A spontaneous topological Hall effect driven by a non-coplanar antiferromagnetic order in van der Waals materials

May 17 2023, by Ingrid Fadelli

Ferromagnets are materials that become magnetized and remain so while they are exposed to an external magnetic field. In these materials, electric currents typically induce a so-called transverse Hall voltage (i.e., a voltage resulting from the deflection of electrons), which is proportional to their internal magnetization.

While this effect, known as the Hall effect, is widely documented in ferromagnets, is not predicted to spontaneously occur in antiferromagnets, materials in which adjacent ions behave like magnets, aligning in regular patterns with neighboring spins facing opposite directions. Recent theoretically studies, however, suggest that a non-coplanar antiferromagnetic order could potentially induce a large spontaneous Hall effect in materials, without applying an external magnetic field to them.

Researchers at University of Tokyo and the RIKEN Center for Emergent Matter Science (CEMS) recently carried out experiments to test this hypothesis on two van der Waals materials, namely CoTa$_3$S$_6$ and CoNb$_3$S$_6$. Their findings, published in *Nature Physics*, confirmed that a specific non-coplanar antiferromagnetic order characterized by scalar spin chirality could elicit a large and spontaneous topological Hall effect in these compounds.

"Hall effect (i.e., current-induced generation of transverse voltage) is
one of the most fundamental electron transport phenomena, and it usually appears in proportion to magnetization in ferromagnets (i.e., anomalous Hall effect)," Shinichiro Seki, one of the researchers who carried out the study, told Phys.org. "On the other hand, recent theoretical studies predict that non-coplanar spin arrangement can induce a giant Hall effect even without magnetization or external magnetic field, because conduction electrons feel a fictitious magnetic field in proportion to a solid angle spanned by neighboring spins."

Inspired by previous works, Seki and his colleagues set out to demonstrate the spontaneous topological Hall effect that recent theories predicted would occur in materials with a specific type of non-coplanar antiferromagnetic order. They specifically focused on two compounds with a triangular lattice and a small net magnetization.

"We selected CoTa$_3$S$_6$ and CoNb$_3$S$_6$ as the target materials," Seki said. "To clarify their detailed spin arrangements, we performed neutron scattering experiments. By analyzing the extinction rule and intensity of magnetic Bragg reflections, the all-in-all-out type spin arrangement has been established unambiguously."

The experiments performed by Seki and his colleagues ultimately confirm theoretical predictions suggesting that a sizeable and spontaneous Hall effect can occur in some antiferromagnets, without requiring an external magnetic field. Further analyses suggested that in this effect could originate from the scalar spin chirality of the compounds that the team examined, which produce a fictitious magnetic field.

"Our results demonstrate that non-coplanar spin arrangement can induce a giant topological Hall effect even without magnetization or external magnetic field," Seki explained. "This phenomenon enables the electrical readout of the antiferromagnetic domains, and it suggests that non-
coplanar antiferromagnets may be utilized as a novel information medium."

Overall, the findings of this recent study highlight the promise of leveraging the scalar spin chirality of materials to realize giant spontaneous Hall responses in non-coplanar antiferromagnets. In the future, this could pave the way for further studies in this area, potentially broadening present horizons for both physics research and technology development.

"Since a fictitious magnetic field plays a similar role as magnetization, non-coplanar antiferromagnets are expected to host similar functional responses as the ferromagnets," Seki added. "In such systems, the fictitious magnetic field is predicted to cause not only a topological Hall effect but also various exotic phenomena such as the topological magneto-optical effect and topological Nernst effect, whose amplitude can be comparable or even larger than typical ferromagnets. The experimental demonstration of the latter phenomena would be our next target."


© 2023 Science X Network


This document is subject to copyright. Apart from any fair dealing for the purpose of private