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Thermodynamic properties of interacting trapped Bose gases

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The understanding of the interplay between quantum-statistical phenomena and the atomic interactions taking place in trapped degenerate gases may yet extend far our ability to control and harness the full potential of such exquisite, dilute quantum systems. In this scenario, a key role is played by the external trap potential, which defines the spatial dissociation of the condensate and thermal fraction, at finite temperatures. The decoupled spatial spread may be clearly observed using simple techniques such as absorption imaging, allowing for detailed studies of the physical properties of the system. Many previous works already mapped the properties of condensed gases at very low temperatures ($\ll T_c$), with negligible thermal fraction. In the Thomas-Fermi regime, the general behavior of condensates is essentially set by the interplay between the external (trap) potential and the atomic interactions. At higher temperatures, yet below Tc, the thermal fraction becomes meaningful to the system, even if it is much more dilute than the condensate. In these conditions, the kinetic energy per thermal atom grow larger than the mean-field energy, though the ideal gas behavior remains mostly valid. Note that, most fundamental thermodynamical properties, such as the condensed/thermal fraction and the mean energy, are experimentally measurable. Detailed comparison of experimental results, acquired under actual laboratory conditions of finite temperature and number, with theoretical frameworks including the atomic interactions are yet very few. Moreover, to the best of our knowledge, simple analytical models, accounting for the interactions, ready to guide experimental measurements and initial analysis are still not available in the literature. We then present here an alternative theoretical framework, based on the density-of-state approach, which allows for an analytical evaluation of the thermodynamics of trapped Bose gases. In this work, we start by determining a better and more accurate density of states for an ideal trapped system, particular to the chosen spheroid geometry (oblate or prolate). We then derive two fundamental state variables of the system, the total number of atoms and the total internal energy. Next we determine other interesting quantities such as the number density, the chemical potential, the heat capacity, and the isothermal compressibility. The results are then analyzed near the temperature range of interest, running across the critical temperature. We compared our result with those presented in the literature to draw the conclusions and suggest some follow-up work.

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