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NEW TYPE OF ANTIFERROMAGNETIC RESONANCE IN α-Fe_2O_3

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The antiferromagnetic α-Fe_2O_3 has been investigated very thoroughly, but interest in it does not subside. Thus, under discussion presently is the question of the anomalies of the magnetization curve $m_x(H_x)$ in a direction perpendicular to the threefold C_3 axis in strong fields and for $T < T_M$, when the magnetizations $\vec{M}_1$ and $\vec{M}_2$ of the sublattices are aligned along C_3 at zero field [1-4]. It is therefore of interest to study experimentally the dynamics of the sublattices in this region of fields and temperatures.

Having in mind α-Fe_2O_3 at $T < T_M$, let us consider the influence of a transverse field on a very simple antiferromagnet with "easy axis" anisotropy and with nonzero Dzyaloshinskii interaction. We direct the z axis along the easy axis and the x axis along the field $\vec{H}$, which is perpendicular to z. The system energy is written in the form

$$H = \frac{B}{2} M^2 + \frac{a}{2}(L_x^2 + L_y^2) - \beta(M_x L_y - M_y L_x) - MH, \tag{1}$$

where

$$M \equiv M_1 + M_2;\ \ L \equiv M_1 - M_2;\ \ |M_1|^2 = |M_2|^2 \equiv M_0^2 .$$

Analyzing then the equations of motion for the vectors $\vec{M}$ and $\vec{L}$ $([\vec{M}\vec{H}] \equiv \vec{M}\times\vec{H})$

$$\frac{1}{\gamma}\dot{M} = [MH_M] + [LH_L];\qquad \frac{1}{\gamma}\dot{L} = [MH_L] + [LH_M], \tag{2}$$

where

$$H_M \equiv -\partial H/\partial M;\ \ H_L \equiv -\partial H/\partial L,$$

we obtain the equilibrium values of $\vec{M}$ and $\vec{L}$.

$$H_x < H_{c\perp}:\ \ m_x = \frac{H_A H_x}{2H_A H_E - H_D^2};\ \ \ell_y = \frac{H_D H_x}{2H_A H_E - H_D^2};\ \ \ell_z = \left(1 - \frac{H_x^2}{H_{c\perp}^2}\right)^{1/2}, \tag{3}$$

$$H_x > H_{c\perp}:\ \ell_z = 0;\ \ \ell_y = \sqrt{1 - m_x^2};\ \ (B - a)m_x - \beta\frac{1 - 2m_x^2}{\sqrt{1 - m_x^2}} = \frac{H_x}{2M_0}, \tag{4}$$

where

$$m \equiv M/2M_0;\ \ \ell = L/2M_0;\ \ H_E \equiv BM_0;\ \ H_A \equiv 2aM_0;\ \ H_D \equiv 2\beta M_0 .$$

The components M_y, M_z, and L_x vanish for all H_x. The critical field $H_{c\perp}$ is defined as the field at which L_z first vanishes. The expression for it is

$$H_{c\perp} = (2H_A H_E - H_D^2)/(H_A^2 + H_D^2)^{1/2} \tag{5}$$

and is more general than that given in [4]* (from (5) we get, for an antiferromagnet without Dzyaloshinskii interaction, $H_{c\perp} = 2H_E$, i.e., the well known "collapse field").

The solution of the system (2) for small deviations $\vec{\mu}$ and $\vec{\lambda}$ from the equilibrium $\vec{M}$ and $\vec{L}$ yields two natural-oscillation frequencies. One of them, the one vanishing at $H_x = H_{c\perp}$, is of special interest:

$$H_x < H_{c\perp}: \ \omega_{10}^2 = \omega_0^2 (1 - H_x^2/H_{c\perp}^2); \quad \omega_0^2 = \gamma^2 (2H_A H_E - H_D^2), \tag{6a}$$

$$H_x > H_{c\perp}: \ \omega_{10}^2 = \left(\frac{\gamma}{2M_0}\right)^2 (H_D M_x - H_A L_y)\left[(2H_E - H_A)L_y + 2H_D M_x + \frac{H_D M_x}{(L_y/2M_0)^2}\right]. \tag{6b}$$

With this, using (4), we can readily deduce from (6b) that in fields that do not exceed $H_{c\perp}$ greatly the frequency ω_{10} increases as $\omega_{10} \approx \omega_0 (H_x/H_{c\perp} - 1)^{1/2}$ - see Fig. 1. The quantities μ_x, λ_x, and λ_z oscillate at the frequency ω_{10} both above and below $H_{c\perp}$, and are excited by the alternating field h_x

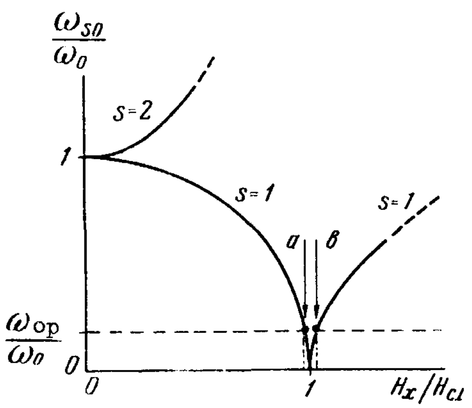

Fig. 1. Calculated field dependence of AFMR frequencies in $\alpha\text{-}Fe_2O_3$ for $H \perp C_3$.

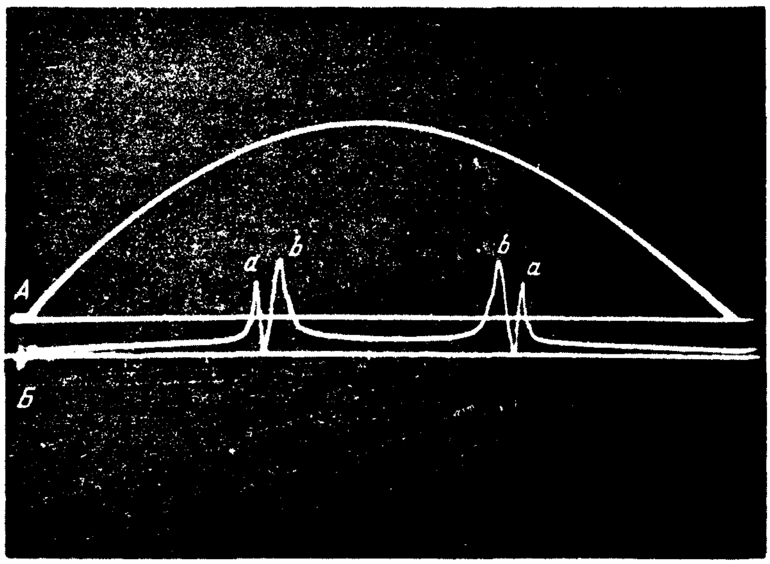

Fig. 2. A - oscillogram of signal proportional to magnetic field intensity in solenoid, B - oscillogram of microwave detector signal proportional to absorbed power

It should be noted that other anomalies of properties of antiferromagnets should also be observed in fields $H_x \sim H_{c\perp}$. Thus, for example, "linear" magnetostriction of the shear type (an effect inverse to the piezomagnetic effect [5]) should disappear from antiferromagnets of the $\alpha\text{-}Fe_2O_3$ type in fields $H_x \geq H_{c\perp}$; when $H_c < H_{c\perp}$ the shear deformation is $U_{yz} = \Lambda H_x \sqrt{1 - H_x^2/H_{c\perp}^2}$ and has a maximum $U_{yz}^{max} = \Lambda H_{c\perp}/2$ in a field $H_x = H_{c\perp}/\sqrt{2}$.

The question whether such a simple theory is applicable to the case of $\alpha\text{-}Fe_2O_3$ in the entire region $T < T_M$ still remains open, since it implies that the dependence of m_x on H_x is continuous in $H_{c\perp}$, which contradicts the experimental data near T_M [3] (what follows from formulas (3)-(5) is only a jump of dm_x/dH_x in $H_{c\perp}$, an effect similar to that observed earlier in CoF_2 [6,7]). Our experiments did reveal, however, the vanishing of one of the antiferromagnetic resonance frequencies at $H_x = H_{c\perp}$, which follows from this calculation.

The measurements were made with a reflex microwave spectrometer for the 8 mm band (operating frequency ν_{op} = 32 GHz) with a pulsed magnetic field. The duration of the field from zero to maximum was $\tau_{0m} \sim 5$ msec. The maximum field was $H_m \sim 250$ kOe. The signal H(t) was calibrated by observing antiferromagnetic resonance in Cr_2O_3 with $H||C_3$ at T = 77°K [8]. The field measurement accuracy was ±3%.

A synthetic single crystal of α-Fe_2O_3 measuring 1 x 3 x 4 mm** was glued to the narrow wall of a waveguide placed along the solenoid axis in such a way that the pulsed magnetic field and the microwave magnetic field parallel to it were in the basal plane of the crystal.

Figure 2 shows oscillograms and of the detector microwave signal, taken at T = 77°K. Absorption peaks are clearly seen at H_a = 130 kOe and H_b = 135 kOe. Assuming that these peaks can be interpreted as resonance above and below the critical field $H_{c\perp}$, we obtain for the constants involved in the calculation the values $H_{c\perp}$ = 132±4 kOe and ω_0/ω_{op} = 6.2±1, whence $(2H_AH_E - H_D^2)^{1/2}$ = 70±10 kOe (we put g = 2.0).

In addition, we obtained a more accurate value of $(2H_AH_E - H_D^2)$ from a separate experiment, in which antiferromagnetic resonance was observed in the same α-Fe_2O_3 sample at $H||C_3$. The resonance took place at H_z = 51 kOe, making it possible to determine the "reversing field" $H_c = (2H_AH_E - H_D^2)^{1/2}$ = 63±3 kOe, in agreement with the results of [9] and [2].

Substituting the foregoing values of $H_{c\perp}$ and H_c in (5) and neglecting the field H_A in the denominator (H_A = 0.54 kOe), we get H_D(77°K) = 30±4 kOe. The difference between this value and that obtained by Rudashevskii [10] from resonance at $T > T_M$ (H_D(295°K) = 22 0.2 kOe) and by Foner [11] from resonance at $H||C_3$ and $T < T_M$ (H_D(77°K) = 40±3 kOe) is worthy of attention, and calls in particular for a continuation of the described experiments at higher frequencies and other temperatures.

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*It also differs from that given in [2], where expression (6) was not differentiated with respect to θ, so that it was not revealed that the value $\theta = 0$ is not an equilibrium value when $0 < H_x < H_{c\perp}$.

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