In any case, the presented experimental data indicate, in addition to the already mentioned discrepancies between the theoretical and experimental values of the photoemission currents in vacuum, also the need for refining the existing models of multiphoton photoemission of metals.

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MAGNETOELASTIC INTERACTION IN ANTIFERROMAGNETIC $MnCO_3$

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This paper reports an experimental investigation of the behavior of a triply-coupled system, viz., the interaction of hypersonic waves with spin waves of an electronic subsystem interacting in turn with nuclear spins. The influence of the nuclear spins becomes manifest in a distinct temperature and frequency dependence of the magneto-acoustic resonance.

In this study, an investigation was made of the influence of the magnetic waves on the propagation velocity of transverse hypersonic waves in $MnCO_3$. The sound was excited by odd harmonics of X-cut $LiNbO_3$ plates (approximate fundamental frequency 80 MHz). To measure the velocity, an echo-pulse method was used (pulse duration 0.3 μsec). The change of the velocity was measured with a modified phase-pulse method, viz., the change of the phase $\Delta\phi_v = -(2\pi f\ell/v)(\Delta v/v)$ of a pulse-modulated signal, due to a change of the sound velocity in the sample (ℓ is the sample length and v is the speed of sound), was compensated for by a change of phase $\Delta\phi_c = 2\pi f c^{-1}\Delta L$ (c is the speed of light and ΔL the change in line length) in the delay line, so that $\Delta\phi_v + \Delta\phi_c = 0$; thus, $(v/c)(\Delta L/\ell) = \Delta v/v$. Invariance of the total phase was revealed by comparison with an HF signal taken from the same generator.

$MnCO_3$ single crystals were grown by a hydrothermal method using the apparatus of the Crystallography Institute of the USSR Academy of Sciences[1]. The samples were rectangular parallelepipeds with dimensions 2 - 3.5 mm.

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We obtained the velocities of the transverse sound waves propagating along the twofold axis L_2

$$v_1 = (4{,}55 \pm 0{,}06) \cdot 10^5 \text{ cm/sec and } v_2 = (2{,}94 \pm 0{,}05) \cdot 10^5 \text{ cm/sec}$$

and their respective polarizations

$$39 \pm 2^\circ \text{and } 51 \pm 2^\circ \text{ to the z axis.}$$

The sound velocities remained constant in the temperature interval from 80 to 1.6°K within the limits of errors.

An influence of the magnetic field on the propagation velocities of the transverse sound v_1 and v_2 was observed in the antiferromagnetic state (the Neel temperature of $MnCO_3$ is 32.5°K).

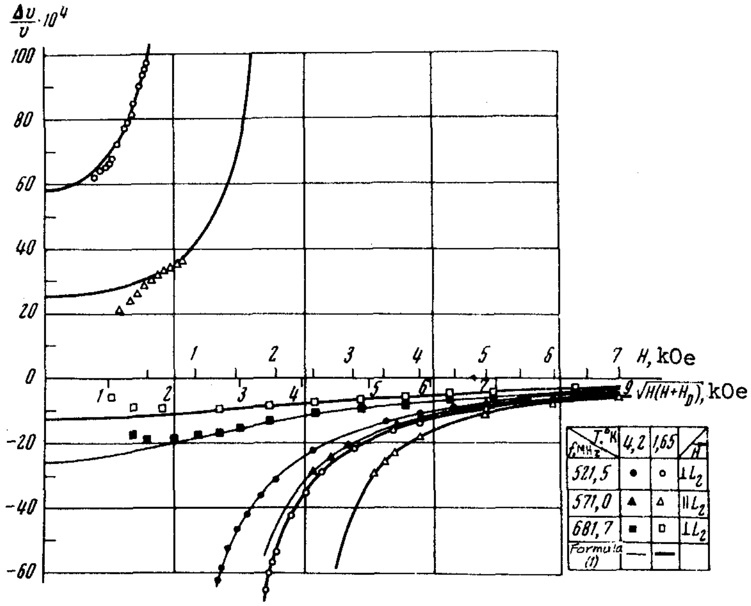
The magnetic field was parallel to the basal plane (i.e., perpendicular to the threefold axis).

The figure shows the experimental dependence of the speed of sound on the magnetic field for hypersonic waves with velocity $v_2 = 2.94 \times 10^5$ cm/sec. The relative measurement error $\Delta v/v$ is 2×10^{-4} and the absolute error 2×10^{-2}. The influence of the magnetic field on the speed of sound is due to the interaction of the acoustic and spin waves.

The spectrum of spin waves with $k = 0$ in $MnCO_3$ was investigated in [2, 3] by antiferromagnetic-resonance and nuclear magnetic resonance methods.

A theoretical analysis of the bound magnetoelastic waves in $MnCO_3$ [4], without allowance for the influence of the nuclear spin subsystem, does not explain the temperature and frequency dependences observed by us for the change in the speed of sound with changing magnetic field.

As seen from the figure, the obtained experimental data can be described by a relation of the type



f, MHz \ T, °K	4,2	1,65	H
521,5	●	○	⊥L_2
571,0	▲	△	∥L_2
681,7	■	□	⊥L_2
Formula (1)	—	—	

$$\frac{\Delta v}{v} = - \frac{a}{-\frac{\omega^2}{\gamma_e^2} + H(H + H_D) + H^2_{\Delta 1} - b(T, f)}, \qquad (1)$$

which is represented by the solid lines in the figure.

Here a characterizes the magnetoelastic coupling, $b(T, f) \approx [f^2/(f^2_{N_0} - f^2)] \times (b_0/T)$ is the result of the electron-nuclear interaction, $H^2_{\Delta_1} \sim 1$ kOe^2 is the magnetoelastic gap in the spin-wave spectrum, $H_D = 4.4$ kOe is the Dzyaloshinskii field, γ_e is the gyromagnetic ratio, $f_{N_0} \approx 640$ MHz is the frequency of the nuclear resonance in the effective field of the hyperfine interaction, and T is the absolute temperature.

The experimental data plotted in the figure in accord with formula (1) reveal a peculiar magneto-acoustic resonance in the presence of electron-nuclear coupling, namely, a resonant change of the speed of sound with changing magnetic field occurs at frequencies $f < f_{N_0}$, and a monotonic change of the speed of sound with changing magnetic field is observed at frequencies $\gamma_e[H(H + H_D) + b_0/T + H^2_{\Delta_1}] > f > f_{N_0}$. The influence of the temperature on the dependence of the velocity on the magnetic field is larger the closer the sound-oscillation frequency to the frequency f_{N_0}, and a decrease of the temperature is equivalent to an increase of the magnetic field when $f < f_{N_0}$ and to a decrease when $f > f_{N_0}$.

The dependence of the velocity on the magnetic field at $H \parallel L_2$ and $H \perp L_2$ turned out to be the same for H > 2 kOe (L_2 is the twofold axis and lies in the basal plane).

A magnetic-field dependence of the magnetic field similar to that in the figure was observed also for hypersonic waves with velocity $v_1 = 4.55 \times 10^5$ cm/sec (with a different value of the constant a).

A strong increase of the sound damping was observed also in the region of resonant variation of the speed of sound (from 3 - 5 dB/cm in fields stronger than 5 kOe to values exceeding 60 dB/cm in resonant fields), whereas at 681.7 MHz the damping of the sound changed little in the entire field range H > 0.5 kOe.

The deviation of the experimental data from the theory at H < 0.5 kOe (see the figure) is obviously due to the increased spin-wave damping in weak fields, which leads to a decrease of the influence of the spin waves on the sound (the antiferromagnetic resonance line width ΔH does not depend on the field, so that the damping $\Delta\omega/\omega = (2H + H_D)\Delta H/2H(H + H_D) \approx \Delta H/H$ increases as $H \to 0$).

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SPECIFIC HEAT OF ANHYDROUS $CrCl_3$ BETWEEN 4.5 AND 20°K IN A MAGNETIC FIELD

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Anhydrous $CrCl_3$ is a layered antiferromagnet in which the antoferromagnetic ordering sets in at T_c = 16.8°K and two-dimensional ferromagnetism properties are observed [1 - 4].

$CrCl_3$ has a layered crystalline structure of the ($R\bar{3}$) type and, as shown by neutron-diffraction [5], in the antiferromagnetic states the spins are ferromagnetically ordered inside each hexagonal layer of the metallic ions and in neighboring layers separated by Cl ions they are antiparallel and oriented in the basal plane.

The magnetic properties of layered antiferromagnets were first predicted by Landau [6]. Recently a number of authors [7, 8, 2] have considered theoretically the energy spectrum of layered antiferromagnets. They have shown that if the antiferromagnetic interaction between the layers is much weaker than the ferromagnetic interaction in the layer, and if the anisotropy is small, a transition from a three-dimensional antiferromagnet to a two-dimensional ferromagnetic system sets in already at low temperatures.

The changes of the susceptibility of single-crystal $CrCl_3$ [9, 2] have shown that the anisotropy in $CrCl_3$ is weak, the antiferromagnetic coupling between layers is very weak, and the antiferromagnetic order is disturbed in weak fields; the exchange interaction between layers, determined in [2] from the value of $\chi_\perp$, was $J_{af}/k = -9.918°K$.

Narath and Davis [2] investigated the dependence of the $CrCl_3$ sublattice magnetization on the field (up to 10 kOe) and on the temperature between 0.4 and 8°K, using the method of nuclear magnetic resonance. They estimated the internal field at which the antiferromagnetic ordering is disturbed and above which the spins in the neighboring sublattices become aligned in parallel (ferromagnetic state) at 1.68 kOe, and found $CrCl_3$ to be practically isotropic in the ferromagnetic state. The temperature dependence of the sublattice magnetization in the absence of a field is attributed by Narath and Davis to singularities of the energy spectrum of the two-dimensional ferromagnetic system, with allowance also for the spin-wave interaction. According to their estimates, the ferromagnetic interaction in the layer is $J_f/k = 5.25°K$ and the effective anisotropy field in the antiferromagnetic state is H_A = 650 Oe.

There are known measurements of the specific heat of anhydrous $CrCl_3$ in the absence of a field above 12°K [10, 11]. In these investigations the temperature was of the transition from the paramagnetic to the antiferromagnetic state of $CrCl_3$ was found to be T_c = 16.8°K.

Low-temperature measurements of the specific heat of $CrCl_3$ [3, 4] without a field were made from 2 to 20°K and made it possible to separate the linear term of the magnetic specific heat; this term is typical of a two-dimensional ferromagnetic system. It was found that the magnetic specific heat of $CrCl_3$ between 2 and 8°K is equal to 0.0535T cal/mole-deg. This led to an estimate $J_f/k = 5.61°K$ of the exchange ferromagnetic interaction in the layer, which is close to the result of Narath and Davis.