

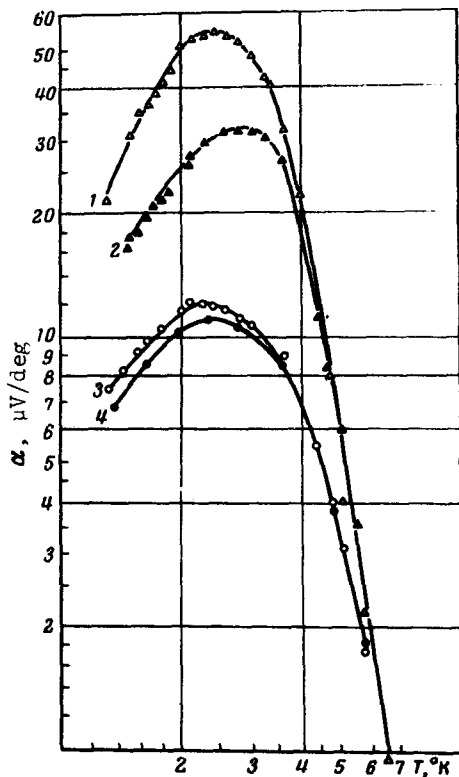
INFLUENCE OF SAMPLE DIMENSIONS ON THE THERMOELECTRIC POWER OF BISMUTH AT HELIUM TEMPERATURES

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The main contribution to the thermoelectric power in bismuth at helium temperatures is made by dragging of the carriers (holes) by phonons [1 - 3].

The phonon-dragging thermoelectric power exceeds by tens of times the ordinary diffusion thermoelectric power, which amounts to $\sim 1 \mu\text{V}/\text{deg}$.

Numerical estimates of the thermoelectric power of bismuth [3], based on a theoretical investigation [2] under the assumption that the main relaxation mechanism is phonon scattering by carriers, agree satisfactorily with experimental results [1, 3]. The question of the applicability of such a model to the calculation of the thermoelectric power of perfect samples with characteristic dimensions on the order of several millimeters remains open, since measurements of the thermal conductivity [4, 5] lead to the estimate that phonon-phonon scattering (N and U processes) and scattering by the boundaries are the main phonon-scattering processes at $T > 1^\circ\text{K}$.



Temperature dependence of the thermoelectric power of Bi:
 1 - 6 mm diameter, $b = \rho(300^\circ\text{K})/\rho(4.2^\circ\text{K}) = 450$; 2 - 6 mm diameter, after deformation, $b = 350$; 3 - 2.5 mm diameter, $b = 250$; 4 - 2.5 mm diameter after deformation, $b = 190$.

We have therefore attempted to investigate the influence of the dimensions on the thermoelectric power of perfect bismuth samples at helium temperatures.

To estimate the influence of the quality of the crystal structure on the character of the transport processes, the sample properties were measured before and after plastic deformation (sag ~ 2 mm at a sample length ~ 60 mm). The results of the measurements of the thermoelectric power (α) of the two most perfect samples with diameters 6 and 2.5 mm are shown in the figure. Analysis of the dependence of α on the temperature T and on the sample diameter points to the following features: 1. The magnitude and position of the maximum of α depend strongly both on the dimensions and perfection of the crystal, and when the characteristic dimensions are increased 2.5 times the value of α near the maximum increases by approximately five times. 2. At $3.5^\circ\text{K} < T < 6^\circ\text{K}$, the value of α of a perfect sample increases exponentially with decreasing temperature, and the thermal conductivity in this region also increases exponentially, i.e., the main dissipation of the quasimomentum of the phonon system is via phonon-phonon U-processes. 3. From the results of a simultaneous measurement of the thermal and electric conductivity and the thermoelectric power it follows that a change in dimensions affects the behavior of α much more strongly; an increase of the diameter changes not only the value of α but also increases sharply the slope of the high-temperature branch of the $\alpha(T)$ curve;

the thermoelectric power reaches a maximum at a lower temperature than the thermal conductivity; in the case of plastic deformation, as well as when the dimensions are decreased, α changes much more strongly than the thermal conductivity and the electric conductivity of the same sample.

The features observed by us in the behavior of the thermoelectric power of perfect bismuth samples can be explained within the framework of a theoretical model recently proposed in [6]. In bismuth at $T \geq 1^\circ\text{K}$, the dimensions of the phonon medium are of the order of the dimensions of the electron and hole parts of the Fermi surface, and it follows from the energy and momentum conservation laws that some of the phonons cannot interact directly with the carriers.

In accord with [6], the phonons that can be scattered by carriers will be called "electronic" and all others "thermal." The electronic phonons have a larger wavelength and therefore (if a carrier density is not too large) a larger relaxation time than the thermal ones, and the principal processes in their scattering are elastic N-collisions with thermal ones, with a relaxation time $\tau_p^N(e)$. When calculating the phonon-dragging thermoelectric power, it is usually [7, 8] assumed that the relaxation time $\tau_p^R(T)$ is small, and their drift velocity can be set equal to zero in the calculation; the N-collisions between thermal and electronic phonons lead only to a loss of the total quasimomentum of the system of electronic phonons, i.e., decrease their drift velocity. In this case $\alpha \sim (1/T)(\tau_p^N(d)/\tau_{ep})$, where τ_{ep} is the relaxation time in the scattering of electrons (carriers) by phonons. In a sufficiently bulky and perfect crystal, $\tau_p^R(T)$ increases exponentially with decreasing temperature, i.e., the drift velocity of the thermal phonons cannot be neglected. When the motion of thermal phonons is taken into account, under conditions of frequency N-collisions between the phonons, a second term appears:

$$\alpha \sim \frac{1}{T} \frac{\tau_p^N(e)}{\tau_{ep}} + \frac{\tau_p^R(T)}{\tau_{ep}}$$

If $\tau_p^R(T) \geq \tau_p^N(e)$, the second term is dominant and can lead to a significant change in the thermoelectric power and its temperature dependence. In a perfect single crystal, τ (as well as the thermal conductivity) increases exponentially with decreasing temperature until phonon scattering by the sample boundary becomes appreciable. If $\tau_p^R(T) = \text{const}$ in scattering by the boundaries, then $\alpha \sim T$ (inasmuch as $\tau_{ep} \sim T^{-2}$ in bismuth [9]). Thus, allowance for the phonon-phonon scattering and phonon scattering by the sample boundaries explains qualitatively the observed regularities in the behavior of the thermoelectric power of perfect samples. At $T < 7^\circ\text{K}$, the thermoelectric power and the thermal conductivity [5] increase exponentially with decreasing temperature (the characteristic relaxation time is $\tau_p^R(T)$), but the relative contribution of the second term to α can decrease with decreasing sample dimensions, i.e., the thermoelectric power in this temperature region depends much more strongly on the dimensions than the thermal conductivity (curves 1 and 3).

At $T \leq 2^\circ\text{K}$, where scattering by the boundaries predominates, $\alpha \sim T$ (accordingly in the thermal conductivity we have $\tau_p^R(T) = \text{const}$). The stronger than linear $\alpha(T)$ dependence of the most perfect sample (curve 1) should be attributed to the drop of $\tau_p^R(T)$ observed in [5] in this temperature region (judging

from the thermal conductivity for the given sample, $\tau_p^R(T) \sim T^{0.4}$ in the interval $1.3 \leq T \leq 2.3^\circ\text{K}$.

It is interesting to note that since the contribution of the phonon-phonon carrier dragging becomes noticeable only in sufficiently bulky samples, a simultaneous investigation of the dependence of the thermoelectric power and of the thermal conductivity on the sample dimensions makes it possible to determine the value of $\tau_p^N(e)$ from the appearance of the size effect in the thermoelectric power. Phonon-phonon dragging can lead to an appreciable growth of the thermoelectric power at low temperatures; bismuth offers advantages in this respect over semiconductors, since even in the purest of the latter it has been practically impossible so far to observe the exponential variation in the thermal conductivity at low temperatures, owing to the strong isotopic scattering.

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SINGULARITIES OF THE DIAGRAM OF STATE OF AN He³-He⁴ MIXTURE DUE TO THE HYDROSTATIC EFFECT

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The diagram of state of the He³-He⁴ mixture has a region of separation into two liquid phases, the phase with the lower He³ concentration remaining superfluid [1 - 4]. The coexistence curve of the liquid phases, when plotted in coordinates T and X, has according to the latest experiments [4] a very unique form (see the figure), which has induced a number of workers to construct specific theories of this phenomenon [5, 6].

We shall show that the form of the coexistence curve of this mixture, under the conditions of the experiment [4], is determined by the hydrostatic effect, i.e., by the concentration inhomogeneity due to the gravitational field [7, 8], and remains therefore a function of the experimental conditions. This explains the discrepancies between the data of different authors [1 - 4] and the resultant polemics.

Let us verify first that the parameters determining the interval of action of the hydrostatic effect near the critical point of the He³-He⁴ mixture are considerably larger than in other mixtures. In [7, 8], such parameters were