LT 21
Proceedings of the 21st International Conference on Low Temperature Physics
Prague, August 8-14, 1996
Part S1 - Quantum Fluids and Solids: Liquid Helium

Concentration Dependence of the Thermal Boundary Resistance between Dilute ^{3}He-^{4}He Solutions and Sintered Silver Powder

D. J. Cousins[a], M. P. Enrico[a], S. N. Fisher[a,b], A. M. Guénault[a], S. L. Phillipson[a], G. R. Pickett[a], P. Thibault[a], and R. P. Turner[a]

[a]School of Physics and Chemistry, Lancaster University, Lancaster LA1 4YB, United Kingdom
[b]CRTBT-CNRS, associé à l'Univ. J. Fourier, BP 166, 38042 Grenoble Cedex, France

We have measured the ^{3}He concentration dependence of the thermal boundary resistance R_B between ^{3}He-^{4}He dilute mixtures and submicron sintered silver between 10 and 150 mK. For concentrations greater than one percent, the results for the boundary resistance per inverse volume are insensitive to the concentration and have a magnitude similar to that predicted by the acoustic mismatch theory. For concentrations less than one percent, we observe an increase of R_B for decreasing concentrations.

1. INTRODUCTION

In experiments[1] using silver sinters of different thicknesses ℓ (cross-sectional area A), we identified the role played by the poor conductivity of a mixture inside the submicronic pores of a sinter. When the mixture resistance $R_M\ell/A$ is large compared to the boundary resistance $R_B/A\ell$, i.e. at high temperature, only an outer layer of the sinter is active, of thickness $\Lambda = \sqrt{R_B/R_M}$. Within the ladder model[1,2], the actual boundary resistance is only seen in the low temperature limit of $\Lambda \gg \ell$. Unfortunately, this point was missed in most of the previous experiments on mixtures which were performed in the regime $\Lambda \leq \ell$, where the true temperature and concentration dependencies of the boundary resistance are obscured. We present in this paper thermal resistance measurements in the temperature region 10-150 mK, over a wide range of concentrations and extract what we believe is the true boundary resistance.

We prepared three different sinters by packing Silbest C-8 silver powder[3] (nominal size 700 Å) on to three very well annealed 1 mm thick 16×16 mm^2 silver plates, another similar bare plate being kept as a reference for bulk silver measurements. Each sinter forms a square of 10.3×10.3 mm^2 having respective thicknesses 0.262, 0.862 and 2.575 mm and a packing fraction of 53%. Sintered for one hour at 140 °C in a 50 mbar H_2 pressure, the final sinters have typical surface areas of about 2 m^2/g. The ^{3}He-^{4}He mixtures are prepared from room temperature by successive addition of ^{3}He. Starting from pure ^{4}He, the concentrations x used were 0.25%, 0.42%, 0.95%, 6.00% and the dilute phase of a 9% saturated solution.

2. RESULTS

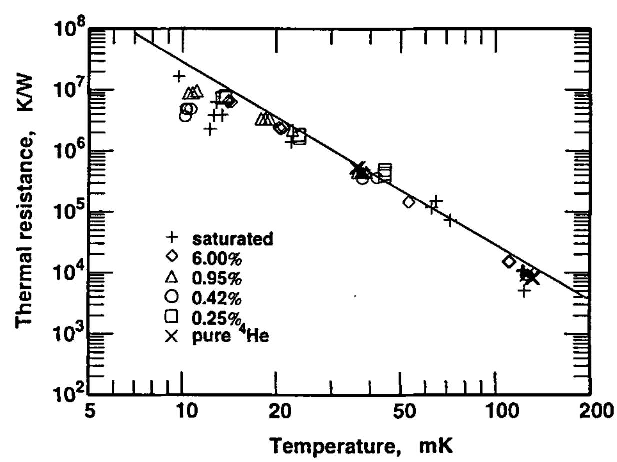

Figure 1: Measured thermal resistance between the bare plate and mixtures of various concentrations as indicated. The full line is obtained from acoustic mismatch theory.

The measured resistances for the bare plate in contact with various mixtures in figure 1 are independant of ^{3}He concentration and the same as for pure ^{4}He. The solid line represents the resistance expected from acoustic mismatch theory[4] using 'F' parameters $F_1 + F_2 = 1.54$. The good agreement with our results emphasises the role of good annealing on increasing the Kapitza resistance to near the expected acoustic mismatch theory value.

In the case of sinters, one might expect from the very large surface area per unit volume of the sinter-helium composite ($\sim 10^7 m^{-1}$) a Kapitza resistance three orders of magnitude lower with $R_B \sim 1.7 \times 10^{-9} T^{-3}$ $KW^{-1}m^3$ and concentration independent. Below 50 mK the measured thermal resistances increase by one order of magnitude while x decreases from 6.4% to 0.25%, whereas above 100 mK they converge to similar values as shown on figure 2 for a 0.262 mm sinter. Furthermore, a parallel path to the ladder model is manifest from the finite resistance R_4 measured in pure ^{4}He. Thus the measured resistance R is a combination of R_4 and of the resistance R_{ladder} so that $1/R = 1/R_{\text{ladder}} + 1/R_4$.

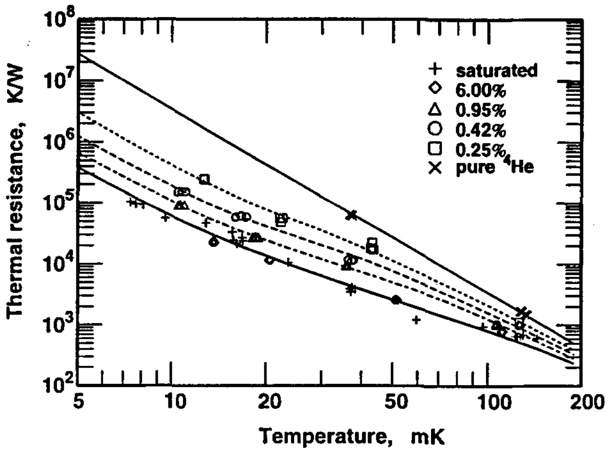

Figure 2: Thermal resistance between a 0.262 mm thick sinter and various mixtures. The full (dashed) lines from top to bottom correspond to constant $R_B T^3$ values for each concentration : pure ^{4}He, 0.25%, 0.42%, 0.95%, 6.00%, and saturated solution.

3. DISCUSSION

In order to extract the true boundary resistance R_B from the measured resistance, we fit the measurements to the equation $R_{\text{ladder}} = A^{-1}\sqrt{R_B R_M}\coth(\ell/\Lambda)$. To do this we compute the resistance of the mixture within the pores of the sinter assuming the mean free path λ for the quasiparticles is given by $1/\lambda = 1/\lambda_b + 1/a$ with λ_b the value in the bulk and a the pore size with a Gaussian distribution. The temperature independent values we obtain for $R_B T^3$ are shown in figure 3 as a function of x for the three sinters. The continuous lines on figure 2 are obtained from the values inferred from the model for each concentration. The result is a rather strong

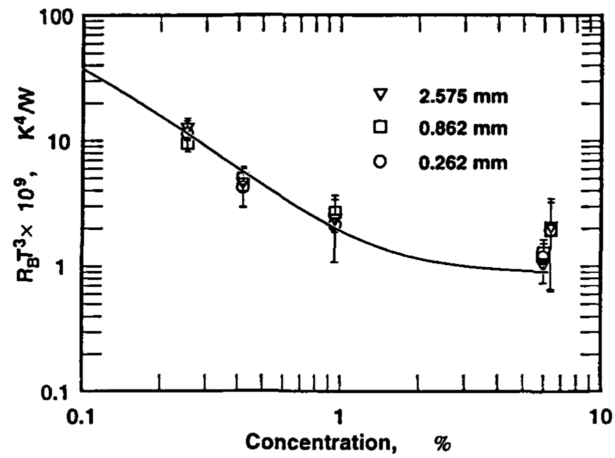

Figure 3: Amplitude of the boundary resistance $\times T^3$ as a function of the concentration as extracted from the ladder model. The continuous curve corresponds to having a series resistance (see text).

concentration dependence below 1% that saturates for higher x values. Such a concentration dependence suggests that the boundary resistance has one concentration dependent and one concentration independent component. If we take the concentration dependent term to be given by the boundary limited quasiparticle resistance R_{PQP} as given by McMullen [5] then we find that our results are consistent with $R_B = R_0 + 0.03 \times R_{PQP}$ as shown by the solid line in figure 3. Interestingly, the concentration independent term R_0 is then found to have a similar magnitude to that expected by acoustic mismatch theory.

4. CONCLUSION

In conclusion, we have measured the concentration dependence of the boundary resistance between ^{3}He-^{4}He mixtures and silver sinters. If the phonon-to-quasiparticle thermal resistance is assumed responsible for the concentration dependence, then we find that its magnitude would have to be some 30 times less than expected from theory.

REFERENCES

[1] D. J. Cousins *et al.*, Phys. Rev. Lett. 73 (1994) 2583.

[2] C. Bäuerle *et al.*, J. Low Temp. Phys. 101 (1995) 259.

[3] Silbest C-8 silver powder, Tokuriki Honten Co., 9-12 Kajicho, Chiyodaku, Tokyo 101, Japan.

[4] L. J. Challis and J. D. N. Cheeke, Proc. R. Soc. London A 304 (1968) 479.

[5] T. McMullen, J. Low Temp. Phys. 51 (1983) 33.