Gas-Liquid Transition and Elementary Excitations in Monolayers of Helium-4

S. Nakamura, K. Matsui, T. Matsui, and Hiroshi Fukuyama

Department of Physics, The University of Tokyo, Japan

The Kosterlitz-Thouless (KT) type superfluid transition in 2D Bosons has been experimentally studied for decades in ^{4}He thin films adsorbed on various substrates. However, little is known about the superfluidity and its relationship to elementary excitations in truly 2D Bose systems, such as monolayers of ^{4}He on graphite. Here, we report the latest results of our heat-capacity (C) measurements for the second layer of ^{4}He on ZYX exfoliated graphite whose microcrystalline size is at least ten times larger than that of Grafoil, a commonly used substrate in previous experiments. At low densities (ρ) below 16 nm^{-2}, where ρ includes the first layer of 12 nm^{-2}, we found C anomalies at $T = 0.73$ K much sharper than those in the previous study using Grafoil, with the logarithmic divergence around the critical point. The observed size dependence and the critical behavior allow us to assign the anomaly to the gas-liquid transition unambiguously, which is in good agreement with the path integral Monte Carlo calculation. At $16.0 \leq \rho \leq 18.7$ nm^{-2}, we found a rounded C bump at $T = 0.9$–1.0 K, whose T- and ρ-dependences are qualitatively different from the sharp anomaly of the gas-liquid transition, but surprisingly, they are similar to those observed with Grafoil at the same densities, which indicates the absence of the size effects. We infer that films in this density region form a uniform and nearly ideal 2D Bose liquid, and that the C bump observed should not be associated with a singularity of phase transitions. The T-dependence of C below 0.8 K of the liquid is nicely described as a summation of *phonon* and *roton* contributions. This is presumably the first experimental evidence for the existence of these two kinds of elementary microscopic excitations in monolayers of ^{4}He. We compare our results with current microscopic calculations.

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