QUANTUM COHESION OSCILLATION OF ELECTRON GROUND STATE IN LOW TEMPERATURE LASER PLASMA

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Abstract

The development of radically new technological and economically efficient methods for obtaining chemical products and for producing new materials with specific properties requires the study of physical and chemical processes proceeding at temperature of 10^3 to 10^4K, temperature range of low temperature plasma. In our paper, by means of Wigner matrix of quantum statistical theory, a formula is derived for the energy of quantum coherent oscillation of electron ground state in laser plasma at low temperature. The collective behavior would be important in ion and ion-molecule reactions.

1 Introduction

The low temperature plasma is characterized by a partial or complete ionization of atoms and molecules, naturally such a plasma is quasi-neutral. Great opportunities for obtaining such a plasma, which from a chemist's viewpoint is temperature range, have arisen as a result for studies in the field of laser[1]. Because of the development of laser techniques, the problem of chemical reactions in a plasma was found to be realizable at a substantially new technological level than was possible many years ago when the first rather timid and technically imperfect attempts were undertaken in this field. At present, the low temperature plasma affords the possibility of conducting chemical processes at temperature up to 10^4K, at pressures ranging from 10^{-4} to $10^4 atm$, under both equilibrium and nonequilibrium conditions. The character of chemical conversions that occur at temperature of the order of several thousand degrees is largely determined by thermodynamic properties of substances which take part in a reaction at one or another of its stage. Given reliable thermodynamic constants, it should be possible to determine, in most cases, optimal temperature conditions for reactions, values of product yields expected, and energy indices of the process. At the same time, the course of reaction depends, as a rule, not only on the thermodynamic properties of a reacting system. Prior to converting to equilibrium state, determined by the thermodynamics of reaction, the system experiences a series of intermediate stages. The rate at which the system goes through these stages is determined by the kinetics of the process. That is, the rate of achieving equilibrium energy distribution according to degrees of freedom is determined by physical kinetics and the rate of achieving equilibrium chemical composition is determined by chemical kinetics[2]. In this case, the plasma chemical reactions are characterized by the strong mutual effects of the factors of the physical and chemical kinetics. The terminal rate of setting up equilibrium energy distribution according to different degree of freedom in some cases limits the possibility of using the classical or quantum methods of chemical kinetics based on assumption about energy distribution in the reacting system. In this paper, the energy of coherent oscillation of electron ground state in laser plasma is derived in the presence of neutralizing background. Laser field and collective cohesion behavior in laser plasma would be important in above physical and chemical kinetics.

2 Quantum Cohesion Oscillation of Electron Ground State

We shall study assemblies of charged particle in conditions such that the laws of classical mechanics are no longer an adequate approximation and quantum effects become important or even dominant. The long range Coulomb interaction retain, of course, their main properties, which have been investigated in detail. However, the manifestation of these properties will in general be different because the Coulomb effects are combined with and corrected by quantum mechanical effects. The most convenient method for doing this is the method of second quantization. In this paper a formula is derived for the energy of quantum coherent oscillation of electron ground state in laser plasma at low temperature by means of Wigner matrix of quantum statistical theory. It shows the change of structure of the ground state in the presence of long range Coulomb interactions. We consider the model of a gas of charged particles in the presence of a continuous neutralizing background. The hamiltonian of this system is :

$$\begin{aligned} H &= \sum_{\mathbf{k}} \epsilon_{\mathbf{k}} \hat{a}^{+}(\hbar\mathbf{k})\hat{a}(\hbar\mathbf{k}) \\ &+ \frac{1}{2}e^2 \sum_{\mathbf{k}}\sum_{\mathbf{l}}\sum_{\mathbf{p}}\sum_{\mathbf{q}} < \mathbf{kl}|V|\mathbf{pq} > \delta_{\mathbf{k+l-p-q}} \hat{a}^{+}(\hbar\mathbf{k})\hat{a}^{+}(\hbar\mathbf{l})\hat{a}(\hbar\mathbf{p})\hat{a}(\hbar\mathbf{q}) \end{aligned} \tag{1}$$

where $\mathbf{k}\cdots\mathbf{q}$ are wave vectors, $\hat{a}^{+}(\hbar\mathbf{k})$ and $\hat{a}(\hbar\mathbf{k})$ are respectively creation and destruction operators of the particle with momentum $\hbar\mathbf{k}$. the normalized one particle wave function is

$$|\mathbf{k} >< \mathbf{k}|\mathbf{x} >= \Omega^{\frac{-1}{2}} e^{i\mathbf{k}\cdot\mathbf{x}}|\mathbf{k} > \tag{2}$$

where Ω is volume. Therefore the matrix is

$$< \mathbf{k}| \sum_{\mathbf{k}} \epsilon_{\mathbf{k}} \hat{a}^{+}(\hbar\mathbf{k}) a(\hbar\mathbf{k})|\mathbf{k} >= \hbar^2\mathbf{k}^2/2m \tag{3}$$

where m is the mass of the particle.

$$< \mathbf{kl}|V|\mathbf{pq} > \delta_{\mathbf{k+l-p-q}} = (8\pi^3/\Omega)[V_{|\mathbf{k-q}|} + \theta V_{|\mathbf{k-p}|}]\delta_{\mathbf{k+l-p-q}} \tag{4}$$

$V_{|\mathbf{k}|}$ is the Fourier transform of the long range potential. Using Wigner matrix[3] and Weyl rule[4] the collective part of correlation energy E of particles becomes:

$$E = (\hbar/8\pi^3 c)(1/4) \int_0^{e^2} d\eta\eta^{-1}\omega_p(\eta) \int_{k<k_c} d\mathbf{k} \int_0^{\infty} d\omega[\delta(\omega+\omega_p) + \delta(\omega-\omega_p)] \tag{5}$$

where k_c is a critical value of k, e is the absolute value of electron charge , ω_p is quantized oscillator frequency. Hence the final result is

$$E = \frac{1}{n}\int_{k<k_c} (\frac{1}{2}\hbar\omega_p)(\frac{d\mathbf{k}}{8\pi^3}) \tag{6}$$

where n is average number density.

3 Conclusions

This result has a extremely suggestive form. It shows that the collective contribution to the ground state energy is precisely the energy of a collection of quantized oscillators of frequency ω_p. It confirms quantitatively the remark, showing how deep is the change of structure of the ground state in the presence of long range interaction. The latter organize the motion of the particle in such a way that a significant part of the ground state energy comes from large groups of particle oscillating in phase[5][6]. This cohesion is perhaps the most characteristic feature of the collective behavior of charged particle. The rate of ionization at a sufficiently high electron concentration is determined by that of Kinetic energy transfer to electron in elastic collisions. In the case of plasma produced by ionizing irradiation of a cold gas, ionization will be ensured by a group of fast electrons with an energy imparted by emission, where as collisions of electrons with heavy particles will decrease the kinetic energy of electron to those inducing no ionization.

References

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