<table>
<tr><td></td><td colspan="2">Experiment title:
Decay of the 3d core hole quadrupole moment in magnetic rare earths</td><td>Experiment number:
HE-442</td></tr>
<tr><td>Beamline:
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<tr><td>Shifts:
21</td><td colspan="2">Local contact:
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Report:

We measured the resonant 3*d*4*f*4*f*, 3*d*4*d*4*f* and 3*d*5*p*4*f* photoemission decay of Gd and Tb metal at the forbidden geometry for magnetic circular x-ray dichroism (MCXD), i.e. with the light polarization, **P**, perpendicular to magnetization direction, **M**.

When in XAS a core electron is excited into a magnetic valence state the dipole selection rules together with the Pauli principle give a difference in absorption probability for left and right circularly polarized light. Hence, XAS measures the monopole of the core hole, i.e. the number of holes created. The polarization, due to the higher-order multipoles, of the core hole in XAS can be studied with the angle dependence of the electrons emitted by the decay of the core hole. In the resonant photoemission decay following the x-ray absorption, the polarization of the core hole is transferred to the localized final state and the continuum electron. The detection of the kinetic energy of the emitted electrons, which determines the final-state multiplet term, together with their angular distribution allows us to measure the core-hole polarization, thereby providing information about the ground-state magnetic moments. For magnetic 3*d* transition metals we already demonstrated this effect by measuring the circular dichroism of the 2*p*3*p*3*p* and 2*p*3*d*3*d* decay spectra [*1,2*] at the forbidden geometry ($\mathbf{P} \perp \mathbf{M}$). In this case the resonant photoemission at the L_3 edge gives a quadrupole decay spectrum, which has a completely different shape than the commonly observed monopole decay. The L_2 edge does not contain a quadrupole moment and therefore lacks the effect.

In the HE-442 experiment we successfully obtained the decay spectra of the 3*d* core hole quadrupole moment in rare earths, specifically the 3*d*4*f*4*f*, 3*d*4*d*4*f* and 3*d*5*p*4*f* decay spectra of Gd and Tb metal. The rare earths provide ideal conditions for a detailed analysis of the angular dependent decay. The intermediate state is characterized by a large 3*d* spin-orbit coupling dividing the absorption into two edges where *j* is a good quantum number. The Tb 4*f* and Gd/Tb 4*d* and 5*p* (resonant) photoemission spectra show a detailed multiplet structure with a large energy separation between high and low spin states. Also the intermediate state in the 3*d* ($M_{4,5}$) absorption shows a detailed multiplet structure. [*3*] Each multiplet component of the $M_{4,5}$ structure gives a different decay spectrum. We are dealing with a 2D plot which can be measured as a function of incoming photon energy and outgoing electron kinetic energy. As an illustration of some of the measured spectra are shown in the figures below. A detailed comparison with calculated spectra using Cowan is currently in progress.

Figure 1 shows the Tb $M_{4,5}$ absorption taken with left and right circularly polarized light parallel and antiparallel to the magnetization (upper panel) together with the difference spectrum, i.e. the XMCD (lower panel). Figure 2 shows the same but with the light helicity perpendicular to the magnetization. The lower panel confirms clearly that the XMCD vanishes in this geometry. Figures 3 and 4 show the resonant 3*d*4*f*4*f* photoemission at the photon energies marked **a** and **b**, respectively, in Fig. 1 using the geometry **P** ⊥ **M** as in Fig. 2. It is clear that the MCD in resonant photoemission is large despite the absence of XMCD in absorption. The MCD in resonant photoemission for the geometry **P** // **M** can be found in Ref. *4*.

Fig. 1 (**P** // **M**)

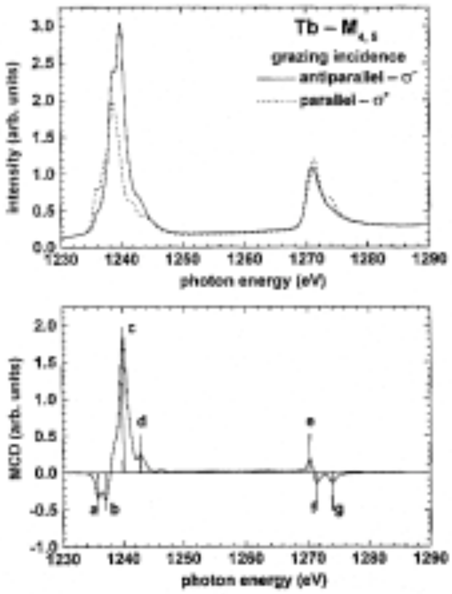


Fig. 2 (**P** ⊥ **M**)

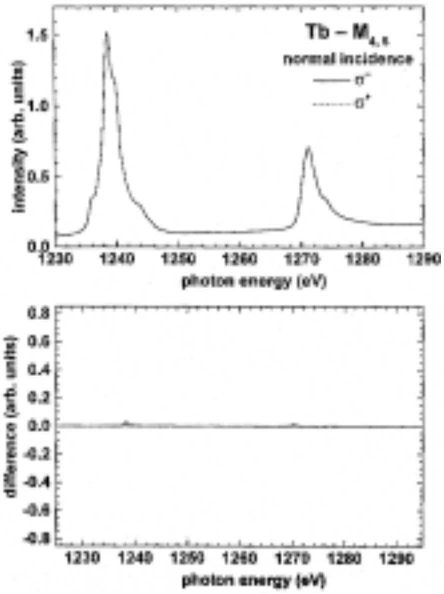


Fig. 3 (**P** ⊥ **M**)

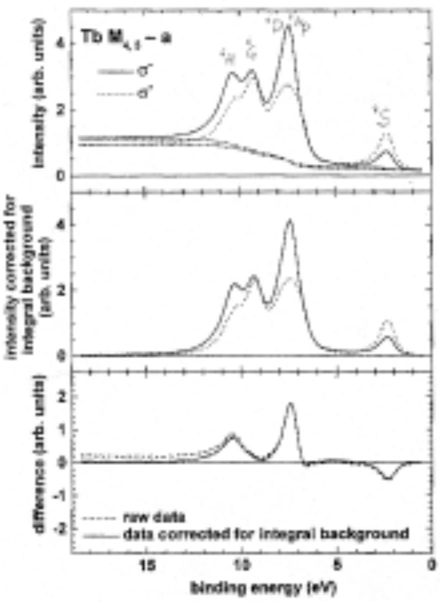
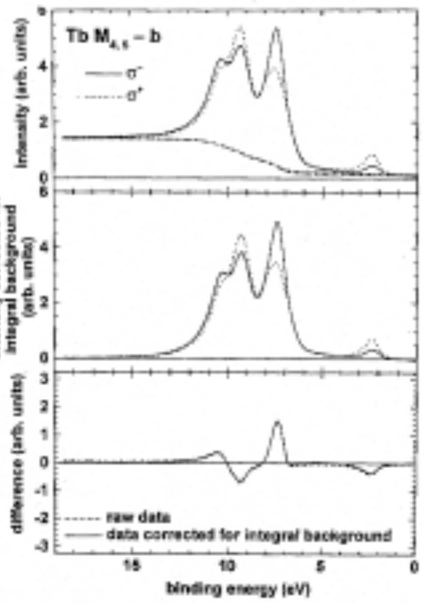


Fig. 3 (**P** ⊥ **M**)



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