Dust grains trapping in magnetized electrostatic sheaths

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In this work, we have investigated the trapping of dust grains (impurities) in electrostatic sheaths of dusty plasmas in presence of electromagnetic field. For this, we have established a steady state model where electrons and negative ions are considered Boltzmannian, positive ions and dust grains are described by fluid equations. Numerous forces acting on dust grains, such as electromagnetic force, gravity force, ion drag force, neutral drag force, etc., are taken into account. To describe the dust grains charge, we have used the orbit motion limited model (OML).The numerical results show the existence of several trapping positions which correspond to dust grains density peaks. The physical parameters controlling these positions are determined and discussed.

When a conductor is immersed in a plasma, such as electrodes in discharge plasmas, it acquires a negative potential with respect to the bulk plasma, and a boundary layer corresponding to a transition layer, where the plasma departs from quasi-neutrality that is called electrostatic sheath gets formed [1].

In the present work, we focus on the effect of a static oblique magnetic field on the dust grains trapping in the plasma sheath (Fig 1).

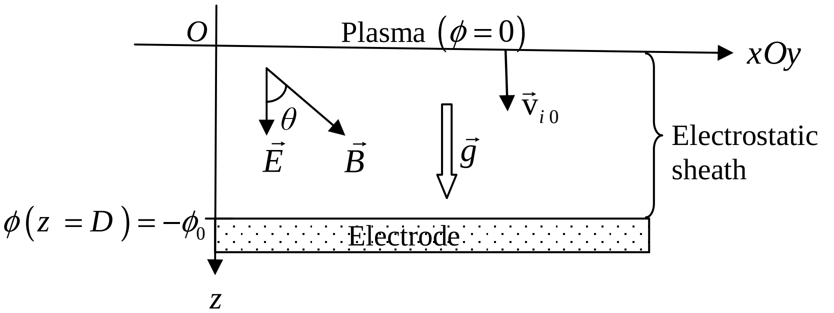

Fig. 1 : The geometry of the magnetized plasma sheath model

For this, electrons *(e)* and negative ions *(j)* are described by Boltzmann's statistics

$$n_{e,j} = n_{e0,j0} \exp\left(e\phi / T_{e,j}\right). \quad (1)$$

The positive ions *(i)* and dust grains *(d)* are described by a steady state fluid equation [2]

$$\nabla.\left(n_{i,d} \vec{v}_{i,d}\right) = 0, \quad (2)$$

$$m_i \vec{v}_i.\nabla\vec{v}_i = e\left(-\vec{\nabla}\phi + \vec{v}_i \wedge \vec{B}\right) - \vec{\nabla}p_i / n_i - m_i n_n \sigma_{in} v_i \vec{v}_i, \quad (3)$$

$$m_d \vec{v}_d.\nabla\vec{v}_d = -q_d \vec{\nabla}\phi + m_d \vec{g} + \vec{F}_{id} + \vec{F}_{nd}, \quad (4)$$

where ϕ is the electrostatic potential, $\vec{B}$ is the magnetic field, σ_{in} is the ion-neutral cross section, $\vec{F}_{id}$ is the ion drag force [3] and $\vec{F}_{nd}$ is the neutral drag force [4] acting on the dust grain, n_k, v_k, p_k, T_k, q_d and m_k are the particles density, the fluid velocity, the partial pressure, the temperature, the charge and the mass of species "k" respectively, $\vec{g}$ being the acceleration of gravity.

The formulation is completed with the Poisson equation for the electric potential,

$$\Delta\phi = -e\left(n_i - n_e - n_j + n_d q_d / e\right) / \varepsilon_0. \quad (5)$$

The dust charge is mainly determined by the currents collected by the dust grain

$$\frac{dq_d}{dt} = I_e + I_j + I_i. \quad (6)$$

For $q_d < 0$, the currents I_e, I_j and I_i in the orbit motion limited model [5] are given by

$$I_{e,j} = -\pi r_d^2 e \left(8T_{e,j} / \pi m_{e,j}\right)^{1/2} n_{e,j} \exp\left(eq_d / r_d T_{e,j}\right), \tag{7}$$

$$I_i = \pi r_d^2 e n_i \mathrm{v}_i \left(1 - 2eq_d / r_d m_i \mathrm{v}_i^2\right), \tag{9}$$

where r_d is the dust grain radius.

We implement the present model by considering an oxygen plasma $\left(O_2, O_2^+, O_2^-\right)$ and the following parameters: $\phi_0 = -12V$, $T_e = 1eV$, $T_i = T_j = 0.1eV$, $T_n = 0.01eV$, $n_{i_0} = 10^9 cm^{-3}$, $r_d = 1\mu m$, $\alpha_c = \lambda_{Di} n_n \sigma_{in} = 0.003$, $n_{d0} / n_{i0} = 10^{-4}$, gas pressure $P_n = 10mTorr$, the mass density of the dust grains $\rho_d = 3gcm^{-3}$ and $\theta = 20°$, λ_{Di} being the ionic Debye length.

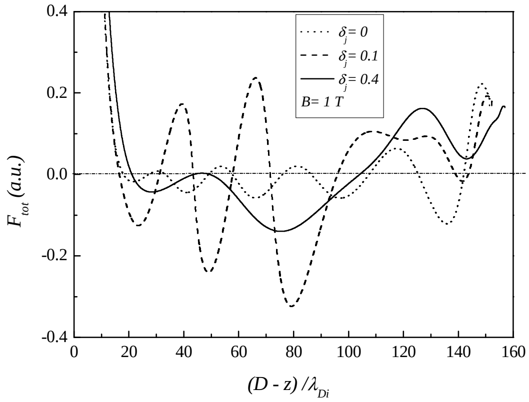

Fig. 2: The total force on the dust grain vs position.

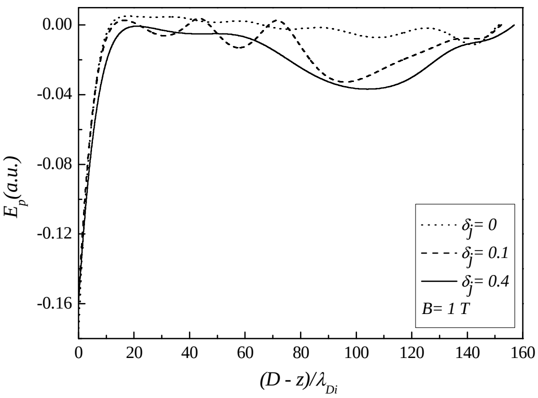

Fig. 3: The potentiel energy vs position

In order to study the dynamic of dust grains in the electrostatic sheath, we have compared the force acting on the dust grains. The magnetic field does not directly act on the dust grains but it affects the others forces acting on the dust grains (and so the dust potential energy) by changing the sheath variables such as ions' number density and their velocity distribution.

First, we found that the contribution of ion drag force and neutral drag force are negligeable compared to electrostatic force and the gravity force. Then, the trapping of dust grains is due mainly to the balance between electrostatic force and gravity force. Therefore, only negatively charged dust grains can be trapped. Moreover, trapping positions that correspond to a dynamical equilibrium with a minimal potential energy and a zero net force, on the grains are multiple. The contibution of negative ions increases the number of trapping positions. We have confirmed numerically that for the same parameters used above with a larger dust grain radius, the number of trapping position decreases.

In conclusion, we have established a theoretical steady state model that describes the dynamic equilibrium of monosized dust grains in a magnetized electrostatic sheath. As an extension of our work, it may be of interest to include the effect of dust size distribution on the electrostatic sheath variables.

References

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