Bulletin of Pure and Applied Sciences.
Vol.39 D (Physics), No.2,
July-December 2020 P.163-168
Original Research Article

Print version ISSN 0970 6569
Online version ISSN 2320 3218
DOI: 10.5958/2320-3218.2020.00024.X
Available online at www.bpasjournals.com

Effects of Externally Applied Electric and Magnetic Fields on Bose-Einstein Condensation of Charged Bose Gas

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Received on 11.03.2020
Accepted on 11.10.2020

ABSTRACT We have studied the effects of the externally applied electric and magnetic fields on Bose-Einstein condensation of the charged Bose gas. We have used a model density of states which takes the finite sample size into account to calculate the thermodynamic quantities. We have obtained condensate fraction, chemical potential, total energy and specific heat of the system using the semi classical density of states. We have studied the possibility for achieving Bose-Einstein condensation in three dimensional non interacting charged Bose gas under the cross electric and magnetic fields. The external fields made the system inhomogeneous and altered the Bose-Einstein condensation characteristics compared to the homogeneous case. We have found that the non interacting system of charged boson undergo Bose- Einstein condensation when external electric and magnetic fields were applied. The discontinuity in the specific heat was found as a function of external potentials. The obtained results were found in good agreement with previously obtained results.

KEYWORDS Bose-Einstein condensation, Bose-gas, density of state, chemical potential, non interacting, inhomogeneous

INTRODUCTION

Griffin et al.[1] and Salje et al.[2] studied that condensation of a charged Bose gas is not a correct picture of superconductivity in metals. They presented the high temperature superconductivity in cuprates. Schafroth[3] pointed out that the charged Bose gas does not condense at any finite temperature in the presence of a homogeneous magnetic field. The charged Bose system in a magnetic field was studied by Tomas[4] and Daicic[5]. Rojas[6] presented the possibility of obtaining Bose-Einstein condensation for charged Bose gas under a constant magnetic field. Standen et al.[7] studied that three dimensional charged Bose gas does not have phase transition for any value of the magnetic field. Charged Bose gas in the presence of harmonic trapping potential and a constant magnetic field was studied within path integral formalism[8]. Anderson et al.[9] and Han et al.[10] observed that the Bose-Einstein condensation in trapped atomic gases have renewed interest in bosonic systems[11-13]. The condensate clouds obtained in the experiments consist of a finite number of atoms and are confined in externally applied trapping potentials. Fujita et al.[14] investigated the magnetism and the superconductivity of the electron doped $\mathrm{Pr}_{1-x}LaCe_xCuSo_4$ by means of zero field muon spin rotation and magenetic susceptibility measurements. Bulk superconductivity was indentified in a wide C_e concentration range of $0.09 \le x \le 0.20$ with a maximum transition temperature of 26K. Abrupt appearance of the superconducting phase at $x \sim 0.09$ was concominant with a destroy of the anti ferromagnetic ordered phase, indicating the competitive relation between two phases. Kurhashi et al.[15] presented universal feature in the phase diagram of electron doped system is still controversial due to the limited number of comprehensive studies on both magnetism and superconducting. Kumar, Gaim et al.[16] studied tunneling spectroscopy of N_b coupled carbon nanotube quantum dot revealed the formation of pairs of Andreev bound states within the superconducting gap. Their experimental findings well supported by model calculations based on the super conducting Anderson model. A weak replica of the lower Andreev bound states was found, which was generated by quasi particle from the Andreev bound states to the Al tunnel probe. The proximity effect in a super conductor coupled to a mesoscopic normal conductor leaded to a wide range of new quantum phenomena. These included Andreev reflection at normal and superconductor interfaces, the formation of Andreev bound states in confined geometries and proximity induced super current flow through normal conductors[17-18]. Mourik et al.[19] showed Majorana states in superconductor coupled nanostructure devices with strong spin orbit interaction received significant experimental and theoretical interest and opened a new area of research. The obtained results were compared with previously obtained results.

METHOD

We have considered N particles of a charged Bose gas in an external field which is described by a monotonic potential $V(x)$ and trapped by two infinite barriers at $x=0$ and L using the semi classical WKB approximation for the energy is gives as

$$\sqrt{2m}\int_0^{x_n}\sqrt{\varepsilon_n - V(x)}dx = \hbar\pi\left(n+\frac{\phi}{4}+\frac{\psi}{2}\right)$$

Where n=0, 1, 2, …… and the classical turning point x_n and the phase factor ϕ and ψ are given by $V(x_n)=\varepsilon_n$, $\phi=1$ and $\psi=1$ for $\varepsilon_n < V(L)$, while $x_n = L$, $\phi=2$ and $\psi=1$ for $\varepsilon_n \ge V(L)$ large values of L, ε_n becomes a quasi-continuous function of n and the semi classical approximation is identical to the exact results. The density of states can be calculated from the trace formula

$$\rho(E) = Tr\delta\left(E-\hat{H}\right)$$

Where $\hat{H}$ is the Hamiltonian of the system? The total number of particles is implicitly related to the chemical potential is given by

$$N = N_0 + \int \rho(E)n(E)dE\,.$$

Where N_0 is the number of particles in the ground state and

$$n(E) = \left\{\exp\frac{\left[(E-\mu)\right]}{k_BT} - 1\right\}^{-1}$$

The critical temperature Tc is determined from above equation by taking $N_0 = 0$ and $\mu = 0$ at T=Tc. For $T < T_C$, the condensate function $\frac{N_0}{N}$ is determined from above equation and total energy of the system is given by

$$E_T(T) = \int \frac{E\rho(E)dE}{\exp(E/k_B T) - 1}$$

For T > Tc after finding μ value and taking $N_0 = 0$, the total energy is calculated as

$$E_T(T) = \int E\rho(E)n(E)dE \, .$$

The discontinuity in the specific heat at Tc is given as

$$\Delta C_V(Tc) = C_V\left(T_C^-\right) - C_V\left(T_C^-\right)$$

$$= \frac{1}{k_B Tc^2} \frac{\left[\int E\rho(E)n(E)^2 \exp\left(\frac{E}{k_B Tc}\right) dE\right]^2}{\int \rho(E)n(E)^2 \exp\left(\frac{E}{k_B Tc}\right) dE}$$

The effects of external potentials i.e. magnetic and electric fields are embodied in the density of states and the resulting thermodynamic properties depend crucially on the choice and construction of the density of states.

RESULTS AND DISCUSSION

Figure (1) shows the temperature dependence of the condensate fraction $\frac{No}{N}$ for various field strengths or external potential value Vo. In the case of a homogeneous system the temperature dependence of the condensate fraction is given by $\frac{No}{N} = 1 - \left(\frac{T}{Tc}\right)^{\frac{3}{2}}$. The other extreme is the bosons trapped by a linear potential. The corresponding depletion of the condensate is given by $\frac{No}{N} = 1 - \left(\frac{T}{Tc}\right)^{\frac{5}{2}}$. For small values of V_0 recover the homogeneous system results. As V_0 is increased the result approached the latter case indicating that the confinement effects become important. The net effect of the external electric field in this model is to provide a confining potential to produce Bose-Einstein condensation in a linear potential. Figure (2) shows the condensate fraction for various combinations of the crossed electric and magnetic field strength. The presence of a magnetic field and the peaked nature of the density of state gives rise to a non monotone dependence in terms of various combinations of the parameters V_0 and E_0. Figure (3) shows that in the presence of the magnetic field, the specific heat discontinuity is observed at the critical temperature. Results show the occurrence of a Bose-Einstein condensation in a confining potential when the applied magnetic field is not too strong. Figure (3) also shows that if we decrease the amplitude of trapping potential V_0 when magnetic field is constant then discontinuity in the specific heat decreases. This shows disappearance of Bose-Einstein condensation in a magnetic field for homogeneous systems.

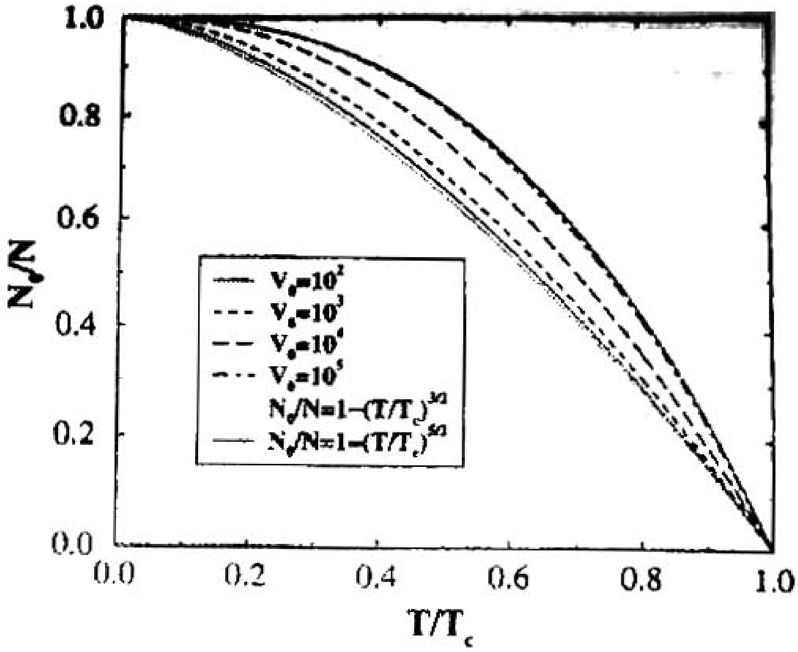

Figure 1: The condensate fraction N_0 / N versus normalized temperature T / T_0 for $N = 10^5$ and for various values of the trapping potential (electric field) V_0.

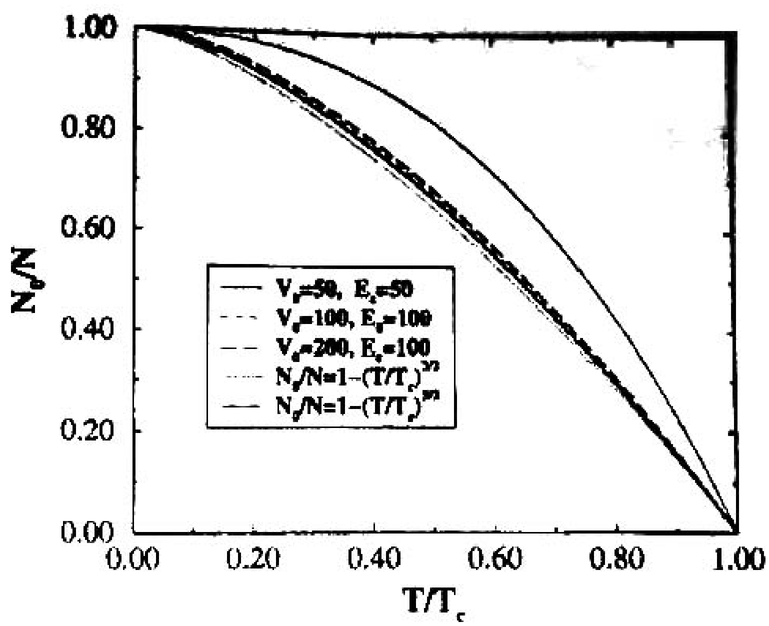

Figure 2: The condensate fraction N_0 / N versus normalized temperature T / T_0 for $N = 10^5$ and for various values of the electric and magnetic fields.

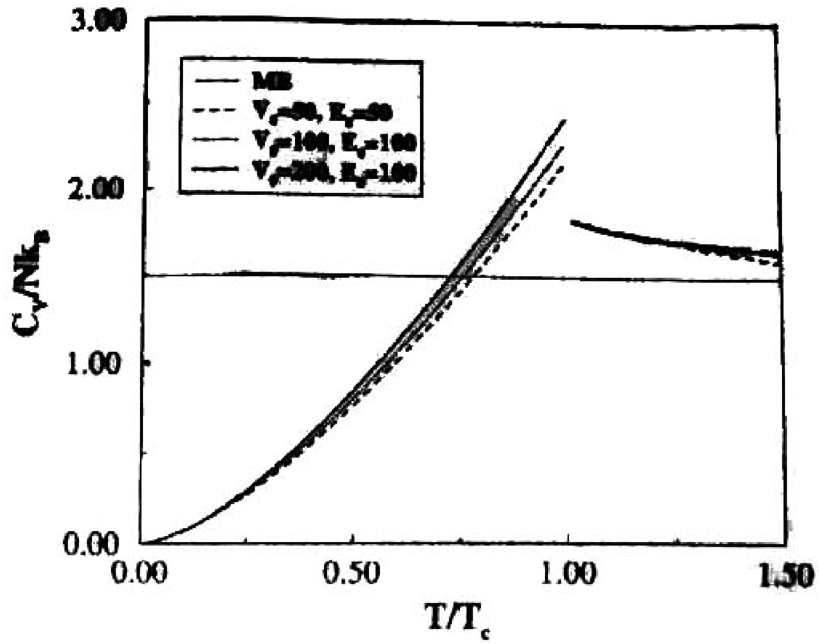

Figure 3: The temperature dependence of the specific heat $C_v(T)$ for $N = 10^5$ and for various values of the electric and magnetic fields.

CONCLUSION

We have studied the effects of the externally applied electric and magnetic fields on Bose-Einstein condensation of charged Bose-gas. The long range interactions between the charged bosons were neglected with assumption that screening effects rendered them short ranged. The thermodynamic properties of non interacting charged bosons in the presence of exgernally applied electric and magnetic fields were studied. We have found that Bose-Einstein condensation of the charged Bose-gas occurred in the crossed electric and magnetic fields. We have used a model density of states in which we have taken the finite sample size into consideration to calculate the thermodynamic quantities. We have obtained the condensate fraction, chemical potential, total energy and specific heat of a system of finite number of charged Bose particles. We have found that Bose-Einstein condensation is possible in three dimensional non interacting charged Bose gas under crossed electric and magnetic fields. The obtained results were compared with previously obtained results of theoretical and experimental works and were found in good agreement.

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