Absorption of High Frequency Sound in Antiferromagnets Located in Strong Magnetic Fields

I. N. Oleĭnik
Institute of Radiophysics and Electronics, Ukrainian Academy of Sciences
Submitted December 21, 1971
Zh. Eksp. Teor. Fiz. **62**, 2287–2289 (June, 1972)

The absorption of high-frequency ($\omega\tau \gg 1$) sound in antiferromagnets is considered in the case in which the basic role is played by collisions of sound quanta with elementary excitations—phonons and magnons. It is shown that in strong magnetic fields, as a result of the overturning of the sublattice magnetic moments and the appearance of the homogeneous exchange interaction mechanism, collisions between sound quanta and magnons are more probable than interaction with phonons, and this leads to an appreciable increase in the sound absorption coefficient. The discontinuous character of the overturning of the moments results in a jump in the sound absorption that may reach several orders of magnitude. The existence of a singularity in the phonon spectrum due to the threshold nature of the interaction between phonons and magnons is noted.

LANDAU and Rumer[1] have shown that the absorption of high-frequency sound ($\omega\tau_{pp} \gg 1$) in sufficiently pure and homogeneous samples of dielectrics at low temperatures can be represented as the result of collisions of sound quanta with thermal phonons. (Here ω is the sound frequency and τ_{pp} is the relaxation time of the thermal phonons.) In this case the sound absorption coefficient Γ has the form[1]

$$\Gamma_{pp} \approx \omega \frac{T}{Ms^2}\left(\frac{T}{\Theta_D}\right)^3, \qquad \hbar\omega \ll T, \tag{1}$$

where Θ_D is the Debye temperature, s the sound velocity, and M the mass of the atom.

Under the considered conditions in ideal samples of antiferromagnets, there arises another mechanism of sound relaxation, due to the collisions of the phonons with magnons, which, as will be shown below, can be much greater than the Landau-Rumer absorption in strong magnetic fields.

It is known[2] that a constant magnetic field of value $H_{EA} = \sqrt{H_E H_A}$ (where H_E is the exchange field, H_A the anisotropic field) applied along the easy axis of the antiferromagnet leads to the overturning of the magnetic moments of the sublattices and to the appearance of a ferromagnetic component, which is directed along the field, and is proportional to its value. As a result of the overturning of the moments in the field $H = H_{EA}$, first one of the branches of the magnon spectrum becomes inactive[2] 1) $\epsilon(\mathbf{k}) = \Theta_N ak$ (Θ_N is the Neel temperature, and $\mathbf{k}$ is the wave vector of the magnon); second, thanks to the appearance of the ferromagnetic components, there comes into play a new mechanism of relaxation of the magnons with one another and with phonons, a mechanism more intense than in weak fields and connected with the homogeneous exchange interaction between the sublattices.[3] (For $H < H_{EA}$, the relaxation processes are determined only by the inhomogeneous exchange interaction.[4,5]) In accord with[3], the transition amplitude Φ_{ps}^{hom} which describes processes with participation of two magnons and a single longitudinal phonon, has the form

$$\Psi_{ps}^{hom} \approx (\mu H)^2(\mathbf{e}_0\boldsymbol{\varkappa})\left[\frac{\hbar\omega(\mathbf{q})}{\rho s^2 V\varepsilon(\mathbf{k}_1)\varepsilon(\mathbf{k}_2)}\right]^{1/2}, \qquad H_{EA} < H \ll H_E. \tag{2}$$

Here $\mathbf{e}_0$ is the unit vector of phonon polarization, $\kappa = \mathbf{q}/q$, ρ the density, and V the volume.

In antiferromagnets, the exchange interaction of the phonons with the magnons takes place both with emission of a phonon by the magnon, and with decay of the phonon into two magnons (and the corresponding inverse processes). These processes have amplitudes Ψ_{ps}^{hom} of the same order of magnitude. When $\Theta_N < \Theta_D$, the velocity of the magnons is less than the sound velocity and the Cerenkov character of the interaction allows only decay processes, while for $\Theta_N > \Theta_D$, only emission processes are possible.[3,5]

The sound absorption coefficient is determined by the ratio $\Gamma = \overline{E}_t/2E$, where E is the sound energy density, $\overline{E}_t = \overline{dE/dt}$ is the mean rate of its dissipation through collisions. By expressing $\overline{E}_t$ in terms of the probability of the elementary processes that preserve $|\Psi_{ps}^{hom}|^2$ we get the following formula for the sound absorption coefficient due to collisions of phonons with magnons in a strong magnetic field:

$$\Gamma_{ps}^{hom}(H) \approx \frac{\Theta_D}{\hbar}\frac{T}{Ms^2}\left(\frac{\mu H}{\Theta_N}\right)^4, \quad \hbar\omega \ll T, \quad \omega\tau_{ss} \gg 1, \quad H_{EA} < H \ll H_E, \tag{3}$$

where $\tau_{ss}^{-1} \approx (T/\hbar)(\mu H/\Theta_N)^4$ is the relaxation time relative to exchange magnon-magnon collisions.[3]

Under the considered conditions, Γ_{ps}^{hom} is determined by the value of the ferromagnetic component ($\sim H^4$) and does not depend on the sound frequency. From (3) and (1) it follows that $\Gamma_{ps}^{hom} \gg \Gamma_{pp}$ if $T^3 \ll (\mu H)^3(\Theta_D/\Theta_N)^4(\mu H/\hbar\omega)$. Therefore, in strong magnetic fields at low temperatures, when the inequalities given above are satisfied, the sound absorption will be determined principally by the interaction of the sound phonons with the magnons, and should differ materially (both in value and in the character of its dependence) from absorption in dielectrics. For example, for typical antiferromagnets ($\Theta_N \sim \Theta_D \sim 10^{2\circ}$K, $H \sim H_{EA} \sim 10^5$ Oe) at helium temperatures the ratio of the sound absorption coefficients ($\omega \sim 10^{10}$–10^{11} sec^{-1}) due to collisions with magnons and with phonons is

$$\frac{\Gamma_{ps}^{hom}}{\Gamma_{pp}} \sim \left(\frac{\mu H}{T}\right)^3\left(\frac{\Theta_D}{\Theta_N}\right)^4\frac{\mu H}{\hbar\omega} \sim 10^2 \div 10^3.$$

In weak magnetic fields ($H < H_{EA}$), when the collisions of phonons with magnons are associated with the inhomogeneous exchange interaction, the inequalities

$$\Gamma_{pp} \gg \Gamma_{ps}^{inhom} \approx \omega\frac{T}{Ms^2}\left(\frac{\hbar\omega}{\Theta_N}\right)^3\frac{\Theta_N}{\Theta_D}, \qquad \Theta_N < \Theta_D,$$

1)Account of the anisotropy in the basis plane leads to a small energy of activation in this branch: $\epsilon_0 \lesssim 0.1$°K.

$$\Gamma_{pp} > \Gamma_{ps}^{\text{inhom}} \approx \Gamma_{pp}\left(\frac{\Theta_D}{\Theta_N}\right)^4, \quad \Theta_N > \Theta_D, \quad \hbar\omega \ll T. \tag{4}$$

are satisfied. In this case, the sound absorption in the antiferromagnets will be the same as in the dielectrics.

As is well known,[2] the interval of fields ΔH in which rearrangement of the magnetic moments of the sublattices takes place is sufficiently narrow ($\Delta H \sim (v/c)^2 H_{EA} \ll H_{EA}$), and therefore, it can be assumed that the transition takes place discontinuously. The latter circumstance leads to the discontinuous appearance of the mechanism of homogeneous exchange interaction and as a consequence to a discontinuity in the sound absorption. In accord with (3) and (4), the size of the jump is

$$\Delta\Gamma = \Gamma_{ps}^{\text{hom}} - \Gamma_{pp} \approx \Gamma_{ps}^{\text{hom}}(H_{EA}), \tag{5}$$

and can reach several orders of magnitude for typical antiferromagnets. The experimental observation of the effects considered above can obviously be a confirmation of the relaxation mechanism associated with homogeneous exchange interaction in antiferromagnets.

It was assumed everywhere above that $\hbar\omega \gg \epsilon_0$, where ϵ_0 is the magnon activation energy connected with the allowance for anisotropy in the basal plane in the spin Hamiltonian. It is evident that in the presence of ϵ_0 processes of decay of a phonon into two magnons assume a threshold character and lead to the appearance of a singularity in the phonon spectrum for $\hbar\omega_0 = 2\epsilon_0(1 - \Theta_N^2/\Theta_D^2)^{-1/2}$. These questions, and also the low frequency case ($\omega\tau \ll 1$) will be considered in more detail in a latter paper.

The author thanks R. N. Gurzhi, B. V. Eremenko, and V. M. Tsukernik for interesting discussions of the results and useful comments.

[1] L. D. Landau and Yu. B. Rumer, Phys. Z. Sowjetunion **11**, 18 (1937).
[2] E. A. Turov, Fizicheskie svoĭstva magnituouporyadochennykh kristallov (Physical Properties of Magnetically Ordered Crystals) (AN SSSR, 1963).
[3] I. N. Oleĭnik, Fiz. Tverd. Tela **12**, 3244 (1970) [Sov. Phys.-Solid State **12**, 2622 (1971)].
[4] M. I. Waganov, V. M. Tsukernik, and I. E. Chupis, Fiz. Met. Metalloved. **10**, 797 (1960).
[5] I. E. Chupis, Zh. Eksp. Teor. Fiz. **46**, 307 (1964) [Sov. Phys.-JETP **19**, 212 (1964)].

Translated by R. T. Beyer
265