TEMPERATURE MAGNETOACOUSTIC RESONANCE IN CRYSTALS WITH AN ANTIFERRO-FERROMAGNETIC TRANSITION

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Coupled magnetoacoustic oscillations are investigated in crystals in which a temperature transition between ferro- and antiferromagnetic phases is possible. It is shown that for a certain value of the temperature in the antiferromagnetic phase of such crystals a resonance between the sound and low-activation spin wave arises in a broad frequency range. It is pointed out that such crystals can be used to excite ultrasound by alternating magnetic fields.

As is well known, there exists a whole series of crystals in which a transition takes place at some temperature T_C between the ferromagnetic and antiferromagnetic states. An example of such crystals is FeRh, for which $T_C = 350°K$.[1] In the description of crystals of such a type, it is natural to use a model of two equivalent magnetic sublattices, and to assume that in one range of temperatures (corresponding to the antiferromagnetic state) minimum energy of the crystal is achieved for antiparallel orientation of the magnetic moments of the sublattices, and in another range of temperatures (corresponding to the ferromagnetic state) —for parallel orientation of the magnetic moments. The constant η of homogeneous exchange interaction between the sublattices in such crystals should depend strongly on the temperature and be positive for the antiferromagnetic states, going to zero at $T = T_C$ and becoming negative for the ferromagnetic state. We shall be interested in spin waves with a linear dispersion law, which can propagate in the antiferromagnetic phase of such a crystal if it possesses magnetic anisotropies in this case of the easy-plane type. The velocity v_S of such a spin wave should be strongly temperature dependent, decreasing as T_C is approached. If $v_S(T) > s$ far from the critical point ($s = s_l$ or s_t is the speed of the longitudinal or transverse sound) then, for some particular value of the temperature of the crystal T_R, we have $v_S(T_T) = s$. For this temperature, a special temperature magnetoacoustic resonance (TMAR) should be observed—a resonance over a wide range of frequencies and wave vectors (and not only for definite values of the frequency and wave vector, as in the usual case).[1)]

We shall begin with the equations of motion of the magnetic moments of the sublattices and the elasticity equation:[3]

$$d\boldsymbol{\mu}_\nu / dt = g[\boldsymbol{\mu}_\nu \mathbf{H}_\nu], \quad \mathbf{H}_\nu = -\delta U / \delta(\rho \boldsymbol{\mu}_\nu),$$
$$\rho \frac{d^2 u_i}{dt^2} = \frac{\partial}{\partial x_j}\left(\rho \frac{\partial (U/\rho)}{\partial(\partial u_i/\partial x_j)}\right), \quad (1)^*$$

where μ_ν is the magnetic moment of a unit mass coupled with the ν-th sublattice ($\nu = 1, 2$), g is the gyromagnetic ratio, u is the displacement vector, and ρ is the density of the crystal. The internal energy of the antiferromagnet U can be represented in the form

$$U = U_m + U_e + U_{me},$$

where U_m is the known expression for the energy of oscillations of the magnetic moments,[3] U_e is the known expression for the energy of oscillations of the lattice,[4] and U_{me} is the coupling energy, which has the form[5]

$$U_{me} = \frac{1}{2} f \rho^2 \lambda_i \lambda_j \frac{\partial u_i}{\partial x_j} - \frac{1}{2}(\beta - \beta')\rho^2 (\boldsymbol{\lambda}\mathbf{n}) \lambda_i (\mathbf{n}\nabla) u_i; \quad (2)$$

$\boldsymbol{\lambda} = \boldsymbol{\mu}_1 - \boldsymbol{\mu}_2$; f is the constant of magnetostriction; β and β' the constants of the magneti anisotropy, and n is the unit vector along the axis of the anisotropy (the z axis).

In the case of longitudinal magnetoacoustic resonance, when the phase velocity v_S of the spin wave is close to the velocity s_l of the longitudinal sound, we obtain the following expression for the frequencies of coupled spin and longitudinal sound oscillations:

$$\omega_{l\pm}^2 = \omega_l^2 \pm 2gM_0\eta^{1/2}\omega_l f \frac{M_0}{\rho^{1/2} s_l} \sin^2\chi |\sin 2\varphi|, \quad (3)$$

where $\omega_{l,t} = s_{l,t}k$, M_0 is the equilibrium density of the magnetic moment associated with each of the sublattices, χ is the angle between the wave vector **k** and the z axis, and φ is the angle between the vector $\boldsymbol{\mu}_{01}$ and the x axis (the u axis is chosen perpendicular to the (k, n) plane). We see that in this case there are two branches of resonance oscillations, the frequencies of which differ by a quantity proportional to the small parameter $\sqrt{\zeta}$ ($\zeta = f^2M_0^2/\rho_S^2$ the constant of magnetoelastic coupling, equal to 10^{-4}–10^{-6} in order of magnitude).

In the case of magnetoacoustic resonance, when the phase velocity v_S of the spin wave is near the velocity s_t of transverse sound, the frequencies of the two branches of coupled spin and transverse sound oscillations have the form

$$\omega_{t\pm}^2 = \omega_t^2 \pm 2gM_0\eta^{1/2}\omega_t f \frac{M_0}{\rho^{1/2} s_t} |\sin\chi| (\cos^2\chi \sin^2 2\varphi + \cos^2 2\varphi)^{1/2} \quad (4)$$

(the third branch of magnetoacoustic waves is almost

[1)] Such a situation is analogous to the well known situation in antiferromagnets which takes place only in a strong magnetic field, equal to the value of the exchange field in order of magnitude. [2]

*$[\mathbf{u}_\nu \mathbf{H}_\nu] \equiv \mathbf{u}_\nu \times \mathbf{H}_\nu$.

completely pure sound; its phase velocity differs from s_t by a quantity of the order of ζ).

The TMAR phenomenon can be used for intense excitation of spin waves in antiferromagnets by means of sound waves (for example, by producing elastic deformations in the crystal) or for the intense excitation of sound waves in antiferromagnets by means of an external magnetic field.

The transformation coefficient of a sound wave into a spin wave (defined as the ratio of the energy density of the magnetic field accompanying the spin wave to the energy density of the sound wave) is equal, in order of magnitude, to

$$T_{t\to m} \sim \frac{1}{\eta}\left(\frac{\omega^2}{\omega^2 - v_s^2k^2}\right)^2 \zeta. \tag{5}$$

The transformation coefficient of a spin wave into a sound wave is equal, in order of magnitude, to

$$T_{m\to e} \sim \frac{1}{\eta}\left(\frac{\omega^2}{\omega^2 - \omega_{l,t}^2}\frac{\omega}{\Delta\omega}\right)^2 \zeta, \tag{6}$$

where $\Delta\omega$ is the width of the ordinary antiferromagnetic resonance. We see that these coefficients increase by a factor of $\zeta^{-1} \sim 10^4$–10^6 near the TMAR.

We emphasize that the resonance transformation of waves in the case of TMAR takes place for a width range of frequencies, while in the ordinary case of resonance transformation, the incident wave must be very monochromatic (the condition $(\omega - \omega_S)/\omega_S \sim \sqrt{\zeta}$ must be satisfied). The width of the resonance frequency range is limited only by the magnetic anisotropies of the crystal in the basis plane $\beta_\perp$, $\omega > gM_0(\eta\beta_\perp)^{1/2}$. The temperature of the crystal in this case can differ from its resonance value only by the amount $\Delta T \lesssim \sqrt{\zeta}\eta\,(\partial\eta/\partial T)^{-1}$ (~0.1–1 deg).

Apparently the TMAR phenomenon takes place only in the case of weak damping of the waves $\gamma < \sqrt{\zeta}\,\omega$, where γ is the damping decrement.

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