Stimulated acoustic Raman scattering in an antiferromagnet

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Parametric excitation of sound by sound has been observed in a magnetic material for the first time. The threshold strain amplitude in the pump wave can be achieved in practice in hematite single crystals, because it is easy to arrange a large effective anharmonicity of the elastic subsystem in antiferromagnets.

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The nonlinearity of low-frequency magnetoelastic waves in magnetic materials is conveniently described in terms of an effective anharmonicity of the elastic subsystem.[1] The simplest manifestations of this nonlinearity can be observed comparatively easily, especially in antiferromagnets.[2,3] In this letter we are reporting the first observation of a more complex nonlinear dynamic magnetoelastic effect, which has been studied theoretically by Ozhogin and Preobrazhenskiĭ[1a]: the parametric excitation of sound by sound. This effect is completely analogous to stimulated Raman scattering in nonlinear optics and may be described as follows: An ultrasonic wave of frequency ω_p and wave vector $\mathbf{k}_p$ with a sufficiently large strain amplitude u_p (higher than the threshold value u_p^c) should generate two quasielastic "Raman" waves $(\omega_1, \mathbf{k}_1)$ and $(\omega_2, \mathbf{k}_2)$ satisfying

$\omega_1 + \omega_2 = \omega_{1a}$ and $k_1 + k_2 = k_{1b}$.

Il'chenko and Oboznenko[4] have recently reported the first observation of stimulated Raman scattering of sound in a nonmagnetic crystal, paratellurite. Experiments with magnetic materials are of fundamental interest because of the possibility of using a magnetic field to influence the magnetoelastic coupling.

The present measurements were carried out at room temperature in a sample with a length $L = 4$ mm along the C_3 axis and a square cross section with a side $a = 2.5$ mm, cut from a hematite (α-Fe_2O_3) single crystal. A constant magnetic field **H** was applied along the U_2 crystallographic axis, which ran parallel to an edge a. A transverse-polarized acoustic signal (the "pump"), with a frequency $\omega_p = 2\pi \equiv f_p = 43$ MHz and a polarization $\mathbf{e}_p \perp U_2$, was excited at one end of the sample and propagated along the C_3 axis. An acoustic damping device, consisting of a 1-mm-thick copper plate was attached to the opposite end of the sample by a micron-thick layer of indium to create traveling-wave conditions. The power of the signal reflected from this damping device did not exceed 1/4 of the incident power. The transverse sound ($\mathbf{e} \parallel U_2$) transmitted through the damping device was detected by a broad-band, lithium-niobate acoustic transducer and measured with a spectrum analyzer. The measurements were carried out with long pulses ($\tau = 1$ ms). When the threshold strain amplitude $u_p^c = (8 \pm 4) \times 10^{-7}$ (for $H = 0.1$-0.4 kOe) was reached in the pump wave, signals at frequencies f_1 and f_2 satisfying condition (1a) appeared simultaneously on the analyzer screen (Fig. 1), along with weaker signals which were higher harmonics of these frequencies. When the threshold power was exceeded by 3 dB, the amplitudes of the signals at f_1 and f_2 reached ~30% of the amplitude of the pump wave.

From the H dependence of f_2 and f_1 we can determine the magnetoelastic modulus, $B_{14} = (13.6 \pm 0.2) \times 10^6$ erg/cm^3, within an error an order of magnitude smaller

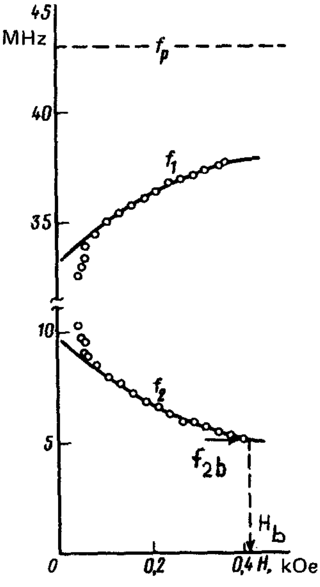

FIG. 1. Dependence of the frequencies f_1 and f_2 of the parametrically excited quasisound on the magnetic field H. The error of the frequency measurements is ±0.1 MHz, and that of the field measurements is ±1 Oe. Dashed line—Pump frequency; solid curves—calculations from Eqs. (2) and (1).

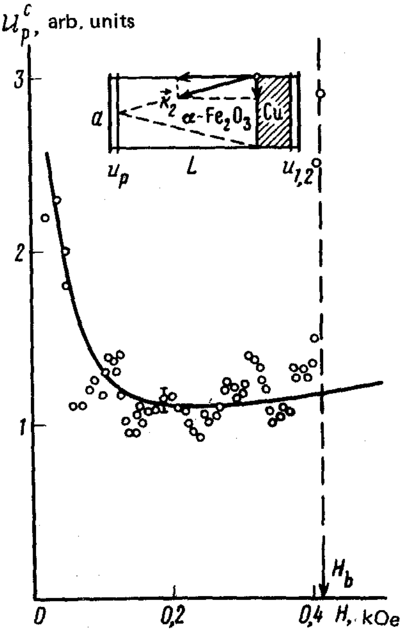

FIG. 2. Dependence of the threshold strain amplitude u_p^c on the magnetic field H. Solid curve—Calculated from Eq. (3); inset—diagram illustrating the propagation of the low-frequency (f_2) "Raman" wave in the sample at the field $H = H_b$, at which this wave "simply does not reach" the receiving transducer. In an unbounded medium, $\mathbf{k}_1$ and $\mathbf{k}_2$ are antiparallel.

than that of static measurements (see the literature cited in Ref. 1c). We used the following expression, which follows from Eqs. (1) (see Ref. 1c for the notation):

$$f_2 = (1 - \sqrt{1 - \varkappa})\, f_p / 2, \text{where } \varkappa = 4 B_{14}^2\, H_E \gamma^2 / M_0 C_{44} \omega_{f0}^2 \,. \tag{2}$$

In a more general approximation than in Ref. 1 [specifically, if we do not use the simplified equation (6) of Ref. 1c] we find the following expression for the threshold strain amplitude u_p^c (the damping of the sound is ignored):

$$u_p^c \equiv \frac{1}{2}\left(\frac{\partial U_y}{\partial z}\right)^c_{\text{ampl}} = \frac{\pi M_0^2 C_{44}^{3/2} (1 - \kappa)^{3/2} (\omega_{f0}/\gamma)^4}{4 \gamma \rho^{1/2} H H_E^2 B_{14}^2 B_{44} L} . \tag{3}$$

In the field range 0.1–0.4 kOe, Eq. (3) predicts a weak dependence $u_p^c(H)$, in complete agreement with experiment (Fig. 2). An estimate puts $u_p^c(H = 0.2$ kOe) somewhere in the range $(2 - 5) \times 10^{-7}$, since there is a substantial uncertainty in the value of the constant B_{44}. If damping is taken into account, the calculated value of u_p^c may increase severalfold (Ref. 1c), approaching the measured value of $(8 \pm 4) \times 10^{-7}$.

The upper boundary H_b on the range of magnetic fields in which the effect is observed (Figs. 1 and 2) is actually set by the particular type of waveguide propagation of the sound through the sample. Because of the finite transverse dimensions of the sample, the acoustic wave vector has a transverse component $\mathbf{k}_\perp$, and this circumstance strongly affects the propagation of sound at the lower frequency, f_2. In our case the boundary frequency $f_{2b} \approx v_s \cdot 2L/a^2$ is ~5 MHz, in good correspondence with the experimental value. Control measurements over the frequency range

$f_p = 37$–46 MHz confirmed that the observed $H_b(f_p)$ dependence agrees with the dependence calculated under these assumptions.

In summary, these results show that an acoustic wave in a magnetic material can parametrically excite a pair of quasiacoustic waves which satisfy the temporal and spatial matching conditions in (1).

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1. V. I. Ozhogin and V. L. Preobrazhenskii, a) Inter. Conf. Magn. Abstracts, 3C-9, Amsterdam, 1976; b) Physica **86–88B**, 979 (1979); c) Zh. Eksp. Teor. Fiz. **73**, **988 (1977)**.

1. V. I. Ozhogin and V. L. Preobrazhenskii, a) Inter. Conf. Magn. Abstracts, 3C-9, Amsterdam, 1976; b) Physica **86-88B**, 979 (1979); c) Zh. Eksp. Teor. Fiz. **73**, 988 (1977) [Sov. Phys. JETP **46**, 523 (1977)].
2. V. I. Ozhogin, A. Yu. Lebedev, and A. Yu. Yakubovskii, a) Pis'ma Zh. Eksp. Teor. Fiz. **27**, 333 (1978) [JETP Lett. **27**, 313 (1978)]; b) "INTERMAG-81," Digests, No. 11-10, Grenoble, 1981.
3. V. L. Preobrazhenskii, M. A. Savchenko, and M. A. Ekonomov, Pis'ma Zh. Eksp. Teor. Fiz. **28**, 93 (1978) [JETP Lett. **28**, 87 (1978)].
4. L. N. Il'chenko and Yu. L. Oboznenko, Fiz. Tverd. Tela (Leningrad) **21**, 1648 (1979) [Sov. Phys. Solid State **21**, 945 (1979)].

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