Letters to the Editor

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Thermal Resistivity of Mercury in the Intermediate State

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THE thermal resistivity along the axis of a 5.2-mm diameter cylinder of approximately 99.99 percent pure mercury was measured as a function of transverse magnetic field at various temperatures between 4.2° and 1.3°K. At temperatures above about 2.1°K, the resistivity in the intermediate state ($0.5<\eta<1$, where η is the reduced field H/H_c) was quite well represented by

$$w=2(w_n-w_s)\eta+(2w_s-w_n), \tag{1}$$

where w_s and w_n are the resistivities in the pure superconducting and pure normal states, respectively. This result might have been anticipated for a specimen composed of alternate superconducting and normal laminas perpendicular to the axis of the cylinder, which is probably a good first approximation to the structure in the intermediate state.[1]

Below 2.1°K, however, departures from Eq. (1) were observed corresponding to an additional component of resistivity $w_a(\eta)$ on the right-hand side, similar in character to that observed in pure lead by Webber and Spohr[2] and in pure tin and indium by Detweiler and Fairbank.[3] For mercury, w_a vanished at $\eta=0.5$ and 1.0 and passed through a maximum at an intermediate value of η which seemed to decrease somewhat with decreasing temperature, but which always lay between 0.74 and 0.70. As shown by Fig. 1, the maximum value of w_a was in good agreement with the empirical formula

$$(w_a)_{\max}=1.3\times10^{-3}t^{-5}\ \text{watt}^{-1}\ \text{cm deg},$$

where t is the reduced temperature T/T_c. The results of Detweiler and Fairbank[3] for two tin specimens of nearly the same diameter and impurity content also yield $(w_a)_{\max}$ values proportional to t^{-5} with a coefficient 7.9×10^{-4} watt^{-1} cm deg, which suggests that this type of behavior may be fairly general.

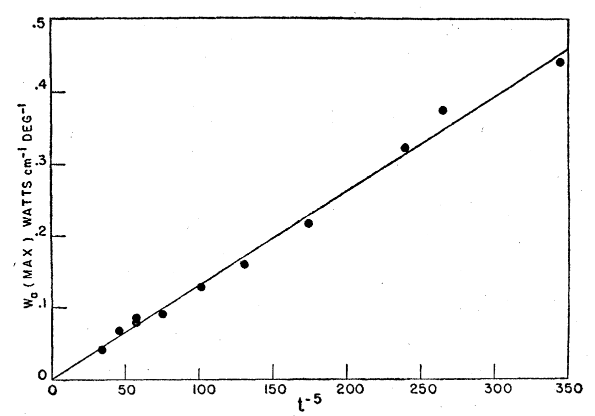

FIG. 1. Maximum additional thermal resistivity *versus* reduced temperature to the power −5, mercury.

It is worth noting that for the mercury specimen in the normal state the mean free path of electrons l_n at 2°K was about 4×10^{-4} cm. While this is small compared to the probable thickness of the normal laminas[1] for $\eta=0.72$, roughly 10^{-2} cm, it is greater than the estimated width of the superconducting-normal boundary layer,[1] about 5×10^{-5} cm. On the two-fluid model these figures seem to imply that as one crosses the boundary from a normal to a superconducting region, the equilibrium population of normal electrons decreases by a factor t^4 in a distance small compared to l_n. If it is assumed that a similar population decrease occurs for normal electrons actually crossing the boundary, a fraction $(1-t^4)$ of these electrons being in some way prevented from taking part in the heat transfer process, then a higher thermal resistivity w_nt^{-4} should occur in a normal layer of approximate thickness l_n in contact with the boundary. Although the reason for the existence of such a layer is not clear, it is interesting that for the specimen as a whole this assumption gives rise to an additional resistivity of the form

$$w_a\sim(w_{nc}l_{nc}/Z)t^{-5}, \tag{3}$$

where w_{nc} and l_{nc} are the values of w_n and l_n for $t=1$, and Z is the combined thickness of one superconducting and one normal lamina. Taking Z as about 10^{-2} cm, one obtains $w_a\sim5\times10^{-3}t^{-5}$ watt^{-1} cm deg, which is comparable with the observed $(w_a)_{\max}$.

I am grateful to Mr. R. J. Sladek for his cooperation in this experiment.

[1] D. Shoenberg, *Superconductivity* (Cambridge University Press, Cambridge, 1952).
[2] R. T. Webber and D. A. Spohr, Phys. Rev. **84**, 384 (1951).
[3] D. P. Detweiler and H. A. Fairbank, Phys. Rev. **88**, 1049 (1952).

The λ-Transition in Liquid Helium

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WE show why the interatomic potential does not alter the existence of an Einstein-Bose condensation[1] in He^4.

The partition function $Q=\sum_n\exp(-\beta E_n)$, with $\beta=1/kT$, is the trace of the operator $\exp(-\beta H)$. A coordinate representation of $\exp(-itH/\hbar)$ may be expressed in terms of an integral over trajectories.[2] An analogous situation applies to $\exp(-\beta H)$. For a system of N atoms of mass m interacting in pairs with a mutual potential $V(\mathbf{R})$ the partition function becomes

$$Q_B=(N!)^{-1}\int d^N\mathbf{z}_i\int_{tr}\exp\left[-\int_0^\beta\left\{\frac{m}{2\hbar^2}\sum_i\left(\frac{d\mathbf{x}_i}{du}\right)^2+\sum_{i,j}V(\mathbf{x}_i-\mathbf{x}_j)\right\}du\right]\mathfrak{D}^N\mathbf{x}_i(u). \tag{1}$$

The integral $\int_{tr}$ must be taken over all trajectories $\mathbf{x}_i(u)$, for $i=1$ to N, of the atoms such that initially they are in the same configuration $\mathbf{z}_i$ as finally, i.e., $\mathbf{x}_i(0)=\mathbf{z}_i$ and $\mathbf{x}_i(\beta)=\mathbf{z}_i$ [for we want the diagonal element of $\exp(-\beta H)$]. Also an integral is taken over all such configurations $\mathbf{z}_i$ (to obtain the trace). This Q_B is for atoms which obey Boltzmann statistics, and the $(N!)^{-1}$ is added, as is conventional. Actually He^4 obeys Bose statistics, the sum on states must only be over symmetrical states. This has the effect that the true Q for He^4 is

$$Q=(N!)^{-1}\sum_P\int d^N\mathbf{z}_i\int_{tr_P}\exp\left[-\int_0^\beta\left\{\frac{m}{2\hbar^2}\sum_i\left(\frac{d\mathbf{x}_i}{du}\right)^2+\sum_{i,j}V(\mathbf{x}_i-\mathbf{x}_j)\right\}du\right]\mathfrak{D}^N\mathbf{x}_i(u), \tag{2}$$

where in this case the integral $\int_{tr_P}$ is taken over all trajectories for which $\mathbf{x}_i(0)=\mathbf{z}_i$ and $\mathbf{x}_i(\beta)=P\mathbf{z}_i$.