SHOCK MAGNETIC EXCITATION OF MAGNETOELASTIC OSCILLATIONS IN HEMATITE AND THEIR OBSERVATION BY MEANS OF ANTIFERROMAGNETIC RESONANCE

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Antiferromagnetic resonance (AFMR) can be a convenient means for observation of magnetoelastic oscillations in those antiferromagnets in which the effect of magnetoelastic interaction on the AFMR frequency is large. This method has been employed to study the magnetoelastic vibrations of a sphere of single-crystal α-Fe_2O_3 excited by a pulsed, short-duration magnetic field.

THE investigation of magnetoelastic properties of dielectric antiferromagnets (AF), especially their dynamic manifestation, promises to yield important information on the interaction between the spin system of the AF and the crystal lattice[1-3]. In the study of analogous phenomena in ferrites, extensive use is made of the induction method of detection of magnetoelastic oscillations[4], which has a number of advantages. However, as applied to AF, it may turn out to be insufficiently sensitive, by virtue of the low total magnetization of these substances. On the other hand, in AF, owing to the peculiar part played by the large exchange field, the influence of the magnetoelastic interaction on the frequencies of the resonant oscillations of the spins is much stronger than in ferrites[5,6]. We have used this fact to observe the natural magnetoelastic oscillations of a small sphere of single-crystal hematite (α-Fe_2O_3) at room temperature, i.e., having anisotropy of the "easy plane" axis.

In the investigation of the kinetics of the reversal of magnetization of the weak ferromagnetic moment of the hematite, we observed that these oscillations can be excited quite successfully with the aid of a pulsed magnetic field (of duration $\tau_{00} \approx 1-10$ sec), directed at an obtuse angle to the constant field H_0. The latter was applied to the basal plane of the crystal and its magnitude was chosen such that in the absence of a pulsed field the sample absorbed in resonant fashion the 8-mm microwave energy incident on the sample. Under these conditions, any changes in the sample leading to a shift of the resonant frequency of the spin system should affect the magnitude of the signal picked off the microwave detector, and the smaller the width of the resonance line $2\delta H$, the stronger this effect (in our case $2\delta H = 410$ Oe).

The oscillograms shown in Fig. 1 illustrate some of the experimental results obtained with a polished sphere of 1.5 mm diameter, at antiparallel orientation of the constant and pulsed fields H_0 and H_p ($\nu_{micr} = 36.7$ GHz, $H_0 = 5.75$ kOe). To increase the sensitivity of the method, the exact value of H_0 was established at that point of the resonance line, where the rate of change of the microwave absorption with changing field was maximal ($H_0 \approx H_{res} - \delta H$).

The geometry of the experiments, in which the dependence of the relative amplitude of the oscillations observed after turning off the pulsed fields on the mutual orientation of the pulse and constant magnetic fields was measured, is shown in Fig. 2a, and the results of

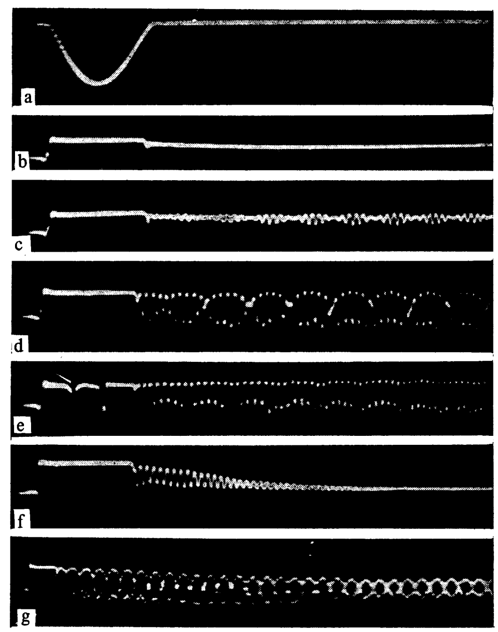

FIG. 1. Oscillograms illustrating the experiment at antiparallel orientation of the constant and pulsed magnetic fields H_0 and H_p (H_0 = 5.75 kOe, $_{micr}$ = 36.7 GHz): a) dependence of the pulsed field on the time, τ_{00} = 5.7 μsec; b–e) time dependence of the microwave signals of the detector at different values of H_0^{max}, which increase from b to e, the single-crystal α-Fe_2O_3 sphere is glued to a quartz rod, $H_0 \perp C_3$; f) sphere surrounded by a viscous medium (vacuum grease), H_p^{max} is the same as in the case d; g) the same as d, but the sweep duration is increased 2.8 times.

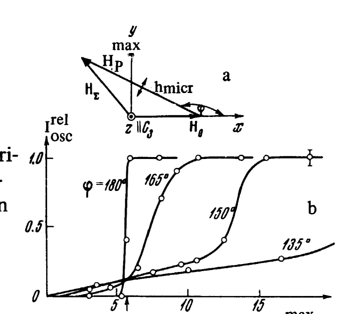

FIG. 2. The geometry of experiment (a) and its result (b)—the dependence of the relative oscillation amplitude on the pulsed field and its orientation relative to the constant field.

these experiments are summarized in Fig. 2b. The fundamental frequency of the indicated oscillations is inversely proportional to the diameter d of the sphere (this was verified for d = 1.5, 1.7, and 2.0 mm) and amounts to 2.60 ± 0.05 MHz at d = 1.5 mm, i.e., it coincides in order of magnitude with the frequency of the natural elastic oscillations of the sphere, $\nu \sim v_s/d$ (v_s—speed of sound). The assumption that the oscillations excited by the method described above are elastic is confirmed by a measurement of the Q (Q ~ 10^5 for the freely lying sphere) and by its strong dependence on the acoustic loading (see Fig. 1f). The overall picture of the phenomenon remains unchanged when microwave radiation in the 4 mm band is used, as well as when a pulsed field of shorter duration (τ_{00} = 1 μsec) is used.

As demonstrated for the easy-plane phase of hematite by Borovik-Romanov and Rudashevskiĭ[5], the superposition of a constant field $H_0 \perp C_3$ causes a magnetostriction change of the shape of the sample, connected with the orientation of the AF vector **L**. In our experiment, the pulsed field H_p, applied for example in a direction opposite to H_0, produces when $|H^{max}| > |H_0|$ a reversal of the magnetization of the ferromagnetic vector **m**, which should be accompanied by a change in the orientation of **L**[7]. The appearance of resonant peaks at $H_p^{max} = -5.75$ kOe on an oscillogram similar to that of Fig. 1e, but taken at τ_{00} = 1 μsec, shows that the reversal of magnetization is completed within a time shorter than or of the order of the characteristic time d/v_s of the elastic processes. Therefore the magnetoelastic equilibrium is violated during the course of attaining the reverse-magnetization state of the spin system, and natural magnetoelastic oscillations appear in the sample[1)]. By virtue of the high Q, they continue to exist also after the pulsed field is turned off.

The frequency of the antiferromagnetic resonance (AFMR) used by us to detect these oscillations is described by the expression[8]

$$\omega^2 = \gamma^2\{H_0(H_0 + \tilde{H}_Д) + 2B[\alpha(L_{y0}^2 - L_{x0}^2) - 2\beta L_{x0}L_{y0}]\},$$

where $H_0 \parallel x$, $\tilde{H}_D$ is the effective Dzyaloshinskiĭ field, B is the exchange constant

$$\alpha \equiv 2\lambda_3(u_{xx} - u_{yy}) + 2\lambda_4 u_{yz}, \quad \beta \equiv 4\lambda_3 u_{xy} + 2\lambda_4 u_{xz},$$

λ_3 and λ_4 are the magnetoelastic constants; u_{ik} is the strain tensor (the strains are assumed to be homogeneous). In the presence of magnetoelastic oscillations, the time variations of u_{ik} take the spin system periodically out of resonance, leading to modulation of the microwave power absorbed by the sample. According to the measurements, the intensity of the oscillations excited by the described method is such as if the external field were to oscillate with an amplitude ~200 Oe.

The presence of beats (with frequency 0.15 MHz in Fig. 1d) indicates that two natural modes of the elastic sphere are excited, presumably T_{21} and S_{21} (using the notation of[4]). If the external field is set equal not to $(H_{res} - \delta H)$, but exactly to H_{res}, then the frequency of the elastic modulation of the microwave power should double, as is indeed observed. We observed also modulation of the microwave absorption, by exciting with the aid of piezoquartz stimulated elastic oscillations in a hematite plate. The subtler details call for additional investigations.

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[1)] This fact is, strictly speaking, the first albeit indirect experimental confirmation of the reversal of the orientation of the AF vector when the weak ferromagnetic moment is reversed.