Helium 4 in narrow nanopores and the crossover from Luttinger liquids to 2D

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We report diffusion Monte Carlo (DMC) and path integral Monte Carlo (PIMC) calculations of the properties of a 1D Bose quantum fluid. The equation of state, the superfluid fraction, ρ_S/ρ_0, the one-body density matrix, $n(x)$, the pair distribution function, $g(x)$, and the static structure factor, $S(q)$, are evaluated. The aim is to test Luttinger Liquid (LL) predictions for 1D fluids over a wide range of fluid density and LL parameter K. The 1D Bose fluid examined is a single chain of ^4He atoms confined to a line in the center of a narrow nanopore. The atoms cannot exchange positions in the nanopore, the criterion for 1D. The fluid density is varied from the spinodal density where the 1D liquid is unstable to droplet formation to the density of bulk liquid ^4He. In this range, K varies from $K > 2$ at low density, where a robust superfluid is predicted, to $K < 0.5$, where fragile 1D superflow and solid-like peaks in $S(q)$ are predicted. For uniform pore walls, the ρ_S/ρ_0 scales as predicted by LL theory. The n(x) and g(x) show long range oscillations and decay with x as predicted by LL theory. The amplitude of the oscillations is large at high density (small K) and small at low density (large K). The K values obtained from different properties agree well verifying the internal structure of LL theory. In the presence of disorder, the ρ_S/ρ_0 does not scale as predicted by LL theory. A single v_J parameter in the LL theory that recovers LL scaling was not found. The OBDM in disorder is well predicted by LL theory. The dynamical superfluid fraction, ρ_S^D/ρ_0, is determined. The physics of the deviation from LL theory in disorder and the dynamical ρ_S^D/ρ_0 are discussed.