Experimental Apparatus for Heat Capacity Measurements of 2D ^{3}He in Magnetic Fields

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Abstract

Previous heat capacity measurement in zero magnetic field for the low density second-layer solid ^{3}He adsorbed on graphite showed a peculiar double peak structure. From this measurement a "quantum spin liquid (QSL)" ground state has been suggested. Increasing the magnetic field, theories predict a transition from a QSL phase to a long-range ordered phase called "uuud" at a certain threshold field, which is a measure of the spin gap of the QSL phase. Here we describe an experimental setup for heat capacity measurements of two-dimensional (2D) ^{3}He to test the predictions at temperatures below 200 μK in magnetic fields up to 1.2 T.

Key words: solid ^{3}He; films; nuclear magnetism;

1. Introduction

Solid monolayers of ^{3}He adsorbed on a graphite surface are ideal 2D quantum spin systems with nuclear spin 1/2. In these systems, strong frustration arises from competing multiple-spin exchange (MSE) interactions in addition to the geometrical frustration coming from the triangular lattice structure. Because of the strong frustration in the second layer, a QSL ground state is suggested for the low density commensurate phase from previous heat capacity measurement in zero magnetic field [1]. This measurement revealed a peculiar double peak structure.

Exact diagonalization calculations based on the MSE Hamiltonian for finite clusters [2] also show that a gapped QSL state stabilizes for exchange parameters determined by experiments [3]. In magnetic fields, it is theoretically predicted that the system undergoes long-range ordering to the "uuud" phase, accompanied by a finite temperature phase transition [4].

Existing heat capacity [1] and magnetic susceptibility [5] measurements suggest a very small spin gap less than 0.1 mK which corresponds to a magnetic field of 0.1 T. In this paper, we describe an experimental setup to measure heat capacities of 2D ^{3}He down to temperatures below 200 μK in magnetic fields up to 1.2 T.

2. Experimental

We have constructed a nuclear demagnetization refrigerator which can cool monolayer samples below 200 μK. The experimental setup for heat capacity measurements is shown in Fig.1.

The sample cell contains a Grafoil substrate (exfoliated graphite, GTA grade, 127 μm thick) with a surface area of about 520 m^2 (20 m^2/g). Two Grafoil sheets are diffusive bonded onto both sides of a 50 μm thick silver foil in vacuum at 650 °C for 3 hrs under a pressure of 2 MPa. In total we used 71 such sandwiches in the sample cell. Tabs of the silver foils are diffusive bonded and screwed to a silver rod which is firmly connected

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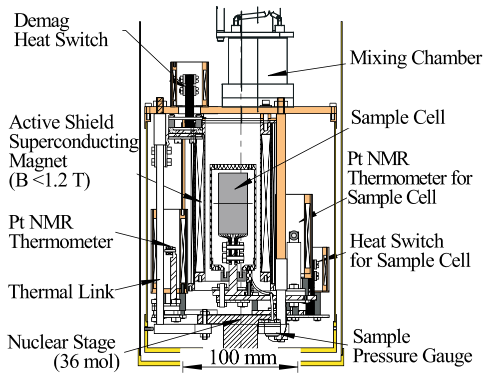

Fig. 1. Schematic drawing of the experimental set up for heat capacity measurements of 2D ^{3}He adsorbed on graphite.

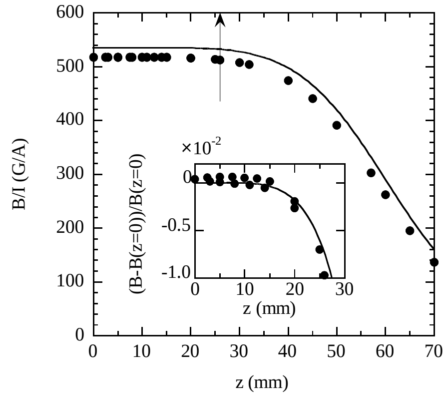

Fig. 2. Field profile along the axis of the active shield magnet. The arrow indicates where the sample region ends ($z = 26.5$ mm). The inset shows the deviation from the central field. The solid lines represent the calculated field profile.

to a heat switch. The sample cell wall which is made of hard-silver (Ag > 99 at.%, Cd < 1 at.%) is thermally anchored to the nuclear stage, but disconnected from the Grafoil stack with Vespel SP-22 spacers. The total amount of silver used in the sample cell is about 400 g and 20% of that is in a magnetic field produced by a superconducting magnet described below.

The sample pressure is monitored with a strain-capacitive pressure gauge located in the vicinity of the cell. The diaphragm (9.0 mm in diameter, 0.2 mm thick) is made of hard-silver, and the pressure resolution is 8.0×10^{-2} Pa.

The temperature of the ^{3}He sample is determined by a platinum pulsed-NMR thermometer below several tens mK and by a carbon resistance thermometer (Matsusita, 68 Ω) above 20 mK. All the thermometers are calibrated against a ^{3}He melting curve thermometer attached to the nuclear stage in a temperature range between 2 and 100 mK. For the Pt NMR thermometer, we used 10000 Pt wires of $\phi\,25$ μm (5N purity). These wires were annealed in air at 500 °C for 2 hours (RRR = 1200) and welded to a silver support. Measured T_2 is 0.73 ms. In addition, a CMN thermometer monitored with a SQUID based ac bridge is installed for high resolution measurements above 5 mK.

Zn foils (5N8 purity, 0.25 mm thick) are used for the superconducting heat switch because of its low critical field. This is in order to reduce the magnetic latent heat released when the switch is opened. The heat flow to the sample cell is minimized by applying an appropriate field gradient. The Zn foils were annealed (RRR = 1860) and gold plated, and we obtain a total electrical resistance of the switch of about 100 nΩ in the normal state. For the cell heater a $PtRh_{13\%}$ wire ($\phi\,40$ μm) with a resistance of about 40 Ω was employed.

A magnetic field up to 1.2 T can be applied to the sample with a specially designed active shield superconducting magnet [6]. The field inhomogeneity over 30 mm around the center is less than 0.1% and over the entire Grafoil stack region ($\phi\,37$ mm, 53 mm long) less than 1%(see Fig. 2). The magnet is surrounded by a lead (4N purity) superconducting shield. The fringing field outside the magnet is less than 3 mT at its maximum field.

Heat capacity measurements of the second layer registered solid ^{3}He are now under way.

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