Journal of Low Temperature Physics, Vol. 113, Nos. 3/4, 1998

^{3}He in 99.5% Porous Aerogel at the Normal-Superfluid Transition

S.C.J. Kingsley, G. Lawes, A. Golov, K. Matsumoto*, J.V. Porto†, E.N. Smith, N. Mulders‡, M.H.W. Chan§, and J.M. Parpia.

Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, NY 14853, USA
**Department of Applied Physics, Tokyo Institute of Technology, 2-12-12 Oh-okayama, Meguro, Tokyo 152, Japan †Massachusetts Institute of Technology, Cambridge, MA 02139 ‡Department of Physics and Astronomy, University of Delware, Newark, Delaware 19716 §104 Davey, Pennsylvania State University, University Park, PA 16802*

We have used a torsional oscillator to measure the superfluid density and dissipation near the superfluid transition of ^{3}He in aerogel of 99.5% porosity. We used a new cell (constructed at Penn State) for which the aerogel was grown in the pores of a ~100 μm silver sinter. The cell was tested with ^{4}He and showed no signs of the second-sound resonances that have interfered with previous torsional oscillator measurements. The measurements with ^{3}He, presented here, were taken at pressures of 1.34 and 4.13 bars. We observed values of ρ_s/ρ in the $T \to 0$ limit of 0.05 and 0.14 respectively. Our measurements show an increase in the dissipation on warming through T_c. This series of measurements is ongoing and temperature sweeps at various pressures are planned.

PACS numbers: 67.57-z, 67.57 Pq

1. INTRODUCTION

Because of their sharpness, studies of the superfluid transitions in bulk ^{4}He offer precise information about critical phenomena[1]. One can examine in detail the effects of structural disorder on phase transitions by adding well-controlled impurities which paradoxically can result in a sharp transition but entirely different critical behavior. Since the observation of superfluidity of both ^{4}He and ^{3}He in silica aerogel[2,3,4] there has been interest in studying the superfluids in aerogel in order to understand the effects of the correlated disorder on critical phenomena and the phase diagrams. Aerogel is a particularly good system to use because its microscopic structure can be tuned chemically during its preparation, and then examined using X-ray[5] or neutron diffraction. In ^{3}He, it has been shown that the correlated disorder suppresses both transition temperature[3,6], the superfluid density[3,6], and the NMR frequency shift[4], effects that are qualitatively understood[7], and alters the power law behavior of the superfluid density at the transition[3,6], an effect that is not completely understood. Previous torsional oscillator experiments on ^{3}He in 98.2% porous aerogel have shown that both T_c and the superfluid density are suppressed as functions of pressure[3,6]. An interesting feature of a second aerogel sample was that there was no observable superfluid transition at pressures below ~6.5 bar[8], suggesting a quantum phase transition at a finite pressure and zero temperature. Unlike ^{4}He there has been no systematic investigation[9] to explore the effect of the aerogel density on T_c (and the A-B transition) of superfluid ^{3}He. A new cell has been constructed with a low aerogel density to explore the phase diagram of ^{3}He.

2. EXPERIMENTAL DETAILS

The oscillator used for this work was of a conventional design using a hollow BeCu torsion rod. Thermal contact to the sample was made through a sintered silver heat exchanger in good contact with the nuclear stage and through the ^{3}He inside the torsion rod. The empty cell had a quality factor of 26,000 and a self-resonant, torsional frequency of 428 Hz measured at 10 mK. A floppy mode was observed at a lower frequency with a smaller Q-factor but was not used for this work. For the period measurements the oscillator had a stability of 8 parts in 10^7 and the dissipation could be measured to within one percent. The oscillator was driven at its self-resonant frequency at a constant amplitude. The sinter also helped damp out unwanted sound modes that have been observed to cross the oscillator frequency near T_c [1,3].

Silica aerogel consists of a self-similar network of SiO_2 strands with the smallest length scales on the order of 30Å and the longest length scales well over 1,000Å. The geometric mean free path of quasiparticles in 99.5% porous aerogel is calculated to be 10^4Å. For comparison, the zero temperature coherence length of the Cooper pairs in bulk ^{3}He varies from 150Å at 29 bar to 800Å at zero pressure. The fractal dimension of the aerogel can be varied by altering the pH of the solution during the gelation process. This factor has been shown to affect the behavior of the ^{3}He in aerogel T_c[5]. Unfortunately we have not yet been able to image the fractal structure of our 99.5% porous sample.

The thermometry for this work consisted of a ^{3}He melting curve thermometer and a Pt NMR thermometer both situated on the copper nuclear demagnetization stage of the Cornell microkelvin cryostat. The ^{3}He superfluid and solid ordering fixed points observed in the melting curve thermometer were transferred to the Pt NMR susceptibility which was then used as the main thermometer.

3. RESULTS

The cell was first tested down to 1.3K filled with pure ^{4}He. The system underwent a sharp normal to superfluid transition and no second-sound resonance modes were apparent. We observed no transition signal from bulk ^{4}He. The tortuosity, defined as the fraction of superfluid coupled inertially to the bob at $T = 0$, measured on a similar sinter-filled cell was $\sim$50%.

With pure ^{3}He filling the cell, two pressures have so far been studied: 1.34 and 4.13 bar. The first temperature sweep at 1.34 suffered from a thermal lag between the thermometers and the experimental cell because of the rapid temperature sweep rate. Therefore no useful data was obtained for the temperature axis but we could still measure changes in the period and drive (or dissipation) of the oscillator. From the period observations and using a tortuosity of 50% we calculated a limiting value of $\rho_s/\rho =$ 0.05. The dissipation of the oscillator during this sweep increased by 5% on warming through the superfluid transition. The cell and thermometer for the temperature sweep at 4.13 bar were in better equilibrium, warming at a speed of less than 100 μK/hour.

Fig. 1 shows the period shift as a function of temperature as indicated by our Pt NMR susceptability thermometer mounted on the stage. The T_c in bulk ^{3}He at this pressure is 1.40 mK. We calculated a value for ρ_s/ρ in the T$\rightarrow$0 limit of 0.14. This shows less supression than the ρ_s/ρ values obtained for similar pressures in 98.2% aerogel[3].

4. CONCLUSIONS

Our preliminary investigation suggests that the T_c and ρ_s/ρ of ^{3}He in 99.5% porous aerogel are not suppressed as strongly as in 98.2% open aerogel. A normal to superfluid transition is clearly observed at pressures as low as 1.2 bar with no evidence of a zero temperature quantum phase transition. However, the strong suppression of ρ_s/ρ as compared to the rela-

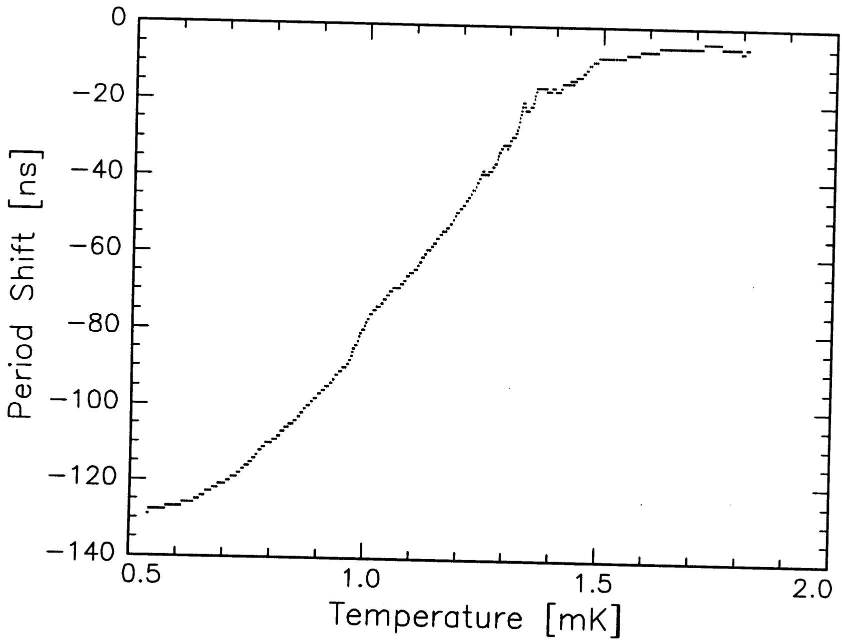

Fig. 1. The period shift is plotted as a function of the temperature indicated by the Pt NMR thermometer for the 4.13 bar sweep. The cell has a period of 2.33542 ms above T_c.

tively modest reduction of T_c is comparable to that observed in the cuprate superconductors[10].

ACKNOWLEDGMENTS

This research was supported by the National Science Foundation through grant numbers DMR-9424131, and DMR-9705295 as well as the Department of Education under P2-00A40551.

REFERENCES

1. J. D. Reppy, *J. Low Temp. Phys.* **87**, 205 (1992)
2. M.H.W. Chan, K.I. Blum, S.Q. Murphy, G.K.S. Wong and J.D. Reppy, *Phys. Rev. Lett.* **61**, 1950 (1988)
3. J. V. Porto and J. M. Parpia, *Phys. Rev. Lett.* **74**, 4667 (1995)
4. D. T. Sprague, T. M. Haard, J. B. Kycia, M. R. Rand, Y. Lee, P.J. Hamot and W. P. Halperin, *Phys. Rev. Lett.* **75**, 661 (1995)

5. J.V. Porto. In preparation.
6. H. Alles, J. J. Kaplinsky, P. S. Wootton, J. D. Reppy and J. R. Hook. To appear in *Physica.*
7. E. V. Thuneberg, S. K. Yip, M. Fogelstrom and J. A. Sauls, *Phys. Rev. Lett.* **80**, 2861 (1998)
8. K. Matsumoto, J. V. Porto, L. Pollack, E. N. Smith, T. L. Ho and J. M. Parpia, *Phys. Rev. Lett.* **79**, 253 (1997)
9. J. Yoon, D. Sergatskov, J. Ma, N. Mulders, and M.H.W. Chan, *Phys. Rev. Lett.* **80**, 1461 (1998)
10. M. Franz, C. Kallin, A.J. Berlinsky, and M.I. Salkola, *Phys. Rev. B* **56**, 7882 (1997)