Direct measurement of the magnetic and deformation contribution to birefringence in the weakly-ferromagnetic phase of hematite (α-Fe_2O_3)

V. S. Merkulov, E. G. Rudashevskiĭ, and A. LeGalle[1]

P. N. Lebedev Physics Institute, USSR Academy of Sciences

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It is shown experimentally that 98% of the entire birefringence in α-Fe_2O_3, with the light propagating along the C_3 axis, is due to the polarizability anisotropy connected with the magnetizations of the sublattices and their orientation relative to the crystallographic axes.

Although birefringence has recently been investigated in a number of antiferromagnets[1,2] there was no direct proof that the dominant contribution is made to the birefringence by the spin subsystem, as compared with the contribution due to the lattice magnetostriction.

For an experimental study of this question, we chose single-crystal hematite (α-Fe_2O_3, crystallographic structure D_{3d}^6), in which we investigated the propagation of light along the principal crystallographic direction ($\mathbf{k} \parallel C_3$). The measurements were made at room temperature in a weakly-ferromagnetic phase of the hematite.

The experimental setup is shown in Fig. 1. The sample 3, a plate measuring 2.35×2.33×0.30 mm, was mounted in micropress 8, which made it possible to apply mechanical tension stresses $\mathbf{p} \perp \mathbf{k}$. The external magnetic field $\mathbf{H}$ was oriented $\mathbf{H} \perp \mathbf{p}$ and $\mathbf{H} \perp \mathbf{k}$.

The radiation source was a helium-neon laser 1 ($\lambda = 1.15\ \mu$). The polarizer 2 and analyzer 6 were Glan-Thompson prisms. The radiation incident on the sample was polarized at an angle 45° with H and p. A mica quarter-wave plate 4, whose principal axes made an angle 45° with H, was placed behind the sample. The light flux was modulated with a rotating Glan-Thompson prism 5. The radiation intensity incident on the photoreceiver 7 is given by

$$I \sim I_0 [1 + \cos(2A - (\pi/2) - 2\Omega t)][1 + \sin(2\Omega t - \alpha)],$$

where I_0 is the intensity of the laser radiation, A is the angle of rotation of the analyzer from the position crossed with the polarizer, α is the phase shift between the components E_x and E_y of the radiation passing through the sample, and Ω is the frequency of rotation of the Glan-Thompson prism. The expression for I contains constant terms and terms with frequencies 2Ω and 4Ω.

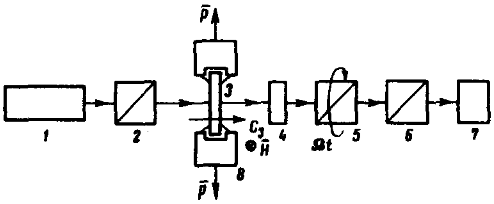

FIG. 1. Setup for the measurement of birefringence.

In the experiment we measured the second-harmonic amplitude

$$I(2\Omega) \sim I_0 \sin(A - (\alpha/2)).$$

At $A_0 = \alpha/2$ we have $I(2\Omega) = 0$. The advantage of the procedure in which a rotating Glan-Thompson prism is used is that $I(2\Omega) \sim A - A_0$ at small deviations of A from A_0, whereas for ordinary modulation with the aid of a chopper we have $I(\Omega) \sim (A - A_0)^2$.

The results of the measurements are shown in Fig. 2. At a pressure $p_1 = 4.2$ bar (the minimum load corresponding to the weight of the sample holder) the birefringence increases abruptly with increasing magnetic field, and at $H > 1$ kOe it remains practically unchanged, corresponding to a transition of hematite from a multidomain state relative to the weak-ferromagnetic mo-

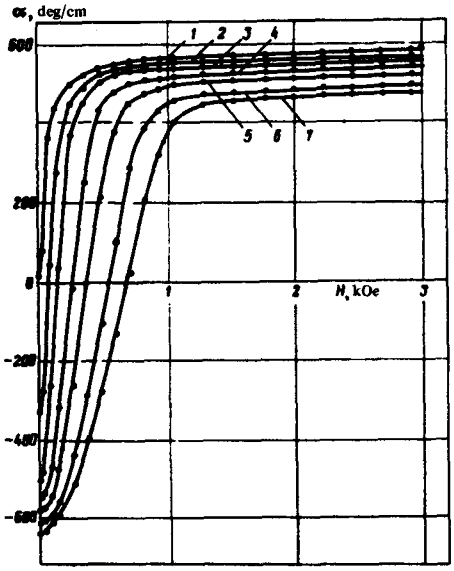

FIG. 2. Dependence of the phase shift α between the components E_x and E_y of the transmitted light as a function of the magnetic field at various tension stresses p. Curves 1, 2, 3, 4, 5, 6, and 7 correspond to p=4.2, 19.8, 33.4, 54.4, 81.9, 109.3, and 133.5 bar.

ment vector m. In constant magnetic fields $H > 2$ kOe the birefringence decreased linearly with increasing mechanical stress. Upon application of a pressure $p_s = 3$ bar, compensating the spontaneous magnetostriction of the lattice,[3,4] the birefringence decreases by an amount $\alpha_s = 12$ deg/cm, which is about 2% of the total birefringence effect.

It is seen from the diagram that when the magnetic field is decreased at a fixed load, a change takes place in the sign of α. The values of $|\alpha|$ are close to each other at $H = 0$ and $H > 2$ kOe. This indicates that the antiferromagnetism vector $\mathbf{l}$ is rotated from a state $\mathbf{l} \perp \mathbf{H}$ to a state $\mathbf{l} \perp \mathbf{p}$.

It can thus be concluded that in the weakly-ferromagnetic phase of hematite the birefringence is due mainly to the magnetic subsystem and is connected with the orientation of the antiferromagnetism vector $\mathbf{l}$.

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1) Laboratory for magnetism and optics of solids, Bellevue, France.

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