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LETTER TO THE EDITOR

IMPURITY OF DUST-ACOUSTIC PLASMA INSTABILITY DUE TO TRAPPED IONS

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We are investigating the low-frequency electrostatic perturbation in tokamak plasma in the "banana" regime by taking account the effects of the Coulomb collision on the trapped ion. We consider the dust-acoustic plasma instability caused by the presence of ion impurities. We point out that the presence of impurity ions, especially if their density gradient is different from the dust plasma density gradient, i.e., if they are peaked near the wall, can generate a new instability which is difficult to stabilize and which leads to diffusion of the impurities into the dust-acoustic plasma.

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It is well known that the two greatest barriers to controlled fusion are the instability and the impurity. The latter being of great importantance since even a small quantity of impurity greatly enhances the radiation losses of the plasma [1]. Such impurities are likely to arise near the wall of a plasma container, especially in the absence of a divertor.

Coppi et al. [2] found drift instability caused by the presence of heavy impurity ions. Using the collisionless Vlasov equation, they investigated the electrostatic perturbation of inhomogeneous multi-ion-species plasma in a uniform magnetic field, and found a strongly unstable mode driven by the Landau damping of background ions. This instability has an important role for the impurity transport in CTR systems.

The effects of nonthermal ions with excess of fast (energetic) ions on linear dust-acoustic (DA) wave propagation has been investigated [3−10] incorporating the dust charge variation and isothermal dust pressure variation. It is seen that due to the dust charge variations, in the presence of nonthermal ions, there is an exponential growth of the DA wave with zero real frequency, provided that the ion nonthermality parameter $a > 15(1+\sigma_i)/(8-72\sigma_i)$, $\sigma_i = (T_i/T_e) \ll 1$, where T_i and T_e are is the ion resp. electron temperature [3−10]. In the absence of dust charge variations, finite dust temperature T_d can stabilize the instability [3−10]. However, in the presence of nonadiabatic dust charge variations, T_d can not stabilize the instability [3−10].

In this paper, we investigate the low-frequency electrostatic perturbation in tokamak plasma in the "banana" regime by taking into account of the effect of the Coulomb collision on the trapped ion. We consider the impurity of dust-acoustic plasma instability component. The charge neutrality $n_e + z_d n_d = n_i$ should hold in the equilibrium state, where n_e, n_i and n_d are the densities (throughout the text, subscripts e, i and d are used to denote electrons, ions and dust particles, respectively). The charge of dust particles is denoted by z_d. We use the usual method of analysis [11, 12] to investigate a drift wave related to the impurity of dust-acoustic plasma.

We consider a perturbation of the electrostatic potential $\phi \propto \exp(\mathrm{i}(ks+m\theta-\omega t)$, where $k \sim 1/Rq$ is the parallel wave number (R is the major radius and q the safety factor), m is the azimuthal mode number and ω is the frequency. We assume that $V_{T_d} \ll \omega/k \ll V_{T_i} \ll V_{T_e}$, where V_T-s are the thermal velocities. We also neglect a small correction due to ballooning effects of the order of $O(\varepsilon)$, where $\varepsilon = r/R$.

For a low-frequency perturbation, the electron distribution function can be assumed to be the Boltzmann distribution, i.e., the perturbation of the electron density is given by $n_e = e\phi/T_e$ (T_e is the electron temperature). The density of the dust-acoustic plasma instability is

$$n_d = -\frac{z_d n_{d_0} k^2 \phi}{m_d \omega(\omega + \mathrm{i}v_d)} \,. \tag{1}$$

As for the background ions, the transit particles can be assumed to have the Boltzmann distribution, but the trapped ion distribution should be determined based on the kinetic equation. Using a result of Ref. [11] on the "trapped electron mode", we can write the perturbed ion density as

$$n_i = -\frac{n_{i_0} e\phi}{T_i} + \sqrt{\varepsilon}\,\frac{e\phi}{T_i}\left\langle \frac{\omega - \omega_T}{\omega + \mathrm{i}v_{\mathrm{eff}}} \right\rangle , \tag{2}$$

where

$$\omega_T = -\frac{k_\perp T_e}{eB_0 n_{i_0}}\,\frac{\mathrm{d}n_{i_0}}{\mathrm{d}r}\left[1+\eta\left(\frac{m_i V_d^2}{2T_i} - \frac{3}{2}\right)\right], \quad \eta = \frac{\mathrm{d}\ln T_i}{\mathrm{d}\ln n_{i_0}}, \quad v_{\mathrm{eff}} = \frac{v_{ii}}{\varepsilon}\,\left(\frac{2T_e}{m_i V_d^2}\right)^{3/2},$$

B_0 is the strength of the magnetic field, $k_\perp = m/r$ and $v_{ii} = 3m_i^{1/2} T_i^{3/2} (4\pi^{1/2}\lambda e^4 n_i)$. V_d is the velocity of dust particles. Here we have assumed a low concentration of the impurity ions. The angle brackets in Eq. (2) mean the average over the Maxwell distribution function.

The dispersion relation for an impurity mode will be derived from Eq. (2) by using the charge-neutrality condition $n_e + z_d n_d = n_i$. We obtain

$$1 - \frac{\sqrt{\varepsilon}}{1+\sigma} \left\langle \frac{(\omega - \omega_T)(\omega - \mathrm{i}v_{\mathrm{eff}})}{\omega^2 + v_{\mathrm{eff}}^2} \right\rangle - \frac{k^2 C_D^2}{(1+\sigma)\omega(\omega - \mathrm{i}v_{\mathrm{eff}})} = 0\,, \tag{3}$$

where $\sigma = (n_{e_0} T_i / n_{i_0} T_e)$, $\omega > v_d$, $C_D^2 = (z_d^2 T_d / m_d)(n_{d_0}/n_{i_0})$ and $\omega = \omega_r + \mathrm{i}\gamma$.

For $v_{\mathrm{eff}} \gg \omega_r$ and constant T_e, the frequency of the mode is

$$\omega_r = \frac{k C_D}{1+\sigma}\,. \tag{4}$$

Moreover, the growth rate of the mode is given by

$$\gamma = \frac{\sqrt{\varepsilon}}{k^2 C_D^2} \omega_r^3 \left\langle \frac{(\omega_T - \omega_r)}{v_{\mathrm{eff}}} \right\rangle . \tag{5}$$

When $\eta < 0$, Eq. (5) shows a strong instability, the growth rate of which is larger than that of the trapped electron mode of Ref. [12] and also is larger than that of the collisionless impurity mode found in Ref. [2]. Here, it should be noted that $v_{ii} \ll v_{\mathrm{eff}}$ holds in the banana regime. We then consider the case of $v_{\mathrm{eff}} \ll \omega_r$. The growth rate of the mode is given by

$$\gamma = \frac{\sqrt{\varepsilon}}{k^2 C_D^2} \omega_r \langle \omega_T - \omega_r \rangle\,. \tag{6}$$

The impurity of dust-acoustic plasma instability examined in this paper may cause an inward transport of impurity ions in future tokamak systems operated in the "banana" regime. The same was noted in Ref. [2] for the collisioless mode.

In conclusion, we have investigated the tokamak plasma in the "banana" regime by taking account the effects of the Coulomb collision on trapped ions. We consider instability dust-acoustic plasma impurities. The dust-acoustic plasma impurity instability examined in this paper may cause an inward transport of impurity ions in future tokamak systems operated in the "banana" regime. The same was noted in Ref. [2] for the collisionless mode i.e., it is clear that in the absence of Coulomb collision we can recover the result of Ref. [2].

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NESTABILNOST PRAŠNJAVO-ZVUČNE PLAZME ZBOG UHVAĆENIH IONA

Istražujemo nisko-frekventnu elektrostatsku smetnju u plazmi u tokomaku u "banana" uvjetima uzimajući u razmatranje učinke Coulombovih sudara na uhvaćene ione. Proučavamo nestabilnost prašnjavo-zvučne plazme uzrokovanu ionskim onečišćenjem. Ističemo da prisustvo ionskog onečišćenja, posebno ako je njihov gradijent različit od gradijenta gustoće plazme, tj. ako je onečišćenje veliko blizu zida, može uzrokovati nestabilnost koja će se teško smiriti i koja vodi k difuziji ionskih nečistoća u prašnjavo-zvučnu plazmu.