Phonon Scattering in Condensed Matter

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SURFACE SUPERCONDUCTIVITY AND KAPITZA RESISTANCE

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It has been shown[1] that surface superconductivity can be used as a localized thermomether to study the temperature close to an interface through which heat is being transported. Knowledge of the temperature profile in the interface region provides evidence which any theory of the heat transport mechanism must take into account. For interfaces between pure lead and HeII we have previously found[1] clear differences between extrapolated surface temperatures T_k and T_m, measured within some 1000Å of the interface using a superconducting thermometer. (The reader is refered to ref.1 for details on the experimental method).

Using the same technique, we have studied the interface between lead and sapphire. We find in this case no measurable difference between the extrapolated and surface temperatures, and, incidentally, that the Kapitza resistance is the same for either direction of heat flow. We find $R_k = 50\ T^{-3}K^4cm^2/W$, for temperatures between 1.5K and 4K, half the value measured by Wolmeyer et al[2] for the same temperature range. The difference could be due to a better lead-sapphire contact in our samples.

We have investigated the temperature profile at the Pb-He interface by means of alloying the lead, thereby changing the coherence length and hence the size of the superconducting thermometer. We have measured three lead-thallium samples (nominal thallium concentrations 2, 7.7 and 17.5 atomic percent), one lead-indium (3 atomic percent indium), and one pure lead sample, all subjected to the same surface treatment. The results for the 2 and 17.5% Pb-Tl samples are shown in Fig.1, and they are typical of the rest. R_k is defined in the usual way: the difference between the extrapolated and helium bath temperatures ($T_k - T_{He}$), divided by the heat flux, whereas in R_m the "surface temperature" T_m is used instead of T_k.

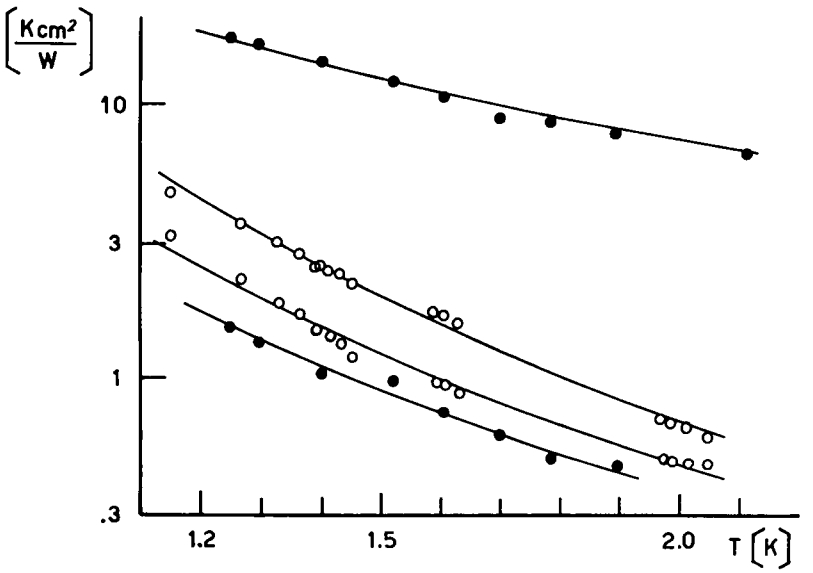

Fig.1. Thermal boundary resistances. Fullcircles: 17,5% Tl alloy; opencircles: 2% Tl alloy. For each case, the upper points are R_k, the lower R_m.

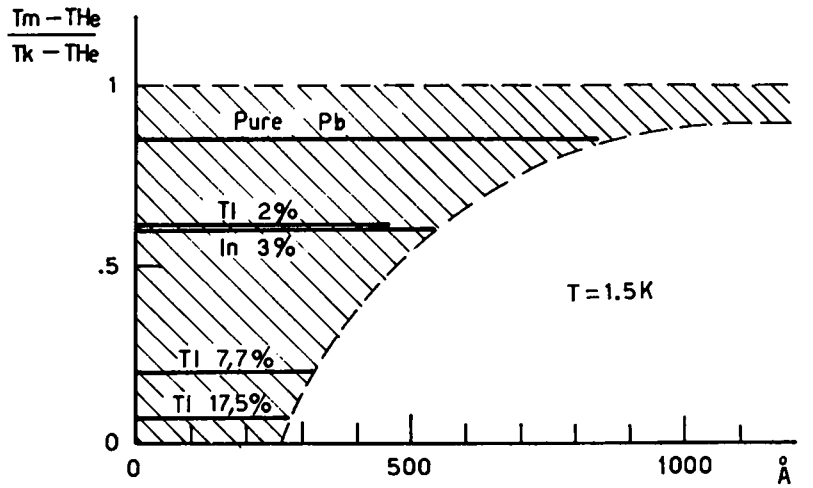

Fig.2. The ratio $(T_m-T_{He})/(T_k-T_{He})$ measured at 1.5K, as a function of the coherence length in lead alloys with the given impurity concentrations.

For each sample, T_m is a measure of the electron temperature in the metal within a distance from the interface of the order of the coherence length of the alloy. In Fig.2 we plot the ratio $(T_m-T_{He})/(T_k-T_{He})$ as a function of the distance from the interface. The result for each sample is plotted as a horizontal line from the interface to the sample's coherence length, showing the uncertainty in the position of the measured temperature. Any spatial profile of temperature should fall inside the shaded part of the diagram. It should be kept in mind that the phonon mean free path in lead at 1.5K is about 2 μm, much longer than any relevant lengths in Fig.2. Because of this, and their size, these profiles cannot be explained by Perrin's calculations[3] which predict very weak phonon- (and negligibly small electron-) temperature variations over distances of the order of the phonon mean free path. The electron mean free path, ℓ, would be the next choice for the characteristic lenght of the temperature profile, but it is disqualified by the fact that $(T_m-T_{He})/(T_k-T_{He})$ decreases with impurity concentration, whereas ξ/ℓ increases with decreasing ℓ. The pure lead sample, for example, has an electron mean free path of some 70 μm in the bulk, which is probably decreased at the surface, but the measured values of H_{c3} show that it is still much larger than the coherence length. Fig.2 would suggest a characteristic length not greater than some 500 Å, and different from either electron or phonon mean free paths.

It should be added that the extrapolated temperature T_k stays constant to one part in at least 2000 as the field is increased beyond H_{c2} to above H_{c3}. The existence of the superconducting sheath does not visibly affect either the thermal conductance of the metal or the Kapitza resistence of the interface. Tunneling experiments[4] show that the electron density of states at the metal surface is strongly affected by surface superconductivity, and the superconducting differential conductivity at zero bias, $\sigma_s(0)$, is reduced to half the normal-state value at fields just above H_{c2}. This indicates that in our case the eventual electron contribution to the Kapitza conductance is less than one thousandth of the phonon contribution.

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DISCUSSION

W. Eisenmenger: Do you have any idea what the phonon mean free path may be in these alloys?

F. de la Cruz: One order of magnitude longer than the coherence length ~ 1 μ.

W. Eisenmenger: One would expect such a temperature change in a layer of thickness of one phonon mean free path.

F. de la Cruz: That is true of you if you accept that you are going to use a sort of Boltzmann equation to describe the phenomon. I don't want to speculate too much on that. Many people are talking here about interactions near the surface. Now we know that our electrons are not coupled to the phonons, but it might be coupled to something else that is causing this high transfer between the helium and the phonons - some other modes, for example. I want to remind you that for the sapphire - which is a classical solid - we have no profile that we can see.

L. J. Challis: Your're saying that the temperature charges abruptly in a distance of 1000 Å, and that this is very short compared to the electron-phonon mean free path. Do you think there's any possibility that this is the sort of distance that a surface wave might be penetrating into the solid?

F. de la Cruz: You have to realize that there are tremendous gradients in a few hundreds of Å. This means that one atom is about 1 mK apart from another! But it's a problem with any superconducting bolometer, so this is not really too different. It's possible that it is related to the waves on the face of the crystals.