[1)] We assume in fact short-range forces of interaction between the defects. It is this which justifies the use of the lattice model (see also Refs. 6–8). Coulomb attraction can only accelerate the relaxation to equilibrium.

[2)] The relaxation process considered above can be regarded as a modification of a diffusion-limited reaction in the solid phase.[6]

[3)] It is easy to verify that by the instant of vanishing of the discrete spectrum the coefficient of reflection from the barrier is generally speaking not yet small.

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The drag of electron-hole drops by ultrasound

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The drag of electron-hole drops (EHD) in germanium over macroscopic distances up to 4 mm, induced by traveling ultrasonic waves, is observed. The drag effect is detected by using a $\lambda = 3.39\ \mu$m probing laser beam. The absorption change in the probing region, which is proportional to the change in the carrier density in the region, is measured. A theoretical model is developed to describe EHD drag by ultrasound, in which the generation of the carriers and their finite lifetimes are taken into account. The model permits a semiquantitative explanation of the dependence of the effect on the intensity of the ultrasonic pulse and also on its duration and on the temperature during the experiment.

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The electron-hole liquid in pure undeformed germanium is formed in the shape of a cloud of fine (with radius 10^{-4}–10^{-3} cm) electron-hole drops (EHD).[1] Another possible method of motion of the drops is the action on them of ultrasound.[5,6] We have previously observed the change in the ultrasonic attentuation in photo-excited germanium with increase in the sound intensity[7] and the "flareup" of recombination radiation of the EHD upon its interaction with the ultrasound.[8] These effects have been explained with the help of representations on the EHD drag by the ultrasonic wave.

The basic purpose of the present research was to obtain direct experimental proof of the EHD drag by the ultrasound predicted in Ref. 5. Theoretically, the drag of the drops of the electron-hole liquid by the ultrasound is considered in the first section of the present paper. In the second section, we describe the experimental method, and in the third, the experimental results that were obtained are set forth and discussed.

I. DRAG OF THE EHD BY ULTRASOUND. REDISTRIBUTION OF THE EHD CLOUD DENSITY

Let current carriers with velocity g be generated continuously at some region of the semiconductor. We shall assume that they are all quickly condensed (within 5×10^{-7} sec[9]) into EHD, which form a cloud in the region of generation with drop density N and mean density of the condensed carriers in the cloud $n = \frac{4}{3}\pi R^3 N n_0$, where n_0 is the density of the liquid in the EHD, R is the radius of the EHD. We now consider how the mean density of the cloud of drops n changes under the action of a longitudinal ultrasonic wave of frequency ω, with a wave vector $\mathbf{k}$ directed along the x axis, and a wavelength that is large in comparison with the dimensions of the drops $\lambda \gg R$, $\lambda = 2\pi/|\mathbf{k}|$. In the deformation field of such a wave, $\varepsilon = \varepsilon_0 \sin(\omega t - \mathbf{kr})$, where $\varepsilon = \operatorname{div}\mathbf{u}$, $\mathbf{u}(\mathbf{r}, t)$ is the displacement of the point $\mathbf{r}$ of the semiconductor from the equilibrium position, the force[5]

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$$\mathbf{F}\equiv\mathbf{F}_0\cos(\omega t-\mathbf{kr})=-D\mathbf{k}\varepsilon_0\cos(\omega t-\mathbf{kr}) \quad (1)$$

acts on the electron-hole pair in the drop.[1)] Here $D=D_e+D_h$ is the total deformation potential on the electron-hole pair.

In the absence of external forces, the EHD are captured by the defects of the semiconductor.[10,11] For example, in pure germanium with a concentration of residual impurities $\lesssim 10^{13}$ cm^{-3}, in order to "tear away" the drops, it is necessary to apply a force (per electron-hole pair) exceeding the value $F_c\sim 1$ meV/cm.[10] We neglect this "dry" friction below. This can be done if the intensity of the ultrasound is $I=\rho S^3\varepsilon_0^2/2$, where ρ is the density of the semiconductor and S is the speed of longitudinal sound in it, is greater than some critical value I_c:

$$I\gg I_c={}^1/_2\rho S^3(F_c/kD)^2. \quad (2)$$

In Ge, $I_c\sim 10^{-4}$ W/cm^2 in order of magnitude (for ultrasound with a wavelength $\lambda\sim 10^{-3}-10^{-2}$ cm).

Then the equation of motion of the EHD has the form[5]

$$\frac{d^2\xi}{dt^2}+\gamma\frac{d\xi}{dt}=\frac{Dk\varepsilon_0}{m}\cos(\omega t-k\xi), \quad (3)$$

where $(\xi-x)$ is the coordinate of the drop, $m=m_e+m_h$, γ is the coefficient of viscous friction of the liquid with respect to the lattice:

$$\gamma=\frac{2}{3(2\pi)^3}\frac{m_e^2D_e^2+m_h^2D_h^2}{\hbar^2m\rho Sn_0}\left(\frac{k_0T}{\hbar S}\right)^5\int_0^{\eta_0}\eta^5\frac{e^\eta}{(e^\eta-1)^2}d\eta; \quad (4)$$

$\eta_0=2\hbar S(3\pi^2n_0)^{1/3}/k_0T$, T is the temperature of the semiconductor, and n_0 is the density of the electron-hole pairs in the drop.

It was shown earlier[5] that if the intensity of the ultrasound is small: $I\ll I_0=m^2\rho S^7/D^2\sim(10-100)$ W/cm^2 in germanium, the solution of Eq. (3) is the sum of the drift in the direction of propagation of the wave with constant velocity $V\ll S$ and small oscillations about this mean motion

$$\xi(t)=Vt+x(t),\quad V=S\frac{\omega^2}{\omega^2+\gamma^2}\frac{I}{I_0}, \quad (5)$$

while $\langle x(t)\rangle=0$. At high ultrasonic intensities, $I\gg I_0$, the drag of the drops is complete: $V=S$.

For a description of the redistribution of the drop cloud density, brought about by motion of the drops, it is natural to use the equation of continuity, taking into account the generation of the carriers and the finiteness of their lifetime. This equation, averaged over the period of the ultrasound, has the form

$$\partial n/\partial t+\operatorname{div} n\mathbf{V}=g-n/\tau, \quad (6)$$

where τ is the lifetime of the carriers in the EHD $\mathbf{V}=(V,0,0)$. In the derivation of (6), it was assumed that all the carriers that are formed in the semiconductor are condensed in the drop and that the ultrasound does not affect the condensation process. Moreover, the diffusion of the drops was not taken into account. This is justified, as can easily be shown, inasmuch as the diffusion coefficient of the drops is very small: $D_d<10^{-3}$ cm^2/sec.[2,11]

The coefficient of diffusion of the EHD in germanium can be estimated by using the Einstein relation and the values of the momentum relaxation time $\tau_p=\gamma^{-1}$ from Ref. 4. We obtain $D_d\approx 10^{-3}$ cm^2/sec.[2] It is experimentally very difficult to determine the diffusion coefficient, inasmuch as it is necessary to reduce the interaction between drops of the type of the phonon wind to a minimum. This problem was solved by the authors of Ref. 11, who obtained the estimate $D_d<10^{-9}$ cm^2/sec for the diffusion coefficient. Such a small value of D_d is explained evidently by the already mentioned dry friction of the EHD in the semiconductor.

We note in passing that the drift of the drops differs from the drag of free carriers or electrons by the ultrasound: in the latter case, the basic contribution to (6) is made by the diffusion term.

We shall assume that the excitation is uniform in a plane perpendicular to the direction of propagation of the ultrasound. Then $n(\mathbf{r},t)\equiv n(x,t)$ and in place of (6) we get

$$\partial n/\partial t+V\partial n/\partial x=-n/\tau+g(x). \quad (7)$$

The stationary solution of Eq. (7) has the form

$$n_s(x)=\frac{1}{V}\int_{-\infty}^{x}g(y)\exp\left(\frac{y-x}{V\tau}\right)dy. \quad (8)$$

For example, if the excitation is uniform in a layer of thickness a,

$$g(x)=\begin{cases}g, & 0<x<a\\ 0, & x<0, x>a\end{cases}, \quad (9)$$

a stationary density distribution is established in the cloud (see Fig. 1d)

$$n_s(x)=g\tau\begin{cases}0, & x<0\\ 1-e^{-x/V\tau}, & 0<x<a.\\ [e^{a/V\tau}-1]e^{-x/V\tau}, & a<x\end{cases} \quad (10)$$

We note that the distribution (10) is established over a relatively long time—$t\geq a/V$. In the experiment described below, the ultrasound acts on the EHD cloud through pulses of length t_1 and it can be shown that $t_1<a/V$ (especially at low ultrasonic intensities, when the drift velocity of the EHD is small). We therefore consider the establishment of the distribution (8), (10).

We limit ourselves to the case of low ultrasonic intensities $I\ll I_0$, such that $V\ll S$. Then, in the time of passage of the leading edge of the sound pulse through the cloud, $t_f=a/S$, the cloud density does not change ap-

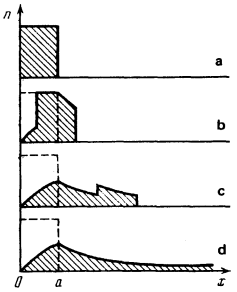

FIG. 1. Establishment of stationary distribution of mean density of the drop cloud at different instants of time in the case $aV/\tau=0.8$: a—$t=0$; b—$t=a/2V$; c—$t=2a/V$; d—$t\gg a/V$.

preciably. We shall therefore assume that the drift of the drops begins simultaneously (at $t=0$) throughout the entire region of generation[2)] and solve the equation (7) at $t>0$ with the initial condition

$$n(x,\ 0)=g(x)\tau, \tag{11}$$

i.e., with the same distribution which is established in the cloud in the case of onset of the ultrasound (see Fig. 1a). We obtain

$$n(x,t)=\tau g(x-Vt)e^{-t/\tau}+\tau\int\limits_{x-Vt}^{x} g(y)\exp\left(\frac{y-x}{V\tau}\right)dy. \tag{12}$$

The first term in (12) is one moving in the direction of propagation of the ultrasound with velocity V, "fading away" the initial distribution (11). The second term describes the establishment of the stationary distribution (8): $n(x,t)-n_s(x)$ as $t\to+\infty$.

If $g(x)$ has the form (9), we get from (12):

$$n(x,\ t)=g\tau\begin{cases}0, & x<0\\ 1-e^{-x/V\tau}, & 0<x<a,\quad t>x/V,\\ 1, & 0<x<a,\quad 0<t<x/V\end{cases} \tag{13a}$$

$$n(x,\ t)=g\tau\begin{cases}e^{(a-x)/V\tau}-e^{-x/V\tau}, & a<x,\ t>x/V\\ e^{(a-x)/V\tau}, & a<x,\ (x-a)/V<t<x/V.\\ 0, & a<x,\ 0<t<(x-a)/V.\end{cases} \tag{13b}$$

The desnity of the EHD cloud at different instants of time after onset of the ultrasound (13) is shown in Fig. 1.

It is also easy to show that if the ultrasound is initiated at the time $t=t_i$, the distribution (11) is established according to the law

$$n(x,t)_{t>t_i}=g(x)\tau(1-e^{(t_i-t)/\tau})+n(x,t_i)e^{(t_i-t)/\tau}, \tag{14}$$

where $n(x,t_i)$ is the distribution (12), (13), which was established in the system at the time t_i.

In conclusion to this section, we now discuss the applicability of the assumed model for germanium. Formally, the calculations that have been made are applicable to EHD in a cubic single-valley semiconductor with isotropic bands. In this connection, we note that in such an anisotropic semiconductor as germanium, EHD drag is also possible by transverse ultrasound. Further, the screening of the deformation potential by the electron-hole liquid is not taken into account in Eqs. (2) and (3). Theoretically, the screening of the deformation potential in EHD was considered in Refs. 12 and 13. It turned out that formula (3) gives the correct (with accuracy to within a factor of order 2) estimate of the value of the friction for $\lambda\gg R$, which is satisfied in our case.

II. EXPERIMENTAL METHOD

The experimental setup is shown in Fig. 2. It can be divided into two parts: "optical" and "acoustical." The optical parts consisted of two He–Ne lasers with radiation wavelengths of 1.15 and 3.39 μ with a system of lenses and rotatable mirrors, and also a system for recording the radiation (PbS receiver, amplifier, synchronous detector, automatic recorder).

Sound is introduced in the sample by means of a quarter-wave coaxial resonator and an electroacoustic transducer (CdS film). Ultrasound of frequency 200

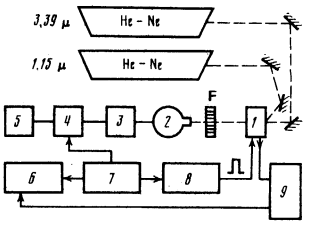

FIG. 2. Experimental arrangement: 1—sample; 2—photoresistor; 3—amplifier; 4—synchronous detector; 5—automatic recorder; 6—oscilloscope; 7, 8—generators; 9—receiver; F—germanium filter.

MHz is fed to the sample from a generator of sinusoidal oscillations, the start of which is brought about by rectangular pulses from a second generator. The repetition rate of the sound pulses was $f=1/t_0=1$ kHz. The pulse length was varies from 0.5 to 100 μsec.

The samples were prepared from pure germanium. Their height in the direction of propagation of the ultrasound [100] amounted to 8 mm. The plane parallel nature of the end faces of the sample, which was strictly maintained in the previous experiments,[6-8] was specially violated here, which made it possible to decrease to a significant amount the action of the reflected ultrasonic wave on the EHD and also to avoid the formation of standing waves in the sample in the case of long acoustic pulse lengths.

Unmodulated radiation from both lasers was focused on the surface of the sample in the region of the sound channel (the cross section of the channel was determined by the dimensions of the thin-film transducer and was ~1.5 mm^2). The radiation with $\lambda=1.15$ μ generated EHD in the sample and the probing ray with $\lambda=3.39$ μ passed through the germanium and was incident on the detecting system. The recombination radiation of the EHD was suppressed by a germanium filter, maintained at room temperature, and was not incident on the PbS detector.

The radiation with $\lambda=3.39$ μ, passing through the sample, was attentuated in proportion to the mean density of the carriers in the probing region.[14] The measurements were carried out at temperatures $T<2.5$ K, i.e., when almost all the carriers were condensed into EHD. Furthermore, it can be assumed that the geometry of the experiment was close to the planar one considered in the first section. This approximation is validated first by the fact that the transverse dimensions of the ultrasonic channel are much greater than the ultrasonic wavelengths. Second, as was shown in the first section, diffusion of the drops is small (and this is the only cloud density redistribution mechanism that competes with the dragging and is strongly dependent on the geometry of the experiment). Taking it also into account that the dimensions of the probing region are about the same as the dimensions of the generation region, we obtain the result that the probing radiation is attenuated in proportion to the average density of the condensed particles in the following way:

$$\bar{n}(l,t)=\frac{1}{a}\int\limits_{l}^{a+l}n(x',t)\,dx', \tag{15}$$

where l is the coordinate of the probing beam.

Since the exciting and probing radiation were continuous, the time modulation of the signal picked off the PbS detector (which is proportional to $\bar{n}(l,t)$ was entirely connected with the redistribution of the cloud in the probing region under the action of the ultrasonic pulses.

The amplitude of the component $\bar{n}(l,t)$ at the ultrasonic pulse-repetition frequency $\Omega = 2\pi/t_0$ was separated by the amplifier-synchronous detector stage. The signal K from this stage was consequently proportional to

$$K(l) \propto \left| \frac{1}{t_0} \int_0^{t_0} [\bar{n}(l,t) - \tau g(l)] e^{i\Omega t} dt \right|, \qquad (16)$$

(here the term $\int_0^{t_0} \tau g(l) e^{i\Omega t} = 0$ is added for convenience). The density $\bar{n}(l,t)$ differs from $g(l)\tau$ in a time interval of the order of $t_i + \tau$. If $(t_i + \tau)\Omega \ll 1$, we can substitute unity for the exponential. Then

$$K(l) \propto \frac{1}{t_0} \int_0^{t_0} |\bar{n}(l,t) - \tau g(l)| dt. \qquad (17)$$

Consequently, a signal in the detecting circuit can arise only when the drops transported by the ultrasonic wave intersect the probing ray (if the region of generation of the EHD does not coincide with the region of probing). On the other hand, in the case of combination of the two laser beams on the surface of the sample, i.e., upon coincidence of the generation region with the probing region, the signal can appear only when the ultrasonic wave takes out part of the EHD from the probing region and changes its spatial distribution (see Fig. 1). Thus in both cases, the *change* in the density of the drop cloud in the probing region was measured.

In the following, the signal K was measured experimentally will be called the "absorption signal" for brevity.

III. RESULTS AND THEIR DISCUSSION

The dependences of the absorption signal K on the distance l between the probing regions and the generation region within the boundaries of the sound channel are shown in Fig. 3. In the experiment, the spot of the exciting radiation was first superimposed on the probing region ($l = 0$) and then gradually transported along the sound channel. As the spot moved from the probing region to the source of the ultrasound, i.e., at $l > 0$ (Fig. 4b), the right side of the curve shown in the drawing was measured. The left side was then obtained when

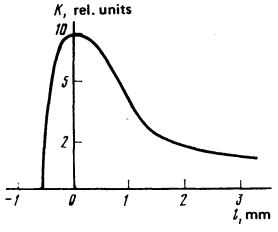

FIG. 3. Dependence of the absorption signal on the distance between the regions of probing and generation of the EHD: $T = 1.9$ K, $I = 3$ W/cm^2, $t_i = 30\,\mu$sec.

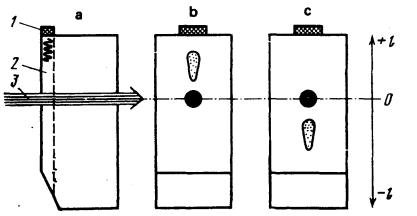

FIG. 4. Schematic drawing of the germanium sample and the location on its surface of the spots of the exciting and probing rays: a) sample in profile: 1—electroacoustic transducer CdS, 2—sound channel, 3—probing ray, $\lambda = 3.39\,\mu$, b) $l > 0$, c) $l < 0$.

the spot of the exciting radiation was moved away from the probing region and from the ultrasonic source ($l < 0$, Fig. 4c).

The character of the measured dependence is indisputably connected with the motion of the drops, which arises as a result of their interaction with the traveling ultrasonic wave. Upon generation of the EHD in the sound channel in the region $l > 0$, the absorption signal was observed up to values $l \approx 3$–4 mm. The drops created at such distances from the probing region drifted along with the ultrasonic wave and were transported to the opposite end of the sample, intersecting the probing ray. The absorption signal was recorded.

A completely different picture existed if the spot of the enciting radiation was displaced from the probing region in the direction of the propagation of the ultrasonic wave ($l < 0$). The absorption signal fell off rapidly and approached zero at $l \approx -0.6$ mm. Under the experimental conditions, the quantity $|l|$ corresponded to the geometric size extent of the region of overlap of the two (probing and the exciting) laser beams on the surface. Upon further increase in l, the EHD, carried by the wave ever further from the probing region, cannot intersect the probing ray and the absorption signal at the drops is practically equal to zero.

Further measurements led to such conditions in which the spot of the exciting radiation was coincident with the probing ray in the region of their incidence on the surface of the sample ($l = 0$).

Using formulas (13) and (17), it can be shown that in this case the absorption signal K is proportional to

$$K \propto g\tau \begin{cases} V\tau t_i/t_0 a, & 0 < t_i < a/V \\ \dfrac{V\tau}{t_0 a} t_i (1 - e^{-a/V\tau}) + \dfrac{\tau}{t_0} e^{-a/V\tau}, & t_i > \dfrac{a}{V} \end{cases} \qquad (18)$$

The existence of two different regimes of behavior of the absorption signal, depending on the relation of a to Vt_1, is explained physically by the fact that the stationary distribution (8), (10) cannot be established in the excitation region within the time of action of the ultrasound, at $Vt_1 < a$, but can be established at $Vt_i > a$.

The absorption signal was determined experimentally: 1) as a function of the intensity of the ultrasound I at fixed temperature of the sample T and pulse duration t_i; 2) as a function of the duration of the ultrasonic pulse t_i at fixed I and T; 3) as a function of temperature T at fixed I and t_i. We consider these cases separately.

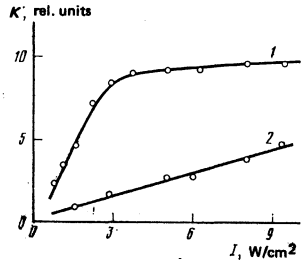

FIG. 5. Dependence of the absorption signal on the intensity of the ultrasound at $T=1.9$ K: 1—duration of the ultrasonic pulse $t_i=30\,\mu$sec; 2—$t_i=3\,\mu$sec.

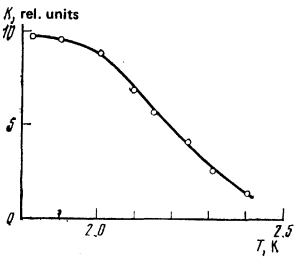

FIG. 7. Temperature dependence of the value of the absorption at $I=5$ W/cm^2 and $t_i=30\,\mu$sec.

1) The experimentally measured dependences of the absorption signal K on the intensity of the ultrasound are shown in Fig. 5. Curves 1 and 2 were plotted as identical temperatures $T=1.9$ K, but at different ultrasonic pulse lengths: curve 1 at $t_i=30$ μsec, 2 at $t_i=3\mu$sec.

It must be noted that because of the impossibility of observation of the first reflected echo on the screen of the oscilloscope (plane parallelism of the ends of the sample is violated) the coefficient of conversion of the electric energy delivered to the sample from the generator into acoustic was determined inaccurately. Its value was found in the limits 10–15 dB. Therefore the absolute values of the acoustic power, shown in Fig. 5, have an error of ±50%.

The curve 1 of Fig. 5 can be divided conditionally into two parts—linear growth and saturation. Curve 2, plotted for a pulse one-tenth shorter, is linear up to the maximum measured intensities. We note that its slope is less than that of the linear portion of curve 1. These features correspond qualitatively to the theoretical picture. Indeed, it follows from formulas (5) and (18) that in the gives case the absorption signal is proportional to

$$K\propto t_i\begin{cases} I, & I<\tau I_1/t_i \\ I\left[1-\exp\left(-\dfrac{I_1}{I}\right)\right]+\dfrac{\tau}{t_i}\exp\left(-\dfrac{I_1}{I}\right), & I>\dfrac{\tau}{t_i}I_1 \end{cases}, \quad (19)$$

where

$$I_1=\frac{a}{S\tau}\frac{\omega^2+\gamma^2}{\omega^2}I_0.$$

It follows from (19) that: a) the absorption signal is linear at low intensities of the ultrasound and goes over into saturation at intensities that are inversely proportional to the duration of the acoustic pulse; b) the slope of the linear part of K is directly proportional to t_i. As was shown above, the transition to saturation is explained by the fact that at ultrasonic intensities $I>\tau I_1/t_i$, within the time of action of the ultrasound on the excitation region, it is possible to establish the stationary distribution (10) in it.

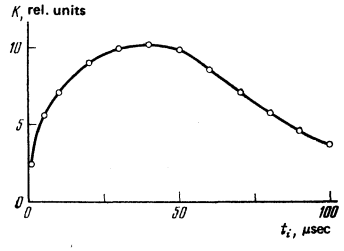

FIG. 6. Value of the absrption signal as a function of the ultrasonic pulse duration at $T=1.9$ K and $I=3$ W/cm^2.

2) When measuring the absorption signal as a function of the ultrasonic pulse duration t_i (Fig. 6), we observed that the value of the absorption increased with increase in t_i and reached a maximum at $t_i\approx 30$–40 μsec. At first glance, such a behavior of K contradicts the theoretical picture. It follows from (18) that the $K(t_i)$ dependence should consist of two linear portions (with greater slope in the region of short duraction of the pulse $t_i<a/V$.

However, we note that although special measures were taken to decrease the effect of the action of the reflected sound on the EHD, in the case of an increase in the duration of the pulses the sample is ever more filled with the sound. This can lead to a decrease in the EHD drag along the sound channel and, consequently, to a drop in the absorption signal. The effect of possible heating of the sample ΔT at $\sigma_i\sim 100$ μsec is also not excluded. In this case, at a mean electric power delivered to the sample of 25 mW, the estimate of ΔT according to Ref. 15 gives the insignificant value ~0.03 K. Actually, however, the amount of heating can be somewhat greater.

Furthermore, Eq. (18) is applicable [see the transition from (16) to (17)] at $t_i\ll t_0/2\approx 160$ μsec. At long durations of the pulses it is necessary to take $e^{i\Omega t}$ into account in (16). This should manifest itself in a decrease in the effectiveness of the detecting system.

3) Figure 7 shows the temperature dependence of the absorption K measured by us and plotted at $I=5$ W/cm^2, $t_i=30$ μsec. In the temperature range $T<2$ K, the signal K is almost constant and then falls off rapidly to zero. Such a behavior of $K(T)$ agrees well with the theoretically predicted model. It follows from (18) and (5) that in the given case the absorption signal

$$K\propto V\propto\frac{\omega^2}{\omega^2+\gamma^2(T)}.$$

The coefficient of viscous friction of the drops relative to the lattice γ increases with increase in the temperature[5]: $\gamma\sim T^5$. Therefore, at low temperatures, when $\gamma\ll\omega$, the quantity $V\sim$ const and does not depend on the temperature, while at $\gamma\gtrsim\omega$ the quantity $V\sim T^{-10}$, i.e., falls off rapidly.

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[1)]In a cubic semiconductor with nondegenerate bands.
[2)]We of course assume that the length of the ultrasonic pulse is sufficiently great: $t_i \gg t_f$.

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Phase diagram of a uniaxial antiferromagnet

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The approximation of molecular-field theory is used to investigate the temperature dependence of the transition field and of the boundaries of the region of metastable states in an easy-axis antiferromagnet for a phase transition in which the magnetic moments of the sublattices turn over (a "spin-flop" transition). It is shown that at high temperatures a spin-flop transition always occurs as a first-order phase transition.

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For orientational phase transitions induced by an external magnetic field and of the type in which the magnetic moments of the sublattices turn over ["spin-flop" (SF) transitions], in easy-axis antiferromagnets, a characteristic property is the presence of various types of phase transitions and of critical points. This fact makes an antiferromagnet a convenient object for study of critical phenomena and of phase transitions. Furthermore, a magnetic field is an easily controlled means of acting on the object of investigation, and this considerably simplifies the experimental technique; on the other hand, the external magnetic field enters in a simple manner in the equation of state, and this substantially facilitates theoretical investigations. All of this explains the large number of experimental and theoretical papers devoted to the study of the SF transition in an antiferromagnet.[1-8 1)]

A detailed theoretical investigation of the nature of phase transitions in easy-axis antiferromagnets at $T=0$ was carried out in Refs. 2 and 6. For temperatures different from zero, the theoretical investigations have been limited either to the low-temperature range ($T \ll T_N$, where T_N is the Néel temperature)[3] or to temperatures close to the triple-point temperature T_t.[4]

In the present paper, the approximation of molecular-field theory is used to study the temperature variation of the SF transition field H_{tr} and of the boundaries of the region of metastable states, in the case in which the magnetic field is directed along the easy axis. In Ref. 2 it was shown that at $T=0$, depending on the character of the anisotropy, the SF transition occurs either as two phase transitions of the second kind or as a phase transition of the first kind. Calculations made in the present paper show that at finite temperatures, the transition field and the instability fields of the individual phases depend little on the anisotropy and are primarily determined by the values of the exchange constants. At high temperatures, the transition from the antiferromagnetic (AF) state to the SF phase always

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