SURFACE MAGNETISM OF HEMATITE

G.S. Krinchik, A.P. Khrebtov, A.A. Askochenskii, and V.E. Zubov
Moscow State University
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We present here the results of the first investigation of the magnetooptical properties of hematite (α-Fe_2O_3) by measuring the equatorial Kerr effect δ [1]. An effect comparable with the effect in iron garnets was observed in the (111) basal plane of the weak ferromagnet α-Fe_2O_3. Measurements in the (100) plane have revealed the presence of a surface magnetic layer, attributed to the lowering of the symmetry of the surrounding Fe^{3+} surface ions. The possible existence of surface ferromagnetic layers on antiferromagnetic crystals is predicted.

Figure 1 shows plots of the frequency dependence of δ for two light-incidence angles, measured at H = 500 Oe in the (111) basal plane. The measurements were made at room temperature on natural faces of synthetic crystals. The effect was isotropic accurate to ±3%.

Figure 2 shows plots obtained for a natural (100) face of hematite magnetized along the [01$\bar{1}$] axis. The main features of the $\delta(\omega)$ frequency dependence were preserved, and some differences between the curves for the planes (100) and (111) are apparently due to anisotropy of the optical constants of the hematite crystal. A comparison of the obtained δ curves with the corresponding curves for rare-earth iron garnets [1] shows that in spite of the appreciable magnetization difference (2 and 400 G/cm^3 for α-Fe_2O_3 and the octahedral sublattice in $Y_3Fe_5O_{12}$, respectively), the value of δ for the weak ferromagnet α-Fe_2O_3 is approximately the same as for iron garnets. Thus, an interesting theoretical problem arises, namely, weak ferromagnets have an unexpectedly large magnetooptical activity not caused

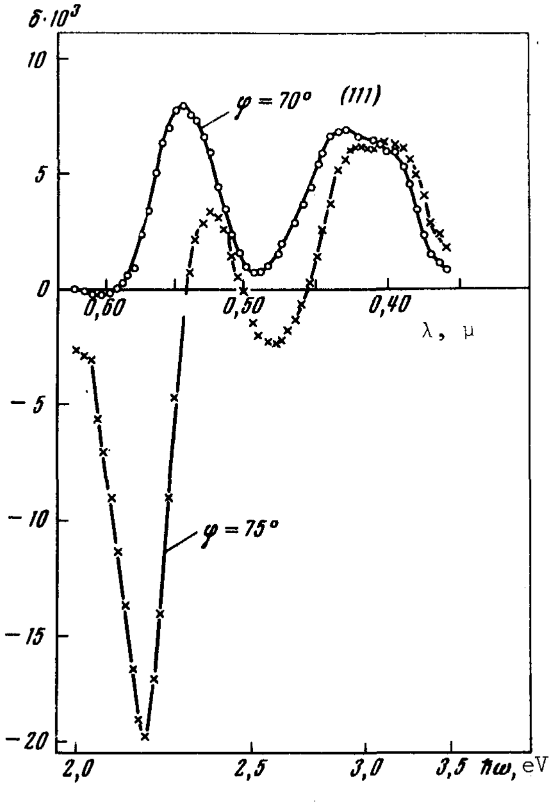

Fig. 1

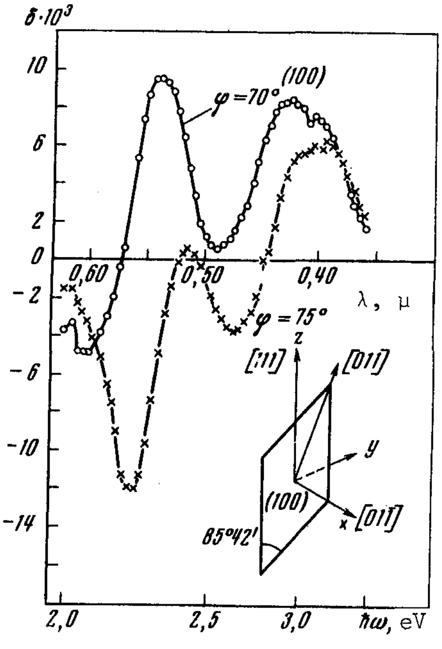

Fig. 2

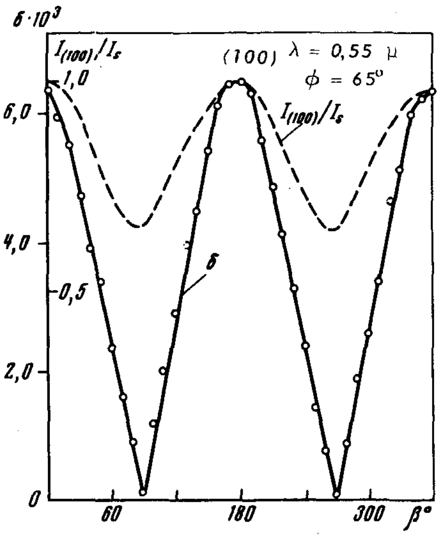

Fig. 3

by the spontaneous magnetization. This activity was attributed in [2] to anisotropic quenching of the orbital angular momentum of Fe^{3+}. Unfortunately, only qualitative arguments were advanced for this assumption, and a phenomenological coefficient g_e was introduced to justify the experimental results quantitatively[1].

The presence of a strongly pronounced maximum of δ at $\hbar\omega \simeq 2.3$ eV can be attributed to the lifting of the parity forbiddenness of the crystalline transition ${}^6A_{1g}({}^6S) \rightarrow {}^4E_g({}^4G)$; ${}^4A_{1g}({}^4G)$, or of the molecular-orbital transition $t_{1g}^{\pi}(\pi) \rightarrow t_{2g}^{*}$ due to the strong displacement of the Fe^{3+} ions relative to the centers of the O^{2-} octahedra in hematite [3].

Measurements of δ along other directions in the (100) plane and the measurement of the polar Kerr effect have led to an entirely unexpected result. Figure 3 shows the dependence of the effect δ, measured in the (100) plane, on the angle between the direction of the field and the $[01\bar{1}]$ axis. When the field is oriented along the [011] axis, the equatorial effect vanishes, although the magnetization component in this direction is equal to $0.53I_s$ in the interior of the crystal. The normal component in the (100) plane is equal in this case to $0.84I_s$, whereas a special experiment performed on non-basal samples have shown that the polar effect does not exist up to H = 8000 Oe. It must be borne in mind that in these experiments, owing to the small depth of penetration of the light into the ferromagnet (~0.05 μ), one measures the magnetic properties of a thin surface layer [3]. The observed anisotropy of the equatorial Kerr effect and the absence of the polar effect on the (100) face can be naturally attributed to the appearance of a transition magnetic surface layer, having a magnetic state different from that in the interior. The appearance of this layer can be due to the lowering of the symmetry of the Fe^{3+} ion surrounding on the surface and to the appearance of additional terms in the expression for the Dzyaloshinskii energy [5]. For the surface Fe^{3+} ions in the (100) plane there remains a single point symmetry element σ_d. The Hamiltonian of the surface layer, without allowance for the crystallographic anisotropy, takes the form

$$H = \frac{A}{2}m^2 + d_1 m_x \ell_y + d_2 m_y \ell_x + d_3 m_x \ell_z + d_4 m_z \ell_x \ .$$

The notation is the same as in [5]. Assuming, for example, that $d_3 = d_4 = 0$ and minimizing H with respect to $\vec{m}$ and $\vec{\ell}$, we obtain a case analogous to weak ferromagnetism of orthoferrites. In particular, the solution

$$m_y = m_z = 0, \quad m_x = \pm \frac{d_1}{A}, \quad \ell_x = \ell_z = 0, \quad \ell_y \cong \mp 1$$

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[1] A.S. Borovik-Romanov and I.E. Dzyaloshinskii (private communication) have suggested that this large effect is connected with a reorientation of the antiferromagnetism vector $\vec{\ell}$.

explain the results of our experiment, i.e., the absence of a normal magnetization component and the reversal of the magnetization $\vec{m}$ along the x axis.

The transition layer from the surface state of magnetization to the volume state should have the character of a domain wall. Let us estimate the width of a 180° Neel wall. Taking into account the magnetostatic and exchange energies we obtain $t = [\pi^2 A/2a(0.86I_s^2)]^{1/2}$. For hematite we have $A = 4.5 \times 10^{-13}$ erg, $a = 3 \times 10^{-8}$ cm, $I_s = 2$ G/cm^3, and $t = 46$ μ. In the case of an external magnetic field normal to the surface, $I_s H >> 0.86I_s^2$, we obtain for the surface layer $t = [(\pi^2/4)(A/2a)(2/I_s H)^{-1}]^{1/2}$; t = 4.3 and 1.36 μ at H = 100 and 1000 Oe, respectively.

On the basis of an analysis similar to that given above, we can predict a new interesting effect, viz., the appearance of weak surface ferromagnetism on certain faces of antiferromagnetic crystals, for example on the face (111) of MnO and NiO as a result of the absence of inversion I, on the faces (100) and (110) of Cr_2O_3, MnO, and Ni (absence of I and C_3), on the (100) face of hematite below the Morin point (no C_3), etc.

[1] G.S. Krinchik and V.A. Krylova, ZhETF Pis. Red. 16, 267 (1972) [JETP Lett. 16, 188 (1972)].
[2] F.J. Kahn, P.S. Pershan, and J.P. Remeika, Phys. Rev. 186, No. 3 (1969).
[3] R.E. Newnham and Y.M. deHaan, Zs. Krist. 117s, 235 (1962).
[4] G.S. Krinchik, Fiz. Tverd. Tela 2, 1940 (1960) [Sov. Phys.-Solid State 2, 1748 (1961)].
[5] I.E. Dzyaloshinskii, Zh. Eksp. Teor. Fiz. 32, 1547 (1957) [Sov. Phys.-JETP 5, 1259 (1957)].
[6] E.A. Turov, Fizicheskie svoistva magnitouporyadochennykh kristallov (Physical Properties of Magnetically Ordered Crystals), AN SSSR, 1963.

SUPERCONDUCTIVITY OF LUTECIUM

E.I. Nikulin, N.V. Volkenshtein, and V.E. Startsev
A.F. Ioffe Physico-technical Institute, USSR Academy of Sciences

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We measured the electric resistance of lutecium in the temperature range 0.03 - 4.2°K. A transition to the superconducting state was observed in the purest (99.9%) samples containing no ferromagnetic impurities. The transition temperature is $T_c = 0.10 \pm 0.03$°K and the critical magnetic field is $H_c < 400$ Oe.

The only previously known superconductor among the rare-earth metals (REM) is lanthanum, which is the first in the REM series. As to lutecium, the last of the REM series, no superconductivity was revealed by measurements of the electric resistance down to 1°K [1] and by measurements of the specific heat down to 0.4°K [4]. This rare-earth element has the same electron shell as lanthanum, $5d^1 6s^2$, and has in the metallic state a hexagonal lattice with parameters and electron structure close to those of lanthanum. It was unclear why lutecium is not superconducting. We have therefore measured the electric resistance of different lutecium samples in the temperature range 0.03 - 4.2°K.

The infralow temperature was obtained by adiabatic demagnetization of a paramagnetic salt that served simultaneously as a thermometer. Measurement of the susceptibility of the salt $\chi \sim 1/T$ determines the so-called "magnetic" temperature. The paramagnetic salt was chromium potassium alum or iron ammonium