Antiferromagnetic and ferromagnetic Faraday effect in yttrium orthoferrite $YFeO_3$

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On the basis of an analysis of the field dependence of the Faraday effect in yttrium orthoferrite, it was found that this effect can be divided into antiferromagnetic and ferromagnetic components.

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The presence of nonequivalent sublattices in magnetic materials may cause the magneto-optical effects produced in them to be disproportional to the magnetic moment. We can cite as an example the rare-earth garnet ferrites, in which the Faraday effect is not proportional to the spontaneous magnetization (see, for example, Ref. 1), or yttrium orthoferrite $YFeO_3$, in which the variation of the Faraday effect in a field is not proportional to the variation of the weak magnetic moment.[2] It was assumed elsewhere[3] that a Faraday effect proportional to the antiferromagnetic moment can occur in magnetic materials; however, to the best of our knowledge, this assumption has not been verified experimentally. In this letter we shall prove the existence of antiferromagnetic and ferromagnetic components in the Faraday effect from an analysis of the field dependences of this effect in $YFeO_3$.

The experiments were carried out at room temperature, using a setup described elsewhere.[4] The sensitivity of the measurements was $\sim 10''$. The polished plate samples ~ 100 μm in thickness, cut out at right angles to the major crystallographic axis (c axis), were magnetized in $\leqslant 25$-kOe fields. The directions of light propagation ($\lambda = 0.63$ μm) and of sample magnetization were parallel to the c axis when the field dependence of the Faraday effect was measured. The polarization $\mathbf{E}$ of light incident on the sample was parallel to the a or b axis. The measured field dependence of the Faraday effect, shown in Fig. 1, is a linear and odd function of the field. The abrupt change of the Faraday effect in small fields (~ 1 kOe) is attributable to magnetic reversal of the ferromagnetic $\mathbf{m}(0)$ and antiferromagnetic $\mathbf{l}(0)$ moments. We have also noticed that magnetization of the sample parallel to the c axis changed the linear magnetic birefringence (LMB) by the amount $\Delta n \approx 4 \times 10^{-5}$ in a 25-kOe field. A large LMB changes considerably the magnitude and nature of the field dependence of the angle of rotation of the polarization plane of light that passes through the sample, if its initial polarization is not parallel to the crystallographic axis.

Figure 1 also shows the field dependence of the relative variation of the weak ferromagnetic $m(H)/m(0)$. We see that the variation of the Faraday effect is not proportional to the variation of the weak ferromagnetic moment, since the slopes of the linear field dependences $\phi(H)/\phi(0)$ and $m(H)/m(0)$ differ by a factor of approxi-

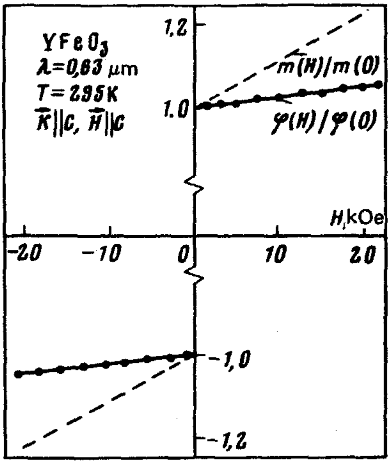

FIG. 1. Field dependence of the Faraday effect (ϕ) and of the weak ferromagnetic moment (m) (Ref. 5) in $YFeO_3$ (in relative units).

mately 6. The results obtained by us are close to those obtained in Ref. 2, where the measurements were carried out using samples cut out at right angles to the optical axis.

Let us analyze the obtained dependences in terms of the phenomenological theory. The important characteristic of the dielectric-constant tensor for orthoferrites, used in Ref. 4, is the fact that the term

$$\epsilon_{12} = -\epsilon_{21} = i\left(f_1 \frac{m_z}{m_o} + \xi_1 \frac{l_x}{l_o}\right) \tag{1}$$

is a linear combination of the **m** and **l** vectors. Since m_z and l_x change identically in all symmetry transformations of the crystal, their individual contributions to the Faraday effect can apparently be determined only by measuring the field dependences of this effect in fields parallel to m_z. The variation of m_z is different from that of l_x:

$$m_z(H) = m_z(0) + \chi_c H, \tag{2}$$

$$l_x(H) = l_x(0) - \frac{\chi_c\, m_z(0)\, H}{l_x(0)}, \tag{3}$$

where χ_c is the magnetic susceptibility along the c axis.[5]

Since the ϵ_{ij} tensor is known, we can derive the expressions for the field dependence of the Faraday effect if the direction of light and of magnetization of the sample is parallel to the c axis if the initial polarization of light incident on the sample is parallel to the $a(b)$ axis

$$\phi(0) = \frac{f_1 \frac{m_z(0)}{m_o} + \xi_1 \frac{l_x(0)}{l_o}}{\epsilon_{11} - \epsilon_{22}} \sin\delta \,, \tag{4}$$

$$\frac{\partial \phi(H)}{\partial H} = \left[\frac{f_1}{m_o} - \frac{\xi_1 m_z(0)}{l_o l_x(0)} \right] \frac{\sin\delta}{\epsilon_{11} - \epsilon_{22}} \,, \tag{5}$$

where δ is the crystallographic difference in phases. The constants f_1 and ξ_1, which were determined from the field dependence of the Faraday effect, are

$$f_1 = (0.51 \pm 0.05) \times 10^{-3}, \; \xi_1 = (3.59 \pm 0.05) \times 10^{-3}.$$

We assume from these values that the spontaneous Faraday effect is comprised of both the antiferromagnetic and ferromagnetic components and that the field dependence of this effect in fields > 1 kOe is related to the variation of the ferromagnetic component.

The Faraday effect in orthoferrites was analyzed in Ref. 6. The authors of Ref. 6 suggested that the antisymmetric part of the ϵ_{ij} tensor for the system with noninteracting sublattices be considered as a pseudovector

$$\mathbf{V} = \frac{1}{2} \Sigma \Gamma(n) \mathbf{S}(n), \tag{6}$$

where $\mathbf{S}(n)$ is the spin of the n-th sublattice, and $\Gamma(n)$ is the orbital-momentum tensor. For a system with two nonequivalent magnetic sublattices whose absolute spins are equal in the presence of a large anisotropic crystalline field, we have

$$V_3 = i\epsilon_{21} = gS \sin\beta \cos(\beta - \alpha) \,, \tag{7}$$

where α is the angle between the a axis and the spin $\mathbf{S}$, and β is the angle between the a axis and the major axis of the tensor $\Gamma(n)$. Since $l = 2S\cos\alpha$ and $m = 2S\sin\alpha$, Eq. (7) reduces to Eq. (1). The quantities g and β, which were estimated from our results, have the values

$$g = \frac{4\xi_1}{l_o \sin 2\beta} = (0.79 \pm 0.08) \times 10^{-3}, \; \beta = \mathrm{arctg} \frac{f_1 l_o}{\xi_1 m_o} = (85.6 \pm 0.5)^\circ.$$

Thus our approach, in spite of the results of Ref. 2, can account for the magnitude and field variation of the Faraday effect in $YFeO_3$. It follows from Eq. (6) that the anisotropy surrounding the magnetic ion implies that the Faraday effect is determined not only by the spin projection in the propagation direction of light but also by its projection perpendicular to it. The existence of antiferromagnetic Faraday effect, however, presupposes the existence of nonequivalent magnetic sublattices, since the antiferromagnetic component of the Faraday effect vanishes in the equivalent sublattices.

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