Pressemitteilung

Max-Planck-Institut für Mikrostrukturphysik
Katja Woldt

27.09.2024
http://idw-online.de/de/news840384

Forschungsergebnisse, Wissenschaftliche Publikationen
Chemie, Energie, Physik / Astronomie, Werkstoffwissenschaften
überregional

Discovery of Orbital Angular Momentum Monopoles Enables Orbital Electronics with Chiral Materials

Orbital angular momentum monopoles, a breakthrough discovery in chiral materials by researchers at the Max Planck Institute in Halle, could revolutionize future information technology. Orbital angular momentum monopoles, which have been predicted to offer significant advantages for the next generation of electronic devices, have now been observed for the first time in chiral materials by scientists at the Max Planck Institute of Microstructure Physics in Halle and their international collaborators. This groundbreaking discovery, published in the prestigious journal Nature Physics, could mark a major step forward in developing chiral electronics.

In traditional electronics, information is transferred using the charge of electrons. However, future technologies may rely on a different property of electrons—their intrinsic angular momentum. Historically, the focus has been on electron spin, a form of build-in angular momentum that creates a magnetic moment, as the leading candidate for next-generation devices. Now, researchers are exploring the potential of orbitronics, a field that utilizes the angular momentum of electrons generated as they orbit the atomic nucleus. Orbitronics holds great promise for memory devices, particularly because it could generate large magnetizations with small charge currents, leading to energy-efficient technology.

A critical challenge in orbitronics has been identifying the right materials to generate large orbital polarizations. Recent advances have made progress using conventional materials like titanium. However, chiral materials, which often have a unique helical atomic structure similar to the DNA double helix, offer an exciting alternative. These materials naturally possess OAM textures as an intrinsic property, making them particularly attractive for orbitronics.

“This offers a significant advantage to other materials because it means you don’t need to apply external stimuli to get orbital textures – they’re just there,” explains Dr. Niels Schröter, an independent group leader at the Max Planck Institute of Microstructure Physics, who led the study. “This gives them the potential to be really stable.”

The perfect solution for orbitronics: spiky hedgehogs

Another unusual and advantageous feature of such materials is their potential to host monopoles of OAMs within their electronic band structures. In this scenario, OAM behaves in ways that defy the rules of symmetry seen in conventional systems. For example, in magnets, we expect a north and south pole, rather than an isolated monopole.

At these monopoles, OAM radiates outwards like the spikes of a scared hedgehog curled into a ball. And this is what makes these materials so attractive: OAM is uniform in all directions – i.e. it is isotropic.

“This is a very useful property as it means flows of OAMs could be generated in any direction,” says Dr. Jonas Krieger, formerly a Postdoc at the Max Planck Institute of Microstructure Physics, who led the experimental team that made the discovery. Dr. Krieger is now a tenure-track scientist at the Paul Scherrer Institute in Switzerland where he still closely collaborates with his colleagues from Germany.

But where are they hiding?

OAM monopoles in chiral crystals have long been an exciting prospect for orbitronics, but until now, they had only existed in theory. Observing them experimentally has been a significant challenge. The key to unlocking this mystery lay in a technique called Circular Dichroism in Angle-Resolved Photoemission Spectroscopy, or CD-ARPES, which uses X-rays from a synchrotron light source. Despite its potential, previous attempts to detect OAM monopoles with this method had been unsuccessful.

“There was a disconnect between theory and experiment. Researchers may have collected the right data, but the evidence for OAM monopoles was hidden within it,” explains Dr. Schröter.

The difficulty stemmed from interpreting the complex data generated by CD-ARPES. In this technique, light is shone onto a material, ejecting electrons. The angles and energies of these ejected electrons provide insights into the material's electronic structure. When circularly polarized light is used, it was initially assumed that the measurements would directly reflect the OAMs.

“That assumption turned out to be too simplistic. Our study revealed that the reality is much more complicated,” says Dr. Michael Schüler from the Paul Scherrer Institute, who supervised the development of theoretical models that were used to interpret the data.

Rigour plugs the gap

Determined to untangle the complex web of CD-ARPES data to reveal the existence of OAM monopoles, Schröter, Krieger, Schüler and colleagues examined two types of chiral crystals: those made of palladium and gallium or platinum and gallium, which were synthesized at the Max Planck Institute for Chemical Physics in Dresden in the Group of Prof. Claudia Felser.

The team approached the puzzle with an open mind to challenge every assumption. They then made an unusual extra step of performing the experiments at various photon energies. “At first, the data didn’t make sense. The signal seemed to be changing all over the place,” says Krieger.

By carefully comparing the experimental data to theoretical models, the scientists unpicked how different contributions complicated calculations of OAM from CD-ARPES data. In this way, they demonstrated how the CD-ARPES signal was not directly proportional to the OAMs, as previously believed, but rotated around the monopoles as the photon energy was changed. The theoretical model that they finally built fitted the CD-ARPES data regardless of the crystal orientation or photon energy tested.

In this way, they proved the presence of OAM monopoles. “The smoking-gun was robustness,” explains Schröter. “Certain features persisted no matter which conditions we used. The only way to have this is with OAM monopoles, where the OAM is isotropic.”

Armed with the ability to accurately visualise OAM monopoles, Schröter and colleagues went on to show that the polarity of the monopole - whether the spikes of OAMs point inwards or outwards - could be reversed by using a crystal with a mirror image chirality. “This is a very useful property, since it tells us that we control the directionality of the orbital response to external stimuli via the handedness of the crystal structure,” says Schröter.

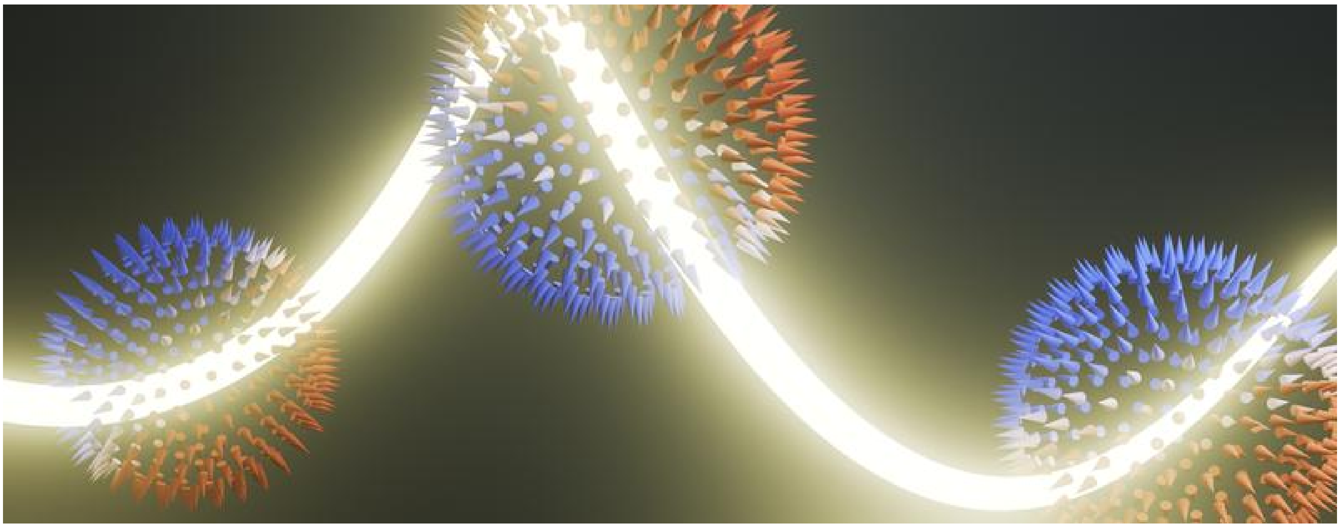
Looking Ahead: The Center for Chiral Electronics

This discovery not only marks a significant milestone in orbitronics but also aligns with the goals of the newly proposed Center for Chiral Electronics, a joint initiative between the Max Planck Institute of Microstructure Physics and the universities in Halle, Berlin, and Regensburg. The Center aims to address the growing need for more efficient data storage and processing technologies. By exploring the unique properties of chirality in electronic applications, the Center will develop new devices with advanced functionalities.

wissenschaftliche Ansprechpartner:
Dr. Niels Schröter niels.schroeter@mpi-halle.mpg.de

Originalpublikation:
https://www.nature.com/articles/s41567-024-02655-1

URL zur Pressemitteilung: https://www.mpi-halle.mpg.de/discovery-of-orbital-angular-momentum-monopoles-enables-orbital-electronics-with-chiral-materials



Discovery of Orbital Angular Momentum Monopoles Enables Orbital Electronics with Chiral Materials
Dr. Niels Schröter
Paul Scherrer Institut PSI/Monika Blétry