Harnessing skyrmions for electronics and spintronics applications

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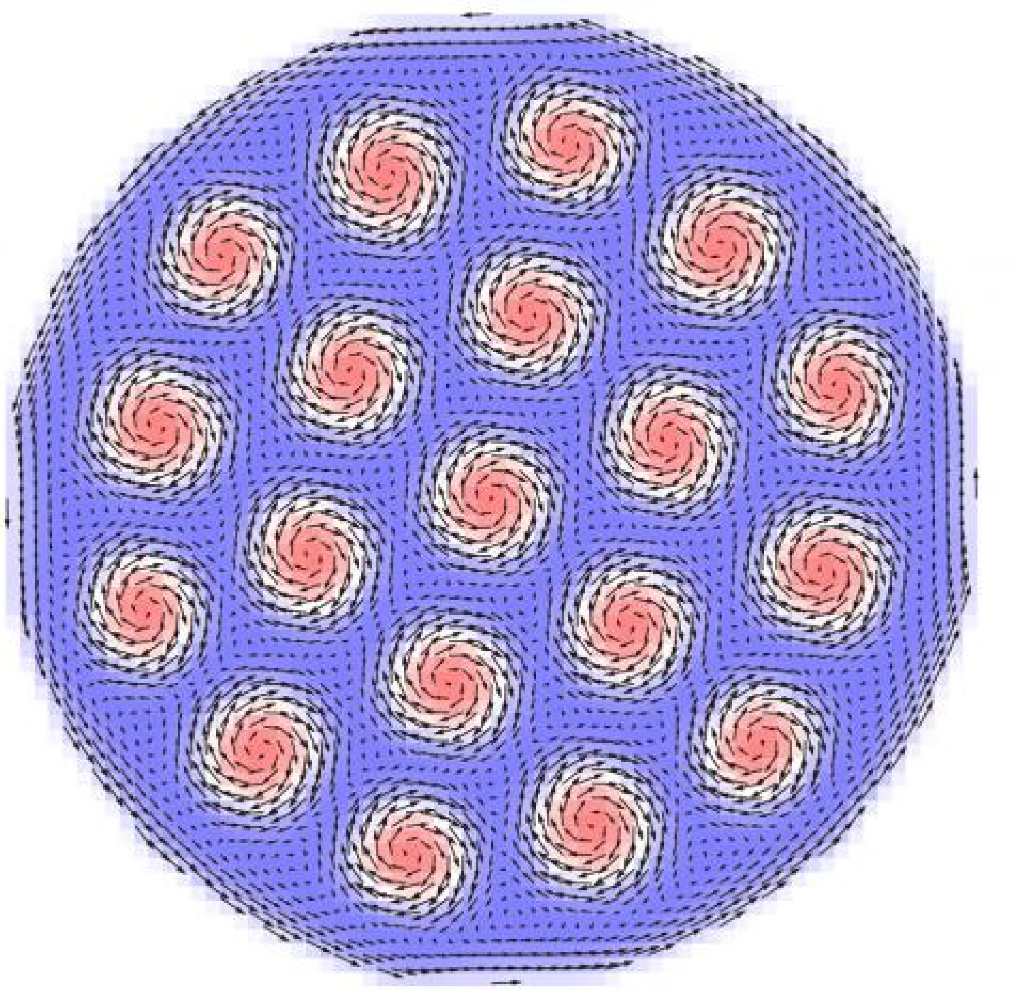

Figure 1: Skyrmions are swirling patterns in the magnetic orientations of atoms (arrows) that can be arranged in ordered patterns. Credit: M. Mochizuki et al.

Skyrmions are 'whirls' in the magnetization of certain magnetic materials that show promise for future electronics and spintronics applications if they can be harnessed and manipulated. Naoto Nagaosa and colleagues from the RIKEN Center for Emergent Matter Science, in collaboration with Masahito Mochizuki from Aoyama Gakuin University and other researchers, have discovered that skyrmions can be manipulated thermally using an electron beam.

Each atom in a ferromagnetic material acts like a tiny bar magnet. Although all of the magnets usually point in the same direction, under certain conditions some can tilt away from their neighbors.

Skyrmions are whirls within this 'sea' of atomic bar magnets. They are usually free to drift around, but an external magnetic field can lock them into regular patterns (Fig. 1) in crystals of manganese silicide and copper oxoselenite.

While studying these materials by transmission electron microscopy, Nagaosa and his colleagues were surprised to find that the skyrmion patterns rotated continuously, completing a full revolution every few seconds. Under a more intense electron beam, they rotated faster.

In searching for a cause, the researchers quickly ruled out the minuscule magnetic field of the electron beam, along with the electric current that the beam might induce. Instead, they concluded that the heating effect of the electron beam was responsible for the skyrmion dance.

Noting that the rotation always occurred in a clockwise direction, the researchers then developed a mathematical model to describe the motion. Their model accurately simulated the observed motion, revealing that the rotation is driven solely by the thermal gradient that runs outward from the center of the sample.

The heat is carried outward by small ripples in the magnetic fabric of the material known as magnons. As the magnons flow, they bounce off the swirling skyrmions—a phenomenon referred to as the magnon Hall effect—and force them to rotate in a clockwise direction. Reversing the external magnetic field switches the rotation to an anticlockwise direction. The discovery is likened to Feynman's ratchet, essentially a tiny engine driven by heat that was described by the physicist Richard Feynman in the 1960s.

Nagaosa says that the findings could aid the development of low-energy memory and logic devices where information is encoded by skyrmions. Previously, electric currents have been used to manipulate skyrmions in metallic magnets. Heat could now be used to drive their motion in electrically insulating magnets, which tend to have lower energy dissipation and would better preserve the high-density data held by the skyrmions.

More information: Mochizuki, M., Yu, X. Z., Seki, S., Kanazawa, N., Koshibae, W., Zang, J., Mostovoy, M., Tokura, Y. & Nagaosa, N. Thermally driven ratchet motion of a skyrmion microcrystal and topological magnon Hall effect. *Nature Materials* 13, 241–246 (2014). dx.doi.org/10.1038/nmat3862

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