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Statistical properties and condensate fluctuation of attractive Bose gas with finite number of particles

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Abstract

We study the condensate fluctuation and several statistics of weakly interacting attractive Bose gas of ^7Li atoms in harmonic trap. Using exact recursion relation we calculate canonical ensemble partition function and study the thermal evolution of the condensate. As ^7Li condensate is associated with collapse, the number of condensate atom is truly finite and it facilitates to study the condensate in mesoscopic region. Being highly correlated, we utilize the two-body correlated basis function to get the many-body effective potential which is further used to calculate the energy levels. Taking van der Waals interaction as interatomic interaction we calculate several quantities like condensate fraction $\frac{<n_0>}{N}$, root-mean-square fluctuation δn_0 and different orders of central moments. We observe the effect of finite size on the calculation of condensate fluctuations and the effect of attractive interaction over the noninteracting limit. We observe the depletion of the condensate with increase in temperature. The calculated moments nicely exhibit the mesoscopic effect. The sharp fall in the root-mean-square fluctuation near the critical point signifies the possibility of phase transition.

Keywords: Attractive BEC, Statistical fluctuations
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1. Introduction

Although the statistics of confined ideal Bose gas is fully understood [1, 2, 3, 4], the same for finite number of interacting bosons in an external confining potential is complex and receives special attention. Some earlier works [5, 6] have been reported in this direction to study the ground state probability distribution (P_{n_0}) of ideal Bose gas and weakly interacting Bose gas in 1D, 2D and 3D also. These studies are basically done within the Bogoliubov approach. However none of the earlier works treats the real experimental situation. In actual experimental condition the number of bosons varies from a quite few to thousand for the attractive Bose-Einstein condensation (BEC) of ^7Li atoms [7]. Thus the attractive Bose gas is truly mesoscopic. Whereas for the repulsive Bose gas (like ^{23}Na, ^{87}Rb), the condensate is always stable even for quite large number of bosons ($\sim 10^7 - 10^8$) [8] in the trap and the statistics in thermodynamic limit is well understood. As the attractive Bose gas is always unstable after a critical number of atoms, the study of statistical properties and condensate fluctuation draw special interest. The effect of quantum fluctuation in truly finite size system makes the system more interesting. Different zero temperature properties of attractive BEC has extensively studied by several groups [9, 10].

However the use of most widely used grand canonical ensemble has been developed serious criticism as it predicts some unphysical fluctuations which is termed as grand-canonical catastrophe [11]. The use of canonical ensemble to calculate the fluctuation of mesoscopic condensate is mathematically complicated. In the first effort in this direction classical field approximation has been utilized for the study of statistical properties of one-dimensional Bose gas with attractive interaction [12]. Depletion of the condensate and several fluctuations in 1D has been reported [12]. Ground state probability distribution and different orders of statistical moments and their temperature dependence have been reported by several groups [13, 14, 15, 16, 17, 18, 19, 20]. In the present manuscript we consider the real experimental situation of ^7Li atoms in the harmonic trap [7]. All the chosen parameters resemble the experiment. For the calculation of energy levels we employ two-body correlated basis function and interatomic interaction is taken as the van der Waals interaction. The usage of the realistic interaction specially for the attractive Bose gas over the contact interaction (δ-type) has been discussed earlier [21]. It is to be noted that the contact interaction in 3D is associated with pathological singu-

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