Contribution of 4*f* states to the magnetic anisotropy of EuO

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Abstract Body: In 4*f* systems such as EuO, the magnetic anisotropy originates from the electrostatic interaction of the 4*f* charge density with the crystalline electric field (CEF) caused by neighboring charges. An applied magnetic field rotates the 4*f* total angular momentum and due to the strong spin-orbit interaction the 4*f* charge density will rotate with it. This re-orientation of the 4*f* charge density in the CEF causes an increase in the electrostatic energy that corresponds to the magnetic anisotropy energy. An important and still open question is to what extent the 4*f* orbitals are able to rotate freely in order to follow the magnetization, or are held back by the CEF and hybridization which couples them to the lattice.

For the half-filled shell $4f^7$, the spin-orbit interaction and orbital magnetic moment vanish, so that the charge density is no longer coupled to the spin and hence does not rotate with the magnetization direction. Previously, 4*f*→5*d* optical spectroscopies as well as magnetization measurements have been used to determine the 4*f* crystal field parameters. However, the large 5*d* crystal field splitting of several eV dwarfs the much smaller 4*f* splitting, which makes the latter difficult to isolate. What is really needed to separate the 4*f* from the 5*d* contribution is an electron shell specific probe such as offered by x-ray absorption (XA) spectroscopy.

We measured the asphericity and the energy splitting of the 4*f* states in EuO – a material with fascinating properties and of technological importance for spintronics applications [1] - using x-ray magnetic linear dichroism (XMLD), i.e. the difference between XA spectra obtained with parallel and perpendicular orientation of magnetization and x-ray linear polarization. Our measurements, which are confirmed by multiplet calculations, show that there is significant 4*f* anisotropy [2]. This suggests that previously the influence of the valence character of the 4*f* states on the magnetic anisotropy might have been underestimated.

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References: [1] A. Schmehl *et al.*, Nature Materials **6**, 882 (2007).

[2] G. van der Laan, E. Arenholz, A. Schmehl, and D.G. Schlom, Phys. Rev. Lett. **100**, 067403 (2008).