Spintronics

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A handy way to rotate chiral spins

Enrique del Barco & Andrew D. Kent

In a non-collinear antiferromagnet, elementary spins rotate with opposite handedness with respect to the collective octupole magnetic moment when stirred by spin currents.

The reorientation and excitation of magnetic moments in magnetic materials by injecting currents is fundamental to the field of spintronics and its wide range of applications. Currently, one of the most relevant applications involves the utilization of ferromagnets in advanced semiconductor memory devices[1]. Yet, recent research in spintronics has envisaged a substantial technological potential in using antiferromagnetic materials[2], which possess a well-defined spin order but have little to no net magnetic moment due to the cancellation of atomic moments. Non-collinear chiral antiferromagnets represent a specific class within this category, characterized by spins rotating around a defined point within a crystal lattice. A key requisite for utilizing these materials in spintronic devices is then to understand how they respond when stimulated by spin currents. Now, writing in *Nature Materials*, Luqiao Liu and colleagues[3] report that the response of chiral antiferromagnets is distinct from that of other magnetic materials in intriguing and counterintuitive ways.

The material they studied is Mn_3Sn, in which the spins of Mn atoms form a non-collinear chiral structure, with the three Mn spins orienting themselves along different axes. To grasp the essence of the findings, envision yourself on the terrace of a fancy restaurant on the French Riviera. You have just ordered an espresso to complement a delightful Michelin-starred dinner while witnessing a captivating sunset as the orange sun slowly disappears over the Mediterranean. The waiter brings you the espresso along with a delicate porcelain container filled with sugar. As you pour some sugar into the cup, you instinctively take the spoon and begin stirring the mixture clockwise, as you usually do. Imagine the surprise when you observe the black liquid swirling counterclockwise instead.

Liu and collaborators may have been equally surprised by the results of their spin–orbit torque switching experiments. In these experiments, spin-polarized electrons, generated by the spin Hall effect in a platinum overlayer, exert an influence on the moments in Mn_3Sn. The team observed that the magnetic order parameter, known as the octupole moment (m_{oct}) – represented by the coffee in the analogy – rotated with opposite handedness compared with the constituent spin moments, akin to the spoons, as illustrated in Fig. 1. This finding stands in contrast to other magnetic systems, such as the magnetic moment in a ferromagnet or the Néel vector in a collinear antiferromagnet.

This observation is of particular importance as it widens our capability of controlling spin dynamics in antiferromagnetic systems. Specifically, it provides a means to generate spin angular momentum dynamics with a chirality opposite to that produced by spin–orbit torques and magnetic fields acting on individual magnetic moments. This finding also comes at a timely moment, as the exploration of antiferromagnetic systems has been experiencing rapid growth

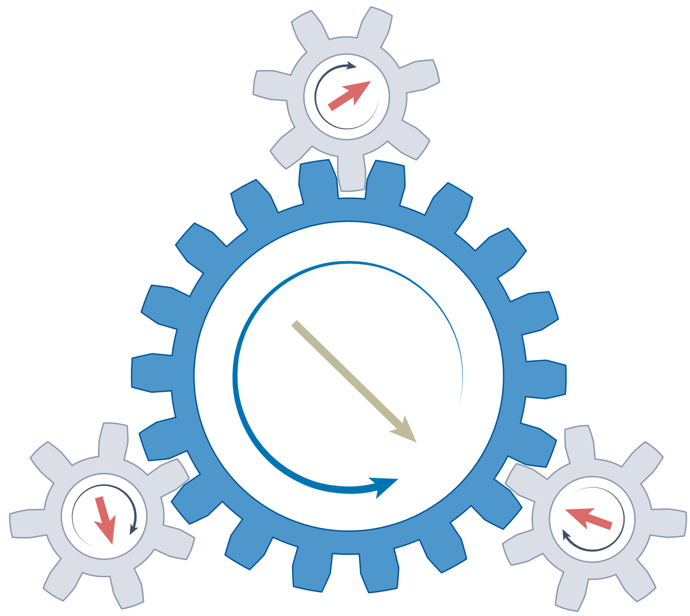

Fig. 1 | Opposite handedness of elemental and collective moments in chiral antiferromagnets. Mechanical analogy illustrating the collective octupole moment in Mn_3Sn, represented by the large blue gear, rotating with opposite handedness compared with the individual Mn spins, symbolized by the small grey gears.

within the scientific community, owing to their numerous advantages compared with ferromagnetic systems[2]. These include substantially higher-frequency spin dynamics in the terahertz range, shorter operation times in the picosecond range, robustness against external perturbations with low susceptibility, the potential for increased storage density in magnetic memory and computing due to the absence of a net magnetic moment that prevents crosstalk between neighbouring elements, and the abundance of antiferromagnetic materials in nature. Notably, the interconversion of Néel spin dynamics and charge current in the subterahertz regime has already been reported in two different collinear antiferromagnets[4,5], highlighting their higher frequency and speed advantage. Furthermore, current-induced switching of the Néel vector has been demonstrated in several antiferromagnetic materials by means of different physical mechanisms[6,7], including spin–orbit torques and magnetoelastic interactions[8,9].

The electronic structure of non-collinear antiferromagnets, specifically the Mn_3X family (where X represents a metalloid from group XIV of the periodic table), has emerged as a central research theme. This is due to the topological nature of their band structure, which gives rise to non-trivial physical effects, including large anomalous Hall and magneto-optic Kerr effects[10,11]. These effects simplify the task of determining the magnetic state, which is a fundamental challenge in antiferromagnetic spintronics. The newfound understanding of the opposite evolution of the octupole moment compared with the constituent spins will thus contribute to the investigation and exploitation of the electronic, thermal and optical properties of these materials.

While the work of Liu and colleagues provides important insights into the dynamics of non-collinear antiferromagnets, it also raises several key questions. For instance, what is the fundamental speed of spin–orbit switching dynamics in these systems? In ferromagnets, the switching speed is determined by spin precession and is observed to occur on subnanosecond timescales. In addition, spins with a dominant easy-plane anisotropy are expected to undergo continuous precession when stimulated by spin currents polarized perpendicular to their easy plane, forming spin oscillators. Despite theoretical predictions[12], this phenomenon has not been observed thus far. Furthermore, why do only approximately 30% of domains undergo switching in this non-collinear antiferromagnet, as opposed to ferromagnets where complete magnetization reversal can be easily achieved through spin–orbit torques? Is this discrepancy a fundamental issue or related to disorder in the antiferromagnetic thin films studied, a materials-related challenge that can be addressed through the production of higher-quality thin films? These are essential questions to consider in future research, as we explore forward routes in harnessing the technological potential of chiral antiferromagnetic spintronics.

Enrique del Barco [1] ✉ **& Andrew D. Kent** [2] ✉
[1]Department of Physics, University of Central Florida, Orlando, FL, USA. [2]Center for Quantum Phenomena, Department of Physics, New York University, New York, NY, USA.
✉e-mail: delbarco@ucf.edu; andy.kent@nyu.edu

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Competing interests

The authors declare no competing interests.