Parametric excitation of phonons in antiferromagnetic $FeBO_3$

B. Ya. Kotyuzhanskiĭ and L. A. Prozorova
Institute of Physical Problems, Academy of Sciences of the USSR

(Submitted 5 February 1982)

Pis'ma Zh. Eksp. Teor. Fiz. **35**, No. 6, 244–246 (20 March 1982)

Phonons with a frequency of 17.7 GHz have been excited parametrically by microwave pumping in the easy-plane antiferromagnet $FeBO_3$. The phonon relaxation frequency calculated from the excitation threshold increases with increasing static field.

PACS numbers: 63.20.Dj, 78.70.Gq

Antiferromagnets exhibit an exchange intensification of the magnetoelastic interaction, which distorts the magnon spectrum $\nu_m(\mathbf{k})$ and the phonon spectrum $\nu_{\text{ph}}(\mathbf{k})$. This effect is seen particularly clearly in antiferromagnets having an easy-plane anisotropy, for which there is a low-activation-energy branch in the spin-wave spectrum. In this case there is a point in weak fields where the spectra intersect and where this distortion is particularly pronounced.[1,2]

The magnetoelastic interaction should also lead to features in the damping of magnons and phonons.[3] The same interaction may give rise to a parametric excitation of phonons by an electromagnetic wave in the microwave frequency range through parallel and perpendicular pumping.[4–7]

In this letter we are reporting a study of the phonon relaxation frequency, which we determined from the threshold for parametric excitation in the easy-plane antiferromagnet $FeBO_3$. We selected $FeBO_3$ (space group D_{3d}^3) because of its comparatively strong magnetoelastic interaction[8] and its high Néel temperature ($T_N = 348$ K).

The measurements were carried out with a direct-gain microwave spectrometer at a pump frequency $\nu_p = 35.4$ GHz. A single-crystal sample with dimensions $\sim 2 \times 2 \times 0.5$ mm is placed at an antinode of the microwave magnetic field $\mathbf{h}$ in a high-Q cylindrical cavity. The conditions for "perpendicular pumping" are arranged: The fields $\mathbf{h}$ and $\mathbf{H}$

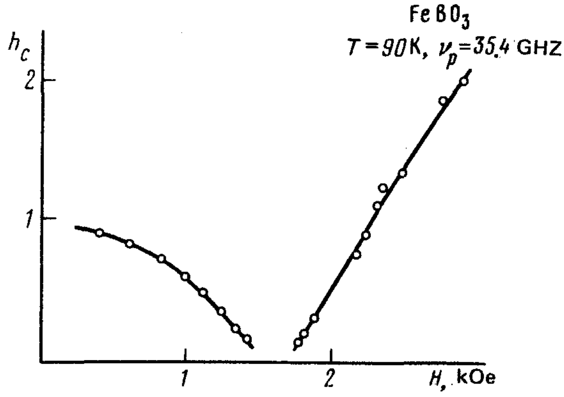

FIG. 1. Dependence of the threshold field h_c on the static field H.

lie in the basis plane of the crystal and are perpendicular to each other. Measurements are carried out over the temperature range 1.2-150 K. The sample is cooled with helium vapor, and its temperature is measured with a semiconductor resistance thermometer.

The parametric excitation with $\mathbf{h}\perp\mathbf{H}$ is carried out in the following manner. The microwave pump field $\mathbf{h}$ excites homogeneous oscillations of the magnetic moments corresponding to the low-frequency branch of the spin-wave spectrum, at the frequency ν_p. When the amplitude of these oscillations reaches a certain critical level, it becomes possible to drive a pair of inhomogeneous oscillations with wave bectors $\mathbf{k}_i$ of both the magnetic (m) and elastic (ph) subsystems at the frequency $\nu_\sigma(\mathbf{k}_i)$ ($\sigma=m$, ph; $i=1,2$). The lowest threshold is that for the "first-order Sulov instability," for which the following conditions hold:

$$v_\sigma(\mathbf{k}_1)+v_\sigma(\mathbf{k}_2)=v_p\,,\qquad \mathbf{k}_1+\mathbf{k}_2=\mathbf{k}_p\approx 0\,. \tag{1}$$

The parametric excitation of oscillations is inferred from the appearance of a characteristic distortion of the microwave pulse passed through the cavity with the sample. The amplitude of the microwave field at the sample was calculated from the equations for the field distribution in the cavity, the power applied to the cavity, the quality factor, and the coupling coefficient of the cavity and the waveguides.

Figure 1 shows the dependence of the threshold field for the parametric instability, h_c, on the static field H at $T=90$ K. The threshold field h_c falls off as H approaches H_R, which is the field corresponding to the antiferromagnetic resonance at the frequency ν_p. This threshold field is at a minimum in the orientation $\mathbf{h}\perp\mathbf{H}$, telling us that we are observing the Sulov instability. Furthermore, since the parametric excitation is observed at both $H<H_R$ and $H>H_R$, it apparently follows that the excited particles are phonons. This conclusion agrees with the results of Ref. 7, in which a parametric excitation of transverse phonons propagating along C_3 was observed in $FeBO_3$ at room temperature with perpendicular pumping at the frequency $\nu_p=9$ GHz.

The threshold field for the parametric excitation of phonons during perpendicular pumping has been calculated for easy-plane antiferromagnets by Lutovinov and Savchen-

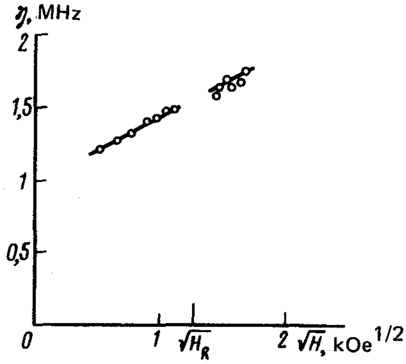

FIG. 2. Dependence of the phonon relaxation frequency η on the static field H.

ko[1)] (Ref. 1):

$$h_c = \zeta\left(\frac{h}{\gamma}\right)^2 \frac{\nu_0^2 + \left(\frac{\nu_p}{2}\right)^2\left[\left(\frac{s}{V}\right)^2 - 1\right]}{\theta^2} \frac{v_0}{H + H_D} \frac{MV^2}{I_0}$$
$$\times \frac{(\nu_p^2 - \nu_0^2)^2 + \Delta\nu_0^2[(\nu_p - \nu_0)^2 + (\nu_p + \nu_0)^2]}{2\nu_p\sqrt{\nu_0^2(\nu_p^2 - \nu_0^2)^2 + \Delta\nu_0^2(\nu_p^2 + \nu_0^2)^2}} (\eta_1\eta_2)^{1/2}, \qquad (2)$$

where $\zeta \sim 1$ is a parameter caused by the anisotropy of the magnetoelastic interaction and the anisotropy of the phonon relaxation; $\nu_0^2 = \gamma^2 [H(H + D_D) + H_\Delta^2]$ is the frequency of the antiferromagnetic resonance (AFMR); $\theta = \beta \, v_0 \approx 1.9 \times 10^{-15}$ erg (Ref. 6) is the magnetoelastic energy; v_0 and $M = \rho v_0$ are the volume and mass of the unit cell, respectively; s and V are the maximum magnon and phonon velocities, respectively; I_0 is the exchange integral; $\Delta\nu_0$ is the linewidth of the antiferromagnetic resonance; and η_1 and η_2 are the relaxation frequencies of the excited phonons. The values of the parameters for $FeBO_3$ are given in Ref. 10.

Under the assumption that pairs of phonons of the same type with wave vectors **k** and -**k** are excited in the present experiments, we assume $\eta_1 = \eta_2$ and $\nu_{ph}(\mathbf{k}) = {}^{\nu}p/2$. Using (2), we carried out calculations for the phonon relaxation from the experimental values of h_c. Ane estimate for $H = 0$ and $T = 90$ K yields $\eta \approx 1$ MHz, which corresponds to an acoustic quality factor $Q = \nu_{ph}/\eta \approx 2 \times 10^4$. Figure 2 shows the dependence $\eta(H)$. We did not use data corresponding to the field interval $|H - H_R| < \Delta H_0/2 = 60$ Oe, where ΔH_0 is the half-width of the AFMR line, since that approach would require knowledge of the exact shape of the AFMR line.

It can be seen from Fig. 2 that the phonon relaxation changes significantly with the strength of the magnetic field, indicating that magnons are important in the relaxation. We take the observed increase in the relaxation frequency with the magnetic field to be a nontrivial result. In our case, $s > V$. This condition means that the intersection of the unperturbed magnon and phonon spectra occurs at $H = 0$ and $k = 0$. As the field is intensified, the spectra move apart, and this effect would seem to weaken the mutual effects of the magnetic and elastic systems.

We are deeply indebted to V. S. Lutovinov for useful discussions.

[1)]We wish to thank V. S. Lutovinov for furnishing Eq. (2), which is a refined version of the equation.

1. A. S. Borovik-Romanov and E. G. Rudashevskiĭ, Zh. Eksp. Teor. Fiz. **47**, 2095 (1964) [Sov. Phys. JETP **20**, 1407 (1965)].
2. A. Tasaki and S. Iida, J. Phys. Soc. Jpn. **18**, 1148 (1963).
3. V. S. Lutovinov, V. L. Preobrazhenskiĭ, and S. P. Semin, Zh. Eksp. Teor. Fiz. **74**, 1159 (1978) [Sov. Phys. JETP **47**, 609 (1978)].
4. V. I. Ozhogin and A. Yu. Yakubovskiĭ, Zh. Eksp. Teor. Fiz. **67**, 287 (1974) [Sov. Phys. JETP **40**, 144 (1974)].
5. V. G. Zhotikov and N. M. Kreĭnes, Pis'ma Zh. Eksp. Teor. Fiz. **26**, 496 (1977) [JETP Lett. **26**, 360 (1977)].
6. V. G. Zhotikov and N. M. Kreĭnes, Zh. Eksp. Teor. Fiz. **77**, 2486 (1979) [Sov. Phys. JETP **50**, 1202 (1979)].
7. W. Wettling and W. Jantz, Appl. Phys. **19**, 175 (1979).
8. M. H. Seavey, Solid State Commun. **10**, 219 (1972).
9. V. S. Lutovinov and M. A. Savchenko, Vsesoyuznaya konferentsiya po fizike magnitnykh yavleniĭ. Tezisy dokladov (Abstracts, All-Union Conference on the Physics of Magnetic Phenomena), Khar'kov, 1979, p. 85.
10. B. Ya. Kotyuzhanskiĭ and L. A. Prozorova, Zh. Eksp. Teor. Fiz. **81**, 1913 (1981).

Translated by Dave Parsons
Edited by S. J. Amoretty