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COLLISION FREQUENCY AND FREE LENGTH PATH OF ELECTRONS OF SEMICLASSICAL DENSE PLASMA

Nowadays the study of collision processes of dense semiclassical plasma is of considerable interest in many experimental facilities. The paper studies the collision processes of dense semiclassical plasma taking into account the quantum mechanical effects of diffraction and symmetry at small distances and the effects of screening of charge's field at large distances. The collision characteristics of dense semiclassical plasma are obtained numerically such as the dependences of the electron collision frequency on the parameter of nonideality and the free length path of electrons on the parameter of nonideality are determined. It has shown that taking into account the screening effect and quantum-mechanical effects of diffraction and symmetry in dense semiclassical plasma leads to a maximum on the electron collision frequency's curve at certain values of the nonideality parameter. The free length path of electrons has a minimum in some values of the nonideality parameter.

Key words: dense plasma, semiclassical plasma, collision processes, collision frequency of electrons, free length path of electrons.

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Частота столкновений и длина свободного пробега электронов плотной квазиклассической плазмы

В настоящее время исследование столкновительных процессов плотной квазиклассической плазмы, реализующиеся во многих устройствах, представляет значительный интерес. В работе исследованы столкновительные процессы плотной квазиклассической плазмы с учетом квантово-механических эффектов дифракции и симметрии на малых расстояниях и эффекты экранировки поля зарядов на больших расстояниях. Столкновительные характеристики плотной квазиклассической плазмы получены численно, например, определены зависимости частоты столкновений электронов от параметра неидеальности и длины свободного пробега электронов от параметра неидеальности и плотности плазмы. Показано, что учет эффекта экранировки и квантово-механических эффектов дифракции и симметрии в плотной квазиклассической плазме при определенных значениях параметра неидеальности приводит к появлению максимума на кривой частоты столкновений электронов. А длина свободного пробега электронов имеет минимум в некоторых значениях параметра неидеальности.

Ключевые слова: плотная плазма, квазиклассическая плазма, столкновительные процессы, частота столкновений электронов, длина свободного пробега электронов.

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Тығыз квазиклассикалық плазмадағы электрондардың соқтығысу жиілігі мен еркін жүру жолы

Көптеген құрылғыларда пайда болатын тығыз квазиклассикалық плазманың соқтығысу құбылыстарын зерттеу бүгінгі таңда айтарлықтай қызығушылық танытады. Бұл жұмыста тығыз квазиклассикалық плазманың соқтығысу процестері шағын қашықтықтардағы квант-механикалық дифракция және симметрия құбылысы мен өріс зарядтарының үлкен қашықтықтардағы экрандалу құбылысы ескеріле отырып зерттелген. Квазиклассикалық тығыз плазмадағы соқтығысу құбылыстары бөлшектердің әсерлесуінің эффективті потенциалы негізінде сандық түрде есептелген, мысалы электрондардың соқтығысу жиілігінің идеал емес параметріне және еркін жүру жолының идеал емес параметріне тәуелділіктері алынған. Тығыз квазиклассикалық плазмадағы экрандалу және кванттық құбылыстарын ескеретін болсақ, идеал емес параметрдің кейбір мәндері үшін электрондардың соқтығысу жиілігінің қисығында максимумның туындауына әкелетіні көрсетілген. Ал электрондардың еркін жүру жолының ұзындығы идеал емес параметрдің кейбір мәнінде минимумға ие болады.

Түйін сөздер: тығыз плазма, квазиклассикалық плазма, соқтығысу процестері, электрондардың соқтығысу жиілігі, электрондардың еркін жүру жолы.

Introduction

Modern theoretical studies of plasma physics suggest comparing the results with a very highly developed experiment, this is true in relation to both laboratory and space plasma. Most of the simplest effects are known, so it is relevant to consider rather complex collision processes of dense semiclassical plasma [1-4]. To date, investigation of the collision processes such as the collision frequency and the free length path of electrons of dense semiclassical plasma are an actual problem, as such plasma is realized in many experimental devices: in the implementation of the idea of controlled thermonuclear fusion, in the collision with a rigid barrier of metal liners, in MHD generators, rocket movements with gaseous nuclear reactors, with a powerful electric discharge in liquid, with an electric explosion of conductors, with optical and microwave discharges in gas and etc [5-9]. For the collision frequency of electrons, the most notable feature is the non-monotonic nature of its dependence on the nonideality parameter of the plasma, which has a maximum in the case of dense plasma containing once charged ions under the nonideality parameter [10-19]. The calculation of the collision coefficients remains one of the most urgent problems of the physical kinetics of the semiclassical plasma. The great interest represents the research, allowed to obtain reliable information on the collisional properties of dense semiclassical plasma. When studying the physical properties of such the plasma located in an external electric field, it is necessary to take into account the effects of screening and quantum mechanical effects of diffraction and symmetry.

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Calculation and discussion

The study used dimensionless parameters characterizing the system: nonideal parameter $\gamma = e^2/(r_D k_B T)$; density parameter $r_S = r_D / a_B$, where r_D, a_B – the Debye radius and the radius of the Bor.

As the description of interaction of charged particles in a classical plasma is used the pseudopotential, which takes into account the correlation effects of higher order at large distances [20-21]:

$$\Phi(R) = \frac{\gamma}{R} e^{-R} \frac{1+\gamma \dfrac{f(R)}{2}}{1+c(\gamma)}, \qquad (1)$$

$$f(R)=(e^{-\sqrt{\gamma R}}-1)(1-e^{-2R})/5\,,$$

$$c(\gamma)=-\,0.008617+0.455861\ \ \gamma-0.108389\ \gamma^2+0.009377\ \gamma^3,$$

where $c(\gamma)$ – is the correction factor for different γ nonideal parameters obtained on the basis of cubic interpolation.

Also to describe the interaction of charged particles in semiclassical dense plasma used the effective potential that takes into account the effect of screening and quantum effects [22]:

$$\Phi_{\alpha\beta}(r)=\frac{Z_\alpha Z_\beta e^2}{\sqrt{1-4\lambda_{\alpha\beta}^2/r_D^2}}\left(\frac{e^{-Br}}{r}-\frac{e^{-Ar}}{r}\right),\qquad(2)$$

$$A^2=\frac{1}{2\lambda^2}\left(1+\sqrt{1-\lambda_{\alpha\beta}^2/r_D^2}\right),$$

$$B^2=\frac{1}{2\lambda^2}\left(1-\sqrt{1-\lambda_{\alpha\beta}^2/r_D^2}\right),$$

$r_D=\left(k_BT/\left(4\pi e^2\sum_j n_jZ_j^2\right)\right)^{1/2}$ – the Debye radius, $Z_\alpha e, Z_\beta e$ – the electric charges of α and β particles, $\lambda_{\alpha\beta}=h/\sqrt{2\pi m_{\alpha\beta}k_BT}$ – the length of the de-Broglie, $m_{\alpha\beta}=m_\alpha m_\beta/(m_\alpha+m_\beta)$ – the reduced mass of the α and β particles.

The free path length of electrons:

$$\lambda_e=\frac{m_e^2\upsilon^4}{4\pi ne^4\lambda(\Lambda)}\qquad(3)$$

The electron collision frequency:

$$v_e=\frac{4\pi ne^4}{m_e^2\upsilon^3}\lambda(\Lambda).\qquad(4)$$

The collisions frequency of electrons and the free length path of electrons are computed using the Coulomb logarithm [23]:

$$\lambda(\Lambda)=\frac{1}{p_\perp^{\,2}}\int_0^{b_{\max}}\sin^2\left(\frac{\theta_c}{2}\right)\rho\,d\rho\,,\qquad(5)$$

where $p_\perp=ee'/\mu\upsilon^2$ is the impact parameter,

The integral (5) was solved numerically by Euler's method and Simpson. Solving the scattering angle of the particles, it is possible to obtain the collisional characteristics of dense plasma, such as scattering cross-section, the free length and frequency of the particles based on the effective pseudopotential models.

Figure 1 shows the dependence of the electron collision frequency on the parameter of the nonideality of dense semiclassical plasma on the basis of different pseudopotentials.

It is shown that the collision frequency curve based on the effective potential (2) is lower than in the case of pseudopotential (1). It is seen that the account of the screening effect and quantum-mechanical effects leads to a decrease in the frequency of electron collisions with an increase in the non-ideal parameter. Figure 2 shows the results of the electron collision frequency calculated using the Coulomb logarithm on the nonideality parameter based on the effective potential (2) of dense semiclassical plasma at different r_s values. It is seen that as the density parameter increases, the frequency of electron collisions also increases [24, 25]. The results of the calculations are presented in figure 3 in dependence of the mean free length path of the electrons on the parameter of the nonideality of dense semiclassical plasma where it is seen that the mean free length path of electrons for the pseudopotential model (1) lies higher than the corresponding data for the effective potential, which taking into account quantum-mechanical effects of diffraction and the effect of screening (2). Figure 4 shows the dependence of the free length path of electrons at different values of the density parameter [26]. The mean free length path of the electrons obtained on the basis of the effective pseudopotential of the interaction of the particles increases with the increase of the density parameter when accounting for the effect of screening and quantum effects. This all effects may be due to the increasing role of quantum effects, which leads to a decrease in the scattering cross section of the particles.

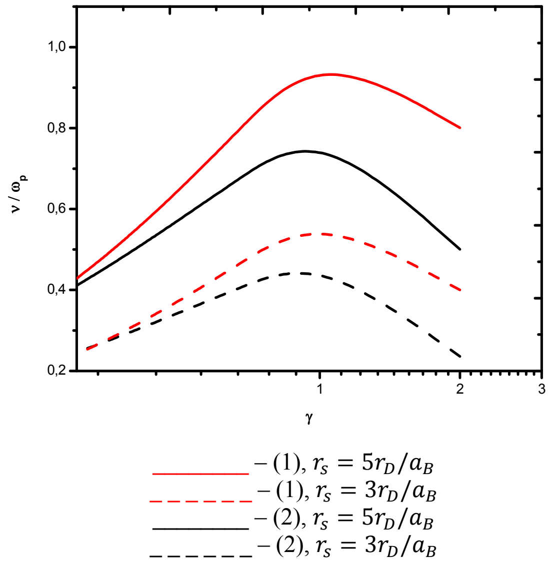

Figure 1 – The dependence of the electron collision frequency on the nonideal parameter based on the (1) and (2) potentials of dense plasma.

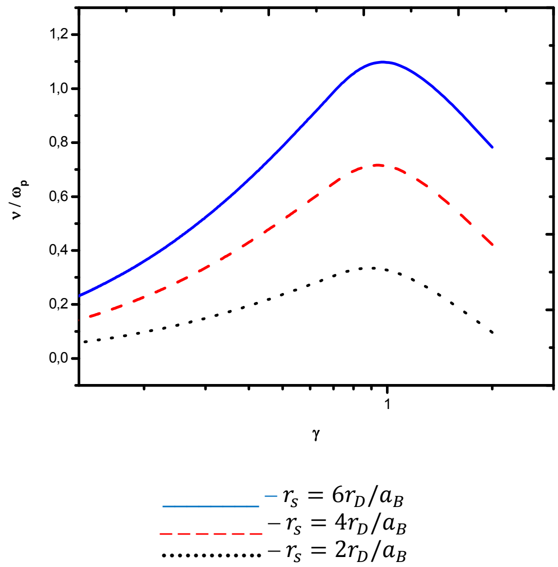

Figure 2 – The dependence of the electron collision frequency on the nonideal parameter based on the effective potential of dense semiclassical plasma.

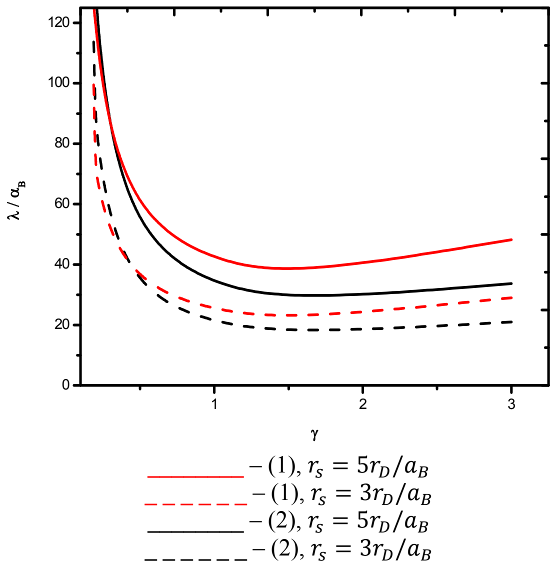

Figure 3 – The dependence of the free length path of electrons on the nonideal parameter based on the (1) and (2) potentials of dense plasma.

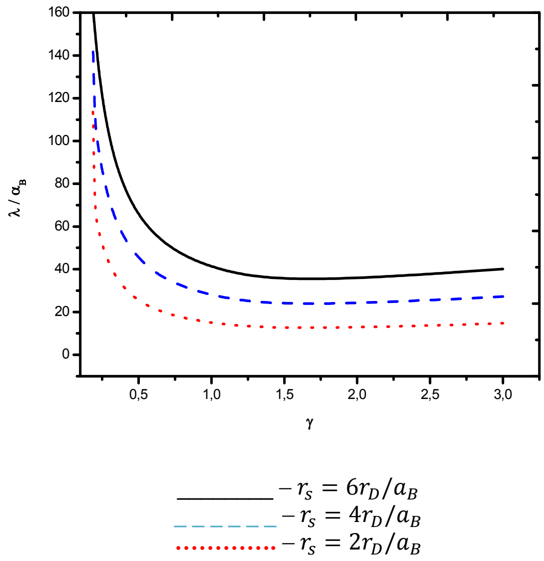

Figure 4 – The dependence of the free length path of electrons on the nonideal parameter based on the effective potential of dense semiclassical plasma.

Conclusion

The collision processes of dense semiclassical plasma are studied taking into account the quantum-mechanical effects of diffraction and symmetry and the screening effect. Thus, the dependences of the electron collision frequency and electron free path length on the nonideality parameter of dense semiclassical plasma are obtained on the basis of the effective interaction potential of particles. When we take into account the screening effect and quantum effects of diffraction and symmetry, the collision frequency of electrons has a maximum in some values of the nonideality parameter and the free length path curve of electrons has a minimum at certain values of the nonideality parameter, which is associated with the formation of some ordered structures in dense semiclassical plasma.

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