In-plane magnetic fields reveal new Hall effect behaviors in advanced materials

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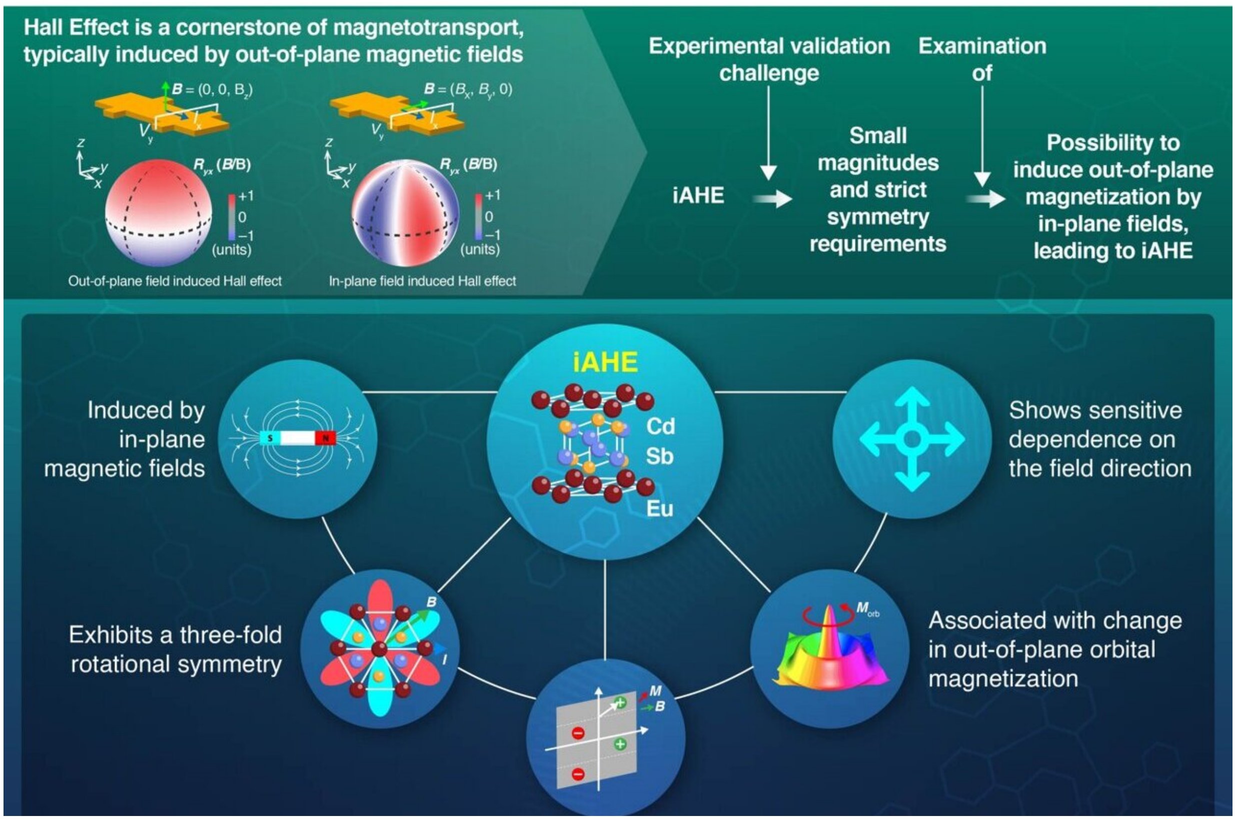

Large iAHE is observed in $EuCd_2Sb_2$ films, providing new insights for manipulating Hall efffects in magnetic materials. Credit: Institute of Science Tokyo

In-plane magnetic fields are responsible for inducing anomalous Hall effect in $EuCd_2Sb_2$ films, report researchers from the Institute of Science Tokyo. By studying how these fields change electronic structures, the team discovered a large in-plane anomalous Hall effect.

These findings, published in *Physical Review Letters* on December 3, 2024, pave the way for new strategies for controlling electronic transport under magnetic fields, potentially advancing applications in magnetic sensors.

The Hall effect is a fundamental phenomenon in material science. It occurs when a material carrying an electric current is exposed to a magnetic field, producing a voltage perpendicular to both the current and the magnetic field. This effect has been extensively studied in materials under out-of-plane magnetic fields. However, research on how in-plane magnetic fields induce this phenomenon has been very limited.

In recent years, in-plane magnetic fields have attracted growing interest due to their potential to unlock new material behaviors, particularly in materials with singular points in their electronic band structures, such as $EuCd_2Sb_2$.

Against this backdrop, a team of researchers from Institute of Science Tokyo and the RIKEN Center for Emergent Matter Science (CEMS), led by Associate Professor Masaki Uchida, explored how in-plane magnetic fields induce the anomalous Hall effect in $EuCd_2Sb_2$ films. Their study sheds light on how these fields induce a distinctive change in electronic band structures.

Uchida explains, "Our findings highlight a new way to manipulate the Hall effect in magnetic materials. This opens up exciting possibilities for future technologies that rely on precise magnetic field measurement, such as magnetic sensing."

The team's efforts revealed that in-plane magnetic fields lead to a significantly large anomalous Hall effect in $EuCd_2Sb_2$ thin films. This effect changes its sign with rotation of the in-plane magnetic field, exhibiting clear three-fold symmetry for rotation of the in-plane magnetic fields.

Furthermore, the study revealed that these effects are linked to an unusual out-of-plane shift of the singular points in electronic band structures. This shift corresponds to the manifestation of orbital magnetization, which is the rotational motion of an electron wave packet, formulated in modern terms as a quantum geometric tensor in solids.

This discovery deepens our understanding of how in-plane magnetic fields change the material's internal structure.

The researchers also discovered that even small adjustments in the angle of the magnetic field could lead to significant variations in the in-plane anomalous Hall effect. This directional dependence further highlights the material's versatility and its potential for use in technologies that require precise measurement of magnetic fields along specific directions.

Uchida concludes, "The present work not only heralds a breakthrough in experimentally studying orbital magnetization, but also stimulates materials development for future applications, revolutionizing the concept of the Hall effect 'from out to in.'"

Overall, this study enhances our understanding of how in-plane magnetic fields influence the electronic properties of advanced materials, such as $EuCd_2Sb_2$, bringing us closer to developing materials with tailored magnetotransport properties for future technologies.

More information: Ayano Nakamura et al, In-Plane Anomalous Hall Effect Associated with Orbital Magnetization: Measurements of Low-Carrier Density Films of a Magnetic Weyl Semimetal, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.133.236602. On *arXiv*: DOI: 10.48550/arxiv.2405.16722

Provided by Institute of Science Tokyo

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