

X-ray Magnetic Circular Dichroism in Hematite

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1 Introduction

Altermagnetism has recently emerged as a novel class of magnetic order characterized by a compensated collinear spin structure that breaks time-reversal symmetry without net magnetization. Unlike conventional antiferromagnets (AFM), altermagnets exhibit momentum-dependent spin splitting and unconventional magneto-optical responses.

X-ray magnetic circular dichroism (XMCD) has traditionally been regarded as a probe of net magnetization in ferromagnets. However, recent theoretical studies have demonstrated that XMCD can also appear in AFM through anisotropic magnetic dipole moments [1,2], so-called T_z term traditionally, even when the total spin and orbital moments are fully compensated. In such cases, XMCD reflects the symmetry of the electronic states rather than net magnetization.

In this study, we investigate the XMCD response of hematite $\alpha\text{-Fe}_2\text{O}_3$, a prototypical altermagnetic material. The aim is to experimentally isolate the intrinsic altermagnetic XMCD signal from conventional weak ferromagnetic contributions and to clarify its microscopic origin in terms of excited-state magnetic multipoles.

2 Experiment

XMCD measurements at the Fe $L_{2,3}$ edges ($2p \rightarrow 3d$ transitions) were performed at beamline BL-16A of the Photon Factory (KEK, Japan). The spectra were recorded in total electron yield (TEY) mode at room temperature using circularly polarized X-rays.

A superconducting magnet providing magnetic fields up to 5 T was used. The external magnetic field was applied parallel to the X-ray propagation direction. The sample was a single-crystalline $\alpha\text{-Fe}_2\text{O}_3$ substrate with a (111) surface orientation.

To enhance the signal-to-noise ratio, the helicity of the circularly polarized X-rays was modulated at 10 Hz, and the XMCD signal was detected using a lock-in technique. Antiferromagnetic domains were controlled by applying a preparatory magnetic field (± 5 T) along the in-plane direction, after which the spectra were measured at zero field.

3 Results and Discussion

Clear XMCD signals were observed at the Fe $L_{2,3}$ edges, where the spectral line shape exhibits a characteristic oscillatory structure, which is distinctly different from the conventional XMCD observed in ferromagnets [1].

Furthermore, the sign of the XMCD signal reverses depending on the direction of the preparatory magnetic field, indicating that the antiferromagnetic domain state is controllable.

Importantly, the experimental geometry was chosen such that the X-ray propagation vector is perpendicular to the weak ferromagnetic moment induced by the Dzyaloshinskii–Moriya interaction. Under this condition, the contribution from weak ferromagnetism is minimized. Theoretical calculations confirm that the XMCD expected from the weak ferromagnetic component is more than an order of magnitude smaller than the observed signal and does not reproduce the spectral features.

These results demonstrate that the observed XMCD cannot be attributed to conventional weak ferromagnetism. Instead, it originates from anisotropic magnetic dipole moments in the excited states. Although the ground state of Fe^{3+} ($3d^5$) is isotropic and does not carry an AMD moment, the excited state ($2p^5 3d^6$) exhibits anisotropic electronic configurations due to crystal-field splitting and spin–orbit coupling. This leads to a finite AMD contribution, which is detected as XMCD.

Magnetic-field-dependent measurements further reveal that the XMCD signal is suppressed under applied fields and recovers at zero field. The behavior is inconsistent with a ferromagnetic hysteresis loop and instead reflects a field-induced reorientation of the antiferromagnetic order parameter. This is interpreted as a transition between different magnetic point group symmetries ($2'/m'$ and $2/m$), where only the former allows a finite XMCD signal along the measurement direction.

4 Conclusion

We have experimentally demonstrated altermagnetic XMCD in $\alpha\text{-Fe}_2\text{O}_3$ at room temperature. By employing a symmetry-selective measurement geometry, we successfully isolated the XMCD signal originating from anisotropic magnetic dipole moments in the excited state and excluded contributions from weak ferromagnetism.

The observed oscillatory spectral line shape and its agreement with full-multiplet calculations confirm that XMCD serves as a direct probe of excited-state magnetic multipoles. Furthermore, the reversible control of the XMCD signal by an external magnetic field indicates the possibility of manipulating altermagnetic states.

These findings establish XMCD as a powerful tool for detecting and studying altermagnetic order and provide a

pathway for exploring novel spintronic functionalities in compensated magnetic materials.

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