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THE INFLUENCE OF THERMAL MOTION OF PARTICLES ON THE FORMATION OF CAVITIES IN PLASMA

N.A. Azarenkov[1,2], A.D. Chibisov[3], D.V. Chibisov[2]

[1]National Science Center "Kharkov Institute of Physics and Technology", Kharkiv, Ukraine;
[2]V.N. Karazin Kharkiv National University, Kharkiv, Ukraine;
[3]H.S. Skovoroda Kharkiv National Pedagogical University, Kharkiv, Ukraine

E-mail: dmitriychibisov@karazin.ua

The effect of the thermal motion of ions and electrons on the formation of plasma density cavities which appear due to inhomogeneous stochastic electric fields is considered. Using the equation of motion of plasma particles in a constant magnetic field and in an inhomogeneous stochastic electric field with a frequency of the order of lower hybrid oscillations, taking into account the thermal motion of particles, the diffusion coefficients and drift velocities of ions and electrons are obtained. These values are used in the Fokker-Planck equation to determine the stationary distribution of the plasma density due to the effect of an inhomogeneous stochastic electric field. The conditions for the thermal velocities of particles under which the formation of a cavity is possible are obtained.

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INTRODUCTION

It was shown in [1] that inhomogeneous stochastic electrostatic fields lead to diffusion and drift motion of ions from a region with an increased level of oscillations, which causes here a depletion of the ion density. This effect is similar to that which occurs in plasma with an inhomogeneous harmonic electric field, when the resulting ponderomotive force pushes electrons out of the region with oscillations [2]. It was assumed in [1], that there was no magnetic field, so the ions were unmagnetized. In [3] the effect of nonuniform stochastic electric fields with a frequency of the order of lower hybrid oscillations on the diffusion and drift motion of particles in plasma in a constant magnetic field was considered. It was assumed that the characteristic oscillation frequency significantly exceeded the cyclotron frequency of the ions; therefore, the ions were considered to be nonmagnetized. Whereas the cyclotron frequency of the electrons significantly exceeded the oscillation frequency and the electrons were magnetized. It was shown that both the diffusion coefficient and the drift velocity of electrons significantly exceed these values for ions, so that the time of formation of the plasma cavity is determined by the electrons. However, in [1, 3] the thermal motion of plasma particles was not taken into account, whereas, the thermal motion of ions and electrons can significantly affect the transport processes in plasma and lead to restrictive conditions for the formation of a plasma density cavity.

In this work, we take into account the thermal motion of particles and obtain the diffusion coefficients and drift velocities of ions and electrons, which include their thermal velocities.

We consider collision less homogeneous plasma in the constant magnetic field $\vec{B}$ directed along the z axis, in which at some point in time a region with a stochastic electric field appears, which is inhomogeneous along the x-axis and homogeneous in other directions. It is assumed that the typical frequency ω of stochastic oscillations is of the order of the lower hybrid frequency ω_{lh}, which is much lower than the electron cyclotron frequency ω_{ce} and much higher than the ion cyclotron frequency ω_{ci}.

We study the evolution of the plasma distribution function due to inhomogeneous electrostatic turbulence using the one-dimensional Fokker-Planck equation

$$\frac{\partial f(x,t)}{\partial t} = -\frac{\partial}{\partial x}\left(A(x) f(x,t)\right) + \frac{\partial^2}{\partial x^2}\left(\frac{B(x)}{2} f(x,t)\right), \quad (1)$$

where A(x) is the drift velocity and B(x)/2 is the diffusion coefficient. These values we determine from the particle motion equation as the averaged over a long time quasi-linear drift velocity $A(x) = d\overline{x}/dt$ and the velocity of the squared root-mean-square displacement $B(x)/2 = d\langle x^2\rangle$.

The equation of motion of charged particles in a magnetic field, taking into account the stochastic electric field, is

$$\frac{d\vec{v}}{dt} = \frac{e_\alpha}{m_\alpha} F(x)\vec{E}(\vec{r},t) + \frac{e_\alpha}{m_\alpha}\left[\vec{v},\vec{B}\right], \quad (2)$$

where $\vec{E}(\vec{r},t)$ is the electric field strength of electrostatic turbulence, far from the region with a high level of turbulence, $F(x) \geq 1$ is the envelope of turbulent pulsations having a maximum at x = 0 and F(∞) = 1.

In the first part we determine the diffusion coefficient of ions in inhomogeneous stochastic electric fields, taking into account their thermal motion, and also find the rate of drift motion due to the ponderomotive force in an inhomogeneous stochastic electric field. In the second part, we determine the diffusion coefficient of the guiding centers of electrons both across and along the magnetic field and also find their rate of drift movement. In the third part, we analyze the Fokker-Planck equation, where we use the obtained values of the diffusion coefficients, as well as the drift velocities of ions and electrons and determine the conditions for the thermal velocities of electrons and ions under which cavities are formed.

1. DIFFUSION AND DRIFT OF IONS

We find the solution of equation (2) for ions, neglecting the effect of the magnetic field, since the frequency of stochastic oscillations significantly exceeds the cyclotron frequency of ions.

$$\vec{v}(t)=\frac{d\vec{r}(t)}{dt}=\frac{e_i}{m_i}F(x)\int_{t_0}^{t}\vec{E}(\vec{r},t')dt'+\vec{v}_{0i}, \quad (3)$$

where $t=t_0$ is the time of occurrence of increased level of stochastic oscillations in plasma, $\vec{v}_{0i}$ is the initial velocity vector of the ion, which is a random vector whose components are random variables distributed according to the normal law. In fact $|\vec{v}_{0i}|=v_{Ti}$ is the thermal ion velocity. Now we find the value of the random displacement $\vec{r}(t)$ of ion by integrating (3) over time,

$$\vec{r}(t)=\int_{t_0}^{t}\vec{v}(t')dt'=\frac{e_i}{m_i}F(r)\int_{t_0}^{t}\int_{t_0}^{t'}\vec{E}(\vec{r},t'')dt''dt'+\vec{v}_0 t, \quad (4)$$

and then obtain the rate of change in mean square displacement by multiplying (3) by (4) and averaging over a large time interval

$$\left\langle \vec{r}(t)\frac{d\vec{r}(t)}{dt}\right\rangle=\frac{1}{2}\frac{d\left\langle \vec{r}(t)^2\right\rangle}{dt}=\frac{e_i^2}{m_i^2}F^2(r)\times$$
$$\times\left\langle \int_{t_0}^{t}\int_{t_0}^{t'}\vec{E}(\vec{r},t'')dt''dt'\int_{t_0}^{t}\vec{E}(\vec{r},t''')dt'''\right\rangle+\left\langle \vec{v}_0 t\cdot\vec{v}_0\right\rangle. \quad (5)$$

In (5) we have

$$\left\langle \vec{v}_0 t\cdot\vec{v}_0\right\rangle=\left\langle |\vec{v}_0|^2\right\rangle t=v_T^2 t.$$

To estimate the integral in equation (5), we represent $\vec{E}(\vec{r},t'')$ in the form of a Fourier integral

$$\vec{E}(\vec{r},t'')=\int_{-\infty}^{\infty}\vec{E}(\vec{r},\omega)\exp(-i\omega t'')d\omega. \quad (6)$$

Substituting (6) into (5) and integrating over t' and t'' we obtain

$$\frac{1}{2}\frac{d\left\langle \vec{r}(t)^2\right\rangle}{dt}=\frac{e^2}{m_i^2}F^2(r)\times$$
$$\times\left\langle \int_{-\infty}^{\infty}\frac{\vec{E}(\vec{r},\omega)}{\omega^2}\exp(-i\omega t)d\omega\int_{t_0}^{t}\vec{E}(\vec{r},t''')dt'''\right\rangle+v_T^2 t. \quad (7)$$

We assume that the width $\Delta\omega$ of the spectrum of stochastic oscillations is of the order of the oscillation frequency $\Delta\omega\approx\omega=\omega_{lh}$ and replace in (7) $1/\omega^2$ by $1/\Delta\omega^2$:

$$\frac{1}{2}\frac{d\left\langle \vec{r}(t)^2\right\rangle}{dt}=\frac{e^2}{m_i^2\Delta\omega^2}F^2(r)\times$$
$$\times\left\langle \int_{-\infty}^{\infty}\vec{E}(\vec{r},\omega)\exp(-i\omega t)d\omega\int_{t_0}^{t}\vec{E}(\vec{r},t''')dt'''\right\rangle+v_T^2 t. \quad (8)$$

In (8) we find the inverse Fourier transform

$$\frac{1}{2}\frac{d\left\langle \vec{r}(t)^2\right\rangle}{dt}\approx\frac{e_i^2}{m_i^2\Delta\omega^2}\times$$
$$\times F^2(x)\int_{t_0}^{t}\left\langle \vec{E}(\vec{r},t)\vec{E}(\vec{r},t''')\right\rangle dt'''+v_T^2 t. \quad (9)$$

We assume that the electrostatic turbulence satisfies the conditions

$$\left\langle \vec{E}(\vec{r},t)\right\rangle=0,$$
$$\left\langle \vec{E}(\vec{r},t)\vec{E}(\vec{r},t''')\right\rangle=\left|\vec{E}^2(\vec{r},t)\right|=\left|\vec{E}^2(\vec{r})\right|, \quad (10)$$

where $\left|\vec{E}^2(\vec{r})\right|$ is the square of the amplitude of stochastic oscillations and we assume that this value does not depend on time. Taking into account (10) and integrating over time in (9), we obtain

$$\frac{1}{2}\frac{d\left\langle \vec{r}(t)^2\right\rangle}{dt}=D_i\approx\frac{e_i^2}{m_i^2\Delta\omega^2}F^2(x)\left|\vec{E}^2(\vec{r})\right|t+v_T^2 t. \quad (11)$$

Equation (11) determines the diffusion coefficient of ions in the turbulent field of electrostatic turbulence taking into account the thermal motion of ions. The first term in (11) describes diffusion in a stochastic electric field, and was previously obtained in [1, 3]. The second term describes diffusion due to thermal motion of ions.

Consider the directed motion of ions caused by the ponderomotive force due to the radial gradient of the amplitude of the turbulent field envelope.

The equation of motion of ion along x-axis is

$$m_i\frac{d^2x}{dt^2}=e_iF(x)E_x(\vec{r},t), \quad (12)$$

where $E_x(\vec{r},t)$ is the projection of the electric field strength of stochastic oscillations onto the x-axis. Using the calculations performed in the papers [1, 3] and taking into account (10) we obtain the equation, describes the drift motion of an ion due to inhomogeneous electrostatic turbulent field

$$m_i\frac{d^2\bar{x}}{dt^2}=\frac{e_i^2}{m_i\Delta\omega^2}\nabla F^2(x_0)\left|E_x^2(\vec{r})\right|. \quad (13)$$

The expression on the right side of (13) is the ponderomotive force arising from the inhomogeneity of the electrostatic turbulent field along the x-axis.

Integrating (13), we obtain the velocity of the drift motion of ion along the x-axis

$$\frac{d\overline{x}}{dt}=\int_{t_0}^{t}\frac{d^2\overline{x}}{dt^2}dt'=\frac{e_i^2}{m_i^2\Delta\omega^2}\nabla F^2(x_0)\left|E_x^2(\vec{r})\right|t\,. \quad (14)$$

Note, that the thermal motion of ions does not affect their drift velocity.

2. DIFFUSION AND DRIFT OF ELECTRONS

The solution of eq. (2) for electrons is found taking into account the magnetic field. First, we neglect the effect of the stochastic electric field and obtain the integrals of motion, which across the magnetic field are the coordinates of the guiding center

$$X=x+\frac{v_y}{\omega_{ce}},\ \ Y=y-\frac{v_x}{\omega_{ce}}, \quad (15)$$

which mean the invariability in time of the coordinates of the guiding center of an electron rotating in a magnetic field. The integral of motion along the magnetic field is the electron momentum, $p_z = mv_z$.

The appearance of stochastic electric fields in plasma leads to slight distortions in these values. Now we consider the solution of (2) in the first approximation and obtain the changes in the integrals of motion caused by stochastic electric fields. Represent $\vec{v}$ in the form:

$$\vec{v}=\vec{v}_{0e}+\vec{v}_{1e},$$

where $\vec{v}_{0e}$ is the initial velocity vector of the electron, which is a random vector whose components are random variables distributed according to the normal law. In fact $\left|\vec{v}_{0e}\right|=v_{Te}$ is the thermal electron velocity. $\vec{v}_{1e}$ is the fluctuation of the velocity, caused by stochastic electric fields and which is determined by the equation

$$\frac{d\vec{v}_1}{dt}=\frac{e_e}{m_e}F(x)\vec{E}(\vec{r},t)+\frac{e_e}{m_e}\left[\vec{v}_1,\vec{B}\right]. \quad (16)$$

The solutions of (16) for the components of velocity are

$$v_{1x}=\frac{e_eF(x)}{m_e\omega_{ce}^2}\frac{dE_x(\vec{r},t)}{dt}+\frac{e_eF(x)}{m_e\omega_{ce}}E_y(\vec{r},t), \quad (17)$$

$$v_{1y}=\frac{e_eF(x)}{m_e\omega_{ce}^2}\frac{dE_y(\vec{r},t)}{dt}-\frac{e_eF(x)}{m_e\omega_{ce}}E_x(\vec{r},t), \quad (18)$$

$$v_{1z}=\frac{e}{m_e}F(x)\int_{t_0}^{t}E_z(\vec{r},t')dt'\,. \quad (19)$$

Write the X coordinate in the form

$$X=X_0+X_1, \quad (20)$$

where X_1 is the random displacement of the coordinate of the guiding center due to stochastic electric fields which is found using (15), (17) and (18) and obtain the rate of change in mean square displacement [3]

$$\left\langle X_1\frac{dX_1}{dt}\right\rangle=\frac{1}{2}\frac{d\left\langle X_1^2\right\rangle}{dt}=\frac{e_e^2}{m_e^2}\frac{1}{\omega_{ce}^2}F^2(x)\times$$
$$\times\left(\int_0^t\left\langle E_y(\vec{r},t')E_y(\vec{r},t)\right\rangle dt'+\frac{1}{\omega_{ce}^2}\frac{1}{2}\frac{d\left\langle E_y(\vec{r},t)\right\rangle}{dt}\right). \quad (21)$$

Neglecting the second term in (21) which is much smaller than the first one, we obtain

$$\frac{1}{2}\frac{d\left\langle X_1^2\right\rangle}{dt}=\frac{e_e^2}{m_e^2}F^2(x)\frac{1}{\omega_{ce}^2}\int_0^t\left\langle E_y(\vec{r},t')E_y(\vec{r},t)\right\rangle dt'. \quad (22)$$

Taking into account the condition (10) we obtain

$$\frac{1}{2}\frac{d\left\langle X_1^2\right\rangle}{dt}=D_{xe}=\frac{e_e^2}{2m_e^2\omega_{ce}^2}F^2(x)\left|E_y^2(\vec{r})\right|t\,. \quad (23)$$

Equation (23) can also be written as

$$\frac{1}{2}\frac{d\left\langle X_1^2\right\rangle}{dt}=\frac{c^2}{2B^2}F^2(x)\left|E_y^2(\vec{r})\right|t\,, \quad (24)$$

or, label

$$v_{dx}=\frac{cE_y}{B}, \quad (25)$$

which is equal to the velocity of the drift motion of a particle in crossed fields along the x-axis we obtain

$$\frac{1}{2}\frac{d\left\langle X_1^2\right\rangle}{dt}=\frac{F^2(x)}{2}\left|v_{dx}^2(\vec{r},t)\right|t\,. \quad (26)$$

Thus, the rate of the root-mean-square displacement of the coordinate of the guiding center along the x-axis is determined by the mean value of the square of y-component of the stochastic electric field, or, otherwise, by the mean value of the square of the particle drift stochastic velocity in crossed fields.

Along the z-axis there is no influence of the magnetic field on the motion of electrons, therefore, similarly to what was done for ions, for the root-mean-square shift of the coordinate along the z-axis we obtain

$$\frac{1}{2}\frac{d\left\langle z(t)^2\right\rangle}{dt}=D_{ze}\approx\frac{e^2}{2m_e^2\Delta\omega^2}F^2(x)\left|E_z^2(\vec{r})\right|t+v_{0e}^2t\,. \quad (27)$$

The first term in (27) determines the diffusion of electrons in a stochastic electric field, and the second one determines diffusion due to the thermal motion of electrons. In order for the contribution of the stochastic term to the diffusion coefficient to exceed the contribution from thermal motion, it is necessary that the condition

$$\frac{e^2F^2(x)\left|E_z^2(\vec{r})\right|}{\Delta\omega^2}>m_e^2v_{0e}^2 \quad (28)$$

hold. This means that the change in the momentum of an electron in a stochastic electric field over a time of the order of the oscillation period must exceed the thermal momentum of the electron.

Comparison of (23) and (27) shows, that the diffusion of electrons along the magnetic field is much greater than the diffusion across the magnetic field so that at least

$$D_{ze}/D_{xe}\sim\omega_{ce}^2/\omega_{lh}^2>>1\,. \quad (29)$$

Moreover, also

$$D_{xe}/D_i\sim\omega_{lh}^2/\omega_{ci}^2>>1\,, \quad (30)$$

that is the diffusion coefficient of the guiding centers of electrons significantly exceeds the diffusion coefficient of ions.

Now we obtain the velocity of the drift motion of electrons along the *x*-axis caused by the ponderomotive force in an inhomogeneous electrostatic turbulence. We represent the random displacement of the coordinate of the guiding center X_1 as the sum of oscillatory $\tilde{X}$ and quasilinear $\bar{X}$ components

$$X_1 = \tilde{X} + \bar{X} \,, \tag{31}$$

where $\langle X_1 \rangle = \bar{X}$ and $\langle \tilde{X} \rangle = 0$. To determine the drift velocity of the guiding center we use (20) and obtain [3]

$$\frac{d\bar{X}}{dt} = \frac{e_e^2}{m_e^2 \omega_{ce}^2} F(X_0) \nabla F(X_0) \int_0^t \langle E_y(\vec{r},t) E_y(\vec{r},t') \rangle dt'. \tag{32}$$

Integration (32) using condition (10) yields

$$\frac{d\bar{X}}{dt} = \frac{e_e^2}{2 m_e^2 \omega_{ce}^2} \nabla F^2(X_0) \left| E_y(\vec{r},t) \right|^2 t \,. \tag{33}$$

Equation (33) determines the velocity of the drift motion of the guiding center of electron along the x-axis. Note, that the thermal motion of electrons does not affect their drift velocity.

Comparison of (14) and (33) shows, that the drift velocities of guiding centers of electron is much greater than the drift velocities of ions

$$\frac{d\bar{X}}{dt} \bigg/ \frac{d\bar{x}}{dt} \approx \frac{\Delta\omega^2}{\omega_{ci}^2} >> 1 \,. \tag{34}$$

Thus, electrons leave the region of increased turbulence level much faster than ions.

Note also that the ratio of the diffusion coefficients of the guiding centers of electrons and ions is of the same order as the ratio of their drift velocities, namely

$$\Delta\omega^2 / \omega_{ci}^2 \,.$$

3. STATIONARY DENSITY DISTRIBUTION AND CAVITY FORMATION CONDITIONS

Inhomogeneous electrostatic turbulence leads to a change in the plasma density distribution. The evolution of the distribution function a *f(x,t)* as a result of diffusion as well as the drift motion of particles is governed by the Fokker-Planck equation (1). Above were obtained the diffusion coefficients along the *x*-axis for electrons (23)

$$\frac{B_e}{2} = D_{xe} = \frac{e_e^2}{2 m_e^2 \omega_{ce}^2} F^2(x) \left| E_y^2(\vec{r}) \right| t \,, \tag{35}$$

and for ions (11)

$$\frac{B_i}{2} = D_{xi} = \frac{e_i^2}{m_i^2 \Delta\omega^2} F^2(x) \left| E_x^2(\vec{r}) \right| t + v_T^2 t \,. \tag{36}$$

The drift velocities are (33)

$$A_e = \frac{d\bar{X}}{dt} = \frac{e_e^2}{2 m_e^2 \omega_{ce}} \nabla F^2(X_0) \left| E_y(\vec{r},t) \right|^2 t \tag{37}$$

for electrons and (14)

$$A_i = \frac{d\bar{x}}{dt} = \frac{e_i^2}{m_i^2 \Delta\omega^2} \nabla F^2(x_0) \left| E_x^2(\vec{r}) \right| t \tag{38}$$

for ions.

We now find the dependence of the plasma density on the x-axis in a stationary state, *n(x) = f(x)*, assuming that the evolution of the distribution function has ended. Equating in (1) the derivative of the distribution function with respect to time to zero, we obtain the equation

$$-\frac{\partial}{\partial x}\big(A(x) n(x)\big) + \frac{\partial^2}{\partial x^2}\left(\frac{B(x)}{2} n(x)\right) = 0 \,. \tag{39}$$

This equation can be simplified

$$-A(x) n(x) + \frac{\partial}{\partial x}\left(\frac{B(x)}{2} n(x)\right) = 0 \,, \tag{40}$$

and then

$$\frac{2A(x)dr}{B(x)} = \frac{d\big(B(x) n(x)\big)}{B(x) n(x)} \,. \tag{41}$$

Equation (41) is valid for both electrons and ions.

Consider first the solution of the equation for electrons, since the processes of diffusion and drift of electrons significantly exceed these processes for ions. Substituting (35) and (37) into (41) we get

$$\frac{dF(r)}{F(r)} = \frac{d\big(F^2(r) n\big)}{n F^2(r)} \,. \tag{42}$$

Integrating (42), we obtain

$$n(x) = \frac{C}{F(x)} \,. \tag{43}$$

Here $C = n_0$, since $F(\infty) = 1$. Thus the plasma density distribution long after the appearance of a region with an increased level of turbulence in homogeneous plasma is

$$n(x) = \frac{n_0}{F(x)} \,. \tag{44}$$

In accordance to (44), the minimum plasma density is reached in the region with the maximum level of low-frequency turbulence. Thus a region with a depleted electron density is formed.

Let us consider a possible limitation of the cavity formation process. As already mentioned, electron diffusion occurs not only across but also along the magnetic field. If it turns out that the longitudinal size L of the region with an increased level of stochastic oscillations is not large enough and the electrons leave this region along the magnetic field rather quickly, then no electron density cavity is formed. The criterion for the formation of a cavity can be chosen as follows. The longitudinal size of the cavity must exceed a certain value, so that when passing this distance along the z axis, the electron is displaced across the magnetic field by an amount exceeding the thermal Larmor radius of the ions ρ_{Ti} (in this case, the transverse size of the cavity will be no less than the thermal Larmor radius of the ions). If this condition is not met and the electrons quickly leave this region, then no cavity is formed. For the case when the stochastic field is strong enough so that inequality (28) holds, the longitudinal size of the plasma must satisfy the inequality

$$L > \frac{\omega_{ce}}{\omega_{lh}} \rho_{Ti} \,. \tag{45}$$

If inequality (28) is not satisfied, then the longitudinal dimension must satisfy the inequality

$$L > \frac{v_{Te}}{F\sqrt{\left|v_{dx}^2\right|}} \rho_{Ti} \,, \tag{46}$$

where v_{dx} is determined by (25). If the plasma has sufficiently large dimensions (infinite in the limiting case), then the transverse dimensions of the cavity are determined by (44), and is equal to *F(x)/∇F(x)*.

Let us now assume that the longitudinal dimensions of the plasma are not sufficient, so that the inequalities (45) or (46) are not satisfied, and no electron density cavity is formed. In this case, the plasma density cavity can be formed due to ions. Substituting (36) and (38) into (41) we obtain for ions

$$\frac{d\tilde{F}^2(x)}{2\tilde{F}^2(x)} = \frac{d\left(\tilde{F}^2(x)n(x)\right)}{n(x)\tilde{F}^2(x)} \,, \tag{47}$$

where

$$\tilde{F}^2 = F^2(x) + \frac{m_i^2 \Delta\omega^2 \left\langle \vec{v}_0^2 \right\rangle}{e_i^2 \left|E_x(\vec{r},t)\right|^2} \,. \tag{48}$$

Integrating (47), we obtain

$$n(x) = \frac{n_0}{\tilde{F}(x)} \,. \tag{49}$$

For the formation of a cavity in the ion density, it is necessary to satisfy the condition

$$\frac{m_i^2 \Delta\omega^2 \left\langle \vec{v}_0^2 \right\rangle}{e_i^2 \left|E_x(\vec{r},t)\right|^2} < 1 \,, \tag{50}$$

which means that the energy received by the ion from the stochastic electric field over time, of the order of the oscillation period, exceeds the thermal energy of the ion. If the inequality opposite to (50) is satisfied, then the depth of the cavity turns out to be smaller and tends to zero as this ratio grows.

CONCLUSIONS

Inhomogeneous stochastic electric fields in the frequency range of the lower hybrid frequency can lead to the formation of density cavities in magnetized plasma. It has been established that the electron density cavity is formed much faster than the ion density cavity, since the drift velocity and the electron diffusion coefficient exceed these values for ions by a factor of $\omega_{lh}^2 / \omega_{ci}^2 >> 1$. The formed cavity of electron density accelerates the formation of the cavity of ion density due to the arising constant electric field, which increases the drift velocity of the ions.

However, the thermal motion of plasma particles can lead to limitations in the formation of cavities. In particular, it is shown that the thermal motion of electrons along the magnetic field does not lead to the formation of electron density cavities if the size of the of region with an increased level of stochastic oscillations in the magnetic field does not satisfy the inequalities (45) or (46), since the electrons leave the structure in the magnetic field faster than the cavity is formed.

If the electron density cavity is not formed, then the plasma density cavity can be formed due to ions (49). However, in this case, the thermal motion of ions along the direction of the inhomogeneity of the stochastic electric field also limits the possibility of the formation of an ion density cavity. It is shown that the cavity is formed if the energy received by the ion from stochastic electric fields during the period of lower hybrid oscillations exceeds the thermal energy of the ion (50). Otherwise, the cavity depth becomes smaller and tends to zero as this ratio increases.

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ВПЛИВ ТЕПЛОВОГО РУХУ ЧАСТИНОК НА ФОРМУВАННЯ ПОРОЖНИН У ПЛАЗМІ

М.О. Азаренков, О.Д. Чібісов, Д.В. Чібісов

Розглянуто вплив теплового руху іонів та електронів на формування порожнин щільності плазми, що виникають внаслідок впливу неоднорідних електричних стохастичних полів. З рівняння руху частинок плазми у постійному магнітному полі та в неоднорідному стохастичному електричному полі з частотою нижньогібридних коливань з урахуванням теплового руху частинок отримані коефіцієнти дифузії та дрейфові швидкості іонів та електронів. Знайдені значення використовуються у рівнянні Фоккера-Планка для знаходження стаціонарного розподілу щільності плазми внаслідок впливу неоднорідного стохастичного поля. Визначено умови на теплові швидкості частинок, за яких можливе утворення порожнини.