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Anomalous Kapitza Resistance to Solid Helium*

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The Kapitza thermal boundary resistance at temperatures near 1 K is anomalously small to solid ^{3}He or solid ^{4}He just as it is to liquid ^{3}He or liquid ^{4}He.

The measured Kapitza thermal boundary resistance R_B between two solids is generally in good agreement (≈10%) with the acoustic mismatch model of thermal energy exchange at low temperature.[1-3] In this model the reflection and refraction of thermal phonons at the interface is calculated by use of classical acoustics. Even R_B to liquid He may be explained in terms of acoustic mismatch at temperatures below ≈0.1 K.[2] An explanation of R_B to liquid He at temperatures of ≳1 K, however, remains elusive. No theory introduced thus far can explain the very small magnitude of R_B,[4-6] the small pressure dependence,[4] the fact that transverse phonons in the solid efficiently transfer energy to the liquid,[7-9] and that the thermal impedance is qualitatively independent of whether the liquid is ^{3}He or normal or superfluid ^{4}He.[10,11] The purpose of the present Letter is to correct a fallacy which is introduced[12,13] in searching for an explanation of R_B at ≳1 K, namely that the anomaly occurs only when liquid He is present. R_B to solid He at ≈1 K is *not* in agreement with the acoustic mismatch model, it is also anomalously small. Hence the anomalous behavior is not to be associated solely with properties of the liquid.

The experimental arrangement for measuring R_B was similar to that of Anderson and Johnson.[14] Two closely spaced 2.5-cm-diam plates of electropolished Cu were separated by a thin layer of He. The thermal impedance of the sandwich, $2R_B$, was measured under conditions of constant heat flux. Some of the data thus obtained are shown in Fig. 1 as R_BT^3 to emphasize the T^{-3} temperature dependence predicted for R_B by the acoustic mismatch theory. Data below 0.3 K were obtained in a dilution refrigerator; data above 0.4 K were obtained in a different cell in a ^{3}He refrigerator. The dashed lines represent previous data obtained in a magnetic refrigerator using an electropolished Cu cell of completely different geometry.[10] Near 1 K the present data agree with pre-

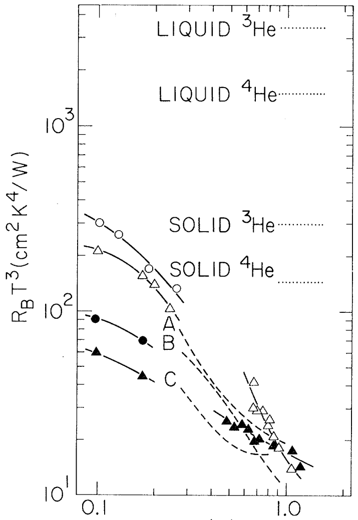

FIG. 1. The Kapitza resistance between Cu and He. Open circles, liquid ^{3}He; closed circles, solid ^{3}He; open triangles, liquid ^{4}He; closed triangles, solid ^{4}He. The sample pressure for liquid He was ≈ 0 atm, for solid He ≈ 37 atm. Curves A, B, and C are for liquid ^{3}He, liquid ^{4}He, and solid ^{3}He, respectively, as obtained from Ref. 10. The dotted lines represent calculations using an acoustic mismatch theory.

vious measurements[4] on liquid ^{4}He, which lie in the range of roughly 10–20 cm^2 K^4/W in the temperature interval from 1–2 K.

The results from the three cells do not agree quantitatively since R_B for Cu is influenced by surface preparation.[14] Also, there may be an additional thermal impedance at the highest temperatures in the solid He samples contributed by the He lattice. Nevertheless, these details do not alter the fact that there is a large reduction of R_BT^3 between 0.1 and 1 K for *solid* He as well as for liquid He.

It is also true that near 1 K, R_B to gaseous ^{3}He or ^{4}He is qualitatively the same in magnitude as for the liquid or solid, provided sufficient atoms are available to prevent a thermal bottleneck in the gas.[7,14] In our opinion this only indicates that R_B is the same to bulk liquid as to the layer of He a few monolayers in thickness which accompanies a gaseous He atmosphere at low temperatures.

The data may be compared with computations using the acoustic mismatch theory which are shown as dotted lines in Fig. 1. In this computation it was assumed that the transverse phonon mean free path in the Cu was much longer than the phonon wavelength.[2] Although there may be some disagreement as to the appropriate theoretical values for R_BT^3, the fact remains that near 1 K the measured R_B for liquid ^{3}He or ^{4}He is a factor of ≈ 100 smaller than the acoustic mismatch value and the measured R_B for solid ^{3}He or ^{4}He is a factor of ≈ 10 smaller.

Thus R_B is anomalously small at temperatures $\gtrsim 1$ K whenever one medium present is He, independent of whether the He is a gas, liquid, or solid. This would appear to eliminate as the dominant mechanism several recent suggestions for enhanced thermal transfer which are based on excitations of the liquid.[14-21]

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