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Bose–Einstein condensation in low dimensional systems with deformed bosons

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HIGHLIGHTS

- The low-temperature behavior of deformed bosons in low dimensions is studied.
- The critical temperature of a deformed boson gas is connected with the values of p, q.
- The conditions under which the Bose–Einstein condensation occurs in low dimensions are analyzed.
- Deformed bosons exhibit anyonic type of behavior in two dimensions in the range $(p, q) > 1$.
- A new generalized bosonic distribution function for Bose systems is proposed.

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ABSTRACT

We study the low and high temperature thermostatistical properties of a deformed boson gas constructed by the bosonic intermediate-statistics particles confined in low spatial dimensions. Many of the deformed thermodynamical functions of the system such as internal energy and entropy are investigated by means of some elements of the Fibonacci calculus. Particular emphasis is given to a careful analysis on low dimensional systems of such deformed bosons, and the conditions under which the Bose–Einstein condensation would occur in such systems are discussed. We show that low dimensional systems with deformed bosons exhibit the Bose–Einstein condensation for values of the model deformation parameters (p, q) greater than one. We also study possible anyonic behavior of the model for high temperatures. The results obtained in this work reveal that the present deformed boson gas model can be used for modeling nonlinear behavior

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of systems with quasiparticles encountered in several areas of research particularly in quantum science.

1. Introduction

Since it was first predicted by Bose [1] and Einstein [2], both theoretical and experimental aspects [3,4] of Bose–Einstein condensation (BEC) have been attracted a great deal of interest in many ways. BEC can be understood as a macroscopically large number of particles accumulating in a single quantum state [5,6] and thus, the system under consideration undergoes a phase transition. Many of the experimental achievements on BEC have been appeared in the literature such as in [7]. These studies have stimulated the related theoretical investigations by using different approximations. It is also known that BEC is possible for free boson gas only when spatial dimensionality of the system is greater than two. We should mention that much effort has been made to discuss the thermodynamical and statistical properties of BEC for systems with arbitrary dimensions [8–12]. Apart from these studies, quantum statistics of the two-dimensional ideal boson and fermion gases has been discussed by May [13], and later by Ziff, Uhlenbeck, Kac [14] thermodynamical properties of the ideal Bose–Einstein gas have been studied for spatial dimensions greater than one. Both of these studies have been reported that there is no condensation for the usual boson gas in the two and one spatial dimensions.

On the other hand, it was recently shown in [4,7,11] that although interactions among the particles of a real gas are very important in every sense, their effects on both the condensation temperature of BEC and the ground-state fraction of particles are several percent. This gives us an important clue to approximate such systems by viewing their particles as free ones. Hence, we pursue such an idea in the present article, and will consider an intermediate-statistics boson gas model containing the particles as deformed bosons confined in the two and one spatial dimensions.

Furthermore, thermodynamical and statistical properties of the one-parameter deformed boson and fermion gases have been extensively investigated for three dimensions [15–32] and some of their implications on the theoretical researches of BEC have been discussed to some extent [33–38]. However, physical applications made by the use of two-parameter deformed boson and fermion oscillator systems have recently emerged some new developments, which are remarkably different from the ones with just one deformation parameter on the same applications. For instance, some of the thermal and electrical properties of a solid through the bosonic Fibonacci oscillators and their applications in the Debye model have been discussed in [39–41]. These studies have led to the result that the deformation parameters (p, q) of bosonic Fibonacci oscillators may act as factors of impurities and disorders. Moreover, a special kind of two-parameter deformed Bose gas model called the $(\tilde{\mu}, q)$-deformed Bose gas model has effectively led to interesting implications on the details of both compositeness of particles and their interactions [42–45]. It is also known from the study of Avancini and Krein [46] that many-body problems of composite particles can be described by q-deformed bosons. Such a proposition has been extended to the case of two-parameter deformed bosonic oscillator system in order to effectively describe the observed non-Bose like behavior of two-pion correlation function intercepts [47]. In addition to this, composite bosons (or quasibosons) are realizable by deformed oscillators and their internal entanglement characteristics have been linked to the parameter of bosonic deformation [48]. Besides, the idea that one-parameter deformed non-interacting many-body system can be interpreted as describing a non-deformed interacting system has been investigated via the virial expansion of q-bosons' ensemble [49,50]. Such an idea has led to a possibility to find out an equivalence between bosonic deformation and physical interactions of particles in the system under consideration. As we have stressed above, the physical results obtained from a two-parameter deformed boson oscillator system exhibit different consequences, and they provide extra advantageous in order to fit some nonlinear behavior observed in phenomenological applications in several areas of research such as in quantum optics [51] and quantum computing [52]. In particular, quantum group covariant boson and fermion gas models have been revealed some interesting consequences, especially when they confined to two dimensional spaces [53]. However, it