Temperature-dependent study of Bose gases: Crossover from three- to one-dimensional behavior

D. Blume and Kwangsik Nho
Department of Physics, Washington State University, Pullman, WA 99164-2814

To investigate the crossover of Bose gases from three-dimensional to one-dimensional behavior we consider N atoms under spherically harmonic confinement as well as under cylindrical harmonic confinement. With increasing aspect ratio λ, where $\lambda = \nu_\rho/\nu_z$ (ν_ρ and ν_z denote respectively the trapping frequency in the radial and axial directions), the energy scale associated with motion in the ρ-direction becomes larger than that associated with motion in the z-direction. For large λ, the system thus behaves effectively one-dimensional. We use the path integral Monte Carlo method to calculate thermal expectation values as a function of temperature, treating the $3N$ nuclear coordinates fully quantum mechanically. The interaction between particles is modeled by hardcore potentials with s-wave scattering length a_{sc}. For this model to be realistic, we require that a_{sc} is much smaller than the oscillator lengths a_ρ and a_z of the radial confinement and the axial confinement, respectively.

Our calculations characterize the high temperature regime, where the gas occupies excited modes in the ρ- and z-directions, as well as the medium temperature regime, where the gas occupies the lowest mode in the ρ-direction but excited modes in the z-direction. Characterization of the system at very low temperatures, where the gas occupies the ground state in the ρ- and the z-directions is computationally very demanding and beyond the scope of this work. We monitor the energetics and structural properties for small atom samples, $N = 27$, as a function of the temperature T, scattering length a_{sc} and aspect ratio λ. In addition, we monitor non-local expectation values such as the superfluid fraction. In the case of spherical confinement, the superfluid fraction reduces to a scalar. In the case of cylindrical confinement, in contrast, it is a tensorial quantity.