

Fig. 2. Dependence of linear (α_1) and quadratic (α_2) magnetoresistance on the electric field.

of the heating of the electrons and goes through a maximum at a definite electric-field intensity.

The appearance of linear magnetoresistance in a bounded many-valley semiconductor can be described in the following manner: the directions of the currents of electrons from different valleys do not coincide with the direction of the total current of all the electrons, which is governed by the contacts to the crystal. When a magnetic field is applied, the resultant Hall field changes both the direction of these currents and the average energy and concentration of the electrons in the valleys. In the general case these changes depend on both even and odd powers of \vec{H} . However, the presence of terms linear in \vec{H} in the average energy and concentration of the electrons in the valleys is still not sufficient for the appearance of linear magnetoresistance, since the terms connected with different valleys can cancel each other. It is

easily seen from symmetry considerations that such a compensation occurs, for example, in the case described above, when the direction of the current and of the magnetic field in the n-Si lies in the (110) plane. It takes place also in germanium and silicon, when the electric current is directed along one of the symmetry axes of the crystal (except for the 100 axis in n-Si, where there are no terms even in \vec{H} also for individual valleys). In general, linear magnetoresistance should be observed if the Hall field has a component along the direction of the anisotropy field that exists independently of \vec{H} in a strong electric field. It follows from the latter that the course of the linear magnetoresistance should correlate with the course of the conductivity anisotropy in a heating electric field. Such a correlation indeed takes place, as is seen from Fig. 2, which shows the dependence of the conductivity anisotropy, characterized here by the ratio $j_{\langle 111 \rangle} / j_{\langle 100 \rangle}$ on the electric field at $H = 0$.

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ACOUSTIC NUCLEAR EFFECT-SOLIDE IN LITHIUM FLORIDE

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The possibility of realizing an acoustic "effect-solid" or "dynamic

nuclear polarization" was predicted already by Abragam and Proctor [1], who first observed in 1958 dynamic polarization of Li^6 nuclei in an LiF crystal subjected to the action of an alternating magnetic field with a frequency equal to the difference or the sum of the precession frequencies of the F^{19} and Li^6 nuclei in an external magnetic field. This possibility, as applied to the same isotope Li^6 , was discussed later in a book by Kessel [2]; however, the acoustic effect-solid was not yet observed experimentally. We have obtained it, in this investigation, in LiF crystals on the isotope Li^7 , which is less convenient from the point of view of the expected magnitude of the effect, but has a larger natural abundance and is therefore more convenient for investigations by a pulse method.

As is well known [3], dynamic polarization is effected as a result of modulation of the internal spin-spin interaction, in this case the dipole magnetic interaction of the nuclei Li^7 and F^{19} . Starting from the results of the general theoretical papers [4 - 7] based on the research of Provotorov [4], it is possible to obtain for this case an expression for the change of the stationary polarization p of the Li^7 nuclei under the influence of ultrasonic perturbation of the difference or summary frequency, a perturbation causing a reorientation of the spins of the nuclei Li^7 and F^{19} .

$$\frac{p}{p_0} = \frac{A_{\text{Li}} \omega_{\text{F}} / \omega_{\text{Li}} + A_{\text{F}} + T_3 (\Delta^\pm)^2 / \Omega^2 + 1/W^\pm}{A_{\text{Li}} + A_{\text{F}} + T_3 (\Delta^\pm)^2 / \Omega^2 + 1/W^\pm} \quad (1)$$

Here $A \equiv T_1 / I(I + 1)C$, where I , T_1 , and C are respectively the nuclear spin, the spin-lattice relaxation time, and the concentration of the nuclei of a given species (labeled by a suitable symbol) in the two-spin system under consideration; T_3 is the relaxation time of the "dipole-dipole reservoir," i.e., the time it requires to reach thermal equilibrium with the lattice, $\omega_{\text{F}} = \gamma_{\text{F}} H_0$ and $\omega_{\text{Li}} = \gamma_{\text{Li}} H_0$ are the frequencies of Larmor precession of the nuclei F^{19} and Li^7 with gyromagnetic ratios γ_{F} and γ_{Li} in an external magnetic field H_0 , $\Delta^\pm = \omega - \omega^\pm$ is the deviation of the running ultrasound frequency ω from the summary or difference precession frequencies $\omega^\pm = \omega_{\text{F}} \pm \omega_{\text{Li}}$. Ω is a quantity characterizing the "heat capacity" of the dipole-dipole reservoir, determined by the local field produced by the nuclei on each other; finally, W^+ and W^- are the probabilities of the transitions accompanied by reorientations of the spins of Li^7 and F^{19} in the same direction under the influence of the field of summary frequency ω^+ , or in opposite directions under the influence of the field of the difference frequency ω^- . Thus, all the superior indices in formula (1) pertain to the summary frequency, and the inferior ones to the difference frequency. As seen from (1), the perturbation of the summary frequency decreases the polarization of the Li^7 nuclei, i.e., the population difference of the Zeeman levels, whereas perturbation of the difference frequency increases the polarization, i.e., increases the stationary population difference. This is the meaning of the concept "dynamic polarization," which should thus be manifest in a corresponding change of the observed nuclear-precession signal amplitude.

The experiments were performed by us with a pulse setup described earlier in [8]. The investigated LiF crystal samples were cylinders of 10 mm diameter and ~50 mm length, cut along the [100] axis, which was oriented perpendicular to the external field \vec{H}_0 in such a way that the other cubic axis was parallel to \vec{H}_0 . For convenience in observing precession signals of nuclei having very large spin-lattice relaxation times, voltage pulses much shorter than 90° were applied to the transmitting coil of the pickup, making it possible to register a series of slowly decreasing precession signals spaced ~0.5 sec apart.

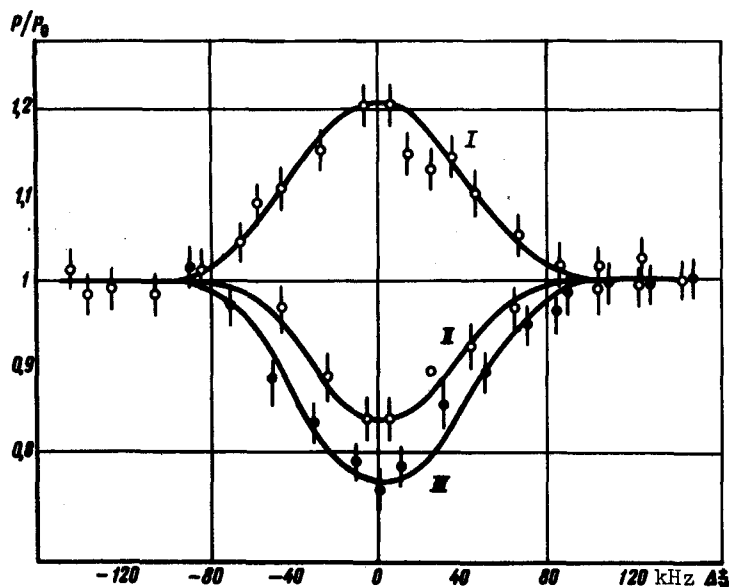
The relaxation time of the nuclei F^{19} , measured by comparing the amplitudes of the precession signals in neighboring series [9], was $T_{1F} = 180$ sec at the indicated orientation of the crystallographic axes. For the Li^7 nuclei, we obtained under these conditions a value $T_{1Li} = 500$ sec. With such a difference between the relaxation times, formula (1) gives a maximum enhancement of the polarization of the Li^7 nuclei ($\Delta^- = 0$, $W^- \rightarrow \infty$) up to a value 1.5; at the summary frequency, on the other hand, this formula admits of complete equalization of the Li^7 level populations, with subsequent inversion.

The ultrasonic oscillations were excited in the samples by X-cut quartz plates attached to their flat faces. The opposite faces of the samples were cleaved to form a diffuse field. The crystals were first heated by ultrasound to approximately $70^\circ C$, and the subsequent investigations of the acoustic effect were carried out at this stabilized temperature. Following excitation of longitudinal ultrasound at the difference frequency ($\omega^-/2\pi = 5.14$ MHz), an electric voltage up to 1200 V was applied to the piezoelectric plate; the voltage applied at the summary frequency ($\omega^+/2\pi = 12.4$ MHz) was up to 350 V. Under these experimental conditions, an estimate of the probabilities W^\pm in accordance with the formula [2]

$$W = (\gamma_{Li} \gamma_F \pi e_0)^2 / r^6 \delta, \quad (2)$$

where r is the lattice constant, e_0 the deformation amplitude, and δ the half-width of the resonance curves, yields, with allowance for the characteristics of the LiF crystal, the values $W^\pm \sim 10^{-3} \text{ sec}^{-1}$, corresponding according to (1) to $\sim \pm 30\%$ change in the polarization of the Li^7 nuclei.

The figure shows experimental plots of the relative amplitudes of the precession signals, which are proportional to the stationary polarization of the Li^7 nuclei, against the ultrasound frequency, which was varied about the theoretical values ω^+ and ω^- within a range much smaller than the emission-frequency band of the piezoelectric plates. Curve I pertains to the difference frequency, and curves II and III, obtained with voltages 250 and 350 V respectively on the plate, pertain to the summary frequency. Since the measurement error in the precession signal amplitude did not exceed 5% in our



Acoustic effect-solid in LiF crystal. Ordinate - change of the stationary polarization p of the Li^7 nuclei relative to the equilibrium value p_0 ; abscissa - deviation of the cyclic frequency of the ultrasound $\Delta_v^\pm = \Delta^\pm/2\pi$ relative to the difference (curve I) and summary (curves II and III) precession frequencies of the nuclei F^{19} and Li^7 .

experiments, we can state that these curves illustrate clearly the effect of changing the polarization of the Li^{7} nuclei under the influence of summary and difference ultrasound frequencies. The magnitude of the effect and the shape of the curves are in good agreement with the calculations; as to their width ($\delta^{\pm} \approx 80$ kHz), it was determined both by the dependence of the probabilities W^{\pm} on Δ , and by the factor T_3/Ω^2 preceding $(\Delta^{\pm})^2$ in formula (1). This factor can be estimated, generally speaking, by comparing the experimental curves II and III obtained at different acoustic-energy densities in the crystal, since the probabilities W^{\pm} for these curves at fixed Δ should be related to each other as the squares of the strains, which are proportional to the voltage on the piezo-electric converter. This can be done more accurately, however, by saturating the forbidden transitions with a radio-frequency field, when the limiting change of the stationary polarization is reached. The results of such experiments will be published later.

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INVESTIGATION OF THE TEMPORAL CHARACTERISTICS OF DEFORMATION LUMINESCENCE

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It was shown in earlier papers [1 - 3] that glow - deformation luminescence - is produced when colored alkali-halide crystals are deformed. The deformation-luminescence process proceeds in two stages. The dislocations moving under the influence of the external stress release electrons from the F centers, and the electrons subsequently recombine at the luminescence centers - the Cu^{++} ions.

We investigate here the temporal characteristics of the luminescence; an analysis of these characteristics confirms the micromechanism proposed in [4] for interaction between the dislocations and the F centers.

The investigations were made on the crystals KBr ($2 \times 10^{-4}\%$ Cu) and KCl ($1.6 \times 10^{-3}\%$ Cu). The samples were colored with γ rays from a Co^{60} source at an irradiation dose 2×10^5 rad. The crystals were deformed by pulses of mechanical stress with duration 50 μsec (at the 0.5 level). To obtain pulsed loading, a setup was developed in which the lower plunger was a magnetostriction converter on which a coil was wound [5]. Passage of current through the coil produced elongation of the converter and deformation of the sample.

The glow was registered with a low-noise photomultiplier (FEU-77), a cathode follower, and an oscilloscope (S1-37 or C1-42). The second channel of