increasing the Ce^{3+} concentration in $CaWO_4$ it is possible to satisfy the condition $L_{21} \gg L_{sL}^{(2)}$ for this object.

A transition from the case $L_{21} > L_{sL}^{(2)}$ to the case $L_{21} < L_{sL}^{(2)}$ is possible also for a single object by changing its temperature.

4. CONCLUSION

As we have shown in Sec. 2, allowance for the satellite of the $J(\omega)$ curve at the frequency $\omega = 0$ leads to a Lorentzian dependence of the probability W_2 on H_0 for sufficiently strong fields H_0, regardless of the shape of the absorption curve. The analysis at the end of Sec. 2 shows that this result does not contradict the available experimental data. It seems of interest to measure the rate of establishment of a single-temperature in the spin system under conditions when the results of Sec. 2 are significant, that is, at values of H_0 exceeding H_{1oc} by several times. In Sec. 3, using the results of Sec. 2, equations were obtained describing the magnetic resonant absorption of energy of an alternating field, and an explanation was presented of the difficulties that arise in the observation, in ESR, of effects connected with the existence of two spin temperatures. It would be of interest to perform experiments aimed at determining the role of the DDP in magnetic resonance under conditions of the transition from the case $L_{21} < L_{sL}^{(2)}$ to the case $L_{21} > L_{sL}^{(2)}$. From the theoretical point of view, it may be useful to study the $J(\omega)$ curve near $\omega = 0$ in order to determine the coefficient L_{21} more accurately.

The author is grateful to Professor B. I. Kochelaev for useful advice and for a discussion of the results.

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Instabilities and characteristics of galvanomagnetic effects in inhomogeneous films subjected to crossed fields

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A theoretical analysis is made of galvanomagnetic effects in thin semiconducting films with inhomogeneous distributions of the carrier density and mobility across the film thickness, subjected to crossed **E** and **H** fields parallel to the film surface. It is shown theoretically that the galvanomagnetic coefficients of inhomogeneous films are greatly affected by reversal of the sign of $\mathbf{E}\times\mathbf{H}$. This nonreciprocity of the coefficients is due to a redistribution of carriers across the film thickness by the Lorentz force. The results are given of an experimental investigation of galvanomagnetic properties of pure two-layer epitaxial films of *n*-type GaAs in the temperature range 4.2–300°K. The predicted nonreciprocity of the galvanomagnetic coefficients is observed and a current instability, nonreciprocal in respect of the direction of the Lorentz force, is found. This instability is observed in fields much lower than the Gunn fields in the absence of a falling region in the current-voltage characteristic but in the presence of a falling region in the current-magnetic field characteristic.

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1. A Hall field, which cancels the Lorentz force acting on free carriers, appears in semiconducting films subjected to crossed electric and magnetic fields parallel to the film surface. The source of the Hall field are free carriers deflected by the Lorentz force to one of the surfaces of the film. In the case of thick films with high electron or hole densities, only a slight redistribution of charged particles is needed to cancel the Lorentz force by the Hall field. In pure and thin films subjected to strong **E** and **H** fields parallel to the film surface a strong redistribution of carriers across the thickness is needed to create the necessary Hall field and, therefore, it is interesting to determine how this redistribution affects the galvanomagnetic properties of semiconducting films.

We must bear in mind that the Hall field, which appears in a film because of a redistribution of impurities, is limited because it cannot exceed E_{max} obtained when all free carriers are concentrated on one of the surfaces of the film.[1)] Therefore, in thin semiconducting films with a low carrier density but a high mobility the Lorentz force may exceed eE_{max}. The distribution of the carrier density across the film thickness is then governed primarily by the diffusion of carriers into the bulk of the film from that face on which carriers are concentrated by the Lorentz force.

A strong redistribution of carriers across a thin semiconducting film is easy to achieve experimentally. For example, in the case of a pure epitaxial n-type GaAs film, $d \sim 1\ \mu$ thick, with a carrier density $n \sim 10^{13}$ cm^{-3} and a mobility $\mu \sim 10^5\ cm^2 \cdot V^{-1} \cdot sec^{-1}$ at $T = 77\ ^\circ K$ the maximum Hall field is $E_{max} \sim 150$ V/cm. Therefore, when such a film is subjected to a magnetic field $H \sim 10$ kOe ($\mu H/c = 10$, where c is the velocity of light), carriers are concentrated on one surface already in a field $E \sim 15$ V/cm and a drift velocity of carriers v_d is of the order of 1.5×10^6 cm/sec.

The effects associated with the redistribution of charge are manifested most strongly in semiconducting films in which the free-carrier mobility and density vary across the thickness. In this case the film behavior is nonreciprocal: the properties of the system change when the sign of the magnetic field is reversed.[1] In fact, when carriers become concentrated at one of the surfaces of an inhomogeneous film, the electrical properties of this film are governed by the mobility of free carriers near this surface. Reversal of the magnetic field (without a change in the direction of the longitudinal electric field) results in reversal of the Lorentz force, so that carriers become concentrated on the opposite surface of the film with a different mobility. Thus, the response of the system changes considerably when **H** becomes **−H**, which makes it easier to observe the effects associated with carrier redistribution.

We shall use the hydrodynamic approximation in an analysis of some nonreciprocal effects in inhomogeneous semiconducting films subjected to strong crossed electric and magnetic fields parallel to the film surface. This analysis will be based on the solution of a model problem on the assumption that the temperature of the free-carrier gas is constant and equal to the lattice temperature,[2)] and attention will be concentrated on the structure of the redistribution of the carrier density across the film and the influence of this redistribution on the current-voltage and current-magnetic field characteristics of films in strong fields. The results will be given of an experimental investigation of both types of characteristic of inhomogeneous epitaxial n-type GaAs films, temperature range of the nonreciprocity of these characteristics, and current instability in crossed **E** and **H** fields.

2. We shall use the hydrodynamic approximation to describe the redistribution of carriers by the Lorentz force in thin semiconducting films. The orientation of the fields relative to the sample is selected in the same way as in the Hall geometry: one surface of the film lies in the $x = 0$ plane and the other in $x = d$, the magnetic field **H** is directed along the y axis, and the electric field **E** has two components, one of which is the Hall field E_x and the other is the longitudinal field E_z. All the quantities are assumed to depend only on x and the fields **H** and **E** are assumed to be homogeneous. The initial equations are

$$\partial\varepsilon/\partial\xi = \eta - \eta_0, \tag{1}$$

$$\partial\eta/\partial\xi = \varkappa^{-1}\eta(\varepsilon - \mu\beta\zeta), \tag{2}$$

$$J(\xi) = \zeta \int_0^\xi \eta\mu\, d\xi, \tag{3}$$

and the boundary conditions are

$$\varepsilon(0) = \varepsilon(1) = 0. \tag{4}$$

In these equations the variables are normalized to the following characteristic quantities: the plasma frequency $\omega_0 = (4\pi q^2 \bar{n}_0/\varepsilon_0 m^*)^{1/2}$; the maximum carrier density $\bar{n}_0$; the characteristic Hall field $E_0 = 4\pi q \bar{n}_0 d/\varepsilon_0$; moreover, the following dimensionless variables are introduced: $\xi = x/d$, $\eta = n/\bar{n}_0$, $\eta_0 = n_0(x)/\bar{n}_0$, $\varepsilon = E_x/E_0$, $\zeta = E_z/E_0$, $\beta = \omega_B/\omega_0$, $\mu = \omega_0/\nu(x)$, $J(\xi) = I/I_0$, $\varkappa = kT/qE_0 d$. Here, n is the free carrier density; $n_0 = n_0(x)$ is the concentration of ionized impurities; $\bar{n}_0$ is the maximum value of n_0; $\nu = \nu(x)$ is the collision frequency; $\omega_B = qB/m^*c$ is the cyclotron frequency with the property $\omega_B(-B) = -\omega_B(B)$; q is the carrier charge; E is the electric field; T is the temperature of the free-carrier gas; k is the Boltzmann constant; $I(x)$ is the current in a layer of the film extending from 0 to x; $I(d)$ is the total current; L is the film dimension along the y axis; d is the film thickness ($L \gg d$ because we are assuming that the film is infinite along the y and z axes).

We shall now consider small deviations of the free-carrier density from an equilibrium distribution, i.e., we shall discuss the case of weak fields. Then, Eqs. (1)–(3) can be solved by perturbation theory in an approximation which is linear in respect of $\mu\beta\zeta$ if we assume that $\eta_0(\xi) = \text{const}$:

$$\eta = \eta_0 + \beta\zeta\Phi(\xi), \tag{5}$$

$$\varepsilon = \beta\zeta\psi(\xi), \tag{6}$$

$$J(1) = \zeta \int_0^1 \eta_0\mu(\xi)\, d\xi + \beta\zeta^2 \int_0^1 \mu(\xi)\Phi(\xi)\, d\xi, \tag{7}$$

where

$$\psi(\xi) = C\,\mathrm{sh}(\delta\xi) + \delta\int_0^\xi \mu(\tau)\,\mathrm{sh}[\delta(\tau - \xi)]\,d\tau,$$

$$\Phi(\xi) = C\,\mathrm{ch}(\delta\xi) - \delta^2\int_0^\xi \mu(\tau)\,\mathrm{ch}[\delta(\tau - \xi)]\,d\tau,$$

$$C = -\delta\,\mathrm{sh}^{-1}(\delta)\int_0^1 \mu(\tau)\,\mathrm{sh}[\delta(\tau - 1)]\,d\tau; \quad \delta = (\eta_0/\varkappa)^{1/2}.$$

Equation (7), which is the current-voltage characteristic, illustrates clearly the nonreciprocal properties of the system in weak fields. In fact, the first term in Eq. (7) gives rise to a current flowing in a film in the absence of Lorentz force and the second term (which is

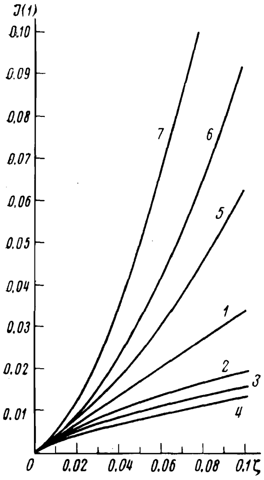

FIG. 1. Current-voltage characteristics calculated for different values of the magnetic field: 1) $\beta=0$; 2) $\beta=1$; 3) $\beta=2$; 4) $\beta=4.35$; 5) $\beta=-1$; 6) $\beta=-2$; 7) $\beta=-4.35$.

of the first order of smallness in respect of $\mu\beta\zeta$) causes splitting of the current-voltage characteristics when **H** is reversed to $-$**H**. It is clear from the function $\Phi(\xi)$ that as we move away from the surface of a sample the carrier density reaches an equilibrium value at a distance $\xi_D=(\varkappa/\eta_0)^{1/2}$, i.e., at the Debye radius.

We shall now consider the other limiting case of strong fields and a strong deviation of the carrier density from the equilibrium distribution ($\mu\beta\zeta\gg1$). Since the Hall field has an upper limit of E_{max} and the Lorentz force rises with the electric and magnetic fields, it is clear that a situation may arise when the Lorentz force is much greater than qE_{max}, so that Eqs. (1)–(3) can be simplified by dropping the Hall field ε compared with $\mu\beta\zeta$. Then, the system (1)–(3) is readily solved and the distributions of the carrier density and current in a film are described

$$\eta=C_2\exp\left(-\varkappa^{-1}\beta\zeta K(\xi)\right), \tag{8}$$

$$K(\xi)=\int_0^\xi \mu(\tau)\,d\tau,\quad C_2=\int_0^1 \eta_0(\xi)\,d\xi\Big/\int_0^1 \exp(-\varkappa^{-1}\beta\zeta K(\xi))\,d\xi, \tag{9}$$

$$J(1)=\zeta C_2\int_0^1 \mu(\xi)\exp(-\varkappa^{-1}\beta\zeta K(\xi))\,d\xi. \tag{10}$$

It follows from Eq. (10) that in the case of an asymmetric distribution of the mobility across the film thickness the current is nonreciprocal. If $\beta\zeta>0$, carriers are concentrated mainly near the film surface $\xi=0$ and the current is governed by the mobility μ near this surface. If $\beta\zeta<0$, carriers are concentrated at the surface $\xi=1$ and the current is governed by the value of μ near this surface. In the case of an asymmetric distribution of μ across the film thickness, the values of μ are different on the opposite surfaces and the current changes as a result of reversal of the sign of the magnetic field. It should be noted that if $\mu\beta\zeta\gg1$, the fall of the carrier density occurs at a distance $\xi_c=\varkappa/\mu\beta\zeta$ and the condition $\xi_c<\xi_D$ may be satisfied, i.e., carriers may be concentrated in a surface layer whose dimensions are less than the Debye radius. This concentration of carriers near the surface of a film allows us to introduce, in accordance with Eq. (8), the "potential"

$$\varphi_L(x)=E_z\int_0^x \omega_H/\nu(x)\,dx,$$

which is due to the Lorentz force. Since this approximation is valid only in strong electric and magnetic fields, the condition $\mu\beta\zeta\gg1$ may be realized experimentally only in very thin semiconducting films with low carrier densities but with high mobilities. A strong redistribution of carriers can be produced in thin films by relatively weak fields, which do not cause significant heating or breakdown.

In the intermediate case of $\mu\beta\zeta\sim1$ the analytic solution of the system (1)–(3) was quite difficult to find so that these equations were solved numerically on a computer. The following parameters were used in such calculations: $\varkappa=0.005$, $\eta_{0e}=1$, $\eta_{0r}=0.1$, $\mu_e=2.3\times10^{-1}$, $\mu_r=2.3$. The values of η_0 and μ were assumed to vary stepwise with ξ. Here, η_{0e}, η_{0r}, μ_r, and μ_e were the values of the functions η_0 and μ, respectively, in the intervals $\xi\in(0;\,0.4)$ and $\xi\in(0.6-1)$; inside the interval $\xi\in(0.4-0.6)$ the step in the functions η_0 and μ was smoothed out by a third-degree polynomial. The results of this numerical integration are presented in Figs. 1 and 2. Figure 1 gives the current-voltage characteristics for the following values of the magnetic field: $\beta=0$, $\beta=\pm1$, $\beta=\pm2$, and $\beta=\pm4.35$; Fig. 2 gives the current-magnetic field characteristics for three values of the electric field: $\zeta=0.1$, $\zeta=0.05$, and $\zeta=0.025$. We can see that the current-voltage characteristics change in shape when the magnetic field is reversed and they diverge in different directions from the curve corresponding to zero magnetic field. It follows from the current-magnetic field characteristics that the sign of magnetoresistance depends on the direction of the magnetic field. Reversal of this sign as a result of reversal of the magnetic field direction is due to a redistribution of carriers by the Lorentz force

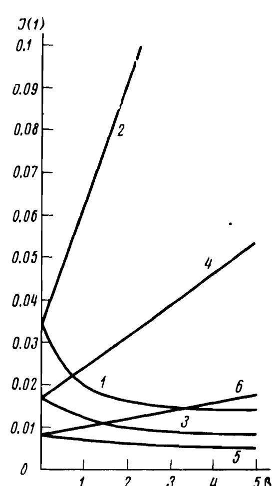

FIG. 2. Current-magnetic field characteristics calculated for different values of the longitudinal field: 1) $\zeta=0.1$, $\beta>0$; 2) $\zeta=0.1$, $\beta<0$; 3) $\zeta=0.05$, $\beta>0$; 4) $\zeta=0.05$, $\beta<0$; 5) $\zeta=0.025$, $\beta>0$; 6) $\zeta=0.025$, $\beta<0$.

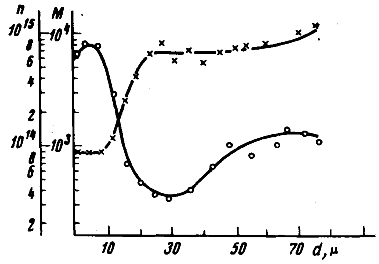

FIG. 3. Distributions of the carrier mobility and density across the thickness of an n-type GaAs film ($T = 300\,°K$): o) mobility; ×) density.

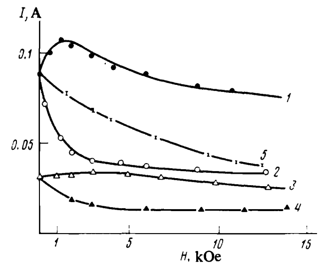

FIG. 5. Current-magnetic field characteristics ($T = 300\,°K$): 1) $E = 1320$ V/cm, H_+; 2) E = 1320 V/cm, H_-; 3) $E = 520$ V/cm, H_+; 4) E = 520 V/cm, H_-; 5) $E = 1320$ V/cm, magnetic field $H_\pm$ perpendicular to the surface of the film.

and is a purely nonlinear effect, i.e., if we adopt the approximation linear in respect of electric field, magnetoresistance vanishes (in the model considered here).

The computer results show that the "complete" concentration of carriers in one region of a film occurs for $\beta\xi \approx 0.43$, if carriers are driven by the Lorentz force to a region with a higher mobility, and for $\beta\xi \approx -0.13$, if carriers are driven to a region with a lower mobility.

3. It follows from the above results that the effects associated with a redistribution of carriers by the Lorentz force are strongest in thin semiconductor structures with a high mobility and a low carrier density. Therefore, our experiments were carried out on relatively pure n-type GaAs films (deposited on semi-insulating GaAs substrates), whose parameters at 300 °K (in the case of inhomogeneous films these were the integrated densities and mobilities) were within the range $n \sim 8\times10^{13}-4\times10^{14}$ cm^{-3} and $\mu \sim (8.3-7)\times10^3$ cm$^2\cdot$V$^{-1}\cdot$sec^{-1}. The homogeneity of the films was checked qualitatively by the decoration method. [2] The distributions of the carrier density and mobility across the film thickness were determined quantitatively in a weak field using layer-by-layer etching method (Fig. 3).

The role of contacts and the state of the surfaces of a film in the effects observed in two-layer film systems were determined in control experiments carried out on one-layer films[3)] and films with a thin transition layer between the film and the substrate. The investigations were carried out in the temperature range from 300 to 4.2 °K. The current-voltage and current-magnetic field characteristics, shown in Figs. 4 and 5, were recorded under pulse conditions. Here, we used H_+ and H_- to denote the magnetic fields in which carriers were deflected toward the surface of the epitaxial film (+) and toward the substrate (−). The characteristics of the two-layer films demonstrated clearly the nonreciprocity of their galvanomagnetic properties. It should be noted immediately that in the case of one-layer films (with the same contacts as the two-layer systems) and in films with a thin transition layer there were no singularities in the current-voltage or current-magnetic field characteristics when **H** was reversed to $-\mathbf{H}$ (or **E** to $-\mathbf{E}$). It was interesting to note that in the $\mathbf{E}\perp\mathbf{H}$ configuration for the same OP-29-17 film (designation given by OKhMZ of the State Scientific-Research and Design Institute of the Rare-Metal Industry, Moscow) but subject to the condition that **H** crossed the plane of the film, there were no reciprocal effects of any kind (curve 5 in Fig. 4). The nonreciprocity of the characteristics of two-layer n-type GaAs films could readily be explained by a redistribution of carriers by the strong fields. The initial rise of the conductance (negative magnetoresistance) of the two-layer film and of the current passing through it (region I) with increasing magnetic field H (Fig. 4) were due to the displacement of carriers by the Lorentz force from a region with a lower mobility (region II) to a region of higher mobility (region III). In stronger magnetic fields the usual magnetoresistance predominated and the current as well as the conductance of the film decreased with rising H_+. In a field H_- carriers were driven from Region III to region II, where the mobility was lower and, therefore, such a redistribution of carriers—like the magnetoresistance effects—increased the resistance of the sample.

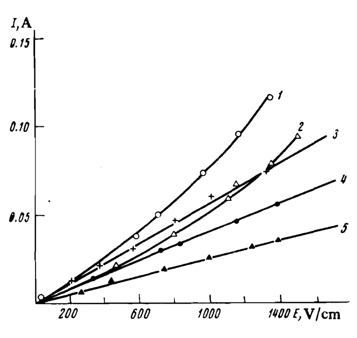

FIG. 4. Current-voltage characteristics ($T = 300\,°K$): 1) $H_+ = 1.2$ kOe; 2) $H_+ = 12.7$ kOe; 3) $H = 0$; 4) $H_- = 1.2$ kOe; 5) $H_- = 12.7$ kOe.

A considerable redistribution of carriers across the film thickness in crossed **E** and **H** fields was indicated also by the current-voltage characteristics of the investigated sample recorded in fixed magnetic fields. In a field H_- the dependence of the current on the electric field was linear in the range 50–1500 V/cm (curves 4 and 5 in Fig. 5), exactly as in the $H = 0$ case (curve 3). This meant that the majority of electrons was driven from region III by the Lorentz force (this force reduced the barrier field of the n-n^+ junction) to region II, and this happened in relatively weak electric fields ($E \sim 50$ V/cm). In this case the slope of the cur-

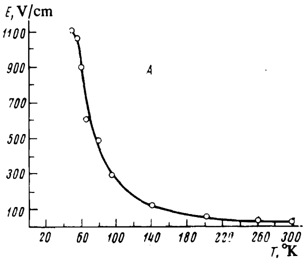

FIG. 6. Dependence of the "threshold" electric field on the lattice temperature, identifying the region A where the nonreciprocal effects were observed.

rent-voltage characteristic was governed mainly by the magneto-resistance of region II, whereas the carrier density in region II, n_{II}, was much higher than n_{III}. In the field H_+ the current-voltage characteristic of an inhomogeneous film was nonlinear (curves 1 and 2 in Fig. 5). The displacement of a small number of carriers from region II (for $n_{II} \gg n_{III}$) to region III could increase severalfold the average carrier density in this part of the film and, consequently, could reduce considerably the resistance of the sample because the mobilities were governed by $\mu_{III} \gg \mu_{II}$. In strong electric fields and in a field H_+ the redistribution of carriers predominated over the magnetoresistance effect. In particular, in the case of the OP-29-27 film in $H_+ = 1.2$ kOe this was observed for $E \sim 100$–150 V/cm (curve 1 in Fig. 1) and in $H_+ = 12.7$ kOe it was observed for $E \sim 1300$ V/cm (curve 2 in Fig. 5).

The current-magnetic field and current-voltage characteristics of an inhomogeneous n-type GaAs film, shown in Figs. 4 and 5, were recorded at 300 °K. The main qualitative features of these characteristics and the changes due to the replacement of **H** with $-$**H** or **E** with $-$**E** (nonreciprocity when the sign of the Lorentz force was reversed) were retained when the film was cooled right down to 50 °K.[4)] However, when temperature was lowered (keeping the field H constant), there was a rise in the electric field at which the nonreciprocity was first observed. (Naturally, this "threshold" field was to some extent an arbitrary criterion because it depended on the sensitivity of the apparatus used to measure the current.) The plane of the parameters E and T was used (Fig. 6) to identify the region in which the nonreciprocity of the OP-29-17 film was observed in a magnetic field 1.5 kOe using apparatus of fixed sensitivity.

An instability of a kind not described before (to the best of our knowledge) was observed when inhomogeneous epitaxial films of n-type GaAs were subjected to crossed electric and magnetic fields. Oscillations of the current were observed in relatively weak (much lower than the Gunn value) electric fields (the field along the sample was measured and found to be constant) and only when the Lorentz force deflected carriers to the surface of the epitaxial film, i.e., to the region with higher mobility. The oscillations disappeared when the magnetic (or electric) field was reversed. The threshold field of these oscillations corresponded to the maximum in the current-magnetic field characteristic, i.e., the oscillations were observed for $dI/dH \leq 0$ but in the absence of a falling region in the static current-voltage characteristic.[5)] In particular, in the OP-29-17 film at 300 °K the oscillations appeared in $E \sim 0.5$ kV/cm and $H \sim 0.5$ kOe and in $E \sim 1.3$ kV/cm and $H \sim 1$ kOe. The oscillation frequency in fields $E \sim 900$ V/cm, $H \sim 3.5$ kOe was about 4 MHz; this frequency increased with the magnetic field rising by an order of magnitude in $H = 13$ kOe. Typical oscillograms of this current instability were reported in[1].

Low-frequency nonreciprocal oscillations of the current in inhomogeneous n-type GaAs films were observed also at low temperatures. The temperature range of their existence was the same as that of the nonreciprocity of the current-voltage and current-magnetic field characteristics. It should be noted that when temperature was lowered, the frequency of the oscillations decreased and they became less regular. At low temperatures the instability threshold field was still governed by the condition $dI/dH = 0$.

4. A distinguishing feature of all the effects observed in two-layer epitaxial n-type GaAs films in the presence of strong crossed **E** and **H** fields was their nonreciprocity with respect to the Lorentz force direction. The asymmetry in the distribution of the electrical properties across the thickness of the film was strongly reflected in the high-field galvanomagnetic effects. Clearly, this could be used as the basis for a method of investigating the distributions of various parameters across the thickness of a semiconducting film without destroying it. It would be interesting to study films with a known distribution of their parameters also from the standpoint of potential high-current high-frequency semiconductor devices. Although the nature of the current instability in two-layer films subjected to crossed **E** and **H** fields cannot be regarded as finally established, we can say that it is related to a redistribution of carriers producing inhomogeneous mobility and density distributions.

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1)This is valid if there is no additional ionization by strong fields.

2)Heating of carriers in a strong electric field will be ignored. This makes it possible to reveal more simply and clearly the relationship between nonreciprocal properties of inhomogeneous semiconducting films and the spatial redistribution of carriers.

3)One-layer films were prepared by etching away the substrate and the inner layer of the film; planar contacts to the outer layer were retained, i.e., they were the same as in the two-layer case.

4)The investigated inhomogeneous films of n-type GaAs included samples in which the difference between the characteristics due to the replacement of H with $-$H disappeared at about 70 °K.

5)A current instability in crossed E and H fields was observed in[3] in an n-type Ge plate, one of whose surfaces was sandblasted. The instability was again observed only for one polarity of the magnetic field but, in contrast to our case, it was associated with a falling region in the current-voltage characteristic.

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A phenomenological theory of the liquid-to-crystal phase transition in He^3

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A theory of the liquid-to-crystal transition in He^3 is proposed on the basis of the assumption that this transition is nearly of second order. In the theory are derived the well-known unusual properties of solid He^3: the formation of a non-closepacked structure and the increase in the compressibility as compared to the compressibility of the liquid. The theory yields a number of dependences that can be experimentally verified.

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1. FORMULATION OF THE PROBLEM

The theory of the liquid-to-crystal phase transition in helium is based on a variational approach: trial wave functions of the liquid and the crystal are given and the variational parameters are determined by a computer calculation.[1] The accuracy of such a method does not turn out to be high enough for preference to be given to any of the structures: face-centered cubic (fcc), hexagonal close-packed, or body-centered cubic (bcc). Therefore, one of the unusual properties of He^3 that distinguishes this substance from the other inert elements–the formation of a non-close-packed (bcc) structure–is not explained.

In the present paper we propound for the liquid-to-crystal phase transition in He^3 a phenomenological theory based on the assumption that this is a nearly second-order phase transition. Then we can, in the spirit of the well-known Landau idea, use the expansion of the thermodynamic potential in powers of a small parameter, which, in the present case, is the deviation of the density from a constant.

Let us give the reason for such a description. Liquid He^3 is extremely sensitive to pressure changes. Let us consider the function $f(\mathbf{k}, \sigma; \mathbf{k}', \sigma')$, which was introduced by Landau in the theory of the Fermi liquid,[2] or, more precisely, the dimensionless quantity $2\nu f = F + (\sigma\cdot\sigma')Z$, where $\nu = m^* k_F/2\pi^2$ is the density of states per spin at the Fermi surface. It turns out (see the review article[3]) that the mean—with respect to the angles—quantity $\langle F\rangle$ undergoes the most rapid variation: There is almost a threefold change in its value (from 31.7 to 94.1) in the interval of pressures from 9 to 34.36 bar (the melting curve), whereas the density increases by only 20% in the same pressure range. This can be ascribed to that part of the interaction between the He^3 atoms that approximates the interaction between hard spheres.[4] On the other hand, the presence of the hard cores of the atoms is the principal cause of the solidification of He^3 (in the opposite case the Fermi liquid would approach the ideal Fermi gas as the pressure increased, and solidification would not occur). Thus, the large values and the rapid variation of the quantity $\langle F\rangle$ apparently indicate that liquid He^3 has, as it were, a "premonition" of crystallization. In other words, the curve of absolute instability of the liquid with respect to crystallization (the spinodal) is located near the melting curve (the binodal).

Since the above-given reason is connected with the properties of the Fermi liquid, the proposed description can be valid at sufficiently low temperatures.

Let us note at once that we obtain, as a result, an explanation for the following unusual properties of solid He^3: the formation of a non-close-packed (bcc) structure and the increase in the compressibility as compared to the compressibility of the liquid, which is an additional argument in favor of the theory.

In the present paper it is convenient to take as the independent thermodynamic variables the pressure and temperature, i.e., to carry out an expansion of the chemical potential μ. The small parameter is the deviation of the density from a constant. The expansion of μ has the form: