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Experiments with chiral magnets may hold the key to a better understanding of fundamental aspects of transformations between different skyrmionic states, necessary for magnetic memory and logic applications to become a reality.

With the aim of developing computing devices that operate with low power dissipation, scientists have been pursuing the idea of encoding information in magnetic states. Specifically, skyrmions, which can be thought of as whirl-like states of magnetic moments, are promising candidates for this purpose. The advantage of skyrmions lies in their topological protection, a property implying that only a 'global' system modification can erase a skyrmion. Realizations of skyrmions and other topologically non-trivial magnetic textures[1,2] such as antiskyrmions — skyrmions with mirror-reflected positions of magnetic moments — and interconversions between them may prove to be useful for magnetic-memory and logic applications. In this regard, researchers are trying to find suitable materials and

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experimental techniques for the design and manipulation of such magnetic textures. Now, writing in *Nature Physics*, Nikolai Kiselev and colleagues[3] report the observation of a process in which skyrmions and antiskyrmions are annihilated and created while topological charge is conserved. These results are expected to drive further studies of various fundamental aspects and control possibilities of topological magnetic states.

The skyrmion was originally proposed by Tony Skyrme as a field configuration with a topological charge of a certain class of nonlinear models describing the nucleon in three-dimensional space plus time.[4] A simplification of this configuration in two-dimensional space plus time corresponds to the magnetic skyrmion. A sketch of a skyrmion's magnetic texture is shown in Fig. 1a. Upon stereographic projection, this texture wraps once around a unit sphere (see Fig. 1b), which is reflected in the topological charge property. As erasing such a texture would require a global modification of the system, this wrapping signifies topological protection and is associated with a positive topological charge of the skyrmion. On the other hand, the wrapping is in the opposite direction for the antiskyrmion's magnetic texture (see Fig. 1c, d) upon stereographic projection, which then corresponds to a negative topological charge. When brought together, skyrmion and antiskyrmion can annihilate, as the antiskyrmion can 'unwrap' the skyrmion's texture into a trivial configuration.

Skyrmions and antiskyrmions have been realized in the form of lattices in chiral bulk B20 compounds,[5] a class of non-centrosymmetric materials, such as FeGe and Heusler compounds[6] (materials with D_{2d} symmetry, for example $Mn_{1.4}PtSn$). Skyrmion lattices have also been discovered in systems with structural asymmetry, such as magnetic monolayers and multilayers.[7] Isolated, metastable skyrmions or antiskyrmions can appear upon the application of magnetic fields of a certain strength in systems that support skyrmion or antiskyrmion lattices. Through careful engineering, isolated skyrmions and antiskyrmions can be realized within one and the same material.[8,9] This is potentially useful for information storage and processing devices using both skyrmions and antiskyrmions as storage bits. The operation of such information storage and processing devices may involve processes in which skyrmion–antiskyrmion pairs are created or annihilated.

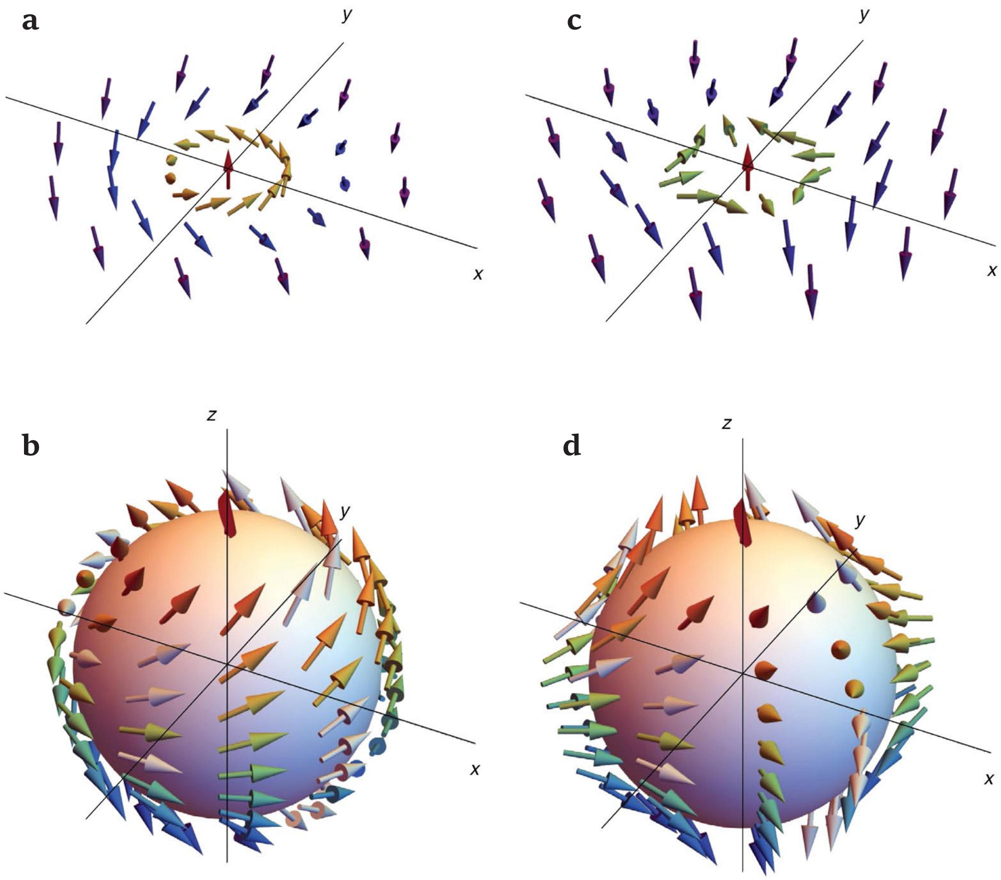

Fig. 1 Examples of topological magnetic textures. **a**, A skyrmion with positive topological charge. **c**, An antiskyrmion with negative topological charge. **b**,**d**, The moments wrap around a unit sphere upon application of stereographic projection.

Theoretically, it had already been shown that the combination of a twist of the magnetization at the edge or interface of a collinear ferromagnet and an applied magnetic field pulse could result in the generation of skyrmion–antiskyrmion pairs in two-dimensional geometry.[10] The experiments by Kiselev and colleagues now generalize this approach to ferromagnets of finite thickness and thus expand our capabilities for controlling the transformations involving skyrmions and antiskyrmions.

The authors used Lorentz transmission electron microscopy to image very thin chiral magnets in FeGe. This technique has potential for imaging other topological charge-conserving transmutations between topologically non-trivial magnetic textures. The key difficulty lies in distinguishing between different topological textures. By careful analysis involving micromagnetic simulations, Kiselev and colleagues managed to resolve skyrmions, antiskyrmions, skyrmioniums (the overlay of two skyrmions with opposite charge) and skyrmion–antiskyrmion pairs. The precise control of magnetic textures was possible through careful tuning of applied magnetic fields, which resulted in skyrmion–antiskyrmion pair production or annihilation.

The multitude of topological textures obtained while sweeping magnetic fields between well-chosen magnetic field strengths shows that the technique used by Kiselev and colleagues can also be used for realizations of other topological magnetic states. As magnetic textures are relevant for spintronics applications, materials science, quantum computing, and future low-power information storage and computing devices, this work may resonate across many disciplines of condensed-matter physics.

Competing interests The author declares no competing interests.

References

1. Kovalev, A. A. & Sandhoefner, S. *Front. Phys.* **6**, 98 (2018).
2. Göbel, B., Mertig, I. & Tretiakov, O. A. *Phys. Rep.* **895**, 1–28 (2021).
3. Zheng, F. et al. *Nat. Phys.* https://doi.org/10.1038/s41567-022- 01638-4 (2022).
4. Skyrme, T. H. R. *Nucl. Phys.* **31**, 556–569 (1962).
5. Mühlbauer, S. et al. *Science* **323**, 915–919 (2009).
6. Nayak, A. K. et al. *Nature* **548**, 561–566 (2017).
7. Heinze, S. et al. *Nat. Phys.* **7**, 713–718 (2011).
8. Kuchkin, V. M. & Kiselev, N. S. *Phys. Rev. B.* **101**, 064408 (2020).
9. Peng, L. et al. *Nat. Nanotechnol.* **15**, 181–186 (2020).
10. Raeliarijaona, A., Nepal, R. & Kovalev, A. A. *Phys. Rev. Mater.* **2**, 124401 (2018).