Specific heat measurements of ^{3}He-^{4}He mixture films

H. Akimoto, R. B. Hallock [1]

Laboratory for Low Temperature Physics, Department of Physics, University of Massachusetts, Amherst, MA, 01003, USA

Abstract

We report specific heat measurements from our on-going experiments on two-dimensional liquid ^{3}He on superfluid ^{4}He films. The ^{3}He coverage dependence of the specific heat was measured for 0.02 - 0.96 bulk-density layers of ^{3}He on 4.33 bulk-density layers of ^{4}He over the temperature range $85 \leq T \leq 170$ mK. We derived two Fermi liquid parameters F_1^s and F_0^a as a function of ^{3}He coverage from the data and by comparison to previous NMR data. These values are compared with those obtained from ^{3}He on other substrates and with theoretical calculations.

Key words: helium3; helium4 ; 2 dimensions; heat capacity

1. Introduction

At sufficiently low temperature, ^{3}He atoms on a thin ^{4}He film occupy a bound state on the free surface of the ^{4}He film[1] and such ^{3}He atoms provide an ideal environment to study this 2-dimensional Fermi system since one can change the Fermi energy by changing the ^{3}He concentration, and change the potential for the ^{3}He by changing the ^{4}He coverage. Much experimental and theoretical research has been done with this system.[2] To date a comprehensive NMR measurement and recent specific heat measurements as a function of ^{3}He coverage with 4.33 layer of ^{4}He have been performed by our group on a Nuclepore substrate.

Our goals are to measure the specific heat of the ^{3}He as a function of ^{3}He coverage for several ^{4}He coverages and to further reveal the two-dimensional properties of the ^{3}He. Here we report further measurements of the specific heat as a function of ^{3}He coverage with 4.33 layers of ^{4}He, confirm general consistency with our earlier measurements[4] and make comparisons to other work. For the work we report here, the experimental apparatus and the procedure were the same as has been reported previously.[5]

[1] Corresponding author. E-mail: hallock@physics.umass.edu

2. Results

A selected set of heat capacity data is shown in Fig. 1 as a function of the temperature for different ^{3}He coverages with 4.33 layers of ^{4}He present. The background heat capacity of the sample cell with only liquid ^{4}He present was subtracted. At lower coverages, the heat capacity data are independent of the temperature and proportional to the coverage. In the low coverage regime the Fermi temperatures are not far from the temperature and the system shows Boltzmann-like behavior. With increasing coverage above ≈ 0.3 layers, the heat capacity acquires a temperature dependence and becomes generally proportional to the temperature. To establish the quality of this proportionality and observe the zero temperature intercept will require data at lower temperatures. Recently completed changes to the apparatus will allow future measurements to extend to ≈ 20 mK.

The value of the heat capacity divided the temperature C/T at 125 mK is shown in Fig. 2 as a function of the ^{3}He coverage. Below 0.2 layer, C/T is proportional to the coverage and the region shows Boltmann gas-like behavior. Between 0.2 and 0.6 layer, C/T is a weak function of the coverage and near 0.6 layer a step feature appears. This step is due to the occupation of

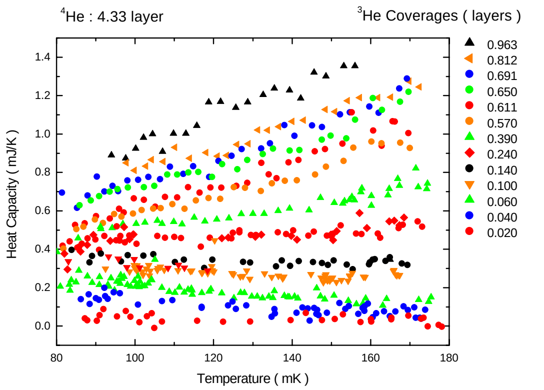

Fig. 1. A selected set of heat capacity data as a function of the temperature for several different ^{3}He coverages.

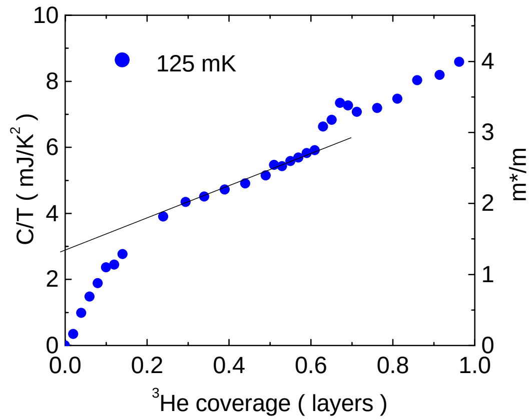

Fig. 2. C/T and the deduced effective mass for different ^{3}He coverages.

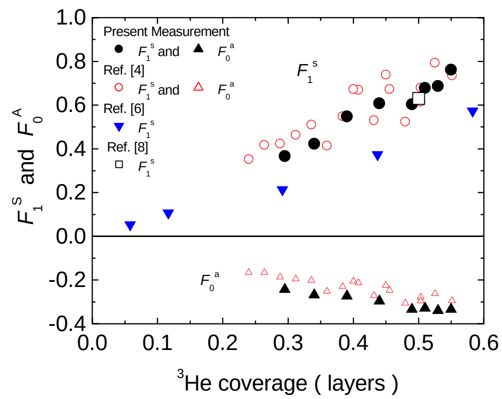

Fig. 3. The Fermi liquid parameters F_0^a and F_1^s.

a second quantum state. These measurements are consistent with those previously reported.[4]

When such a system is well below the Fermi temperature, it can be analyzed by Fermi liquid theory, The specific heat and the effective mass m_3^* are given by $C/T = \pi m_3^* k_B^2 A/(3\hbar^2)$, with $m_3^* = m_{3H}(1 + F_1^s/2)$. Here A is the surface area of the system and m_{3H} is the hydrodynamic effective mass. m_{3H} is evaluated by extrapolating the slope in the Fermi degenerate region and this yields 1.4m$_3$ where m$_3$ is the bare mass of a ^{3}He atom; 1.4m$_3$ is consistent with NMR measurements.[3]

By combining earlier NMR Measurements with these heat capacity results, we are able to obtain F_0^a. At low temperature the magnetic susceptibility is $\chi \approx \chi_0(m_3^*/m_3)/(1+F_0^a)$ and described by two Fermi liquid parameters. Here χ_0 is the susceptibility of the non-interacting case.

The derived Fermi liquid parameters are shown in Fig. 3. Both F_1^s and F_0^a have larger values at higher coverages and appear as a roughly linear function of the coverage. Future data at lower temperatures will enhance the confidence in these numbers. F_1^s on graphite substrates[6] with 5.2 layers of ^{4}He is shown by triangles and shows similar coverage dependence. A microscopic theoretical calculation of the Fermi liquid parameters by Kroscheck et al.[7] is also shown. Although the theoretical calculation based on a Fermi gas model in two dimensions for s-wave repulsive interactions by Engelbrecht[8] did not give explicit values of F_1^s and F_0^a, the relation of the two Fermi liquid parameters $F_1^s = -0.719\, F_0^a \geq 0$ and the nearly linear dependence on the coverage agree with the experimental results.

3. Summary

We present results from our on-going measurements of the specific heat of ^{3}He-^{4}He films. We obtained m_{3H} and two Fermi liquid parameters.

Acknowledgements

Supported by the NSF through DMR98-19122 and DMR01-38009

References

[1] A. F. Andreev, Sov. Phys. JETP **23** (1966) 939.

[2] R. B. Hallock, in *P*rogress in Low Temperature Physics, W. P. Halerlin ed. (North Holland 1995), vol. XIV, ch. 5.

[3] R.H. Higley, D.T. Sprague, R.B. Hallock, Phys. Rev. Lett. **63** (1989) 2570.

[4] P. -C. Ho, R. B. Hallock, Phys. Rev. Lett. **87** (2001) 135301.

[5] P. -C. Ho, R. B. Hallock, J. Low Temp. Phys. **121** (2001) 501.

[6] M. Dann, J. Nyéki, B. P. Cowan, J. Sanders, Phys. Rev. Lett. **82** (1999) 4030.

[7] E. Krorscheck, M. Saarela, J. L. Epstein, Phys. Rev. Lett. **61** (1988) 1728.

[8] J. R. Engelbrecht, M. Randeria, L. Zhang, Phys. Rev. B **45** (1992) 10135.