Effect of the magnetic field on the electron-phonon relaxation time

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It is shown that the electron-phonon relaxation time in beryllium is $\sim T^{-3}$ or T^{-5} for different orientations of the magnetic field.

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The temperature dependence of the resistivity in metals at low temperatures must obey the Bloch-Grüeisen law $\rho \sim T^5$. Generally, deviations from this law are observed in some cases for different reasons. We had noted previously[1] that $\rho \sim T^{3.7}$ in beryllium samples in the temperature range up to ~ 80 K. Subsequent measurements of polycrystalline samples and single crystals gave a coefficient equal to 3.7 ± 0.2. Such a deviation from the Bloch-Grüneisen law can be explained qualitatively in this case by the fact that the efficiency of small-angle scattering of electrons by phonons near Bragg planes is significantly higher, and the Fermi surface of beryllium is realized entirely in narrow pockets along the edge of the second band (the Jones band). As is known, this results in the formation of closed electron surfaces (cigars) and a hole (corona) surface (see, for example, Ref. 2). Two types of transfer processes can be distinguished—band-to-band transfer process from the corona to the cigar and an intraband process between the cigars. The characteristic distances in momentum space for both processes are ~ 1–2% of the band size, i.e., ~ 20–30 K for typical phonon energies. Such transfers must be efficient within the indicated temperature range,

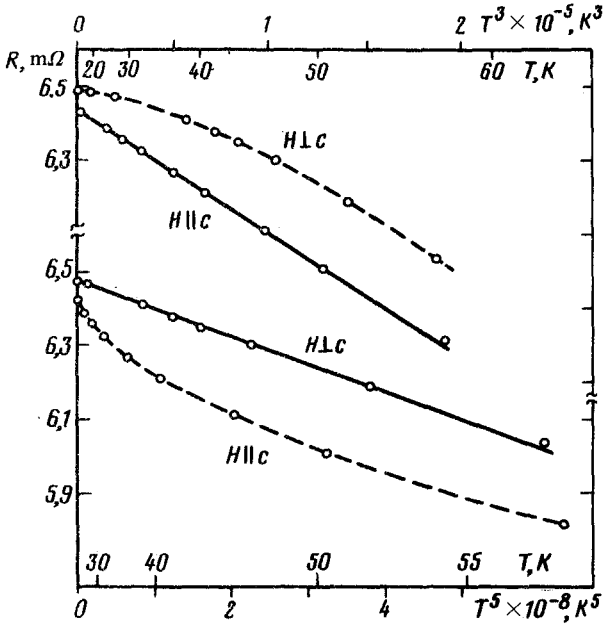

FIG. 1. Temperature dependence of the magnetic resistance of a beryllium samlpe ($\rho_{300}/\rho_0 = 76$ and $H = 39$ kOe) for different orientations of the magnetic field relative to the hexagonal C axis of the crystal. The upper curves are $H||C$ and $H \perp C$ (dashed curve) in the T^3 temperature scale. The lower curves are $H \perp C$ and $H||C$ (dashed curve) in the T^5 temperature scale.

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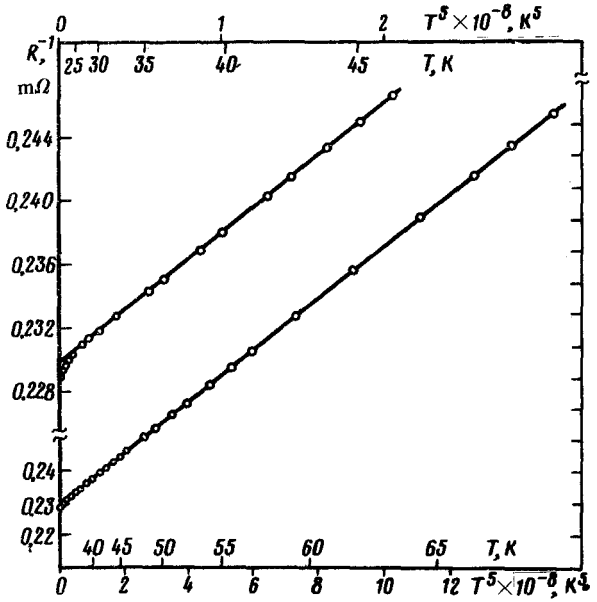

FIG. 2. Temperature dependence of the magnetic resistance of a beryllium sample ($\rho_{300}/\rho_0 = 440$ and $H = 40$ kOe) in the T^5 scale for $H \perp C$. The upper curve represents the initial part of the dependence in a magnified scale.

which results in the power of 3.7—intermediate between 3 and 5.

It was found (see Fig. 1) that any temperature dependence of the resistivity, or, more precisely, of the electron-phonon relaxation time τ, can be realized in a strong magnetic field: from $\tau^{-1} \sim T^3$ to $\tau^{-1} \sim T^5$. In other words, the small-angle scattering efficiency is completely determined by the direction of the magnetic field. Kaganov *et al.*[3] pointed out that if the conductivity is completely determined by a narrow layer of open trajectories, then each electron collision with a phonon will be efficient, and the law $\rho \sim T^3$ must apply. Essentially the same result was obtained in our experiments, but under different circumstances. Figure 1 shows the temperature dependences of the magnetic resistance $\rho_H(T)$ of a single-crystal beryllium sample ($\rho_{300}/\rho_0 = 76$) in the $H \| C$ and $H \perp C$ directions (C is the hexagonal axis of the crystal). In both cases, the current is perpendicular to the magnetic field and to the C axis. To facilitate comparison, the magnetic field is such that the initial magnetic resistance is the same in both directions ($H = 30$ kOe); the probability of magnetic breakdown for $H \| C$ is lower than the scattering probability, i.e., the magnetic resistance is an increasing function of the magnetic field.

As we can see in the graphs, $\rho_H(T)$ for $H \| C$ is linear in the T^3 scale, while for $H \perp C$ it is linear in the T^5 scale. *If it is assumed* in the general case that $\rho(H,T) = f[H,\rho(T)]$ ($f = f[H/\rho(T)]$ if the Koller rule is satisfied), then the measured variation of the magnetic resistance $\rho_H(T)$ will have the same temperature dependence as the electron-phonon relaxation time $\tau(T)$ as long as the phonon part of the resistance without the magnetic field $\Delta\rho(T)$ is small compared to the residual resistance ρ_0. In other words, we can expand $\rho_H(T)$ in a series and retain the first term: $\Delta f(T) = f'_\rho(0)\Delta\rho(T)$. The constant $f'_\rho(0)$ is negative. The obtained result, therefore, shows that $\tau^{-1} \sim T^3$ for $H \| C$ and $\tau^{-1} \sim T^5$ for $H \perp C$. These laws are satisfied exactly to at least $T \sim 50$ K. The measurement errors of the temperature and resistivity are

smaller than the points on the graphs; the magnetic field instability was less than 10^{-4} during the temperature variation. The observed deviations from a straight line at $T > 50$ K are attributable to the crude approximation, rather than to a deviation from the corresponding law. In fact, for the $H \perp C$ direction without a magnetic breakdown, we can assume that the transverse conductivity is $\sigma_H \sim D_\perp \sim \tau_{\text{eff}}^{-1}$, where $D_\perp$ is the diffusion coefficient in a transverse magnetic field and $\tau_{\text{eff}}^{-1} = \tau_0^{-1} + \tau^{-1}$, and $\sigma_H = \rho_H^{-1}$ for a compensated metal. Figure 2 shows such a temperature dependence of ρ_H^{-1} in the T^5 scale, which was obtained for a very pure beryllium sample ($\rho_{300}/\rho_0 = 440$). There is no deviation from a straight line up to $T \sim 70$ K to within a greater accuracy than that of the plot, i.e., the $\tau^{-1} \sim T^5$ law is apparently satisfied to higher temperatures.

[1]S. V. Varyukin and V. S. Egorov, Zh. Eksp. Teor. Fiz. **76**, 597 (1979) [Sov. Phys. JETP **49**, 299 (1979)].
[2]T. L. Loucks and P. H. Cutler, Phys. Rev. A **133**, 819 (1964).
[3]M. I. Kaganov, A. M. Kadigrobov, and A. A. Slutskin, Zh. Eksp. Teor. Fiz. **53**, 1135 (1967) [Sov. Phys. JETP **26**, 670 (1968)].

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