Study of 'Solitons' Adds Insight into Nanomagnet Behavior

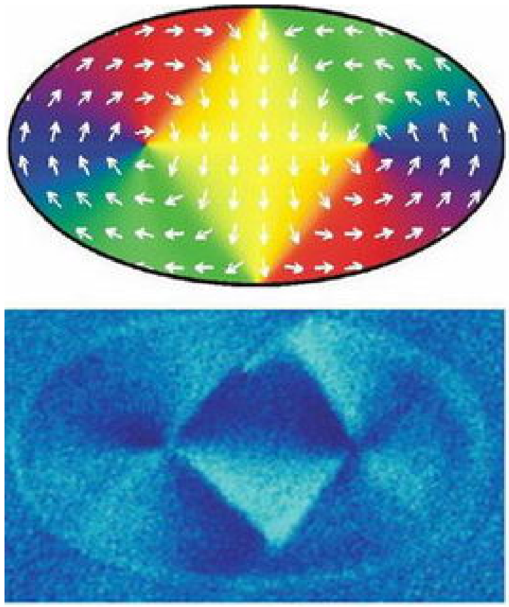
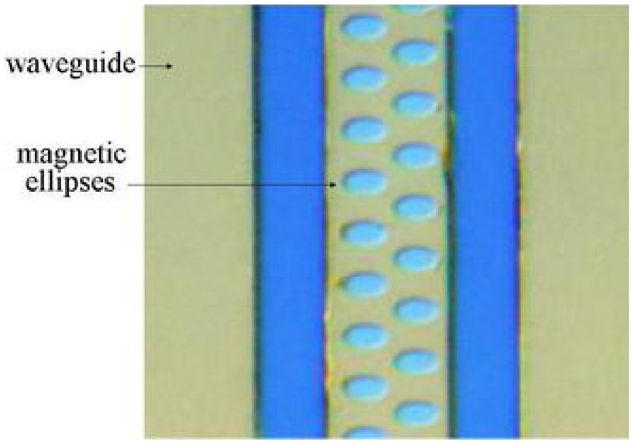


Image: (top) A map of the two magnetic fields. (bottom) A simulation of the vortex-pair magnetization state in one of the particles.

Scientists are a long way off from a complete understanding of the interactions and behaviors that govern nanomagnets — magnets on the scale of a billionth of a meter. However, a groundbreaking new study helps answer some basic questions about nanomagnets, which could one day revolutionize (and drastically miniaturize) computer data-storage systems, telecommunications devices, and other technologies that rely on magnets.



A microscope image of magnetic ellipse-shaped particles patterned onto a waveguide.

As reported in the December 2005 edition of *Nature Physics*, researchers from Argonne National Laboratory and Uppsala University (Sweden) created two spiral-shaped magnetic regions, called “solitons,” within a tiny, ellipse-shaped metallic particle and discovered that they exhibit very interesting behavior. Because of its shape, this type of soliton is also known as a magnetic vortex, and it possesses an interesting trait: When excited by an outside source of energy, a magnetic vortex will rotate in a spiral motion.

“Vortices represent a type of collective behavior that is commonly found in nature, such as swarming schools of fish in the ocean, birds swarming in flight, and tornadoes and hurricanes in global weather systems,” the project’s lead investigator, Argonne Lab materials scientist Valentyn Novosad, told PhysOrg.com. “Magnetic vortices, which have cores just 10 to 20 nanometers wide, are one of the smallest examples of this."

In past work, Novosad and his group investigated the physics laws that govern the behavior of a single confined vortex. This study, however, marks the first time that researchers have examined the dynamics of two vortices trapped within a magnetic particle. They discovered — rather surprisingly — that the collective motion of two interacting vortices is governed by a different set of physics rules than two vortices that do not interact.

The motion of a magnetic vortex is described by two key parameters: the direction of the motion (clockwise or counter-clockwise) and the "polarity" of the vortex core — that is, whether the very center of the magnetic field points upward (perpendicular to the plane of the particle) or downward. To study these parameters, the scientists used a technique called microwave reflection. But first, using a surface-patterning method known as "lithography," they created several thousand tiny ellipse-shaped "particles" on top of a metal waveguide — essentially a flat wire just a few microns (millionths of a meter) wide. Then, they applied a microwave-frequency electric current to the wire, which, as it propagated down the wire's length, excited the magnetic vortices. The microwave signals reflected away from the ellipses weakly or very intensely, depending on the collective motion of the vortices.

The group measured several strong reflections, also called resonances. Then, they used computer simulations to show that each resonance corresponds to a different type of collective vortex motion. For example, some of the resonance frequencies correspond to vortices that are spinning in unison, or are "in phase." Others correspond to "out of phase" motion. The key to what occurs, the scientists discovered, is whether the vortex cores have the same polarization.

"This is a very surprising result, considering that whether the core polarizations line up or do not line up is unimportant in determining the static properties of exactly the same magnetic ellipse," said Novosad.

"It is really quite amazing that changing something as small as the magnetic core, which occupies less than 0.01% of the particle volume, can have such a profound effect on dynamic behavior of the entire system," added Kristen Buchanan, the paper's lead author and a postdoctoral scientist at Argonne.

Novosad and his group plan to continue this work using an investigation technique that involves x-rays rather than microwaves. They hope to obtain x-ray images that they can string together to form a "movie" of the resonant motion of the vortex pair, which they will compare to the computer-modeling results. Also, because the microwave reflection technique proved to be very successful at probing nanomagnetic systems, the group may use it to probe spin dynamics in other multiple-vortex configurations.

Reference: "Soliton-pair dynamics in patterned ferromagnetic ellipses," K.S. Buchanan, P.E. Roy, M. Grimsditch, F.Y. Fradin, K. Yu. Guslienko, S.D. Bader, V. Novosad, *Nature Physics*, Vol. 1, 172 - 176 (2005)

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