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Orbital moment at the Curie temperature in $ErCo_2$ ☆

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Abstract

X-ray magnetic circular dichroism (XMCD) at the $L_{2,3}$ Co and $M_{4,5}$ Er absorption edges through the magnetic ordering transition of $ErCo_2$ has been measured as a function of temperature. Below T_C the cobalt orbital moment is strongly increased. The correlation between the Co orbital moment and the spontaneous anisotropic magnetostriction in $ErCo_2$ at T_C is evidenced.

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In the RCo_2 Laves phase compounds (R = rare earth, Sc or Y) the hybrid 3d–5d band is near the critical condition for the Co-magnetic moment formation (see the recent review by Gratz and Markosyan [1]). When R is a non-magnetic rare earth, RCo_2 are exchange-enhanced paramagnets. The Co moment can be induced by applying high magnetic fields through a metamagnetic transition. In the RCo_2 compounds with a magnetic rare-earth (except Tm) the internal f–d exchange field polarizes the Co sub-bands driving the magnetic moment formation. An interesting effect, closely related with the metamagnetic properties of the d subsystem is that the magnetic transition at T_C is of first-order type in RCo_2 with R = Dy, Ho and Er. As the rare earth system orders, the R-Co internal field induces the metamagnetic transition at T_C on the Co sublattice, which abruptly developes a magnetic moment of about 1 μ_B per Co atom [1].

The first order Curie point on $ErCo_2$ is associated to strong magnetovolumic effects, as shown by the temperature dependence of the lattice parameters [2]. Below T_C, the $ErCo_2$ unit cell is distorted due to the appearance of a spontaneous anisotropic magnetostriction (SAM), which cannot be attributed solely to the rare-earth sublattice [3]. Therefore, an orbital part in the total Co magnetization must exist to give account, at least partially, of the observed SAM. Indeed, an elaborated analysis of the hyperfine field anisotropy allowed to obtain a value of 0.1 μ_B for the Co orbital component in $ErCo_2$ at 1.5 K [4].

To further investigate the correlation between $\langle L_z^{Co} \rangle$, the metamagnetic transition and the SAM, we have measured X-ray magnetic circular dichroism (XMCD) at the $L_{2,3}$ Co and $M_{4,5}$ Er absorption edges through the magnetic ordering transition.

The experiments were performed under an applied field of 1 T with total electron yield detection on a polycrystalline $ErCo_2$ ingot. The sample was freshly cleaved and maintained on Ar atmosphere prior to exposure to X-rays in order to avoid surface oxidation. The experiments were carried out at beamline 4.0.2 at the ALS using a low-temperature endstation equipped with a 6 T magnet.

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Fig. 1 shows the temperature dependence of the XMCD intensity at the Co L_3 and Er M_4 edges. Co and Er XMCD intensities are scaled to the low-temperature magnetic moments in $ErCo_2$ at $H = 1$ T, obtained by neutron diffraction ($\mu_{Er} = 8.9\ \mu_B$, $\mu_{Co} = 1\ \mu_B$ per atom at 4 K [5]). Fig. 1 also shows the $ErCo_2$ magnetization as a function of temperature under an applied field of 1 T.

The resulting $\mu_{Er}(T) + 2\mu_{Co}(T)$ sum of the experimental XMCD as a function of temperature properly coincides with the magnetization curve. This implies that the XMCD experiments are, therefore, consistent with the low temperature value $\mu_{Co} \approx 1\ \mu_B$ found in literature.

The ordering temperature can be appreciated at both, the Er and Co edges, but the jump of the Co XMCD at T_C is not as large as one would expect at the first-order metamagnetic transition.

In principle, XMCD sum rules [6] can be used to determine quantitatively the orbital and the spin magnetic moments of 3d systems. However, the number of holes of the 3d band has not been precisely determined, to our best knowledge, and we can only obtain $\langle L_z^{Co} \rangle$ and $\langle S_z^{Co} \rangle$ per Co 3d hole (Fig. 2). When applying the spin sum rule, we have assumed $\langle T_z^{Co} \rangle = 0$, as usual for metallic 3d systems [7,8], particularly in cubic compounds. Once extrapolated to low-temperature and saturation we obtain the following values: $\langle S_z^{Co} \rangle = 0.68(6)\ \mu_B$ and $\langle L_z^{Co} \rangle = 0.13(1)\ \mu_B$ per hole. If one compares those values with previous determinations of the total Co magnetic moment [1,4,5] the number of holes needed to explain the μ_{Co} values is 1.1 ± 0.1. A more detailed analysis will be published elsewhere.

Our results evidence that erbium ordering strongly increases the net cobalt orbital magnetic moment upon cooling below T_C. The step-like temperature dependence of $\langle L_z^{Co} \rangle$ allows to qualitatively understand the spontaneous anisotropic magnetostriction observed in $ErCo_2$.

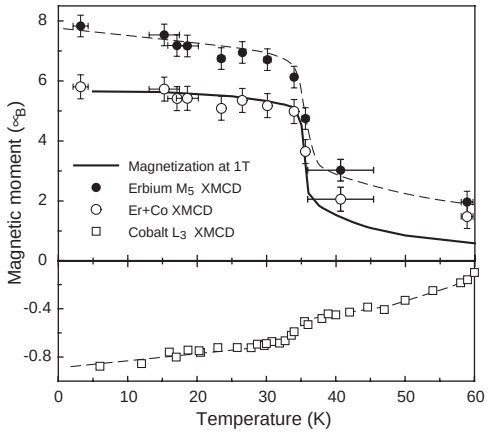

Fig. 1. Temperature dependence of the XMCD intensities at the Co L_3 (□) and Er M_4 (●) edges. The XMCD sum for an $ErCo_2$ formula unit (○) and the SQUID magnetization at $H = 1$ T are also shown (full line). Dashed lines are guides to the eyes.

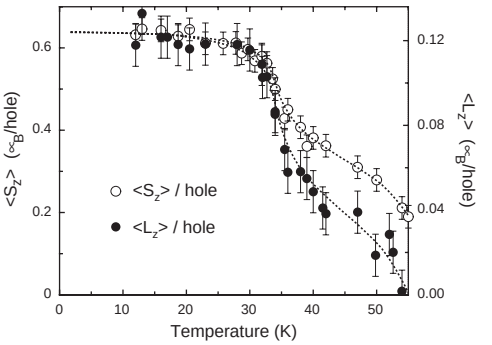

Fig. 2. $\langle L_z^{Co} \rangle$ and $\langle S_z^{Co} \rangle$ per 3d hole obtained from sum rule analysis. Dashed lines are guides to the eyes.

We already reported the first example of a direct correlation between a 3d orbital moments and a SAM through a magnetic phase transition [9], namely the spin reorientation transition of $Nd_2Fe_{14}B$. In that case, a sharp peak was observed in both, the $\langle L_z^{Fe} \rangle$ and the anisotropic magnetostriction at the phase transition. We would like to point out that the phenomenology involved in $Nd_2Fe_{14}B$ is very different to that found in $ErCo_2$. In the former, one has a second-order ferro-ferromagnetic phase transition in a perfectly stable magnetic alloy, whereas in the later a first-order para-ferrimagnetic phase transition takes place in an itinerant metamagnet. It is worth to emphasize that in those two very different scenarios a direct correlation between the 3d orbital moment and the anisotropic magnetostriction has been evidenced. Our works confirm the relationship that theory and phenomenology use to establish between those two magnitudes.

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