Specific heat of ^{4}He film adsorbed on three-dimensional pores

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Abstract

We have measured heat capacities of ^{4}He and ^{3}He films adsorbed on a new mesoporous material with the pore diameter 27 Å called HMM-2, which has an ordered 3D network of pores. The substrate is an organic-inorganic hybrid material made of C_2H_4 and Si_2O_3, and consists of cages connected in the hcp structure ($a = 55.4$ Å, $c = 88.6$ Å). When adsorptions are above one layer, heat capacities below about 0.3 K are qualitatively different between ^{3}He and ^{4}He. It indicates that the Bose fluid of the ^{4}He film appears at the second layer.

Key words: ^{4}He; restricted geometry; Bose fluid; low-dimension;

1. Introduction

Helium films adsorbed on porous materials or flat substrates are ideal systems in order to study behavior of low-dimensional quantum fluids dependent on their dimensionality. Numerous studies have been done on helium film in porous materials such as Vycor, and extensive discussions have been made *e.g.* in views of the dilute Bose gas [1] or the dimensionality of superfluidity [2]. Recently we reported that 1D Bose fluid is realized in the 1D straight-porous material FSM with the pore diameter 18 Å [3]. It is interesting to study the behavior of film in pores with 3D connectivity, in comparison with the case of the 1D system.

In this article, we have reported on the heat capacity of helium film adsorbed on a new mesoporous material called HMM-2 with an ordered 3D network of 27 Å pores. We have measured temperature dependences of the heat capacity of ^{4}He film in various amounts of adsorption. To examine the statistical difference between Bose and Fermi fluids, we have also measured heat capacities of ^{3}He film.

2. Experimentals

HMM-2 is an organic-inorganic hybrid material made of C_2H_4 and Si_2O_3, in which cages are connected in the hcp structure (a =55.4 Å, c =88.6 Å) [4]. The distribution of pore diameter has a sharp peak at 27 Å. This diameter is almost the same as pores of FSM(28 Å), which is favorable to study dependences on the dimensionality [5]. In addition, the ordered network of pores should make analysis of data clearer.

The sample cell contains about 0.1 g of the substrate HMM-2. The adsorption area was estimated from a fit of the N_2 pressure isotherm at 77 K to the BET equation in the region of relative pressures of $0.05 < P/P_0 < 0.25$. The surface area is 79 m^2 for our cell, using 16.2 Å^2 as the area per one N_2 molecule. Assuming the density of the first layer completion for ^{4}He is the same as that on FSM(28 Å) [5], the first layer completion for HMM-2, n_{1st}, was estimated to be at 17.6 μmol/m^2 as well.

We have measured heat capacities of ^{4}He film, C_4, and C_3 of ^{3}He by the usual adiabatic heat pulse method. The measuring temperature ranges from 0.1 to 4.2 K. Amounts of adsorbed helium per unit area, n, is from 10 to 35 μmol/m^2 that seems to correspond to the second-layer completion.

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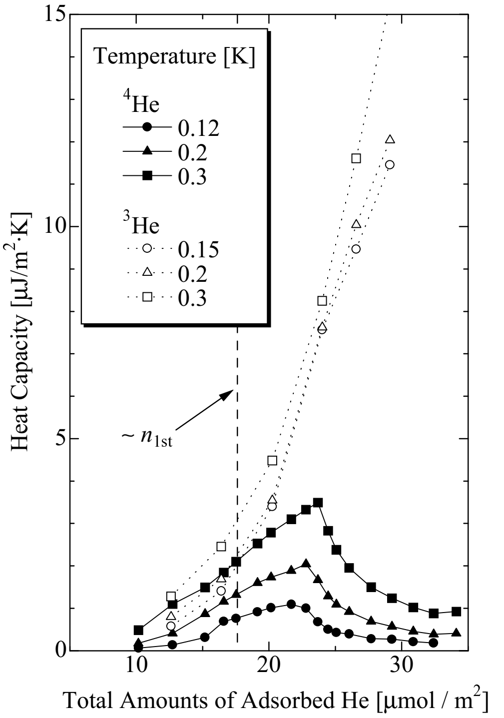

Fig. 1. Heat capacity isotherms against amounts of adsorbed helium. Dashed line shows the amount of adsorption, n_{1st}, corresponding to the amount to be expected to complete the first layer. Qualitative difference appears above about n_{1st}.

3. Results and discussions

Figure 1 shows heat-capacity isotherms for ^{4}He (solid symbols) and for ^{3}He (open symbols). Each temperature is shown in the figure. Dashed line shows n_{1st}. As n increase up to n_{1st}, both C_4 and C_3 increase. A qualitative difference between C_4 and C_3 appears above n_{1st}, where C_4 has a maximum, in contrast to monotonic increase of C_3 against n. Steep increase of C_3 is attributed to the contribution of nuclear heat capacity. The relatively large C_3 at T = 0.1 - 0.3 K suggests that a ^{3}He liquid layer is formed above n_{1st}. The difference between C_4 and C_3 should be attributed to the isotope effect, *i.e.* the statistical difference between ^{4}He and ^{3}He. Similar isotope effects have been observed in the other systems such as He films on the flat substrate hectorite [6] and 1D fluid He in FSM(18 Å) [3]. As a result, we can conclude that Bose fluid appears in ^{4}He film above n_{1st} on this substrate. Coincidence of n_{1st} with the onset of the statistical difference suggests that the second layer of adsorbed ^{4}He is a Bose fluid state.

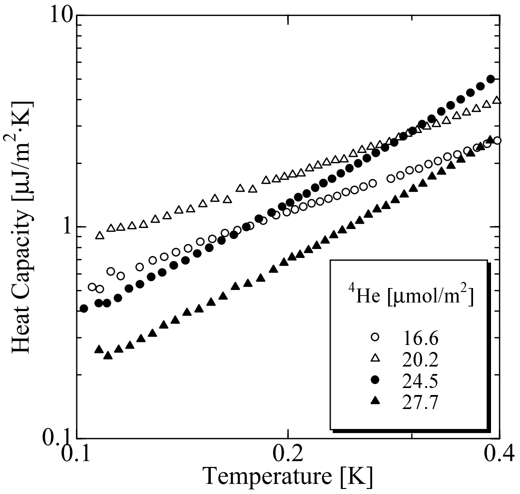

Fig. 2. Temperature dependences of C_4 at several n. Solid symbols are for the density above the maximum of C_4 in Fig. 1 and open symbols for below that. Clear difference of the power law can be seen.

The difference between the first layer of adsorbed ^{4}He and Bose fluid of the second layer also appear in the temperature dependences of the heat capacity. Figure 2 shows temperature dependences of C_4 below 0.4 K at several amounts of adsorption. Open symbols are for n below the maximum of C_4 in Fig. 1, and solid symbols are for n in the region that C_4 decreases as n increases. A clear difference of the power law can be seen, which suggests that a different state exists for the adsorption above n of the maximum of C_4. It should be noted that at the low temperature, heat capacities including the second layer are smaller than that of only one layer (16.6 μmol/m^2).

We have shown that Bose fluid appears in the second layer of adsorbed ^{4}He on 27 Å pores of the substrate HMM-2. For further analysis, more precious measurements are required. In addition to them, we are doing experiments to check relations of our results with superfluidity.

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