A bubbly new way to detect the magnetic fields of nanometer-scale particles

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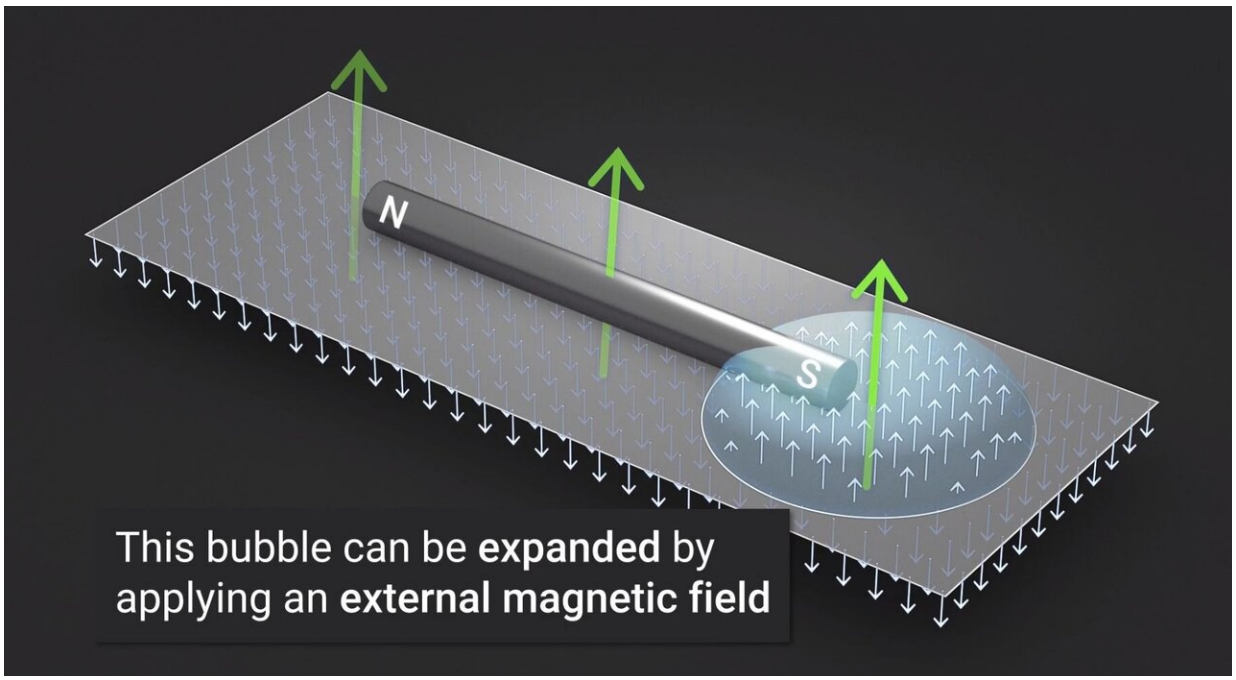

As if they were bubbles expanding in a just-opened bottle of champagne, tiny circular regions of magnetism can be rapidly enlarged to provide a precise method of measuring the magnetic properties of nanoparticles.

The technique, uncorked by researchers at the National Institute of Standards and Technology (NIST) and their collaborators, provides a deeper understanding of the magnetic behavior of nanoparticles. Because the method is fast, economical and does not require special conditions—measurements can occur at room temperature and under atmospheric pressure, or even in liquids—it provides manufacturers with a practical way to measure and improve their control of the properties of magnetic nanoparticles for a host of medical and environmental applications.

Magnetic nanoparticles can serve as tiny actuators, magnetically pushing and pulling other small objects. Relying on this property, scientists have employed the nanoparticles to clean up chemical spills and assemble and operate nanorobotic systems. Magnetic nanoparticles even have the potential to treat cancer—rapidly reversing the magnetic field of nanoparticles injected into a tumor generates enough heat to kill cancer cells.

Individual magnetic nanoparticles generate magnetic fields like the north and south poles of familiar bar magnets. These fields create magnetic bubbles—flat circles with initial diameters less than 100 nanometers (billionths of a meter)—on the surface of a magnetically sensitive film developed at NIST. The bubbles surround the nanoparticle pole that points opposite to the direction of the magnetic field of the film. Although they encode information about the magnetic orientation of the nanoparticles, the tiny bubbles are not easily detected with an optical microscope.

However, like bubbles in champagne, the magnetic bubbles can be expanded to hundreds of times their initial diameter. By applying a small external magnetic field, the team enlarged the diameter of the bubbles to tens of micrometers (millionths of a meter)—big enough to see with an optical microscope. The brighter signal of the enlarged bubbles rapidly revealed the magnetic orientation of individual nanoparticles.

After determining the initial magnetic orientation of the nanoparticles, the researchers used the enlarged bubbles to track the changes in that orientation as they applied an external magnetic field. Recording the strength of the external field required to flip the north and south magnetic poles of the nanoparticles revealed the magnitude of coercive field, a fundamental measure of the magnetic stability of the nanoparticles. This important property had previously been challenging to measure for individual nanoparticles.

Samuel M. Stavis of NIST and Andrew L. Balk, who conducted most of his research at the Los Alamos National Laboratory and NIST, along with colleagues at NIST and the Johns Hopkins University, described their findings in a recent issue of *Physical Review Applied*.

The team examined two types of magnetic nanoparticles—rod-shaped particles made of a nickel-iron alloy and irregularly shaped particle clusters made of iron oxide. The applied magnetic field that expanded the bubbles plays a similar role to that of the pressure in a bottle of champagne, Balk said. Under high pressure, when the champagne bottle is corked, the bubbles are essentially nonexistent, just as the magnetic bubbles on the film are too small to be detected by an optical microscope when no external magnetic field is applied. When the cork is popped and the pressure is lowered, the champagne bubbles expand, just as the external magnetic field enlarged the magnetic bubbles.

Each magnetic bubble reveals the orientation of the magnetic field of a nanoparticle at the instant that the bubble formed. To study how the orientation varied with time, the researchers generated thousands of new bubbles every second. In this way, the researchers measured changes in the magnetic orientation of the nanoparticles at the moment that they occurred.

To enhance the sensitivity of the technique, the researchers tuned the magnetic properties of the film. In particular, the team adjusted the Dzyaloshinskii-Moriya (DMI) interaction, a quantum-mechanical phenomenon that imposes a twist in the bubbles within the film. This twist reduced the energy needed to form a bubble, providing the high sensitivity necessary to measure the field of the smallest magnetic particles in the study.

Other methods to measure magnetic nanoparticles, which require cooling with liquid nitrogen, working in a vacuum chamber, or measuring the field at only a single location, do not allow such rapid determination of nanoscale magnetic fields. With the new technique, the team rapidly imaged the magnetic fields from the particles over a large area at room temperature. The improvement in speed, convenience and flexibility enables new experiments in which researchers can monitor the behavior of magnetic nanoparticles in real time, such as during the assembly and operation of magnetic microsystems with many parts.

The study is the most recent example of an ongoing effort at NIST to make devices that improve the measurement capabilities of optical microscopes, an instrument available in most labs, said Stavis. This enables rapid measurement of the properties of single nanoparticles for both fundamental research and for nanoparticle manufacturing, he added.

More information: Andrew L. Balk et al, Bubble Magnetometry of Nanoparticle Heterogeneity and Interaction, *Physical Review Applied* (2019). DOI: 10.1103/PhysRevApplied.11.061003

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