registered both virtual and real reconstructed images. The virtual image was photographed with a camera, and the real one was produced on a screen behind the hologram and photographed with a camera without a lens.

Since the angle between the signal and reference beams was small, the hologram was photographed on an ordinary film of type MZ-2.

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MAGNETOSTRICTION OF ANTIFERROMAGNETIC COBALT FLUORIDE

A. S. Prokhorov and E. G. Rudashevskii
P. N. Lebedev Physics Institute, USSR Academy of Sciences
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Odd magnetostriction (linear in the magnetic field) is a thermodynamically reversible effect relative to piezomagnetism [1]. The piezomagnetic effect, which is linear in the applied stress, was first observed experimentally in the antiferromagnetic fluorides of cobalt and manganese [2, 3]. An experimental investigation of antiferromagnetic CoF_2 in magnetic fields up to 1.5 kOe [4] has revealed a linear dependence of the magnetostriction on the applied magnetic field. An experimental study of hematite (α-Fe_2O_3), in which the piezomagnetic effect also exists, has shown that the magnetostriction deviates from linearity at $H > 1.5$ kOe [5].

We have investigated the magnetostriction of antiferromagnetic CoF_2 using a capacitive dilatometer of 5 Å sensitivity, in magnetic fields up to 20 kOe at a temperature 4.2°K. The CoF_2 crystal was grown at the Physics Problems Institute of the USSR Academy of Sciences.

Figures 1 and 2 show the experimental curves, plotted with an automatic x-y recorder, corresponding to magnetic-field orientations along the [001] and [$\bar{1}$10] axes of the CoF_2 single crystal; the deformation was measured in both cases in the [110] direction. The experimental curves for the linear (Fig. 1) and quadratic (Fig. 2) magnetostriction are described by the respective relations

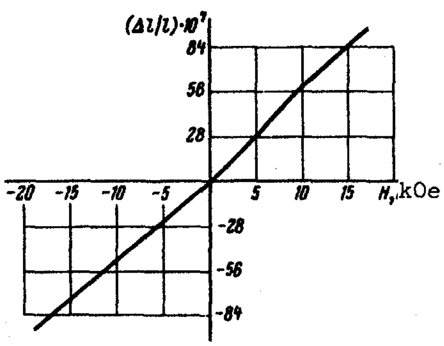

Fig. 1. Dependence of relative deformation of CoF_2 along the [110] axis on a magnetic field parallel to the [001] axis.

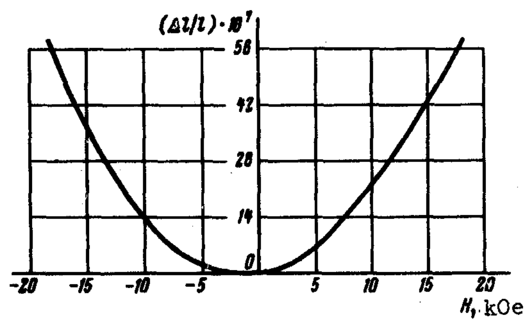

Fig. 2. Dependence of relative deformation of CoF_2 along the [110] axis on a magnetic field parallel to the [1$\bar{1}$0] axis.

$$\Delta \ell/\ell = (4{,}9 \pm 0{,}2)\, 10^{-10} H, \tag{1}$$

$$\Delta \ell/\ell = (1{,}75 \pm 0{,}05)\, 10^{-15} H^2 + (2{,}5 \pm 1{,}0)\, 10^{-12} H, \tag{2}$$

where H is the magnetic field intensity in Oe.

To explain the experimental results, we write down the thermodynamic potential for CoF_2 [6] with allowance for the magnetic (Φ_m), magnetoelastic (Φ_{me}) and elastic (Φ_e) energies

$$\Phi_m = (B/2)\, m^2 + (b/2) m_z^2 - (a/2)\gamma_z^2 + e(\gamma_y m_x + m_y \gamma_x) - (2M_o)\,\mathrm{mH}, \tag{3}$$

$$\begin{aligned}\Phi_{me} = {} & \lambda_1 (m_x u_{yz} + m_y u_{xz})\gamma_z + \lambda_2 m_z \gamma_z u_{xy} + \lambda_3 (\gamma_x m_x + \gamma_y m_y) u_{xy} + \\ & + \lambda_4 (\gamma_x u_{yz} + \gamma_y u_{xz}) m_z + \eta_1 (\gamma_y u_{yz} + \gamma_x u_{xz})\gamma_z + \\ & + \eta_2 \gamma_x \gamma_y u_{xy} + \delta_1 m_z (m_x u_{xz} + m_y u_{yz}) + \delta_2 m_x m_y u_{xy}\,,\end{aligned} \tag{4}$$

$$\begin{aligned}\Phi_e = {} & 1/2 C_{11} (u_{xx}^2 + u_{yy}^2) + 1/2 C_{33} u_{zz}^2 + C_{13}(u_{xx} + u_{yy}) u_{zz} + \\ & + C_{12} u_{xx} u_{yy} + 2C_{66} u_{xy}^2 + 2C_{44}(u_{xz}^2 + u_{yz}^2) - \sum_{i,j = x,y,z} \sigma_{ij} u_{ij},\end{aligned} \tag{5}$$

where

$$(2M_o)\mathrm{m} = \mathrm{M}_1 + \mathrm{M}_2,\ (2M_o)\boldsymbol{\ell} = \mathrm{M}_1 - \mathrm{M}_2,\quad |\boldsymbol{\ell}|\ \vec{\gamma} = \boldsymbol{\ell},$$

and $\vec{M}_1$ and $\vec{M}_2$ are the sublattice magnetization vectors, $\vec{M}_0 = \vec{M}_1 = M_2$, σ_{ij} and u_{ij} are respectively the components of the stresses and of the strains.

By varying the thermodynamic potential

$$\Phi = \Phi_m + \Phi_{me} + \Phi_e \tag{6}$$

with respect to u_{xy}, we obtain

$$u_{xy} = -\frac{\lambda_2}{4C_{66}} m_z \gamma_z - \frac{\lambda_3}{4C_{66}} (\gamma_x m_x + \gamma_y m_y) - \frac{\eta_2}{4C_{66}} \gamma_x \gamma_y - \frac{\delta_2}{4C_{66}} + \frac{\sigma_{xy}}{2\,C_{66}}\,. \tag{7}$$

The components of the vectors $\vec{\gamma}$ and $\vec{m}$ in (7) can be determined by minimizing the thermodynamic potential Φ_m [(Eq. (3)] with respect to the components of the vector $\vec{m}$ and with respect to the angles θ and ϕ, which characterize the direction of the unit vector $\vec{\gamma} = \{\sin\theta\cos\Phi,$ $\sin\phi\sin\phi,\ \cos\phi\}$ relative to the coordinate frame in which the axes OX, OY, and OZ are directed along the crystal axes [100], [010], and [001], respectively. This gives rise to three solutions corresponding to the equilibrium values of the angles ϕ and ϕ:

$$\begin{aligned}&\mathrm{I}\quad \theta = 0\\ &\mathrm{II}\quad \sin\theta = -\lfloor e/(aB - e^2)\rfloor 2M_o [H_x \sin\phi + H_y \cos\phi],\\ &\mathrm{III}\quad \theta = \pi/2,\ \ tg\phi = H_x/H_y\,.\end{aligned} \tag{8}$$

$$\mathrm{H} \parallel [001]\ (H_x = H_y = 0,\ H_z = H_\parallel,\ H_\parallel \leqslant 20\,\mathrm{kOe},\ \sigma_{xy} = 0,\ u_{xy} = \Delta\ell/\ell),$$

which corresponds to the experimental curve of Fig. 1, the system is in state I, and it follows from (7) that

$$\Delta \ell / \ell = -\frac{\lambda_2}{4C_{66}(B+b)} 2M_0 H_\parallel \quad . \tag{9}$$

The experimental curve of Fig. 2 corresponds to the case H || [$\bar{1}$10]

$$(-H_x = H_y = \frac{1}{\sqrt{2}} H_\perp , \quad H_z = 0, \quad H_\perp \leq 20 \text{ кэ}, \quad \sigma_{xy} = 0 , \quad u_{xy} = \Delta \ell / \ell)$$

in which case the system is in state II and

$$\Delta \ell / \ell = [\delta_2 - (2e/a)\lambda_3 + (e/a)^2 \eta_2] \frac{(2M_0)^2 H_\perp^2}{(B - e^2/a)^2 8C_{66}} \tag{10}$$

The small deviation of the experimental curve of Fig. 1 from linearity may be due to a nonzero component of the magnetic field $H_\perp$ (see (10)). The term linear in the magnetic field in (2) is due to the presence of a small component of the magnetic field H along the [001] axis (see (9)), which may produce a magnetostriction linear in the magnetic field. Our experimental data on linear magnetostriction agree, within experimental accuracy, with the experimental data of A. S. Borovik-Romanov [3], who meansured the piezomagnetic effect in CoF_2. A comparison of the theoretical and experimental relations (9) and (1), respectively, for the linear magnetostriction with allowance for the values of B + b and of C_{66} from [7 - 9] makes it possible to calculate the magnetoelastic constant $\lambda_2 = 2.5 \times 10^7$ erg/cm^3.

From the relation for the quadratic magnetostriction (10) it follows that in the expansion (4) of the thermodynamic potential Φ_{me} the term $\delta_2 m_x m_y u_{xy}$ describes the usual quadratic magnetostriction of a uniaxial ferromagnet without weak ferromagnetism ($\vec{e} = 0$). The presence of weak ferromagnetism ($\vec{e} \neq 0$) results in quadratic magnetostriction connected with the rotation of the vector $\vec{\gamma}$ in the (110) plane (cf. (8), state II). Rotation of the vector $\vec{\gamma}$ produces $\gamma_x \neq 0$ and $\gamma_y = 0$, and contributions are made as a result to the quadratic magnetostriction by magnetic terms in the form $\eta_2 \gamma_x \gamma_y u_{xy}$ and $\lambda_3(\gamma_x m_x + \gamma_y m_y)$.

It can be seen from (10) that our experimental results do not make it possible to calculate the magnetoelastic constants δ_2, λ_3, or η_2 separately. Indeed, if it is not assumed beforehand that the coefficients of any of the invariants $(\gamma_x m_x + \gamma_y m_y)$, $\gamma_x \gamma_y y_{xy}$, or $m_x m_y u_{xy}$ are small, then we can, by using the values of a and $\vec{e}$ from [7], express the factor determining the corresponding magnetostriction in the form

$$\delta_2 - (2e/a)\lambda_3 + (e/a)^2 \eta_2 = \delta_2 - 3\lambda_3 + 2{,}3\eta_2$$

and our experiment yields a value 1×10^7 erg/cm^3 for this quantity.

As already indicated above, to calculate the magnetoelastic constants we used in this paper the numerical values of B, a, $\vec{e}$, and B + b from [7] and $C_{66} = 20 \times 10^{11}$ dyne/cm^2 from [8, 9]. For this value of the elastic constant C_{66}, the error in the determination of the numerical values of the magnetoelastic constants is governed by the accuracy with which the quantities B, a, $\vec{e}$, B + b are known (± 10%), and also by the measurement errors of our experiment, adding up to a total of ± 18%.

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OBSERVATION OF THE PHONON "BOTTLENECK" WITH THE AID OF MADEL'SHTEM-BRILLOUIN SCATTERING

S. A. Al'tshuler, R. M. Valishev, and A. Kh. Khasanov
Kazan' State University
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The possibility of investigating the spin-phonon interaction in paramagnets with the aid of Mandel'shtam-Brillouin scattering (MBS) was indicated in [1, 2]. So far, only one experiment was performed in this direction.

By using the usual MBS technique, we observed directly the phonon "bottleneck" effect in cerium-magnesium double nitrate (CeMN) under the following conditions. The investigated sample, measuring 4.5 x 4.5 x 9 mm, was placed in a rectangular resonator cooled to 1.5°K, in which a type H_{10} mode was excited at a frequency 14.2 GHz. A constant magnetic field was applied perpendicular to the trigonal axis of the crystal C_3, since $g_{\parallel} = 0$ and $g_{\perp} = 1.83$ for the Ce^{3+} ions in the double nitrate. In view of the absence of a hyperfine structure, a single EPR line was observed in a field H_0 = 5550 Oe, corresponding to spin transitions between the levels of the lower doublet of the Ce^{3+} ions. The exciting light was emitted by a helium-neon laser of 25 mW power, operating at a wavelength of 6328 Å. The scattered light was observed at 90° to the incident beam and was directed along the C_3 axis. Under these conditions, the MBS spectrum is produced only by the Debye elastic waves propagating at an angle of 45° to the C_3 axis. To observe the phonon "bottleneck" we chose longitudinal elastic waves, for in accordance with our measurements they yield more intense spectral MBS line in the investigated crystal. At the indicated optical orientation of the sample, the frequency of these oscillations was 14.2 GHz at helium temperatures.

The stationary saturation of the EPR line of the cerium ions led to a sharp increase of the intensity of the observed MBS component; this increase is obviously due to the "heating" of the phonons in the frequency band determined by the width of the EPR line, due to the spin relaxation in the presence of the phonon "bottleneck". Comparative measurements of the intensity of these components under saturation conditions and in the absence of the latter, yielded for the temperature of the "hot" phonons a value of 100°K. Thus, the temperature of the resonant phonons was increased by almost 70 times over their equilibrium temperature 1.5°K.

Starting from the experimental conditions, we can estimate theoretically the temperature