A tailor-made magnetic vortex: A closer look at a special kind of quasiparticle

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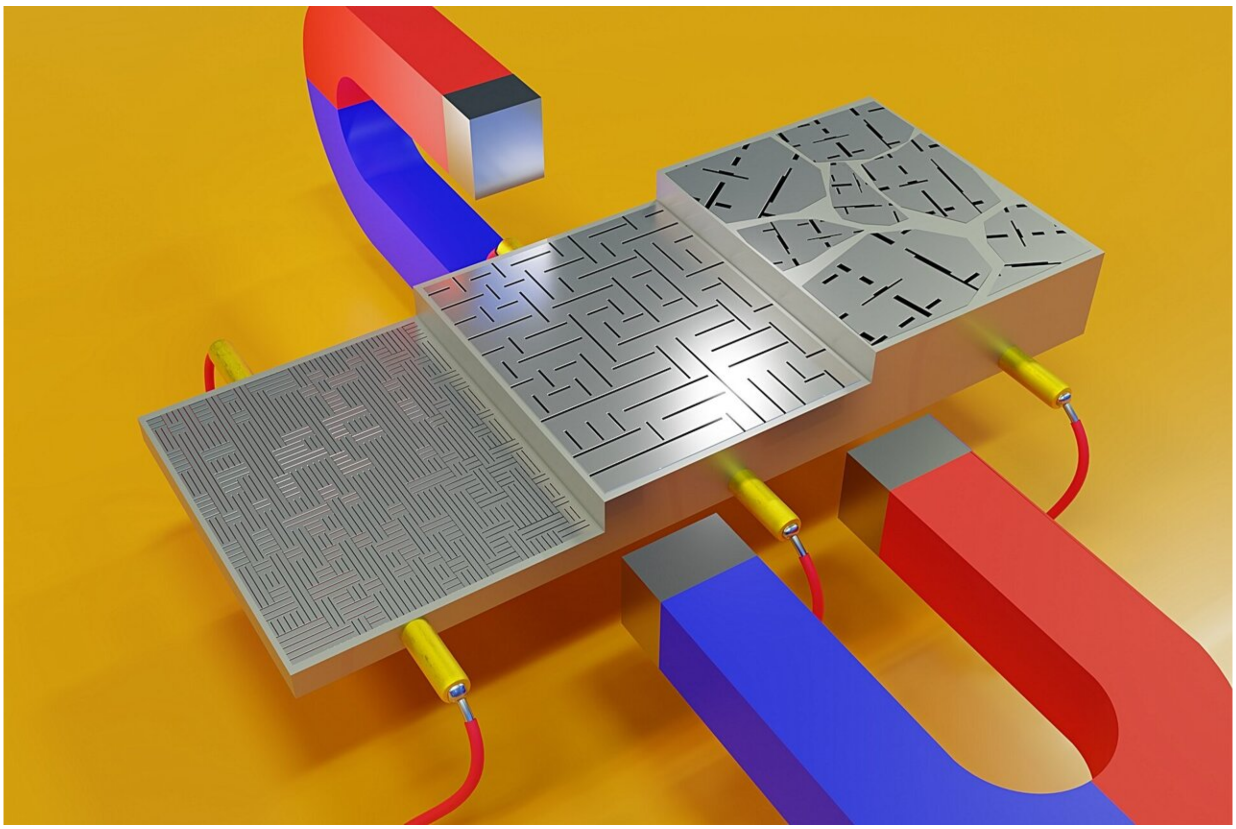

3D model: A single-crystalline sample of the Heusler compound, tailored by means of ion beams with graded thickness, is shown. Magnetic domain structures (black lines) form under the influence of the magnetic field. Credit: B. Schröder/HZDR

Skyrmions are microscopic magnetic vortices that can form in certain materials. First detected in 2009, they are of interest to researchers because they could be harnessed for new forms of data storage. As theoreticians predicted, there are also so-called antiskyrmions, which were discovered 10 years after skyrmions.

Researchers from HZDR, MPI CPfS, IFW Dresden, and the University of South Florida have now used an ion beam saw and sophisticated measurement techniques to get to the bottom of this complex phenomenon, which they report on in the journal *Communications Materials*.

"In a sense, an antiskyrmion is the antiparticle of the skyrmion. Both are called quasiparticles, which owe their properties to the collective interaction of a large number of particles in solid matter. Their properties differ greatly from those of their underlying elementary particles," says Dr. Toni Helm of the Dresden High Magnetic Field Laboratory (HLD) at HZDR.

Helm uses a metaphor to illustrate the behavior of the two quasiparticles: "In special materials, microscopic skyrmion vortices form in a sea of magnetic particles and behave quite strangely. A 'magnetic' seafarer approaching them would either be attracted or repelled. Antiskyrmions, on the other hand, would be almost impossible to find because these peculiar 'anti' vortices combine the different behaviors of skyrmions within themselves."

A characteristic footprint hidden in electrical signals

As the analogy suggests, antiskyrmions are quite difficult to detect. But Helm's team followed a theoretical prediction that points to a way to discover them. Due to their unique geometric properties—their topology—antiskyrmions cause additional voltage in the electrical conduction of the material. The team combined electrical measurement methods with magneto-optical microscopy to reveal the electrical signature of antiskyrmions in the material studied for the first time.

The characteristic footprint of the magnetic anti-vortex is hidden in the so-called Hall effect. To attain it, an external magnetic field is applied perpendicularly to the direction of the current and deflects it. Any topological vortices that are present generate a local magnetic field that causes additional voltage. According to the theory, this signal is directly connected with the topology of the vortices. This is how skyrmions could be distinguished from antiskyrmions—by measuring the Hall effect.

"Our study suggests that this contribution is extremely small and that the signature measured is mainly due to the magnetic properties of the antiskyrmions. Our results help to distinguish the actual Hall signature better from other effects and give a first estimate of its magnitude, which refutes previous research results," Helm says.

Scalable: The smaller, the more structured

For the study, Helm's team used a particular magnetic compound from the class of Heusler compounds, made of the metals platinum, manganese, and tin. These crystalline compounds behave differently than their composition would suggest. For example, they are ferromagnetic, although none of their elementary building blocks is ferromagnetic in itself.

Under certain conditions, various topological structures such as skyrmions or antiskyrmions can form in the compound studied. And the scientists noticed another fascinating detail: The size of the antiskyrmions depends on, and can be controlled via, the thickness of the sample.

"They are not detectable in a big chunk of starting material, but they do occur when the material is cut into flat slices less than 10 micrometers thick," Helm explains. The physicists used a kind of ion beam gun to saw the crystals of the starting material into tiny pieces.

Scalability plays a crucial role in technological applications. Nanoscale devices are needed, for example, to create novel magnetic storage and data transmission systems based on quasiparticles.

In collaboration with colleagues from the HZDR Ion Beam Center, the team researched further properties of the material and incorporated these insights into supplementary theoretical calculations and simulations. Helm's team was thus able to substantiate the existence of antiskyrmions and show precisely how they can form in a highly complex magnetic environment.

More information: Moritz Winter et al, Antiskyrmions and their electrical footprint in crystalline mesoscale structures of Mn1.4PtSn, *Communications Materials* (2022). DOI: 10.1038/s43246-022-00323-6

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