Comment on "Microscopic Origin of Magnetic Anisotropy in Au/Co/Au Probed with X-Ray Magnetic Circular Dichroism"

Recently, Weller *et al.* [1] reported angle-dependent x-ray magnetic circular dichroism (XMCD) experiments on a Au/Co/Au sandwich sample by forcing the Co magnetization direction away from the easy axis (along the surface normal) by an external magnetic field. This study demonstrated the important relationship between the magnetocrystalline anisotropy (MCA) and the anisotropy of the orbital moment as predicted theoretically [2]. However, in the data analysis Weller *et al.* assumed that the spin and orbital moments are collinear under their experimental conditions. This is not generally correct when spins are aligned along nonsymmetry directions. We show in this Comment that one can include this effect which leads to a different orbital moment anisotropy.

In XMCD sum rules are used to obtain the orbital moment $\mathbf{m}_{\text{orb}}$ and $\mathbf{m}_s^{\text{eff}} = \mathbf{m}_{\text{spin}} - 7\mathbf{m}_T$, with $\mathbf{m}_{\text{spin}}$ the spin moment and $\mathbf{m}_T$ the magnetic dipole term. Note that the expectation values of the moments $\mathbf{m}$ are vector quantities. $\mathbf{m}_T$ is the product of a second rank tensor, the quadrupole moment, and the spin moment [3]. A similar relation holds for the orbital moment, i.e., $\mathbf{m}_{\text{orb}} = \mathbf{R} \cdot \hat{\mathbf{S}}$. Here $\hat{\mathbf{S}}$ is a unit vector along the spin direction and $\mathbf{R}$ a second rank tensor. Such a relationship can, e.g., be derived by a spin-orbit perturbation treatment of the exchange split ground state [2]. Since $\mathbf{m}_s^{\text{eff}}$ and $\mathbf{m}_{\text{orb}}$ are of similar form, it is sufficient to discuss in the following the properties of $\mathbf{m}_{\text{orb}}$. For the C_{3v} symmetry of the sample in Ref. [1] the tensor $\mathbf{R}$ is diagonal and has two independent components, $\mathbf{R}_{zz}$ and $\mathbf{R}_{yy} = \mathbf{R}_{xx}$. The vectors $\mathbf{m}_{\text{orb}}$ and $\hat{\mathbf{S}}$ are collinear only along the main axes of $\mathbf{R}$ which include the easy magnetization axis. In XMCD one measures the projection of $\mathbf{m}_{\text{orb}}$ along the photon spin $\hat{\mathbf{P}}$ [1,3]. An external magnetic field orients $\hat{\mathbf{S}}$ in the y-z plane at an angle ϑ with respect to the sample normal, and the photon spin has an angle γ. The value observed for the orbital moment is then

$$\begin{aligned}\hat{\mathbf{P}} \cdot \mathbf{m}_{\text{orb}} &= \hat{\mathbf{P}} \cdot \mathbf{R} \cdot \hat{\mathbf{S}} \\ &= \mathbf{R}_{yy} \sin\vartheta \sin\gamma + \mathbf{R}_{zz} \cos\vartheta \cos\gamma\,. \qquad (1)\end{aligned}$$

If the magnetic field applied along $\hat{\mathbf{P}}$ is strong enough to give magnetic saturation of the sample, Eq. (1) simplifies to the one used in Ref. [1], i.e., $\hat{\mathbf{P}} \cdot \mathbf{m}_{\text{orb}} = \mathbf{R}_{yy} \sin^2\gamma + \mathbf{R}_{zz} \cos^2\gamma$. However, Fig. 2(c) in Ref. [1] shows that this is not the case so that Eq. (1) has to be used. In Fig. 1(a) we plot the angle ϑ for $\hat{\mathbf{P}}$ along the sample normal ($\gamma = 0°$) and for $\gamma = 65°$ obtained from Fig. 2(c) of Ref. [1] and from Ref. [4]. Substituting the values of ϑ from Fig. 1(a) into Eq. (1) we obtain the in-plane and out-of-plane $\mathbf{m}_{\text{orb}}$ in Fig. 1(b). The values of Weller *et al.* (lines) give a deviation which is especially distinctive at lower coverages. Here an incorrect use of Eq. (1) is more severe, since the MCA and, hence, the anisotropy of $\mathbf{m}_{\text{orb}}$ is stronger. From Fig. 1(b) we obtain that the anisotropy in the orbital moment $\mathbf{m}_{\text{orb}}^z - \mathbf{m}_{\text{orb}}^y$ is 165% of its isotropic value $(\mathbf{m}_{\text{orb}}^z + 2\mathbf{m}_{\text{orb}}^y)/3$.

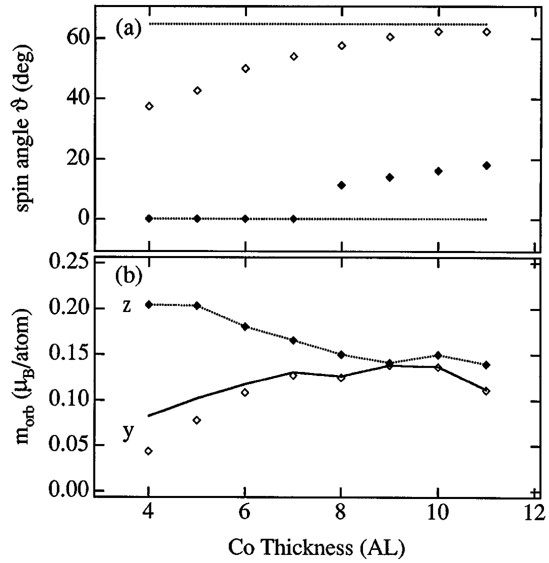

FIG. 1. (a) Angle between spin direction $\hat{\mathbf{S}}$ and surface normal (z axis) versus Co thickness. The external magnetic field to force the spins out of the easy direction (z axis) was applied in the y-z plane at angles of 0° and 65° relative to the surface normal shown as solid and open diamonds, respectively. (b) z and y components of the orbital moment versus Co thickness shown as solid and open diamonds, respectively. Lines depict the values of Fig. 3(c) in Ref. [1].

Since $\mathbf{m}_s^{\text{eff}}$ is also given by a second rank tensor times $\hat{\mathbf{S}}$, angle-dependent MCXD measurements of $\mathbf{m}_s^{\text{eff}}$ can be described by a relationship similar to the one given in Eq. (1). We used Fig. 1(a) and Eq. (1) to describe the MCXD measurements of $\mathbf{m}_s^{\text{eff}}$ in Ref. [1]. As it turns out, the anisotropy of $\mathbf{m}_s^{\text{eff}}$ is smaller than that of $\mathbf{m}_{\text{orb}}$ and the deviations in Ref. [1] are less severe; in this case they are smaller than the experimental uncertainty.

H. A. Dürr, G. van der Laan, and B. T. Thole
Daresbury Laboratory
Warrington WA4 4AD, United Kingdom

Received 28 November 1995
PACS numbers: 78.70.Dm, 78.20.Ls

[1] D. Weller *et al.*, Phys. Rev. Lett. **75**, 3752 (1995).
[2] P. Bruno, Phys. Rev. B **39**, 865 (1989).
[3] J. Stöhr and H. König, Phys. Rev. Lett. **75**, 3748 (1995).
[4] D. Weller *et al.* (to be published).

 0031-9007/96/76(18)/3464(1)$10.00