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Correlation functions of weakly inhomogeneous plasma

Abstract. This article focuses on the kinetic theory of inhomogeneous plasma and explores the interaction between a high-frequency electric field and weakly inhomogeneous plasma. Particularly, it examines the impact of an external variable field on the kinetic and high-frequency properties of the plasma, including kinetic equations, correlation functions, and distribution functions of charged particles. The study derives expressions for the pair (two-particle) correlation function and the corresponding distribution function, taking into account the spatial inhomogeneity of the plasma and electric field, as well as the collisions between charged particles. The results were obtained using the kinetic equation for the spatial-temporal spectral density of fluctuations and the method of successive approximations (separation of slow motions and fast oscillations). The field amplitude is considered a slowly varying function of time and coordinates. The calculations neglect the contribution of the magnetic component of the electromagnetic field, which is applicable to longitudinal electric fields. The results obtained in this article are primarily of theoretical interest, they reveal the picture of the interaction of a weakly inhomogeneous plasma with a high-frequency electric field and can be used in the construction of a kinetic theory of an inhomogeneous plasma located in high-frequency electromagnetic fields. Note that for charged particles of the same sign, the correlation function is negative, and for particles of different signs it is positive. In addition, the correlation function is exponentially small when the distance between the particles is greater than the Debye radius. In all calculations, the contribution of the magnetic component of the electromagnetic field is neglected, which is quite true for the longitudinal electric field.

Keywords: High-frequency properties, inhomogeneous plasma, kinetic equation, variable field, collision integral.

Introduction

The correlation function is a function of time and spatial coordinates that defines the correlation in systems with random processes. The correlation function is a measure of system ordering. It shows how microscopic variables correlate at different moments in time and in different points on average. Sometimes it is required to consider the temporal evolution of microscopic variables. In some cases, it is necessary to consider the temporal evolution of microscopic variables, which is why the spatial correlation function is used. It is important to understand that although in equilibrium some macroscopic variables are not dependent on time, microscopic variables (for example, the particle velocity vector). Therefore, similar correlation functions, essentially macroscopic quantities, may also depend on time. The correlation function is a measure of system ordering. It shows how microscopic variables correlate at different moments in time and in different points on average. The physical meaning of the correlation function of the particle number density is that it shows the probability density of the relative positions of the particles. The correlation is caused by the presence of interactions between particles, leading to short-range order. It is known that isolated charged particles interact with each other according to Coulombs law. However, due to the long-range nature of Coulomb forces, the interaction between two particles in a plasma is influenced by the presence of other charged particles, i.e. correlation effects (collective interactions between particles) play a significant role in plasma. When describing irreversible processes and constructing the kinetic theory of fluctuations in fully ionized plasma, it is crucial to account for the correlations between particles. This problem is well described, particularly in Klimontovich Yu. L papers [1] and in the works of other authors [2, 3]. For example, [4, 5] presents the binary (pair) correlation function and the corresponding distribution function of plasma particle coordinates and momenta for a homogeneous and equilibrium plasma, without considering the influence of external fields. Much attention is paid to the effects of external fields on the kinetic properties of plasma in [14–18]. In particular, large–scale fluctuations are considered-fluctuations with correlation times of the order or greater than the free path time and with correlation lengths of the order or greater than the free path length in the presence of a high-frequency electric field. The effect of the interdependence of the motion of individual particles is usually described by introducing correlation functions. Temporal correlation functions play a fundamental role in studying the electrodynamic properties of plasma. Two-particle correlation functions are considered in [19–21], in particular, three functions of paired correlations in a two-component (electrons and ions) plasma are calculated in the second order by the plasma parameter. In [22], a system of equations was obtained for the paired correlation function of phase density fluctuations and the renormalized linear response function, taking into account linear electromagnetic processes that are quadratic in intensity of fluctuations. In [23–25], a kinetic theory of a highly ideal plasma in an external field was constructed. The resulting linearized kinetic equation for the external field and the relations of the theory of linear response allow us to obtain a closed equation for a single-particle distribution function.

Main part. Experimental

Developing a consistent collision theory in plasma encounters significant difficulties associated with the slow decrease of Coulomb forces with increasing distance between interacting particles. At any given time, each charged plasma particle is exposed to a huge number of surrounding particles, and all of these effects shall be somehow taken into account. Instead of a simple two-body problem, we face the challenging problem of many-body interactions. In a strict formulation such a problem is hardly solvable. To make a solution possible, it is necessary to introduce some simplifications. The simplest is the pair collision approximation, in which the plasma particle interactions are reduced to independent and instantaneous interactions of pairs of particles. The effect of interdependence of the motion of individual charged particles is typically described by introducing correlation functions. In this article, expressions for the simultaneous correlation function g_{ab} of particles of components a, b and the two-particle distribution function f_{ab} will be obtained by the method of successive approximations based on the kinetic equation for the space-time spectral density of fluctuations

$$\overline{\delta N_a\left(\vec{q},\vec{p},t\right)\delta N_b\left(\vec{q}\,',\vec{p}\,',t\right)}. \tag{1}$$

In this case, let's assume that the plasma is weakly inhomogeneous, i.e. all statistical processes occurring in the six-dimensional phase space of coordinates $\vec{q}$, $\vec{q}\,'$, and momenta, are different, $\vec{p}$, $\vec{p}\,'$ and it is subjected to a longitudinally high-frequency and weakly inhomogeneous electric field $\vec{E}=\vec{E}_o\left(\vec{q},\varepsilon t\right)\sin\omega_o t$ (as well as $\vec{B}_o=0$).

Results and Discussion

To statistically describe processes in plasma under the condition $\varepsilon=\dfrac{V_T}{\omega_o L}\ll 1$, a closed system of equations for the single-particle distribution functions f_a, f_b and for the functions $\left(\overline{\delta N_a\delta N_b}\right)_Q$, g_{ab} can be used (where $Q=\vec{q},\vec{q}\,',\vec{p},\vec{p}\,',t$). The higher correlation functions g_{ab} etc. are thus found to be small of order ε^2. Therefore, to determine g_{ab}, the kinetic equation for function (1) is used, which can be written as [6–10]

$$\hat{A}_o\left(\overline{\delta N_a\delta N_b}\right)_Q=-A_1, \tag{2}$$

where

$$\hat{A}_o=\frac{\partial}{\partial t}+\nu_o+\vec{\upsilon}\frac{\partial}{\partial\vec{q}}+\vec{\upsilon}\,'\frac{\partial}{\partial\vec{q}\,'}+e_a\vec{E}\frac{\partial}{\partial\vec{p}}+e_b\vec{E}\frac{\partial}{\partial\vec{p}\,'};$$

$$A_1 = e_a n_a \left(\overline{\delta N_b \delta \vec{E}}\right)_\varphi \frac{\partial f_a}{\partial \vec{p}} + e_b n_b \left(\overline{\delta N_a \delta \vec{E}}\right)_\psi \frac{\partial f_b}{\partial \vec{p}'};$$

$$\nu_o \ll \omega_o;\ \varphi = \vec{q}, \vec{q}', \vec{p}, \vec{p}', t;\ \upsilon = \frac{\vec{p}}{m_a};\ \psi = \vec{q}, \vec{p}, t.$$

$m_{a,b}$, $e_{a,b}$, $n_{a,b}$ — and respectively mass, charge and concentration; $\delta\vec{E}$ — electric field fluctuation. It should be noted that equation (2) is written under the condition of weak plasma inhomogeneity. This means that the functions f_a, f_b, $\vec{E}$, $\left(\overline{\delta N_a \delta N_b}\right)_Q$, $\left(\overline{\delta N_a \delta \vec{E}}\right)_\psi$, $\left(\overline{\delta N_b \delta \vec{E}}\right)_\varphi$ vary little over distance of the Debye radius r_d. It is known that in weakly inhomogeneous plasma, correlations at points $\vec{q}$ and $\vec{q}'$ depend on $\vec{r} = \vec{q} - \vec{q}'$ and

$$\vec{r}_o = \frac{\vec{q} + \vec{q}'}{2} = \vec{q} - \frac{\vec{r}}{2}$$

perform a decomposition by $\vec{r}\frac{\partial}{\partial \vec{q}}$. In the first approximation, we get

$$\left(\overline{\delta N_a \delta N_b}\right)_Q = \hat{A}_2 \left(\overline{\delta N_a \delta N_b}\right)_B, \tag{3}$$

where

$$\frac{\vec{r}}{2}\frac{\partial}{\partial \vec{q}}\ \hat{A}_2 = 1 - \frac{\vec{r}}{2}\frac{\partial}{\partial \vec{q}};\ B = \vec{q}, \vec{r}, \vec{p}, \vec{p}', t.$$

Substitute (3) into (2), using the Fourier integral transformation of the following functions:

$$\left(\overline{\delta N_a \delta N_b}\right)_B,\ \left(\overline{\delta N_a \delta \vec{E}}\right)_{\psi_1},\left(\overline{\delta N_b \delta \vec{E}}\right)_{\varphi_1},\ \frac{\vec{r}}{2}\frac{\partial}{\partial \vec{q}}\left(\overline{\delta N_a \delta N_b}\right)_B.$$

As a result of the calculations, we get [11]:

$$\hat{A}_o \left[1 - \frac{i}{2}\frac{\partial^2}{\partial \vec{k} \partial \vec{q}}\right] \left(\delta N_a \delta N_b\right)_{B_o} = -A_3, \tag{4}$$

where

$$\hat{A}_3 = e_a n_a \left(\overline{\delta N_b \delta \vec{E}}\right)_{\varphi_o} \frac{\partial f_a}{\partial \vec{p}} + e_b n_b \left(\overline{\delta N_a \delta \vec{E}}\right)_{\psi_o} \frac{\partial f_b}{\partial \vec{p}'};$$

$$\varphi_1 = \vec{r}, \vec{q}, \vec{p}', t;\ \psi_1 = \vec{r}, \vec{q}, \vec{p}, t;\ B_o = \vec{k}, \vec{q}, \vec{p}, \vec{p}', t;\ \psi_o = \vec{k}, \vec{q}, \vec{p}, t;\ \varphi_o = \vec{k}, \vec{q}, \vec{p}', t,$$

where $\vec{k}$ is the wave vector, with $\vec{k} \parallel \delta\vec{E}$. We will solve equation (4) by the method of successive approximations for the range of wave numbers $k \gg \frac{1}{L}$, i.e., we represent the general solution of this equation as

$$\left(\overline{\delta N_a \delta N_b}\right)_{B_o} = \left(\overline{\delta N_a \delta N_b}\right)_{B_o}^{o} + \varepsilon \left(\overline{\delta N_a \delta N_b}\right)_{B_o}^{1}. \tag{5}$$

From (4) and (5), we obtain the following zero and first approximation equations:

$$\hat{A}_o \left(\overline{\delta N_a \delta N_b}\right)_{B_o}^{o} = -A_3; \tag{6}$$

$$\hat{A}_o \left(\overline{\delta N_a \delta N_b}\right)_{B_o}^{1} = \hat{C}_o \left(\overline{\delta N_a \delta N_b}\right)_{B_o}^{o}; \tag{7}$$

$$\hat{C}_o = \left(\hat{A}_o \frac{i}{2}\right)\left(\frac{\partial^2}{\partial \vec{k} \partial \vec{q}}\right).$$

Let's make variable transformations:

$$\vec{p} \to \vec{C}_1;\ \vec{p}' \to \vec{C}_2 \tag{8}$$

$$\vec{\upsilon} \to \vec{V}_a = \frac{\vec{P}_a}{m_a}. \tag{9}$$

And instead of spectral and single-particle distribution functions, we introduce the following new functions:

$$f_b\left(\vec{q},\vec{C}_2,t\right);\ f_a\left(\vec{q},\vec{C}_1,t\right);\ \left(\overline{\delta N_a \delta \vec{E}}\right)_\rho,\left(\overline{\delta N_b \delta \vec{E}}\right)_R,\left(\overline{\delta N_a \delta N_b}\right)_\eta^{0;1}. \quad (10)$$

Let's remind that in (8) – (10) the following notations were used:

$$\vec{C}_1=\vec{P}_a+e_a\vec{C}_3 \qquad \vec{C}_2=\vec{P}_b+e_b\vec{C}_3 \qquad \vec{C}_3=-\frac{\vec{E}_o}{\omega_o}\cos\omega_o t$$

$$\rho=\vec{k},\vec{q},\vec{C}_1,t \qquad R=\vec{k},\vec{q},\vec{C}_2,t \qquad \eta=\vec{k},\vec{q},\vec{C}_1,\vec{C}_2,t$$

In order to simplify the further calculations and avoid complicating the introduced functions 10) we will separate the slowly changing parts in each of them, which depend only on the slow variables, by $\vec{q},\vec{P}_a,\vec{P}_b,t$ averaging over the period of external field $\frac{2\pi}{\omega_o}$, i.e.

$$F\left(\vec{q},\vec{P}_a,t\right),F\left(\vec{q},\vec{P}_b,t\right),\left(\overline{\delta N_b \delta E}\right)_H,\left(\overline{\delta N_a \delta E}\right)_Y,\left(\overline{\delta N_a \delta N_b}\right)_X^{0;1}.$$

Here

$$H=\vec{k},\vec{q},\vec{P}_b,t \qquad Y=\vec{k},\vec{q},\vec{P}_a,t \qquad X=\vec{k},\vec{q},\vec{P}_a,\vec{P}_b,t\,.$$

In this case, equations (6) and (7) are written as

$$\hat{C}_4\left(\overline{\delta N_a \delta N_b}\right)_X^{o}=-A_4, \quad (11)$$

$$\hat{C}_4\left(\overline{\delta N_a \delta N_b}\right)_X^{1}=-\frac{i}{2}\hat{C}_4\hat{C}_5, \quad (12)$$

and the solutions of the initial equation (4), according to (5, 11, 12), can be represented as [12]

$$\left(\overline{\delta N_a \delta N_b}\right)_X=\left(\overline{\delta N_a \delta N_b}\right)_X^{o}+\varepsilon\left(\overline{\delta N_a \delta N_b}\right)_X^{1}, \quad (13)$$

where

$$\vec{C}_4=\frac{\partial}{\partial t}+\nu_o+\left(V_a+V_b\right)\frac{\partial}{\partial t}+e_a\vec{E}\frac{\partial}{\partial \vec{P}_a}+e_b\vec{E}\frac{\partial}{\partial \vec{P}_b};$$

$$\hat{C}_5=\frac{\partial}{\partial \vec{k}}\left(\frac{\partial}{\partial \vec{q}}\left(\overline{\delta N_a \delta N_b}\right)_X^{o}\right);$$

$$A_4=e_a n_a\left(\overline{\delta N_b \delta \vec{E}}\right)_H\frac{\partial F_a}{\partial \vec{P}_a}+e_b n_b\left(\overline{\delta N_a \delta \vec{E}}\right)_Y\frac{\partial F_b}{\partial \vec{P}_b}.$$

In the local equilibrium approximation, the solution of equation (11) is written as

$$\left(\overline{\delta N_a \delta N_b}\right)_X^{o}=-D_o\int_0^\infty \exp\left(D_2-D_1\right)d\tau F_a F_b, \quad (14)$$

where

$$D_o=\frac{e_a e_b n_a n_b}{k_Б T_o}\frac{4\pi r_d}{1+r_d^2 k^2}; \qquad D_1=i\left(\vec{k}\vec{V}_a-\vec{k}\vec{V}_b-i\nu_o\right);$$

$$D_2=-i\left(A_a-A_b\right)\left(\sin\omega_o\left(t-\tau\right)-\sin\omega_o t\right); \qquad A_{a,b}=\frac{e_{a,b}\vec{k}\vec{E}_o}{m_{a,b}\omega_o^2}.$$

$k_Б$ — Boltzmann constant; T_o —the plasma temperature. We solve equation (12) under the condition $\varepsilon=\frac{V_T}{\omega_o L}\ll 1$ and in the limit $\nu_0\to 0$. Using decomposition

$$\exp\left(-iA_{a,b}\sin\omega_o\left(t-\tau\right)\right)=\sum_{n=-\infty}^{\infty}I_n\left(A_{a,b}\right)\exp\left(-in\omega_o\left(t-\tau\right)\right);$$

$$\exp\left(iA_{a,b}\sin\omega_o t\right)=\sum_{n=-\infty}^{\infty}I_m\left(A_{a,b}\right)\exp\left(im\omega_o t\right)$$

from (12) we get:

$$<\overline{(\delta N_a \delta N_b)_X}^{\,1}> = -D_o \sum_{n=-\infty}^{\infty} (D_3 + D_4) = -D_o \sum_{n=-\infty}^{\infty} (\eta_1 + \eta_2 + \eta_3), \quad (15)$$

where the symbol < > means averaging over the electric field period $\vec{E}$; $I_{n,m}(A_{a,b})$ — Bessel functions of order n and m;

$$\eta_1 = C_6 \frac{\partial F_a}{\partial \vec{P}_a} F_b \vec{f}_a; \qquad \eta_2 = C_7 \frac{\partial F_b}{\partial \vec{P}_b} F_a \vec{f}_b; \qquad \eta_3 = C_8 C_9$$

$$C_6 = 2I_n^2(A_b) I_n(A_a) I_n'(A_a); \qquad C_7 = 2I_n^2(A_a) I_n(A_b) I_n'(A_b); \qquad C_8 = \{I_n(A_a) I_n(A_b)\}^2;$$

$$C_9 = n_a U_a \frac{\partial^2 F_a}{\partial \vec{P}_a \partial \vec{q}} F_b + n_b U_b \frac{\partial^2 F_b}{\partial \vec{P}_b \partial \vec{q}} F_a,$$

$\vec{f}_{a,b}$ and $U_{a,b}$ — respectively, Miller forces and high-frequency quasi-potential [13]. Thus, the averaged solution of the initial equation (4), according to (13), follows from expressions (14, 15), i.e.

$$<\overline{(\delta N_a \delta N_b)_X}> = -D_o \sum_{n=-\infty}^{\infty} (D_3 + D_4), \quad (16)$$

where

$$D_3 = C_8 (C_9 + F_a F_b); \qquad D_4 = \eta_1 + \eta_2 .$$

Using the integral

$$(2\pi)^{-3} \int_{-\infty}^{\infty} (n_a n_b)^{-1} <\overline{(\delta N_a \delta N_b)_X}> \exp(i\vec{k}\vec{r}) d\vec{k}, \quad (17)$$

we find the averaged two-particle correlation function $< g_{ab}{}^H (\vec{r}, \vec{q}, \vec{E}_o, \vec{P}_a, \vec{P}_b, t)>$ for weakly inhomogeneous plasma in the presence of an external field $\vec{E}$, i.e.

$$< g_{ab}{}^H > = -\frac{e_a e_b}{k_Б T_o r} \sum_{n=-\infty}^{\infty} (D_3 + D_4) \exp(-r r_d^{-1}), \quad (18)$$

where the index "*H*" means "inhomogeneity" of the plasma and field $\vec{E} = \vec{E}_0(\varepsilon \vec{r}, \varepsilon t) \sin \omega_0 t$: the field amplitude $\vec{E}_0$ is a slowly varying function in time t (εt) and coordinates $\vec{r}$ $(\varepsilon \vec{r})$. The parameter ε characterizing the slowness of the amplitude change satisfies the condition $\varepsilon = (V_T / \omega_0 L) << 1$, here V_T — the thermal velocity of electrons; ω_0 — frequency; L — characteristic size of change F_e. It should be noted that expression (18) is obtained under the condition

$$L_{\omega_o} = \frac{e_{a,b} E_o}{m_{a,b} \omega_o^2} < r_d ,$$

where $r_d \sim \ell_o < \lambda \sim \frac{1}{k}$. From here, L_{ω_o} — the path length of the more movable plasma particles (a or b) over the period T; ℓ_o — free path length; λ — wave length. With this approach, we can neglect the dependence of the Bessel function, in expression (17), on the wave vector $\vec{k}$. From formula (18), it follows that for charged particles of the same sign the correlation function is negative, and for particles of different sign is positive. Moreover, g_{ab} is exponentially small when the distance between particles is larger than r_d, i.e. $r > r_d$. Finally, the averaged two-particle distribution functions of coordinates and momenta is determined by the expression:

$$< F_{a,b}{}^H > = F_a F_b - \frac{e_a e_b n_a n_b}{k_Б T_o r} \sum_{n=-\infty}^{\infty} (D_3 + D_4) \exp\left(-\frac{r}{r_d}\right). \quad (19)$$

If there is no external field ($\vec{E} = 0$) and the plasma is homogeneous and in equilibrium, we obtain the well-known expression for the functions and from equations (18, 19), where the index "O" denotes "homogeneity".

Conclusions

Thus, in this article, the problem of the interaction of a high-frequency electric field with a weakly inhomogeneous plasma is investigated. In particular, the influence of an external alternating field on the kinetic and high-frequency properties of plasma, such as kinetic equations, correlation functions and distribution functions of charged particles, is considered. Expressions for the simultaneous two-particle correlation function and the corresponding distribution function have been derived using the method of successive approximations. This method separates slow motions and fast oscillations based on the kinetic equation for the spatial-temporal spectral density of fluctuations. The expressions take into account electron-ion collisions and the influence of a strong inhomogeneous electric field. To obtain these results, the kinetic equation for the space–time spectral density of fluctuations and the method of successive approximations (separation of slow movements and fast oscillations) were used. These results may be of interest to researchers working in the field of kinetic theory of plasma and can be applied to the electrons motion theory in high-frequency fields, fluctuations, nonequilibrium processes, stability of inhomogeneous plasma, and other collective and nonlinear phenomena.

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Әлсіз біртексіз плазманың корреляциялық функциялары

Мақала біртексіз плазманың кинетикалық теориясына арналған. Мұнда жоғары жиілікті электр өрісінің әлсіз біртексіз плазмамен әсерлесуіне қатысты мәселе қарастырылған. Нақтырақ айтар болсақ, сыртқы айнымалы өріс плазманың кинетикалық және жоғары жиілікті қасиеттеріне жататын кинетикалық теңдеуге, корреляциялық функцияға және зарядталған бөлшектердің үлестірім функциясына қаншалықты дәрежеде әсер ете алатындығы зерттелген. Жұптық (екі бөлшектік) корреляциялық функция мен оған сәйкес келетін үлестірім функциясына арналған өрнектер шығарылып, көрсетілді. Бұл өрнектерде плазма мен электр өрісінің кеңістіктік біртексізділіктері және зарядталған бөлшектердің соқтығысулары ескерілген. Сонымен бірге, аталған нәтижелерге қол жеткізу үшін флуктуациялардың кеңістікті-уақыттық спектрлік тығыздығына арналған кинетикалық теңдеу мен тізбектестік жуықтаулар (баяу қозғалыстар мен шапшаң тербелістерді бөлу) тәсілі қолданылды. Өрістің амплитудасы координаталар және уақыт бойынша баяу өзгермелі функция деп танылады. Жүргізілген барлық есептеулерде электрмагниттік өрістің магниттік құраушысының әсері ескерілген жоқ және бұл жағдай сыртқы электр өрісінің бойлық қасиетіне сәйкес келеді. Аталған барлық нәтижелер теориялық сипатта болғандықтан оларды жоғары жиілікті электрмагниттік өрістердің әсеріндегі біртексіз плазманың кинетикалық теориясын жасау барысында қолдануға болады. Сонымен бірге, алынған нәтижелер электрондардың жоғары жиілікті өрістердегі қозғалыс теориясында, флуктуацияларда, тепе-теңсіздік процестерде және басқа да сызықты емес құбылыстарда қолданыла алады. Корреляциялық функция жүйенің реттілік өлшемі болып табылады және ол микроскоптық айнымалылардың әртүрлі нүктелерде әртүрлі уақыт мезеттерінде қалай корреляцияланатынын көрсетеді. Зарядтары аттас бөлшектер үшін корреляция функциясы теріс, ал зарядтарының таңбалары әртүрлі бөлшектер үшін оң мәнді болады. Сонымен бірге, бөлшектердің ара-қашықтығы Дебайлық радиустан үлкен болған жағдайда корреляциялық функция экспоненталдық заңдылық бойынша кеми береді.

Кілт сөздер: жоғары жиілікті қасиеттер, біртексіз плазма, кинетикалық теңдеу, айнымалы өріс, соқтығысулар интегралы.

Т. Коштыбаев, М. Алиева

Корреляционные функции слабо неоднородной плазмы

Статья посвящена кинетической теории неоднородной плазмы. Авторами исследована проблема взаимодействия электрического поля высокой частоты со слабо неоднородной плазмой. В частности рассмотрено влияние внешнего переменного поля на кинетические и высокочастотные свойства плазмы, такие как кинетические уравнения, корреляционные функции и функции распределения заряженных частиц. Получены выражения парной (двухчастичной) корреляционной функции и соответствующей функции распределения, учитывающие пространственную неоднородность плазмы и электрического поля, а также столкновения заряженных частиц. Для получения этих результатов использовались кинетическое уравнение для пространственно-временной спектральной плотности флуктуаций и метод последовательных приближений (разделение медленных движений и быстрых осцилляций). Амплитуда поля является медленно меняющейся функцией по времени и по координатам. Во всех вычислениях пренебрегается вклад магнитной составляющей электромагнитного поля, что вполне справедливо для продольного электрического поля. Все перечисленные результаты, представляющие, прежде всего, теоретический интерес, могут быть применены при построении кинетической теории неоднородной плазмы, находящейся в электромагнитных полях высокой частоты. Кроме того, эти результаты могут быть использованы в теории движения электронов в высокочастотных полях, флуктуаций, неравновесных процессов, устойчивости неоднородной плазмы и в других коллективно-нелинейных явлениях. Корреляционная функция является мерой упорядоченности системы. Она показывает, как микроскопические переменные коррелируют в различные моменты времени в различных точках в среднем. Заметим, что для заряженных частиц одинакового знака функция корреляции отрицательна, а для частиц разного знака — положительна. Кроме того, корреляционная функция экспоненциально мала, когда расстояние между частицами больше радиуса Дебая.

Ключевые слова: высокочастотные свойства, неоднородная плазма, кинетическое уравнение, переменное поле, интеграл столкновений.

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