureate and former DOE secretary Steven Chu, and former DOE undersecretary for science Raymond Orbach. As of mid-July, the foundation expected by year's end to raise about $5 million and to begin hiring staff and building equipment.

Kirk Dorius, president of the foundation and CEO of Atom Mines, says the foundation will start with ytterbium-176. It can be bombarded with neutrons to create radioactive lutetium-177, which shows promise for treating a wide range of cancers. Dorius estimates that it will take two to three years to start distributing ^{176}Yb.

Any desired isotope would require a dedicated MAGIS machine because of the specific requirements for the oven and lasers. And each dedicated apparatus will cost a few million dollars, says Dorius.

As of now, fewer than a handful of radioisotopes are readily available for medical use, says Neil Bander, a physician at Weill Cornell Medical College. He says the impediments to adopting new isotopes for widespread clinical use are twofold. The infrastructure for developing applications and producing isotopes is lacking, as is interest on the part of pharmaceutical companies in investing in isotopes.

Orbach warns that the sources of stable isotopes the US relies on as feed materials for the production of medical isotopes are in danger of disappearing. Many isotopes could become unavailable to US hospitals, he says. MAGIS could help fill that need by creating the stable precursors to short-lived medical isotopes. But even more exciting, says Orbach, is that the Pointsman Foundation could explore new isotopes that have prospects for medical and energy uses.

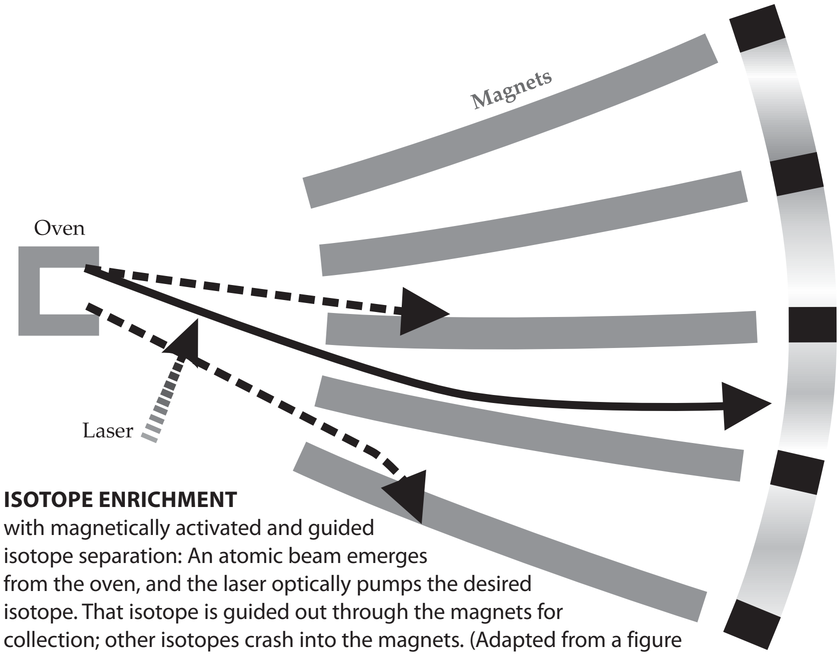
On the foundation's to-do list is enriching calcium-48, which can be used as a metabolism tracer to see how calcium is absorbed in bones. And the observation of neutrinoless double beta decay in

KIRK DORIUS

THE INITIAL STARTUP GRANT for the Pointsman Foundation came from the Smart Family Foundation. Douglas Stone (left), a Yale University physicist and Pointsman board member, hands Mark Raizen the check.

^{48}Ca could be used to determine the neutrino rest mass (see PHYSICS TODAY, January 2010, page 20). "A colleague told me 8 g would cost about $1 million. He wants 10 kg," says Raizen. "I believe we could eventually produce it at much lower cost."

For medical uses, worldwide demand for many isotopes is on the order of a few moles per year. That should be doable with MAGIS, Raizen says. Producing several kilograms would be pushing the limits of the method, at least as currently envisioned. "I don't think we would ever be able to produce tons of anything," he says.



ISOTOPE ENRICHMENT with magnetically activated and guided isotope separation: An atomic beam emerges from the oven, and the laser optically pumps the desired isotope. That isotope is guided out through the magnets for collection; other isotopes crash into the magnets. (Adapted from a figure provided by Mark Raizen.)

Fluorescent lighting

Unlike for the foundation, where the focus is isotopes to benefit humanity, at Atom Mines the aim is to exploit MAGIS for commercial gain. The first project at the startup company will be to separate the isotopes of mercury. By adjusting the proportions of the seven naturally occurring isotopes of the element, "we should be able to significantly increase the efficiency of fluorescent lighting," says Raizen, who last year patented the invention with James Lawler of the University of Wisconsin–Madison. In rebalancing the isotope mixture, Raizen explains, the absorption profile changes, and fewer atoms end up in a nonradiating state. It could be a quick way to save electricity, he says. The same mercury isotope remix could also be used in UV lamps for sterilizing water.

For both the Pointsman Foundation and Atom Mines, success hinges on scalability and cost. "This is laboratory scale right now," says Orbach. "It's that 'valley of death'—getting from the lab to practical applications and the commercial market."

Toni Feder