NIST neutron detection method—long-sought workaround to helium shortage?

June 12 2018

Physical scientist Kerry Siebein of NIST's Center for Nanoscale Science and Technology operates a scanning electron microscope while process engineer Josh Schumacher looks on. One-on-one training in nanofabrication and nanotools helps prepare young scientists and engineers for careers in nanomanufacturing. Credit: K. Dill/NIST

Doctors use X-rays to see inside people, and scientists use neutrons to peer inside advanced materials and devices such as fuel cells to better understand and improve them. But a critical shortage of a rare form of helium used for detecting neutrons—which are difficult to spot directly—threatens to slow advances in this critical type of materials research.

To solve the problem, a NIST team found a way to replace expensive and scarce helium-3 gas with previously studied crystals of more abundant materials. Their improved approach achieved greater than 90 percent efficiency in detecting neutrons, making it a viable alternative.

Helium-3 is a rare isotope of helium with one neutron instead of two. Its nucleus breaks apart easily when struck by a neutron, and the fragments can be detected when they strike a high-voltage wire. For decades, this has made helium-3 an ideal tool for materials scientists, who use neutrons to probe the innards of dense objects. National security officials also use it in ports and at border crossings to spot the stray neutrons emanating from illicit radioactive materials such as the ingredients for nuclear bombs.

Ironically, it is the manufacture of nuclear weapons that provided a steady supply of helium-3 in the first place. The isotope is hard to come by; it only makes up about 0.0001 percent of Earth's natural helium reserves. But it is one of the decay products of tritium, a key element in hydrogen bombs, and scientists have siphoned off the helium-3 from idle warheads for decades. Now that the United States has reduced its production of such explosives, materials scientists need a new way to detect the neutrons they beam at cutting-edge materials, which scatter the neutrons in ways that reveal their internal structure.

Scientists have long known of another detection method that uses the more available chemicals zinc sulfide and lithium-6 fluoride, but its utility has been limited for exploring dense materials because of its inefficiency. Scientists need the most efficient detection method they can find, since even the most intense neutron sources only produce low-intensity trickles of neutrons.

"Helium-3 is the gold standard for neutron detection work because its efficiency is around 95 percent," said Kevin Pritchard, one of the NIST engineers collaborating on the project and a Ph.D. candidate at the University of Maryland, Baltimore County. "The lithium-6 fluoride approach is down around 30 percent, which isn't nearly good enough for our purposes. We spent several years trying to optimize it."

The alternative approach demands that small crystals of zinc sulfide and lithium-6 fluoride be made at just the right sizes and mixed together with even distribution and spacing in a single medium. When a neutron hits lithium-6, it breaks into two smaller particles that strike some nearby zinc sulfide, making it glow. The team repeated past experiments indicating that with crystals of the correct size, the efficiency should rise to nearly 100 percent, but even with properly sized crystals it wasn't lighting up brightly enough.

Figuring out why took the help of NIST's Center for Nanoscale Science and Technology. Electron microscope images revealed that the crystalline particles were clumping together in ways that prevented the lithium-6 fragments from reaching the zinc sulfide. The team worked with industry to tweak the concentration of the binding agent holding the crystal mix together, and this change finally gave them an efficiency greater than 90 percent, rivaling helium-3's.

The team details their work in a series of five scientific papers, some of which are in press. An overview of the approach is presented in a paper published today in *Nuclear Instruments and Methods in Physics Research A*.

Aside from freeing the neutron detection community from its dependence on hydrogen bombs, the method has other potential advantages. Most importantly, detectors can be made much thinner, as a gas requires more volume than a solid and needs to be kept at high pressure as well.

"This might allow us to fit more detectors into a space, so we can collect more neutrons and get a more accurate picture," Pritchard said. "It would be an advantage even if we had plenty of helium-3."

It might help with fossil fuel exploration as well, he said, as mining companies have used neutron detectors for years. Smaller, cheaper detectors could provide answers about rock structures deep underground more effectively.

For Pritchard and his co-authors, the advantages for neutron science will have the most personal impact.

"It's hard to collect data efficiently when the intensity of your neutron beam is limited," he said. "I think this is an incremental but substantive step in improving instruments for studying condensed matter."

More information: A. Osovizky et al. Design of an ultrathin cold neutron detector, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* (2018). DOI: 10.1016/j.nima.2018.02.073

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Provided by National Institute of Standards and Technology