A. S. Borovik-Romanov, E. G. Rudashevskiĭ, E. A. Turov, and V. G. Shavrov. *Magnetoelastic effects of spontaneously broken symmetry and soft modes in magnetic phase transitions.* The effects which are discussed in the paper were observed and their study was begun about 20 years ago in Refs. 1–4. References 1 and 3 almost simultaneously and independently discovered an effect which in the Soviet and western literature has been called respectively the magnetoelastic gap[2,4] and the frozen lattice (see for example Ref. 5). It was experimentally observed that in an antiferromagnetic material with an anisotropy of the easy-plane type α-Fe_2O_3 the low-frequency resonance branch ω_0 cannot be described by the contributions of magnetic anisotropy and the magnetic field **H** known at that time (we shall denote both of these contributions by ω_M). It turned out that

$$\omega_0^2=\omega_M^2+\omega_{ME}^2, \tag{1}$$

where the second term did not depend on the direction of **H** in the easy plane and thus could not be related to the anisotropy. It was shown that this term is due to spontaneous magnetoelastic deformations in the ground state of the magnetic material. It is important that these deformations seem to be "frozen" and do not follow the uniform oscillations of the magnetic moments, which correspond to the quasimagnon branch of the magnetoelastic waves (for $k\to 0$). In this way they create an effective internal magnetic field

$$H_{ME}=\zeta M, \tag{2}$$

which is isotropic in the easy plane and which gives the additional term ω_{ME}^2 in Eq. (1); here ζ (B^2/C^2) is the magnetoelastic coupling parameter. M is the magnetization of the magnetic material (or its magnetic sublattice), and C and B are respectively the elasticity and magnetostriction constants.

Turov and Shavrov[4] also predicted a very large magnetoelastic gap (of the order of 10 K) in the rare earth ferromagnetic materials Dy and Tb, which was later found experimentally by study of inelastic scattering of neutrons.[6]

The above studies and their further development in Refs. 7–9 have led to the conclusion that the magnetoelastic gap is an effect common for all magnetically ordered materials—an effect of spontaneously broken symmetry in the system of the two interacting fields (in our case— magnetization and deformations). It is in this that the general physical significance of the discovery of the magnetoelastic gap lies, since analogous effects may occur in other areas (in the theory of superconductivity—the Meissner effect, and in the the theory of coupled oscillations of electrons and nuclear spins—the dynamic frequency shift).

The approach from the point of view of spontaneously broken symmetry[8,9] reflects most completely the physics of the phenomenon. In this approach the individual terms in (1) must be treated as follows. The first term ω_M^2 corresponds to equlibrium coupling between the oscillations of the magnetic moments (ΔM) and of the deformations (Δu_{ij}), in which the inclusion of magnetostriction is reduced to a simple renormalization of the magnetic-anisotropy constants without change of the general form of the anisotropy energy, which is

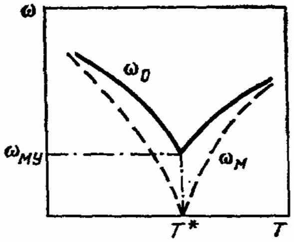

FIG. 1.

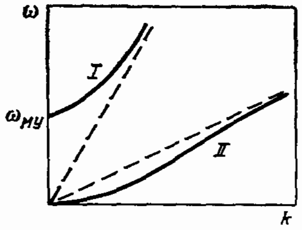

FIG. 2.

determined by the unbroken symmetry of the paramagnetic crystal. The second term ω_{ME}^2 is the magnetoelastic contribution to the gap of the magnon branch, which does not fit into the framework of the above renormalization and thus is entirely due to breaking of the symmetry of the ground state of the magnetic material with respect to the symmetry of the paramagnetic crystal. It is important to emphasize that this effect in the general case is determined not by the spontaneous deformations of the ground state themselves, but by the difference from those striction deformations which correspond to equlibrium coupling between the $\Delta\,\mathbf{M}$ and Δu.

In view of this definition, the term ω_{M}^2 in (1) is characterized by vanishing in magnetic orientational phase transitions. At points of phase transitions of the second kind and at points of instability for phase transitions of the first kind, the quasimagnon gap has a minimal value, giving in pure form the spontaneously broken symmetry effect—the magnetoelastic gap, as is shown in Fig. 1, where we have plotted the dependence of ω_0 and ω_{M} on temperature near the phase transition point $T = T^*$.

The magnetoelastic gap is due to the influence of the elastic subsystem on the magnetic subsystem. Of coure, there is another aspect of the phenomenon—the inverse influence of spin oscillations on the branch of the acoustic oscillations (phonons) which interacts with them. These two coupled modes of oscillation (quasimagnon—I and quasiacoustic—II) are shown schematically in Fig. 2 for an antiferromagnetic material in the simplest "pure" case, in which in (1) $\omega_{\mathrm{M}} = 0$, so that the quasimagnon gap as a whole reduces to ω_{ME} (the minimum point in Fig. 1). In this case the interaction of the modes turns out to be the strongest. The dashed line shows the spectra without interaction, and the solid lines show the spectra with inclusion of the magnetoelastic interaction. Together with the appearance of the gap in ω_{ME} for $\omega_{\mathrm{I}}(\mathbf{k})$, a strong deformation of the acoustic branch arises—$\omega_{\mathrm{II}}(\mathbf{k})$, and in the limit of sufficiently small k the dispersion law for this branch can change from linear to quadratic.[7] This corresponds to vanishing of the effective elasticity modulus (or the velocity of sound for $k \to 0$) for a given quasiacoustic mode. This effect appears experimentally as a significant decrease of the velocity of sound with the decrease of ω_{M} near phase-transition points.[7,10] At the present time data exist in the literature on observation of a decrease of the velocity of sound as the result of the spontaneously broken symmetry effect by more than a factor of two.[11] Theoretically the effect may be much larger. We note that in antiferromagnetic materials there is an exchange enhancement of magnetoacoustic effects due to the fact that for excitation of dynamic magnetization in them it is necessary that the exchange interaction, which determines antiferromagnetism, be dominant. The magnetoelastic effects of spontaneously broken symmetry open up still another field of practical application of magnetoacoustics, related to the enormous influence on the velocity of ultrasound of the magnetic field and other external actions.

A more complete list of references has been given in a review article.[9]

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