Heat Capacity of ^{3}He in Aerogel

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Abstract

The heat capacity of ^{3}He in a silica aerogel with 98 % porosity has been measured in both the normal and superfluid phases at a pressure of 20 bars with an adiabatic method. The results indicate a sharp peak at $T_{ca} = 1.8$ mK with $\Delta C_a/C = 1.0 \pm 0.1$. The value of $\Delta C_a/C$ for superfluid ^{3}He in aerogel is smaller than that for bulk ^{3}He ($= 1.8$) directly indicating supression of the amplitude of the order parameter.

Key words: superfluid ^{3}He; heat capacity; aerogel

1. Introduction

The considerable recent efforts to study superfluid ^{3}He confined to highly porous silica aerogel arises in part from interest in this system as an example of an unconventional pairing condensate with quenched disorder. Since the discovery[1,2] that superfluid ^{3}He in aerogel has a well-defined transition temperature which is suppressed from that of the bulk, experiments have now provided a picture of the suppressed superfluid phase diagram as a function of pressure and magnetic field[3], the superfluid density[1,4], NMR frequency shifts and susceptibility[5–7], as well as various transport measurements. The identification of two equilibrium states that correspond to two thermodynamic phases of the 'dirty' superfluid ^{3}He has been established, at least for the spin part of the order parameter. These correspond to an equal spin pairing (ESP) state that is stablized by a magnetic field and a non-equal spin pairing (non-ESP) state in zero field that fills the pressure temperature phase diagram for the case of a 98% aerogel. Analysis of superfluid density measurements and the NMR frequency shifts have given a picture of a strongly suppressed order parameter, even more strongly suppressed than might have been expected from a homogeneous scattering model (HSM)[8] used in conjunction with the measured suppression of the transition temperature. However, a more precise measure of this suppression can be obtained, in principle, from heat capacity for which there are now preliminary reports[9]. For a BCS type pairing system we expect a sharp discontinuous change in the heat capacity signaling the onset of superfluidity. The magnitude of the heat capacity jump is proportional to the square of the temperature derivative of the order parameter at the transition. Consequently, the measurement of the heat capacity can provide an unambiguous determination of the suppression of the order parameter sufficiently close to T_{ca} that it can be interpreted within a framework of Ginzburg-Landau theory. In this report we present our measurements of a discontinuous jump in heat capacity for superfluid ^{3}He in a 98% silica aerogel at a pressure of 20 bars and its interpretation in terms of the homogeneous scattering model[8].

2. Experiment

The experimental arrangement is based on demagnetization cooling of a calorimeter with a cadmium heat switch to a $PrNi_5$-nuclear demagnetization refrigera-

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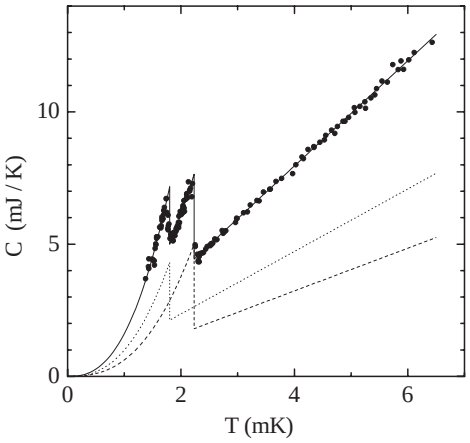

Fig. 1. The total heat capacity of ^{3}He as a function of temperature at a pressure of 20 bars. The fitting procedure isolates the contribution of the bulk ^{3}He from that in the aerogel and the results of this analysis are shown as dashed lines in the figure. A small temperature independent addendum contribution to the heat capacity has been subtracted.

tor. An adiabatic calorimetric method was used, details to be provided elsewhere. The thermometry was based upon LCMN susceptibility calibrated with the known bulk superfluid phase diagram and a melting curve thermometer attached to the demagnetization stage. A small temperature independent background addendum of 0.88 mJ/K was attributed to solid ^{3}He on the heat exchanger and aerogel surfaces[10]. The nominal liquid volume calculated from geometry of the cell including the silver heat exchanger was 1.8 cm^3 and the aerogel sample volume was calculated to be 1.12 cm^3.

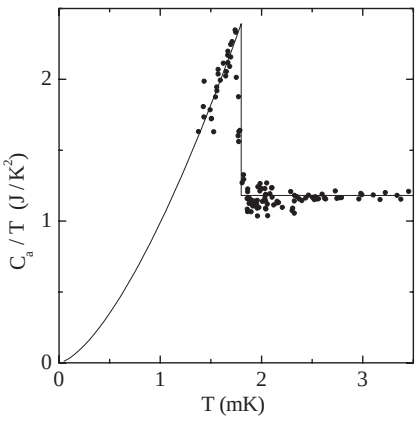

Fig. 2. The heat capacity of ^{3}He in aerogel divided by the temperature at a pressure of 20 bars.

3. Results and Discussion

A straightforward analysis of the data, after addendum subtraction, Fig. 1, includes the following steps. The linear temperature dependence of the heat capacity at $T > T_c$ determines the total liquid content using the known bulk heat capacity[11]. The temperature dependence in the region $T_c > T > T_{ca}$ consists of the normal aerogel liquid, which is proportional to the temperature, and the known heat capacity of the bulk superfluid[11]. Together, these two regions of temperature allow a precise determination of the liquid volume in the aerogel which we find to be 1.0 ± 0.1 cm^3 in excellent agreement with the calculated geometric volume, 1.1 cm^3. After subtraction of the bulk heat capacity in the region $T < T_{ca}$, we determined the aerogel-superfluid heat capacity as a function of temperature, displayed as C_a/T in Fig. 2. The heat capacity jump at 20 bars is $\Delta C/C_a = 1.0 \pm 0.1$. We can understand[8] this result using the HSM, using rescaled strong-coupling interactions[3], and we find a transport mean free of 200 nm consistent with other experiments, notably the AB-phase diagram[3].

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