cross on Fig. 2 denotes the limit of the spectrum. Here the elementary-excitation attenuation due to the possibility of emitting a photon becomes too large ($|\epsilon''| \sim \epsilon'$).

The foregoing singularities of the spectra can occur if the uncertainty of the wave vector, connected with the finite size of the crystal, is smaller than the wave vector $k \sim E_\mu/\hbar c$, in the vicinity of which the retardation is significant. It follows therefore that the retardation effects can take place if the dimensions of the crystals exceed the wavelength $\lambda = hc/E_\mu$. The excitons should have in such crystals a lifetime $\sim 10^{-13} - 10^{-15}$ sec, which can be discerned from the luminescence damping time, from the absorption and emission line shapes, etc. There should be practically no Stokes shift of the lines in such systems.

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CONTRIBUTION TO THE QUANTUM THEORY OF ELECTRIC CONDUCTIVITY OF SEMICONDUCTORS WITH NON-STANDARD BAND

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We generalize here the theory developed by Adams and Holstein [1] to include the case of an isotropic but nonstandard band (such as the conduction band of InSb, InAs, etc.), and discuss the influence of the spin splitting of the Landau levels on the oscillations of the transverse magnetoresistance in n-InSb. The dispersion law for such semiconductors was obtained by Kane [2], and also by Bowers and Yafet [3] for the case when a magnetic field is present.

To solve the equation of motion for the density matrix by the method of Adams and Holstein [1], we have determined the electron spectrum in crossed electric and magnetic fields

with allowance for the interaction between the conduction band and the valence bands, and have found that in the linear approximation the electric field $\vec{E}$ enters the spectrum in this case in the form eER^2k_y, where $\vec{k}$ is the electron wave vector and $R = (\hbar c/eH)^{\frac{1}{2}}$. Leaving out all the intermediate steps, we present here only the final results of the calculation: The off-diagonal component of the electric conductivity tensor σ_{yx}, as in the case of the standard band, is determined by the conduction electron density n; the nonstandard effect enters the diagonal component σ_{xx} only through the law of energy conservation in the scattering process [1]. We shall show that this difference leads to significant qualitative results.

Let us consider the Shubnikov - de Haas oscillations for a nonstandard band. Carrying out the necessary integrations with allowance for the conservation laws, we obtain the following expression for σ_{xx} in the case of degenerate semiconductors:

$$\sigma_{xx} = \sum_{NN'\sigma} \frac{A_{NN'\sigma}(\zeta_F)}{k_z(\zeta_F)k_z'(\zeta_F)}, \tag{1}$$

where $A_{NN'\sigma}(\zeta_F)$ contains all possible constants as well as a smooth function of the Fermi boundary ζ_F, and N is the Landau oscillator quantum number.

To investigate the singularities arising in σ_{xx} when $k_z(\zeta_F) = 0$ or $k_z'(\zeta_F) = 0$, it is necessary to start from a definite dispersion law. In our case the dispersion law is obtained from the equation

$$\epsilon(\epsilon + \epsilon_g)(\epsilon + \epsilon_g + \Delta) - P^2(\epsilon + \epsilon_g + \tfrac{2}{3}\Delta)[(2N + 1)R^{-2} + k_z^2] \mp P^2\frac{\Delta}{3R^2} = 0. \tag{2}$$

Here ϵ_g is the width of the forbidden gap, Δ the spin-orbit splitting of the valence bands, and P the matrix element of dipole transition between the valence and conduction bands. The latter is connected with the effective mass m_0^* at the bottom of the conduction band by the relation

$$P^2 = \frac{\hbar^2}{2m_0^*}\frac{\epsilon_g(\epsilon_g + \Delta)}{(\epsilon_g + \frac{2}{3}\Delta)}. \tag{3}$$

As seen from (1) and (2), σ_{xx} becomes infinite if

$$B(\zeta_F) = (N + \tfrac{1}{2})\hbar\Omega + \sigma g^*(\zeta_F)\mu_B H, \tag{4}$$

where

$$B(\zeta_F) = \frac{\zeta_F(\zeta_F + \epsilon_g)(\zeta_F + \epsilon_g + \Delta)(\epsilon_g + \frac{2}{3}\Delta)}{(\zeta_F + \epsilon_g + \frac{2}{3}\Delta)(\epsilon_g + \Delta)\epsilon_g}, \tag{5}$$

$$g^*(\zeta_F) = -\frac{\frac{2}{3}\Delta}{(\zeta_F + \epsilon_g + \frac{2}{3}\Delta)}\frac{m_0}{m_0^*}, \tag{6}$$

$\Omega = eH/m_0^*c$, m_0 is the mass of the free electron, $\mu_B = \hbar e/2m_0c$ is the Bohr magneton, and $\sigma = \pm\frac{1}{2}$.

Substituting (4) in the expression for the density, we obtain an equation for the positions of the oscillation maxima of σ_{xx} or $(\Delta\rho/\rho)_\perp$:

$$n = \frac{(2m_0^*)^{3/2}\hbar\Omega}{4\pi^2\hbar^3}\sum_{N'\sigma'}[(N - N')\hbar\Omega + (\sigma - \sigma')g^*(\zeta_F)\mu_B H]^{1/2}. \tag{7}$$

We present here only the position of the possible zeroth maximum

$$H_0^- = \frac{\hbar c}{e}\left[\frac{4\pi^4 n^2}{|g^*(\zeta_F)|}\ \frac{m_0}{m_0^*}\right]^{1/3}. \tag{8}$$

The value of ζ_F which enters in this formula is determined from the condition (4) with allowance for (6)

$$(\zeta_F)_0^- = -\frac{\epsilon_g}{2}\left(1 - \sqrt{1 + \frac{2\hbar}{\epsilon_g}\ \frac{eH_0^-}{m_0^* c}\ \frac{(\epsilon_g + \Delta)}{(\epsilon_g + \frac{2}{3}\Delta)}}\right). \tag{9}$$

For other maxima, ζ_F is determined from a cubic equation.

From (8) we can determine the $g^*(\zeta_F)$-factor, knowing the effective mass of the electron at the bottom of the conduction band. Such an attempt was made by Amirkhanov and Bashirov [4] in an interpretation of the Shubnikov - de Haas oscillations in n-InSb. They used the formulas derived by L. Gurevich and A. L. Efros [5] for a standard band, modified to include formally the anomalous g-factor. The g-factor calculated from these formulas decreased rapidly with increasing density (a change in density by two orders of magnitude caused the g-factor to decrease by one-half). These results were compared by them with the values of the g-factor calculated theoretically by the Roth formula [6], and the agreement was seemingly good. However, this conclusion is in error, since Roth's formula contains the effective mass at the bottom of the conduction band and therefore cannot yield the variation of the g-factor with density.

A correct interpretation of the experimental data of [4] can be made on the basis of formula (8). Indeed, if we use the values [2] of H_0^- and the density from [4] and calculate $g^*(\zeta_F)$ from (8), we obtain values that decrease slowly with increasing density. These values coincide, even without allowance for temperature corrections, within the limits of experimental accuracy (7 - 10% for H, yielding ~20% for g*), with the values theoretically calculated from (6). The theoretical decrease in g* in the given density range is ~10%.

Formula (8) can be used also to determine H_0, knowing the value of the g*-factor. Since the g*-factor for the purer samples ($\rho_F \ll \epsilon_g + 2\Delta/3$) does not depend on the density, we can use here data on spin resonance in relatively pure samples [3].

We note also the following. As seen from (6) and (7), the effective mass does not enter at all in the formulas that determine the positions of the maxima of $(\Delta\rho/\rho)_\perp$. Therefore, from data on the zeroth maximum we can determine, for example, the value of the spin orbit splitting Δ, which has hitherto not been determined for InSb by a direct method.

Thus, the formulas obtained allow us to interpret the experimental data on the influence of spin on the Shubnikov - de Haas oscillations in semiconductors with nonstandard band.

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1) In addition, the electron-lattice interaction constant is renormalized.

2) Amirkhanov and Bashirov [4] indicate a position H_0^+, but in fact this should be H_0^-, since the g*-factor is negative.

3) The g*-factor determined from spin resonance can coincide with (6) only for pure samples.

ERRATUM

In the article by B. M. Askerov and F. M. Gashimzade, JETP Letters 3, No.9, transl. p. 228 (orig. p. 353), in the 13th line from the bottom, the text should read "Formula (8) can be used also to determine m_o^*" instead of "to determine H_o."