Physics

VIEWPOINT

Spin Current in an Antiferromagnet is Coherent

Experiments show that a spin current moves as a coherent evanescent spin wave through an antiferromagnet layer sandwiched between two ferromagnets.

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Antiferromagnets are trending in the field of spintronics. Originally thought to be of limited use for magnetic information processing and storage, experiments now show that antiferromagnets could allow for faster and more robust memory operation than current technologies [1] and for transporting spin current over long distances [2]. But many fundamental physics questions remain about these materials and how they transport spin. For example, why does an insulating antiferromagnet boost the efficiency of spin pumping (a method for generating a spin current)? Maciej Dąbrowski of the University of Exeter, UK, and co-workers now offer an important contribution to this discussion by experimentally identifying a mechanism for spin transport in an antiferromagnet [3]. They show that a spin current moves as a coherent evanescent spin wave through a thin antiferromagnet layer that is sandwiched between two ferromagnets. Their result represents a key step in understanding how antiferromagnetic materials can increase spin transport efficiency.

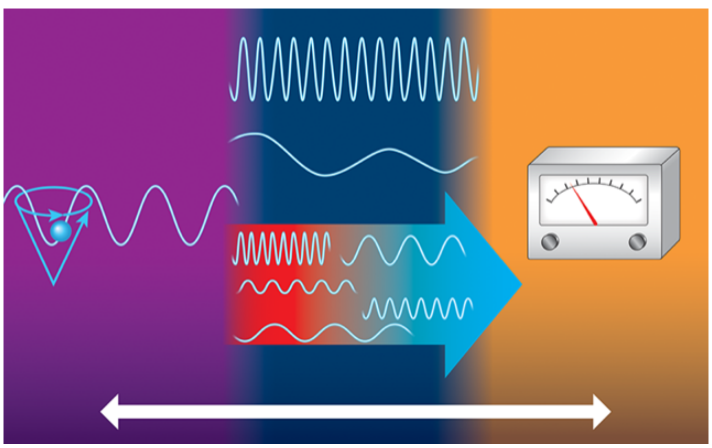

Figure 1: In spin pumping experiments, there are four possible mechanisms for transporting a spin current through an antiferromagnet layer (blue) that is sandwiched between two ferromagnets (purple and orange). (Top to bottom) The spin current could be transported by coherent THz spin waves, by evanescent GHz spin waves, through an incoherent spin current driven by a thermal gradient, or through a direct magnetic exchange between the two ferromagnets. New experiments indicate that when the antiferromagnet NiO is sandwiched between the ferromagnets NiFe and FeCo, the spin transfer between NiFe and FeCo occurs via a coherent evanescent spin wave. (APS/Carin Cain)

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Ferromagnets are popular materials for making memory devices that store information, locking away digital data's 0's and 1's in their up- and down-pointing spins. Antiferromagnets, on the other hand, are far less utilized, despite having appealing features. Such features include much faster dynamics; no net magnetization, which makes them insensitive to external magnetic fields; and substantially reduced bit-to-bit interaction via magnetic stray fields, which can eliminate crosstalk between neighboring memory cells. Moreover, employing antiferromagnets would greatly broaden the pool of available materials for spintronic applications and potentially enable fundamentally new functionalities. For example, antiferromagnets could be used to make memory storage devices with multiple stable values (not only 0 and 1). These could be leveraged by neural networks, which require a multilevel memory architecture with learning capabilities [1].

To successfully implement antiferromagnets in spintronics devices, a number of questions about how they transfer spin currents need to be answered. One method to generate and detect a spin current is spin pumping, where a "spin injector" material pumps a spin current into an adjacent "spin sink," which detects the spin polarization. A variety of materials have been employed as injectors and sinks in spin pumping experiments. But, despite their conceptional simplicity, the results of these experiments can be inconsistent or even contradicting [4].

One notorious issue relates to the microscopic nature of the resulting spin current. A spin current generated by spin pumping should have a single wave mode, carrying the fingerprint of the coherent magnetization excitation in the injector. But spin currents can also be generated by thermal gradients, which produce incoherent currents with a continuum of spin excitation modes (Fig. 1) [5]. This problem is even more complex when an antiferromagnet is inserted between the spin injector and the spin detector, as the magnetic excitations in antiferromagnets typically have THz frequencies, while the resonant excitation of the ferromagnetic injector is in the GHz range. Which modes matter with this obvious frequency mismatch? Typical spin pumping experiments measure only the dc—time averaged—component of the spin current. They thus cannot disambiguate the current's modes and frequencies, which is needed to determine how the current propagates. To do that, more sophisticated experiments need to be performed that instead measure the ac—time varying—spin current, which is what Dąbrowski and colleagues have done [3].

In their experiments, the team studied a device with three layers. The top (injector) and bottom (sink) layers were made from the ferromagnets NiFe and FeCo, respectively, and the middle layer was made from the insulating antiferromagnet NiO. They generated a spin current in the NiFe layer and then detected it with the FeCo layer. They implemented a method to independently measure the precession of spins in the injector and in the detector, from which they could infer the spin-wave modes in the NiO layer (see Synopsis: Watching Spin Currents) [6]. This method has been used to study spin transfer through nonmagnetic materials, but it had not previously been applied to antiferromagnets.

The team found that magnetization modes in the ferromagnetic layers oscillate in phase. They also observed that the efficiency of the spin transfer varied with the thickness of the antiferromagnet, finding a maximal efficiency for a 2-nm-thick layer. Together, these results indicate that a spin current propagates coherently through the NiO antiferromagnet layer. Comparing their results to theory, Dąbrowski and colleagues show that their measurements agree with the prediction that this spin transfer occurs via two evanescent spin waves [7]. And, the nonmonotonic dependence of the detected spin current as a function of NiO thickness excludes the possibility that the spin current transfer occurred via direct exchange interaction between the injector and detector.

Dąbrowski and colleagues also discuss other possible interpretations of their results. In particular, they consider that a thermally induced THz spin wave in the antiferromagnet could excite the ferromagnetic detector. They argue that this scenario is unlikely, as they do not observe a strong variation of the measured signal with temperature, as expected for thermal spin-wave population.

However, other experiments conducted on a ferromagnet-antiferromagnet-ferromagnet system made of different materials suggest that spin current transport in an antiferromagnet occurs via thermal spin-wave excitations [8]. The contrast between these results and those obtained by Dąbrowski and colleagues indicate that the spin transport mechanism may depend strongly on the exact antiferromagnet or the experiment temperature, or that several competing mechanisms may be at play. Clearly, further studies are needed to fully resolve this puzzle. These studies might include experiments that probe the role of geometry (for example whether the mechanism changes when altering the angle between the spin current and the spin orientation in the antiferromagnet) or the role of magnetic anisotropy in both of the antiferromagnet and ferromagnet layers.

It will be extraordinarily interesting to extend the research beyond experiments that pump spin current from a ferromagnet to an antiferromagnet. Inspired by the recent exciting experiments that proved the viability of antiferromagnetic spin pumping [9, 10], one could imagine studying the inverse scenario, where spin pumping occurs from an antiferromagnet. With many new ideas being tested experimentally, it is likely that antiferromagnets will play an important role in devices based on the transport and generation of spin currents.

This research is published in *Physical Review Letters*.

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10.1103/Physics.13.83

