$$L = \ell_s \ln(1 + \gamma \frac{\ell_V}{\ell_N}) . \quad (6)$$

The rise in temperature along the thermal flux occurs at high phonon drift velocities and is a consequence of the nonlinearity of the gasdynamic equations for phonons [3]. In our case, however, such a behavior of the phonon gas follows already from the linearized equations (1), the validity of which can always be ensured by choosing not too large values of Q_0.

The described effect can apparently be observed experimentally only in solid helium, where Poiseuille flow of the phonon gas [4] and second sound [5, 6] have been observed. In solid He^4 at T = 0.6°K and 54 atm we have $\ell_N \simeq 0.01$ cm and $\ell_V \simeq 10$ cm [5]. For crystals with large cross sections, ℓ_s can be roughly approximated by extrapolating to the low-frequency range the data on the free path of thermal phonons, using the relation $\ell_s \sim \Omega^{-1}$ [1]. For $f = \Omega/2\pi$, which is readily attained in the experiment, this procedure yields $\ell_s \sim 1$ cm. In a thin crystal ℓ_s is smaller, owing to the diffuse scattering of the sound by the boundaries, which leads to a decrease of γ, too. As proposed earlier, when f = 300 MHz and T = 0.6°K we have $\Omega\tau_p \simeq 100 \gg 1$ and $\ell_N/\ell_s \simeq 0.01 \ll 1$ in solid He^4. Thus, under the indicated conditions and at $\gamma = 1$ we get $L \simeq 2.5$ cm. It is possible to observe the growth of the temperature along the flux either by plotting its distribution with the aid of pickups, or by using a sample of length $\lesssim L$ and comparing the values of the temperature on its ends.

By measuring L and ℓ_s in the experiment, it is easy to calculate $\gamma\ell_V$ with the aid of (6), and to obtain directly ℓ_V for a sample with characteristic transverse dimension $d > \ell_s$ ($\gamma \simeq 1$). This makes it possible to compare the values of ℓ_V determined by fundamentally different methods - that proposed above and that used in [5] - and is of independent interest.

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CYCLOTRON-PHONON ABSORPTION IN DEGENERATE SEMICONDUCTORS

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Free electrons placed in a strong magnetic field with $\omega_c\tau \gg 1$ (ω_c - cyclotron frequency, τ - relaxation time) absorb light only at frequencies ω in a narrow band of width $1/\tau$ near ω_c. If we take into account processes in which the absorption of a photon occurs simultaneously with the emission or absorption of a phonon, then absorption becomes possible at all frequencies ω. It was shown in [1] that when electrons interact with optical phonons (of frequency ω_0 without dispersion), there should be observed cyclotron-phonon resonance, i.e., peaks of absorption at frequencies $\omega = n\omega_c \pm \omega_0$, where n is an integer and the upper and lower signs refer to emission and absorption of a phonon. Such peaks (n = 1, 2, 3) with phonon emission were observed in n-InSb [2, 3, 4].

We wish to call attention in this paper to other features of absorption in which optical phonons take part; these features are connected with degeneracy of the electron gas, $\zeta >> kT$ (ζ - Fermi level) and with the quantizing properties of the magnetic field, $\hbar\omega_c >> kT$. It is also assmumed that $kT << \hbar\omega_0$, so that phonon-absorption processes proportional to $\exp[-\hbar\omega_0/kT]$ can be disregarded. We assume henceforth that T = 0. Then, in the case of absorption, the initial states of the electron lie in the region $\varepsilon_i < \zeta$, and the final ones, owing to the Pauli principle, in the region $\varepsilon_f > \zeta$. The change of electron energy upon absorption of a photon $h\omega$ and emission of a phonon $h\omega_0$ is $\varepsilon_f - \varepsilon_i = \hbar\Omega$, where $\Omega = \omega - \omega_0$. We therefore find that the only states participating in the transitions are those whose energy differs from ζ by not more than $\hbar\Omega$, namely

$$\zeta - \hbar\Omega < \epsilon_i < \zeta, \qquad \zeta < \epsilon_f < \zeta + \hbar\Omega. \tag{1}$$

This is illustrated by Fig. 1, which shows (for simplicity in the ultrquantum case) the Fermi distribution $f(\varepsilon)$, the density of states in the magnetic field $g(\varepsilon)$, and the energy intervals (1).

If we increase ω, then new Landau levels $\varepsilon_\ell = (\ell + 1/2)\hbar\omega_c$ will fall in the interval (1) at certain critical frequencies. The absorption coefficient $K(\omega)$ has singularities at these frequencies.

At the frequencies $\hbar\omega^*_{\ell'} = \varepsilon_{\ell'} - \zeta + h\omega_0$, a new level $\varepsilon_{\ell'}$ falls in the interval of allowed final states. Starting with the frequency $\omega^*_{\ell'}$, transitions become possible to a "new branch" of final states, and therefore $K(\omega)$ has a threshold singularity. When the frequency $\hbar\omega^{**}_\ell = \zeta - \varepsilon_\ell + \hbar\omega_0$ is approached, a very rapid increase takes place in the number of electrons at the level $\varepsilon_{\ell'}$ in the allowed interval of the initial states, and therefore $K(\omega)$ increases rapidly. However, when $\omega > \omega^{**}_\ell$, after the level ε_ℓ falls entirely in this interval, the rapid growth stops. Therefore $K(\omega)$ has an "inverted" threshold singularity. The behavior of $K(\omega)$ near the points is shown in Fig. 2. At these points, $dK/d\omega$ becomes infinite on one side of the singularity in accordance with the same law as $g(\varepsilon)$ near the Landau levels ε_ℓ, i.e., in proportion to the square root. The finite value of $dK/d\omega$ on the other side can be either positive (as in Fig. 2) or negative.

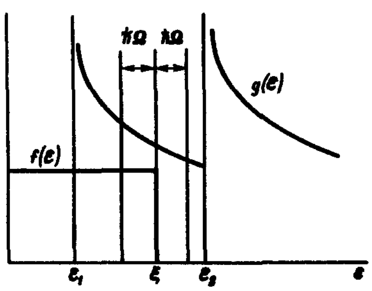

Fig. 1

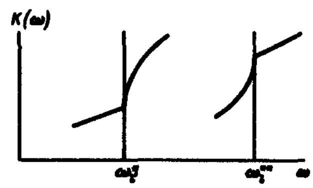

Fig. 2

To gain an idea of the order of magnitude of the quantities, let us consider n-InSb, assuming the band to be parabolic ($m = 0.013m_0$) and neglecting spin-splitting effects. At a density $n = 10^{17}$ cm^{-3} we have $\zeta(H = 0) = 700$ °K. A situation close to that shown in Fig. 1 is realized in a field H = 60 kOe, when $\zeta = 680$°K and $\omega_c = 0.8 \times 10^{14}$ sec^{-1} = 620 °K. Bearing in mind that $\omega_0 = 3.7 \times 10^{13}$ sec^{-1} = 280°K, we find the wavelengths corresponding to the critical frequencies, namely $\lambda_2^* = 27$ μ and $\lambda_1^{**} = 22$μ. Assuming that $\tau = 10^{-12}$ sec, we have a collision spreading of the Landau levels $\hbar/\tau = 10$°K, which is small compared with all the distances between the Landau levels and the Fermi level. The temperature spreading is also small at helium temperatures. The value of $K(\omega)$ can be estimated on the basis of the fact that experiment yields [2] $K = 0.1$ cm^{-1} for $n = 2 \times 10^{14}$ cm^{-3} at the principal peak of the cyclotron-phonon absorption, which is in good agreement with theory [5]. Therefore we can expect $K = 10$ cm^{-1} for $n = 10^{17}$ cm^{-3} away from the peak.

We note that the foregoing features of the absorption can occur also in transitions with spin flip [3, 6] and when intervalley phonons take part [7]. We point out also that they are related to the singularities in magnetoresistance [8].

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