Hysteresis and Avalanche Phenomena of Helium in Nuclepore

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We report on the hysteresis and avalanche behavior of $^4$He capillary condensing into the nearly cylindrical pores of the porous membrane Nuclepore. Following capillary condensation, withdrawal of the $^4$He results in distinct jumps or avalanches where $10^7$ pores can be involved in a single avalanche. By using Nuclepore with 2000Å and 300Å pore diameters, we find that the avalanche distribution depends on details of the pore structure.

1. INTRODUCTION

Capillary condensation of a fluid in a porous material is a complicated process in most systems due to the complex microscopic geometry. In addition, all normal fluids have a viscosity, and when confined to small pores, the behavior of the system will be influenced by the viscosity. In order to study capillary condensation with the goal of learning about the hysteresis, we have chosen to use $^4$He as the fluid and Nuclepore as the porous material. Nuclepore is a polycarbonate membrane threaded by straight, intersecting cylindrical channels, a geometry much simpler than that encountered in most porous systems. Below the temperature $T_x$, a fraction of the $^4$He becomes superfluid with no viscosity, so very thin films can move and the time constants for pore draining by film flow are short.

2. EXPERIMENT

The pores of Nuclepore are slightly barrel shaped, with a larger interior diameter than pore opening. The pores are randomly distributed in a
plane with axes oriented at a random angle, $\theta$, from the normal to the plane of the membrane and a random angle, $\phi$, in the direction in the plane, $0^\circ \leq \theta \leq 34^\circ$, $0^\circ \leq \phi \leq 360^\circ$. Using the nominal density, pore diameter and membrane thickness, we simulate the material on a computer by building a pore space with cylindrical pores oriented with the same parameters, $\theta$ and $\phi$, as the real material. Results of the simulation indicate that the pores intersect in the interior of the material creating clusters of connected pores. For the case of 2000Å diameter pores, the largest cluster percolates, while the 300Å system appears to be very close to the percolation threshold.

To study capillary condensation we mount Nuclepore samples in a chamber attached to a standard cryostat insert. The cryostat is cooled to a temperature between 1.35K and 1.55K by pumping on the helium bath and stabilized to about ±0.5 mK with a bath heater controlled by an electronic feedback circuit. As the chemical potential, or number of $^4$He atoms, varies in the chamber, hysteresis of the volume of liquid $^4$He in the pores occurs and this is measured using a capacitive technique. 1000Å thick Ag plates with an area of 1.9 cm$^2$ are evaporated to both sides of the Nuclepore membrane. The Ag does not block the pore openings, so when helium enters the pores, a shift in the capacitance is detected. In order to monitor the chemical potential, $\mu$, we measure the velocity of third sound, $r$, where third sound is a wave on a superfluid $^4$He film which is a thickness and temperature oscillation. The measurement is of the time of flight, $v$, of a third sound pulse on a flat borosilicate glass slide in equilibrium with the Nuclepore. $r$ is related to $\mu$ by $r \sim \mu^{-1/2}$. Both the capacitance and third sound measurements are made simultaneously in situ.

3. RESULTS AND DISCUSSION

To create a typical hysteresis loop we start at a low chemical potential when all of the pores in the system are empty except for a thin film of $^4$He adsorbed to the pore surfaces. Slowly admitting $^4$He gas into the system increases the chemical potential at a rate small enough to allow the system to remain very close to equilibrium. Fig. 1 shows a hysteresis loop for Nuclepore with 2000Å pores. During filling (circles), a film forms on the walls of the pores and the capacitance and $r$ increase gradually. Then, as the surface energy overcomes the van der Walls potential, the pores capillary condense in order of increasing pore size. Before enough atoms are added to the system to reach saturated vapor pressure all of the pores have filled with liquid. The draining curve (squares), obtained by the gradual removal of $^4$He from the chamber, does not follow the same path due to a difference in the shape of the liquid-vapor interface (filling, cylindrical; draining, surface meniscus).