COLLECTIVE PROCESSES IN SPACE PLASMAS

ACCELERATING FIELD EXCITATION, OCCURRENCE AND EVOLUTION OF ELECTRON BEAM NEAR JUPITER

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When electron beam, formed Io-Jupiter penetrates into Jupiter plasma the beam-plasma instability develops. Then electron distribution function becomes wider by excited fields. These electrons cause UV polar light. The conditions of formation, properties, stability and evolution of a formed intensive double layer have been described. Beam reflection leads to semi-vortex formation.

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INTRODUCTION

In this paper, the dynamics of an electron beam, which leads to polar light of Jupiter [1 - 13], in the vicinity of Jupiter has been investigated, which according to model [14] is accelerated in the Io vicinity. Electron bunches move along a magnetic tube from Io to Jupiter. Since the magnetic field lines of Jupiter meet at its poles, the beam is focused while moving toward Jupiter, and the density of the beam electrons increases. When the beam penetrates into the plasma to a certain depth, the beam-plasma instability (BPI) develops. In this case, the excited oscillations expand the electron distribution function. Thus, from their energy distribution function, a tail grows, which determines the observed aurora in the UV range.

Since BPI in an inhomogeneous plasma develops locally, it can at some height lead to the formation of a double layer (DL). The conditions for the formation of this DL have been formulated, its properties have been obtained, the dynamics of plasma particles and the reflection of the beam back in its field have been described. After reflection from Jupiter upper ionosphere electron bunches change the direction of motion [15].

The effect of the space charge of a decelerated beam and its collision with particles of partially ionized plasma lead to a gradual expansion of the decelerating beam. Thus, the reflected beam moves back on a larger radius, leading to vortex dynamics.

1. BEAM-PLASMA INSTABILITY

The energy of the beam electrons is too high to cause UV auroras. However, the BPI [16], caused by them, forms the tail of the electron distribution function up to the UV range (Fig. 1).

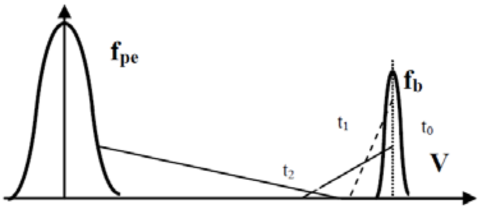

Fig. 1. The distribution functions of the beam and plasma electrons formed at $t_2>t_1>t_0$ as a result of the electron beam interaction with the Jovian plasma

Thus, when a beam penetrates into the plasma to such depth that the plasma electron density n_{0e} becomes large and at a significant focusing of the electron beam, so that its density n_b becomes larger than some threshold, the BPI develops [16]. Growth rate γ_b of BPI equals.

$$\gamma_{bq} = \frac{\sqrt{3}}{2^{4/3}}\left(\frac{n_b}{n_{0e}}\right)^{1/3}\omega_{pe} \propto n_b^{1/3} n_{oe}^{1/6}, \qquad (1)$$

at a rapid stage of evolution and

$$\gamma_{bs} \approx \left(\frac{n_b}{n_{0e}}\right)\omega_{pe}, \qquad (2)$$

at a slow stage of evolution. If the beam is initially wide in energy, then BPI from the very beginning begins with a slow stage of evolution. As growth rate γ_b is proportional to n_b and to the plasma electron density, the instability develops at a certain height, where the electron density n_{0e} of the inhomogeneous plasma is large and beam density due to focusing is large.

2. PROPERTIES OF DOUBLE ELECTRIC LAYER, REFLECTING ELECTRON BEAM

Since the current must be closed, the beam at some height should be reflected and go back. Let us consider a possible mechanism of beam reflection. The reflection mechanism from the ionosphere is associated with the formation of double layers at entering the bunches of fast electrons with density $n_b \approx 10^4$ cm^{-3} in the ionosphere at heights where the density of ionosphere ions n_i approximately equals to n_b [15].

1D numerical simulation [17] has shown that at injection of an electron beam into a plasma, DL can be formed. Let us show that at an electron beam injection from a source into the plasma with a density comparable to the plasma density $n_b=n_i$, the formation of DL is possible, which reflects the beam from the plasma [18 - 22].

Let us study the phenomena, accompanying injection from a certain time from a source (for example, from a natural satellite of Jupiter) to Jupiter plasma an electron beam with a density n_b which is comparable to the plasma density, n_i.

At a beam injection from an isolated source into the plasma, the plasma electrons are accelerated towards the source of the electron beam in the field of the potential drop arising between the source and the beam. At $n_b \approx n_i$, the plasma electron current to the source is small compared to the injected beam current, $j_b=n_bV_b$. The resulting reverse plasma current is small, since plasma electrons close to the boundary are accelerated insignificantly, and those plasma electrons, located in the interior of the plasma near the beam reflection region, are accelerated to velocities reaching the injection velocity, but their density becomes much smaller than the beam density. Thus, the reverse plasma current does not compensate the accumulation of a positive source charge. Therefore, the potential drop reaches the kinetic energy of the beam. The beam returns to the source, being reflected from the potential jump and compensating the accumulation of a positive charge on the source. Then the potential can separate from the source and move inside the plasma with a certain velocity V_{dl}. So DL is formed (the potential jump from $\varphi_o=\varphi(x=0)$ on the injection boundary to zero on Δx).

Let us consider DL that the perturbation of the ion density in its field is insignificant

$$\left|\delta n_i\right| = n_i \frac{e\phi_o}{m_i V_{dl}^2} << n_i . \qquad (3)$$

The appearance of charge separation in the form of two oppositely charged regions is necessary for the DL formation. For an electron DL formation at an electron beam injection into the plasma, two groups of injected electrons are necessary for this charge separation. The second group, in contrast to the beam, should be slow. The second group cannot be plasma electrons that fly into the DL region and are accelerated in its field to velocity $(V_{dl}^2+2e\varphi_o/m)^{1/2}$, since their density deceases in DL to a small value $n(V_{th}/V_b)$. V_{th} is the thermal velocity of the plasma electrons. A slow group is formed by trapping a part of the plasma electrons by DL, which is rapidly formed, or it is injected together with a fast beam. First we consider the case of injection of two groups.

Let us consider a semi-infinite plasma, $x>0$, into which, high-energy, $V_b>>V_{th}$, V_{thb}, and slow, $V_{sl}<V_{tho}<<V_b$, beams are injected with densities n_b and n_o. $V_{thb}=(T_b/m)^{1/2}$, $V_{tho}=(T_o/m)^{1/2}$ – thermal velocities of electron beams. Since the distribution function of the slow group of electrons after reflection from the DL becomes symmetric with respect to the velocity of the DL V_{dl}, the average velocity of the slow group V_{sl} can be set equal to $V_{sl}=V_{dl}<<c$.

First, we find from the kinetic equation and the equations of the balance of energy and momentum fluxes the stationary characteristics of Dl.

Electrons move along trajectories

$$mc^2(\gamma-1) - e\varphi = \text{const} . \qquad (4)$$

In this case, plasma electrons in the DL rest system are accelerated in its field from $-V_{dl}$ to $-c(1-\gamma_o^{-2})^{1/2}$, $\gamma_o=[1-(V_b-V_{dl}+V_{thb})^2/c^2]^{-1/2}$. At the same time, their density changes as

$$n_e(x) = n_e\left(\frac{V_{dl}}{c}\right)\left\{1-\left[\left(1-\frac{V_{dl}^2}{c^2}\right)^{-\frac{1}{2}} + (\gamma_0-1)\frac{\varphi}{\varphi_0}\right]^{-2}\right\}^{-\frac{1}{2}} . \qquad (5)$$

decreasing from

$n_e(\varphi=0)=n_e$ to $n_e(\varphi=\varphi_o)=n_e(V_{dl}/c)(1-\gamma_o^{-2})^{-1/2}$.

Dynamics of the slow electron group is nonrelativistic, and their density varies according to

$$n_0(x) = n_0 \exp\left[\frac{e(\varphi-\varphi_0)}{T_0}\right]. \qquad (6)$$

One can see from (6) that the density of the slow group decreases exponentially and forms a positive charge at $\varphi_a<\varphi<\varphi_o$. Densities of fast beam

$$n_b(z) = n_b\sqrt{1-\frac{1}{\gamma_0^2}}\left[1-\left(1+\frac{e\varphi}{mc^2}\right)^{-2}\right]^{-\frac{1}{2}} . \qquad (7)$$

and of the plasma electrons (5) increase in a power law, which leads to a negative charge at $0<\varphi<\varphi_a$. φ_a is determined from $\delta n(\varphi_a)=0$

$$\varphi_a = \frac{\varphi_0}{\gamma_0-1}\left\{\sqrt{\frac{\gamma_0+1}{2}}-1\right\} . \qquad (8)$$

One can derive that at $\varphi_c=\varphi_o(2V_{bth}/c)\gamma_o^2$ the beam reflection begins. As a result, quasineutrality is restored after DL.

Since the nonresonant beam electrons, passing through DL, penetrate into the plasma, where they are decelerated, their density increases. Therefore, the quasineutrality condition behind DL (for $x>>\Delta x$) requires that V_{dl} be less than the thermal velocity of the plasma electrons $V_{dl}<V_{th}$, and the density of the beam electrons, penetrating through the DL, should be small $n_{bo}<<n_e$. Consequently

$$\varphi_0 \approx \frac{mc^2}{e}(\gamma_0-1) . \qquad (9)$$

All electrons transmit a momentum to DL. The fluxes of momenta transmitted to the DL by beam electrons, passing through DL, by electrons of the slow group and by beam, which are reflected from DL, are equal to $cmn_eV_{dl}(\gamma_o^2-1)^{1/2}$, $n_{bo}mc^2(\gamma_o^2-1)/\gamma_o$, n_oT_o, $2(n_b-n_{bo})mc^2(\gamma_o^2-1)/\gamma_o^2$. In DL field only ions receive a momentum whose flux is equal to $n_ie\varphi_o$. Electrons and plasma ions take energy from DL, whose fluxes are $n_ee\varphi_oV_{dl}$, $n_ie\varphi_oV_{dl}$. The electrons of the beam and the slow group lose energy when interacting with DL. The energy fluxes, which are transmitted to DL by slow group, which are reflected from DL, and by passing through DL beam electrons, are equal to $V_{dl}n_oT_o$, $(n_b-n_{bo})mc^22V_{dl}(\gamma_o^2-1)/\gamma$, $n_{bo}e\varphi_oc(1-\gamma_o^{-2})^{1/2}$. Using the equations for the balance of the energy and momentum fluxes, as well as the quasi-neutrality condition on the beam injection boundary, one can obtain:

$$\frac{V_{dl}}{c} = \frac{n_{b0}}{n_e}\sqrt{1-\frac{1}{\gamma_0^2}} << 1, \qquad (10)$$

$$n_{b0} = \left[\frac{n_i}{2} - n_0\frac{T_0}{2e\varphi_0}\right]\frac{\gamma_0}{\gamma_0+1} ,$$

$$n_0 = \left[1+\frac{T_0}{e\varphi_0}\frac{\gamma_0}{\gamma_0+1}\right]\frac{n_i}{\gamma_0+1} .$$

Let us find the DL profile and estimate its width. From (6) we find that in the reflection region of the slow group $\delta n(\varphi_b)\approx -n_o$, φ_b is determined from $dn(\varphi_b)/d\varphi=0$ and equal to $\varphi_b/\varphi_o=1-T_o/e\varphi_o$. I.e. in a region, where the perturbation of the charge density is determined by the change in the density of the slow group, the potential drop is insignificant. In a region, where the perturbation of the charge density is determined by the change in the density of a fast beam upon its deceleration, δn increases to $\varphi=\varphi_{dl}$. The maximum δn is reached in the region of strong deceleration of the beam and it is equal to $\delta n(\varphi_{dl})=n_b(2V_b/V_{thb})^{1/2}/\gamma^{3/2}$. In neglecting small intervals (widths of φ_c and φ_o-φ_b) near $\varphi=0$ and $\varphi=\varphi_o$, we obtain

$$\frac{(\partial\varphi/\partial x)^2}{3\pi e}=n_i\sqrt{\varphi\varphi_0}\left[\sqrt{\frac{(\gamma_0+1)\varphi/\varphi_0+2}{(\gamma_0+1)}}-\sqrt{\frac{\varphi}{\varphi_0}}\right]. \quad (11)$$

From here

$$\frac{\varphi}{\varphi_0}=1-\frac{x\omega_p\sqrt{2}}{c\gamma_0}. \quad (12)$$

Let us determine the width D:

$$\Delta x=\frac{\varphi_0}{(\partial\varphi/\partial x)\big|_{\varphi=\varphi_a}}\approx\frac{c}{4e}\sqrt{\frac{2m}{\pi n_i}}\frac{(\gamma_0-1)}{\sqrt{1-\sqrt{\dfrac{2}{\gamma_0+1}}}}. \quad (13)$$

And at $\gamma_o>>1$ $\Delta x=(c/\omega_p\sqrt{2})\gamma_o$, $\omega_p=(4\pi n_i e^2/m)^{1/2}$.

We now consider the case of injection from a source into the plasma of only a fast beam. It follows from (13) that for $\gamma_o>>1$ the double layer is formed during the time $\gamma_o/\omega_p\sqrt{2}$. And the response time of plasma electrons to the formed field, according to (11), is equal to

$$t_o=\left(\gamma_o/\omega_p\sqrt{2}\right)\left(\phi_o/\phi_o(t)\right)^{1/4}. \quad (14)$$

Hence it can be concluded that during the formation time DL the plasma electrons do not have time to react to the formed field. Before the beam is reflected and reaches the boundary, the plasma electrons close to it are thrown out to the source under the action of the arisen field. When the plasma density is reached, which satisfies the inequality $n_e(t)<n_i-n_b$, the self-consistent potential ceases to be monotonic. The potential grows inside the plasma from $\varphi_o(t)$ to $\varphi_1(t)$. Further, inside the plasma the potential falls sharply from $\varphi_1(t)$ to zero. This distribution of the potential keeps from the ejection to the source of the part of the plasma electrons which were during the DL formation in its vicinity, to neutralize, together with the charge beam, plasma ions. These trapped plasma electrons form the slow group necessary for DL formation. After completion of DL formation, the plasma electrons, fly into DL region, are accelerated toward the beam.

Let us consider the stability of the relative motion of electron fluxes. From (4), (5) - (7) we have an equation describing the excitation of HF perturbations in the DL neighborhood:

$$1-\frac{\alpha}{z^2}-\frac{(1-\alpha)}{2\gamma_0^3}\left[(z-y)^{-2}+(z+y)^{-2}\right]=0, \quad (15)$$

$\alpha=n_o/n_i$, $z=\omega/\omega_p$, $y=k_b/\omega_p$. It follows from (15) that HF noise is generated in the DL region due to the development of BPI. They lead, as noted above, to the spreading of the electron distribution function. In [17, 23], noise does not lead to a significant DL destruction due to: spreading of the electron distribution function; inhomogeneity of the potential, which ensures the violation of the wave-particle resonance condition and the large relative noise velocity and DL.

Since DL moves slowly inside the plasma, the density of trapped electrons n_o decreases in the case of non-monotonic DL, since the localization region of these electrons increases. The study of the stability of electron fluxes with respect to LF perturbations on the basis of equation

$$1+\frac{\alpha}{(kd_0)^2}-\frac{(1-\alpha)}{2\gamma_0^3}\left[(z-y)^{-2}+(z+y)^{-2}\right]=0, \quad (16)$$

$d_o=(T_o/4\pi n_e^2)^{1/2}$, shows that when the density of the trapped electrons falls below the critical value

$$\frac{(V_{tho}/V_b)^2}{\gamma_0^3}>\alpha+(kd_0)^2. \quad (17)$$

DL becomes unstable with respect to perturbations with the phase velocity equal to V_{dl}. Numerical simulation [17] has shown that in this case DL, which has shifted into the plasma, decays, forming a vortex in the electron phase space and a new DL appears on the boundary.

It was shown in [18 - 22] that DL can be formed in a beam-plasma system only, as observed, when $n_b\approx n_i$.

Thus, it has been shown that injection from a source into a plasma of an electron beam with $n_b\approx n_i$ can lead to the DL formation.

DL reflects the beam from the plasma, so the electron velocity distribution function at the injection boundary has three maxima, which was observed in [17].

If the beam and plasma parameters differ from those, necessary for the formation of a monotonous DL, then within some limits of such a deviation near the DL in its low potential region a potential dip can be formed. The depth of the dip is self-consistently adjusted to the parameters of the beam and plasma, facilitating the DL formation and the beam reflection. In particular, the potential well, reducing the fraction of the beam passing to the low potential region, ensures quasi-neutrality in this region. The potential well in the region of low potential of DL is also formed due to 3D beam dynamics and the limited radius of the beam.

A similar spatial distribution of the electrostatic potential and the behavior of the beam were observed in the experiment and in numerical simulation [17]. The injection of an electron beam into the plasma in numerical simulation [17] leads under certain conditions to the DL formation.

So, DL is formed at a fast beam density, which takes values in a small interval near $n_b/n=1/4$. The considered DL moves with a velocity much less than the beam velocity. The DL width is comparable to the wavelength of the most unstable mode of beam instability. The perturbation of the ion density in the double-layer field is small.

It should be noted that the electron distribution function remains unstable. Indeed, in [17], excitation in the DL region of weak electron oscillations has been observed.

3. NUMERICAL MODELING OF DOUBLE LAYER GENERATION

Generation of a quasistationary double layer resulting from interaction of an electron beam with plasmas was numerically simulated using particle-in-cell method in the nonrelativistic case. For the sake of simplicity 1D electrostatic model was used. This approximation appears to be justified, since the transverse motion of electrons is suppressed by external magnetic field and the intrinsic plasma magnetic field is assumed to be small.

The simulation was performed in the spatial region of the size of $100\lambda_D$ with open boundary conditions. In this case, the particles that leave the considered region are excluded from the calculations. In the initial moment the considered region was filled with equilibrium plasma of the temperature kT and the electron number density of n_0. The ion component was assumed to be ‘freezed in’ and spatially uniformly distributed. A continuous electron beam was injected into the plasma from the left, having the drift velocity of $10v_T$ and the velocity distribution equal to that of the plasma. The number density of the beam is chosen to be equal to $0.4n_0$.

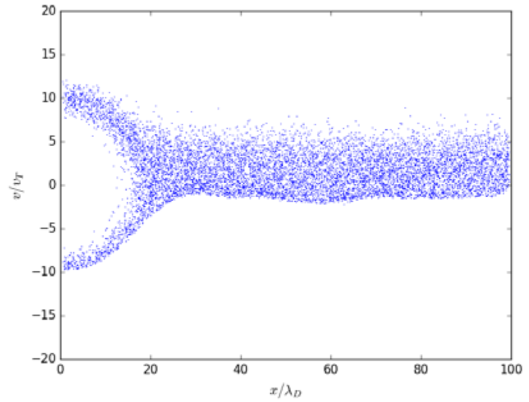

Fig. 2. Phase portrait of a double layer in plasma

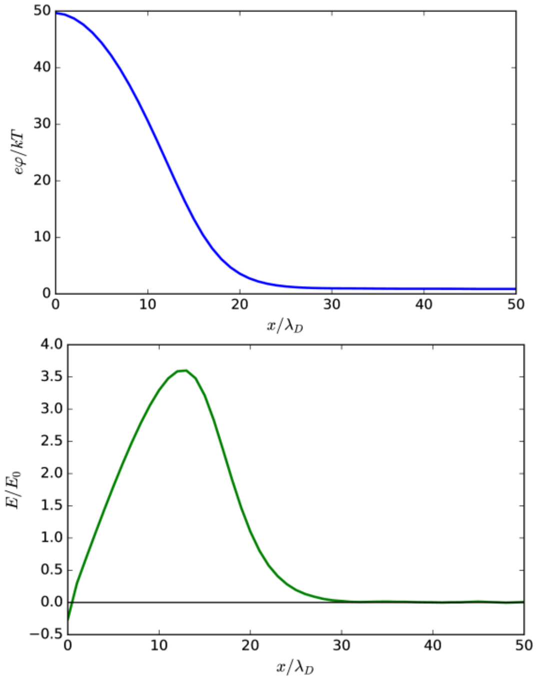

Fig. 3. The electrostatic potential and the electric field strength as functions of coordinate. Here $E_0 = 4\pi\sigma$, where σ is the surface charge density of a spatial cell of a size λ_D

After a relatively short period of time of about $30/\omega_p$ from the beginning of the simulation, a quasistationary picture is formed in the phase space of the system, containing small plasma oscillations and a double layer that reflects some part of the beam. Typical instantaneous phase portrait is shown in Fig. 2.

The double layer contains a typical drop of the electrostatic potential. Fig. 3 shows plots of the potential and electric field strength as functions of the coordinate. These dependencies have been obtained by averaging of the potential and the field strength over a time interval that is much greater than the period of plasma oscillations. Note that instantaneous values can be substantially distorted by plasma waves. It can be seen from Fig. 3 that the double layer has the width of about $20\lambda_D$. The drop of the potential is determined by the energy of the beam particles according to $E = e\varphi_{\text{dl}}$.

Fig. 4 depicts distribution functions of the electron component in the regions before and behind the double layer when the quasistationary flow is established, $t > 30/\omega_p$. The solid blue line depicts the distribution function before the double layer near the coordinate $x = 0$. The right maximum corresponds to the injected beam with a fixed normal velocity distribution and the left one combines the reflected part of the beam and the plasma electrons extracted and accelerated by the field of the double layer. The dashed green line depicts the distribution function behind the double layer. Note that the interaction with the beam results in distortion of the initial distribution and the appearance of a high-energy tail, in accordance with aforesaid.

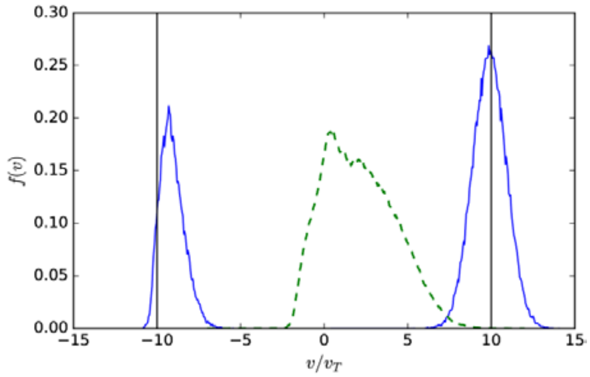

Fig. 4. The velocity distribution function of the electron component in the regions before (solid blue line) and after (green dashed line) the double layer. The vertical lines shows the interval of velocities where the electron energy is not enough to penetrate the double layer

4. NONLINEAR EQUATION, DESCRIBING EXCITATION AND PROPERTIES OF SEMI-VORTEX

The radial defocusing effect of the space charge of a decelerating beam and its collision with particles of partially ionized plasma lead to a gradual expansion of the decelerating beam. Thus, the reflected beam moves back on a larger radius, leading to a vortex-type dynamics (Fig. 5).

In an unperturbed plasma, an electron beam of finite radius r_b moves with velocity V_b along the magnetic field H_0 of Jupiter in the direction of its surface.

α is the vorticity, vortical characteristic of electrons.

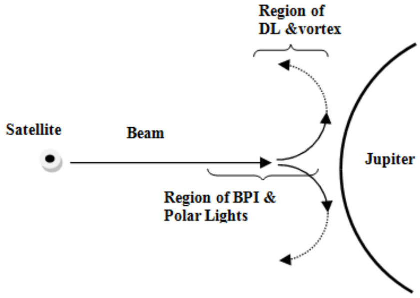

Fig. 5. A vortex dynamics of decelerated and reflected by double layer electron beam near Jupiter

$$\alpha \equiv \vec{e}_\theta \mathrm{rot}\vec{V} = \partial_z V_r - \partial_r V_z \,. \quad (18)$$

We use hydrodynamic equations for electrons taking into account collisions with the frequency ν_e

$$\frac{\partial \vec{V}}{\partial t} + \nu_e \vec{V} + \left(\vec{V}\vec{\nabla}\right)\vec{V} = = \left(\frac{e}{m_e}\right)\vec{\nabla}\phi + \left[\vec{\omega}_{He}, \vec{V}\right] - \left(\frac{V_{th}^2}{n_e}\right)\vec{\nabla} n_e, \quad (19)$$

$$\frac{\partial n_e}{\partial t} + \vec{\nabla}\left(n_e \vec{V}\right) = 0 \,, \quad (20)$$

and Poisson equation for the electric potential, φ,

$$\Delta\phi = 4\pi\left(e n_e - q_i n_i\right). \quad (21)$$

Here $\vec{V}$, n_e are the velocity and density of electrons, V_{th} is the thermal velocity of electrons, $\vec{V}_i$, n_i, q_i, m_i are the velocity, density, charge and mass of ions.

Since the dimensions of the vortex perturbations are much larger than the electron Debye radius, $r_{de} \equiv \frac{V_{th}}{\omega_{pe}}$, and beam velocity, directed along z, is much more than thermal velocity of electrons $V_b >> V_{th}$, one can neglect the last term in (19).

$$\frac{\partial \vec{V}}{\partial t} + \nu_e \vec{V} + \left(\vec{V}\vec{\nabla}\right)\vec{V} = \left(\frac{e}{m_e}\right)\vec{\nabla}\phi + \left[\vec{\omega}_{He}, \vec{V}\right], \quad (22)$$

$\omega_{pe} \equiv \left(\frac{4\pi n_{oe} e^2}{m_e}\right)^{1/2}$ is the electron plasma frequency.

Since in the region of formation of the described half-vortex the density of the decelerated beam is much larger than the density of the electrons of the surrounding plasma, then in the first approximation we neglect the density of the electrons of the surrounding plasma in comparison with the beam density.

From (20) - (22) we obtain a nonlinear equation, describing the vortex dynamics of the electrons.

$$d_t\left(\frac{\vec{\alpha} - \vec{\omega}_{He}}{n_e}\right) + \frac{\nu_e \vec{\alpha}}{n_e} = \frac{1}{n_e}\left(\left(\vec{\alpha} - \vec{\omega}_{He}\right)\vec{\nabla}\right)\vec{V}\,. \quad (23)$$

Since the problem is symmetric along the azimuth θ, $\vec{\alpha}$ is directed along θ, and $\vec{\omega}_{He}$ is homogeneous and stationary, then

$$d_t\left(\frac{\vec{\alpha}}{n_e}\right) + \frac{\nu_e \vec{\alpha}}{n_e} = -\frac{1}{n_e}\left(\vec{\omega}_{He}\vec{\nabla}\right)\vec{V}\,. \quad (24)$$

Thus, we have derived the nonlinear vector equation, describing the vortex dynamics of electrons, without any approximations.

At $V_\theta=0$

$$d_t\left(\frac{\alpha}{n_e}\right) + \frac{\nu_e \alpha}{n_e} = 0\,. \quad (25)$$

In the state of a stationary semi-vortex, we have

$$\left(\vec{V}\vec{\nabla}\right)\left(\frac{\alpha}{n_e}\right) + \frac{\nu_e \alpha}{n_e} = 0\,. \quad (26)$$

In the linear stationary case, assuming that the electron flux is inhomogeneous in the transverse direction, one can obtain

$$-\frac{\alpha}{n_{0e}}\left(V_r \partial_r\right) n_{0e} + \left(\vec{V}\vec{\nabla}\right)\alpha + \nu_e \alpha = 0\,. \quad (27)$$

In the linear nonstationary case, assuming that the electron flux is inhomogeneous in the transverse direction, one can obtain

$$-\frac{\alpha}{n_{0e}}\left(V_r \partial_r\right) n_{0e} + \left[\partial_t + \left(V_0 \partial_z\right)\right]\alpha + \nu_e \alpha = 0\,. \quad (28)$$

CONCLUSIONS

So, the electron beam dynamics, formed near Io, the Jupiter natural satellite, and moved to Jupiter, has been described analytically. When a beam penetrates into the Jupiter plasma to a certain depth, the beam-plasma instability develops. Due to this the electron distribution function becomes wider by excited fields. These electrons, when their energy reaches a certain value, cause UV polar light. For closing of a current a double electric layer is formed. The necessary conditions for the formation and properties of the double layer of an electric potential large amplitude, its stability, evolution and beam reflection in its field have been described. It has been shown that reflection of the beam leads to semi-vortex formation. The equation, describing the semi-vortex, has been derived.

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ВОЗБУЖДЕНИЕ УСКОРЯЮЩЕГО ПОЛЯ, ПОЯВЛЕНИЕ И ЭВОЛЮЦИЯ ЭЛЕКТРОННОГО ПУЧКА ВБЛИЗИ ЮПИТЕРА

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Когда электронный пучок, образованный Ио-Юпитера, проникает в плазму Юпитера, развивается пучково-плазменная неустойчивость. Тогда функция распределения электронов становится шире, благодаря возбужденным полям. Эти электроны вызывают ультрафиолетовое свечение. Описаны условия формирования, свойства, устойчивость и эволюция сформировавшегося интенсивного двойного слоя. Отражение пучка приводит к образованию полувихря.

ЗБУДЖЕННЯ ПРИСКОРЮЮЧОГО ПОЛЯ, ПОЯВА І ЕВОЛЮЦІЯ ЕЛЕКТРОННОГО ПУЧКА ПОБЛИЗУ ЮПІТЕРА

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Коли електронний пучок, утворений Іо-Юпітера, проникає в плазму Юпітера, розвивається пучково-плазмова нестійкість. Тоді функція розподілу електронів стає ширше завдяки збудженим полям. Ці електрони викликають ультрафіолетове світіння. Описано умови формування, властивості, стійкість і еволюція інтенсивного подвійного шару, що формується. Відбиття пучка призводить до утворення напіввихору.