J. At. Mol. Sci.
doi: 10.4208/jams.060410.070410a

Vol. **2**, No. 1, pp. 43-50
February 2011

Influence of homogeneous weak electric field on the chemical potential and heat capacity of charged fermion system

Yan-Qing Sun*, Shu-Ming Long, Chao-Jun Huang,
and Ben-Zhuo Lou

Department of Physics, Shaanxi University of Technology, Hanzhong 723001, China

Received 4 June 2010; Accepted (in revised version) 4 July 2010
Published Online 17 January 2011

Abstract. In light of the semiclassical (Thomas-Fermi) approximation method, the thermodynamic properties of the charged fermion system in homogeneous weak electric field are studied. After deriving the relationship of chemical potential and heat capacity of charged fermion system changed with the external electric field, then the analytic formula of the chemical potential and heat capacity of charged fermion system in the high and low temperature approximation condition is desired. Moreover, the influence of the homogeneous weak electric field on the chemical potential and heat capacity are analyzed.

PACS: 05.30.-d, 51.30.+i

Key words: charged fermion, chemical potential,heat capacity, homogeneous weak electric field

---

1 Introduction

The Bose-Einstein condensation (BEC) was originally conceived in 1925 by Albert Einstein, who calculated that if a gas of atoms could be cooled below a transition temperature, it should suddenly condense into a remarkable state in which all the atoms have exactly the same location and energy. In other words, the wave-function of each atom in a Bose-Einstein condensate should extend across the entire sample of gas. In 1995, Eric A. Cornell, Carl E. Wieman and Wolfgang Ketterle directly proved BEC by using the optic cooling and magnetic trap techniques in experiment [1–7]. The abnormal properties of BEC possess potential appliance value in the fields of chip technology, precision measurement, nano-technology, etc. With the development and improvement of experimental techniques, extensive research on the thermodynamic properties of Fermi gas in an external electric field there has been conducted and a large number of meaningful results have been obtained [8–21].

---

*Corresponding author. *Email address:* yqsun_hz@163.com (Y. Q. Sun)

Uniform electric field is easy to realize and control experimentally. In uniform electric field, the charged system contains particles has different properties compared with the free-particle system [22]. Therefore, it is very meaningful to study the thermodynamic properties of charged fermion system in uniform electric field and compare with the one of free-particle system. The study on the effect of weak electric field with the simplest space distribution on the thermodynamic properties of matter system will lay a foundation for further study on the external electric field with the complex time-space distribution.

In this paper, the thermodynamic properties of charged fermion system in homogeneous weak electric field are studied by using the semiclassical approximation of statistical physics. After deriving the relationship of the chemical potential and heat capacity of charged fermion system changed with external electric field, then the analytic formula of the chemical potential and heat capacity of charged fermion system at high and low temperature, and the influence of the homogeneous weak electric field on the chemical potential and heat capacity are analyzed. In addition, the thermodynamic properties of charged and free fermion system in homogeneous weak electric field are also compared.

2 Total population and total energy of fermion system

It is assumed that N fermion system are restricted in a cylindrical chamber with a basal area of S and height of L, the charge and mass of each fermion system are q and m respectively. When a uniform electric field is external along the axial direction of the cylindrical chamber regarded as x axis, the energy of a single fermion in the case of ignoring the influence of gravity can be expressed as

$$\varepsilon=\frac{p_x^2+p_y^2+p_z^2}{2m}-qEx, \tag{1}$$

where E is the strength of homogeneous weak electric field, and then the electric potential energy $u(x)$ in this electric field is $-qEx$.

The N rarefied charged fermion with the energy of ε occupy the space volume of V in a weak uniform electric field, where the population N tends to infinity. If neglecting the interparticle weak interaction and the kinetic energy of fermion being much larger than its potential energy, the semiclassical (Thomas-Fermi) approximate method is applicable. Let g be the possible spin degeneracy of the charged fermion (as the electronic spin degeneracy $g=2$), the possible quantum state density with the consideration of all above can be represented as

$$\begin{aligned} D(\varepsilon)&=\frac{2\pi g(2m)^{3/2}V}{h^3L}\int_0^L\sqrt{\varepsilon+qEx}\,dx\\ &\approx\frac{2\pi g(2m)^{3/2}V\varepsilon^{1/2}}{h^3}\left(1+\frac{qEL}{4\varepsilon}\right). \end{aligned} \tag{2}$$

Defining the system fugacity $z=e^{\mu/kT}$, the particle occupation number of the energy state ε