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Altermagnetism experimentally demonstrated

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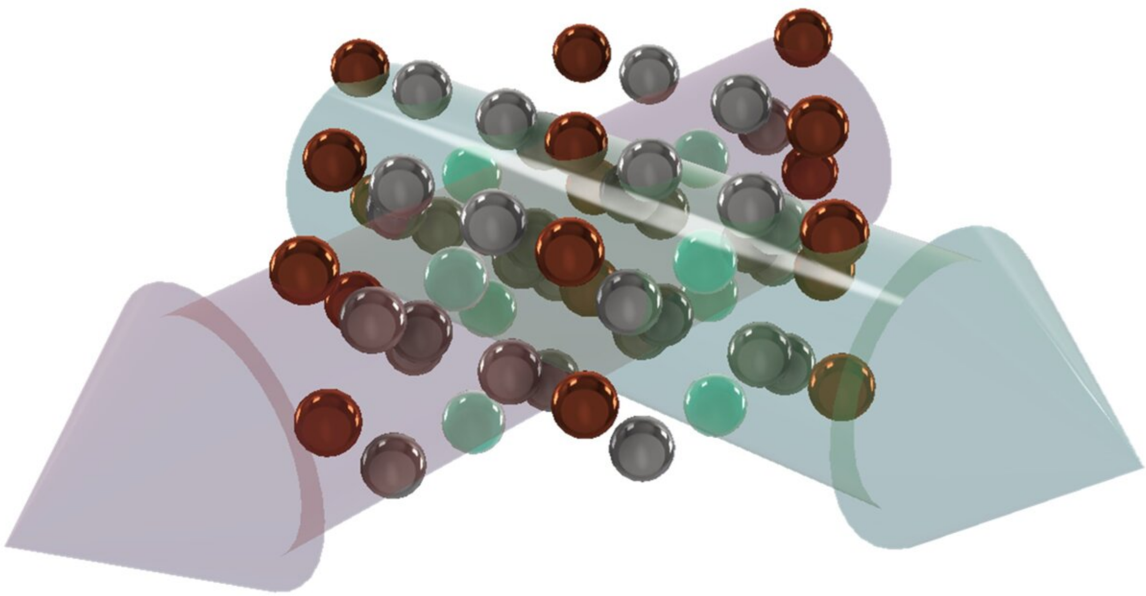

The direction of an electron spin is determined by the direction of motion of electrons. Credit: Hans-Joachim Elmers / JGU

Ferromagnetism and antiferromagnetism have long been known to scientists as two classes of magnetic order of materials. Back in 2019, researchers at Johannes Gutenberg University Mainz (JGU) postulated a third class of magnetism, called altermagnetism. This altermagnetism has been the subject of heated debate among experts ever since, with some expressing doubts about its existence.

Recently, a team of experimental researchers led by Professor Hans-Joachim Elmers at JGU was able to measure for the first time at DESY (Deutsches Elektronen-Synchrotron) an effect that is considered to be a signature of altermagnetism, thus providing evidence for the existence of this third type of magnetism. The research results were published in *Science Advances*.

Altermagnetism: A new magnetic phase

While ferromagnets, which we all know from refrigerator magnets, have all their magnetic moments aligned in the same direction, antiferromagnets have alternating magnetic moments. Thus, at the macroscopic level, the magnetic moments of antiferromagnets cancel each other out, so there is no external magnetic field—which would cause refrigerator magnets made of this material to simply fall off the refrigerator door.

The magnetic moments in altermagnets differ in the way they are oriented. "Altermagnets combine the advantages of ferromagnets and antiferromagnets. Their neighboring magnetic moments are always antiparallel to each other, as in antiferromagnets, so there is no macroscopic magnetic effect, but, at the same time, they exhibit a spin-polarized current—just like ferromagnets," explained Professor Hans-Joachim Elmers, head of the Magnetism group at JGU's Institute of Physics.

Moving in the same direction with uniform spin

Electric currents usually generate magnetic fields. However, if one considers an altermagnet as a whole, integrating the spin polarization in the electronic bands in all directions, it becomes apparent that the magnetic field must be zero despite the spin-polarized current. If, on the other hand, attention is restricted to those electrons that move in a particular direction, the conclusion is that they must have a uniform spin.

"This alignment phenomenon has nothing to do with spatial arrangements or where the electrons are located, but only with the direction of the electron velocity," Elmers added. Since velocity (v) times mass (M) equals momentum (P), physicists use the term "momentum space" in this context. This effect was predicted in the past by theoretical groups at JGU led by Professor Jairo Sinova and Dr. Libor Šmejkal.

Proof obtained using momentum electron microscopy

"Our team was the first to experimentally verify the effect," said Elmers. The researchers used a specially adapted momentum microscope. For their experiment, the team exposed a thin layer of ruthenium dioxide to X-rays. The resulting excitation of the electrons was sufficient for their emission from the ruthenium dioxide layer and their detection.

Based on the velocity distribution, the researchers were able to determine the velocity of the electrons in the ruthenium dioxide. And using circularly polarized X-rays, they were even able to infer the spin directions.

For their momentum microscope, the researchers changed the focal plane that is normally used for observation in standard electron microscopes. Instead of a magnified image of the surface of the ruthenium oxide film, their detector showed a representation of momentum space.

"Differing momentums appear at different positions on the detector. Put more simply, the different directions in which the electrons move in a layer are represented by corresponding dots on the detector," said Elmers.

Altermagnetism may also be relevant to spintronics. This would involve using the magnetic moment of electrons instead of their charge in dynamic random access memory. As a result, storage capacity could be significantly increased.

"Our results could be the solution to what is a major challenge in the field of spintronics," suggested Elmers. "Exploiting the potential of altermagnets would make it easier to read stored information based on the spin polarization in the electronic bands."

More information: Olena Fedchenko et al, Observation of time-reversal symmetry breaking in the band structure of altermagnetic RuO 2, *Science Advances* (2024). DOI: 10.1126/sciadv.adj4883

Provided by Johannes Gutenberg University Mainz