# Dynamics of Dust grains in Magnetized Electrostatic Sheath

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**Abstract**

In this work, we have established a stationary and three-dimensional theoretical model describing the dynamics of dust grains in magnetized electrostatic sheath. For this, we have modeled the electrons and the negative ions by Boltzmann's densities. While the positive ions and dust grains are modeled by fluid equations. The interactions between dust grains are neglected. To describe the dust grain charge, we have used the orbit motion limited model (OML). Moreover, the numerous forces acting on the dust grains are taken into account, viz, electric force, gravity force, ion drag force and neutral drag force. The numerical results show that the presence of magnetic field reduces the electrostatic sheath thickness, and the existence of trapping position it affects only negatively charged dust grain. The trapping position is determined and the physical parameters controlling the later are discussed.

**Introduction:**

When a conductor is immersed in 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 sheath gets formed [1].

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

**Theoretical Model**

The electrons *(e)* and negative ions *(j)* are assumed to be in thermal equilibrium, thus, their number densities $n_e$ and $n_j$ satisfy the Boltzmann relations [2].

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

where $T_k$ is temperature of specie $k$ $(k = e, j)$.

The positive ions and dust grains are described by a cold fluid equations [2],

$$\nabla.\left(n_i \vec{v}_i\right) = 0, \quad (2)$$

$$\vec{v}_i.\nabla\vec{v}_i = -\frac{e}{m_i}\left(-\nabla\phi + \vec{v}_i \wedge \vec{B}\right), \quad (3)$$

$$\nabla.\left(n_d\vec{v}_d\right) = 0, \quad (4)$$

$$\vec{v}_d.\nabla\vec{v}_d = -\frac{q_d}{m_d}\nabla\phi + \vec{g}, \quad (5)$$

where $n_i$, $v_i$ and $m_i$ are the density, the fluid velocity and the mass of the positive ions respectively, $q_d$, $m_d$ and $v_d$ are the charge, the mass, and the fluid velocity of dust grains respectively, and $g$ being the acceleration of gravity.

In order to relate the self-consistent potential to electron, negative and positive ions as well as dust densities in the sheath, we use Poisson's equation

$$\Delta\phi = -\frac{e}{\varepsilon_0}\left[n_i - n_e - n_j + n_d\frac{q_d}{e}\right]. \quad (6)$$

The various forces acting on the dust grains are (Fig. 1) [3]:

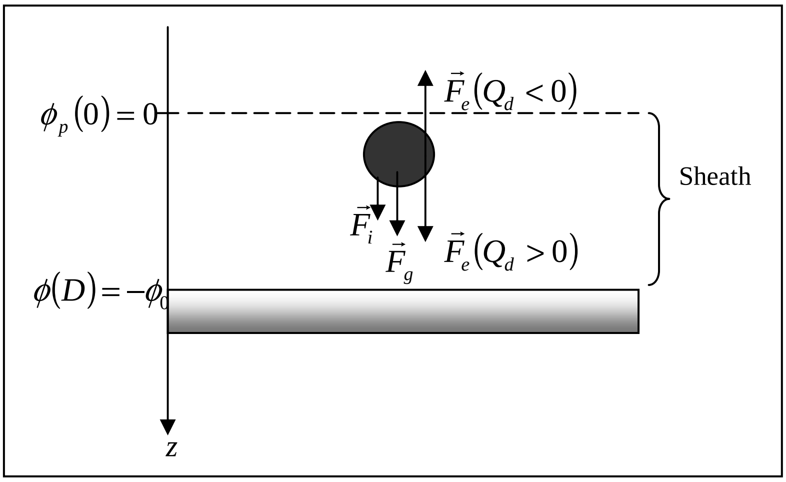


Fig. 1: The various forces acting on the dust grain

the electromagnetic force,

$$\vec{F}_e = q_d\left(\vec{E} + \vec{v}_d \times \vec{B}\right), \quad (7)$$

the gravity force,

$$\vec{F}_g = m_d\vec{g} = \frac{4}{3}\pi r_d^3\rho_d\vec{g}, \quad (8)$$

the neutral drag force,

$$\vec{F}_n = -\frac{4}{3}\pi\left(1 + \beta\frac{\pi}{8}\right)r_d^2 m_n n_n v_{tn}\left(\vec{v}_d - \vec{v}_n\right), \quad (9)$$

and the ion drag force [4],

$$\vec{F}_i = \vec{F}_i^{coll} + \vec{F}_i^{coul}, \tag{10}$$

where $\vec{F}_i^{coll}$ and $\vec{F}_i^{coul}$ are the collection and Coulomb diffusion parts of the ion drag force given by

$$\vec{F}_i^{coll} = \pi b_c^2 n_i m_i \mathrm{v}_{i_{tot}} \vec{\mathrm{v}}_i, \tag{11}$$

$$\vec{F}_i^{coul} = 4\pi b_{\pi/2}^2 \Gamma n_i m_i \mathrm{v}_{i_{tot}} \vec{\mathrm{v}}_i. \tag{12}$$

$\Gamma = \ln\left(\frac{\lambda_D^2 + b_{\pi/2}^2}{b_c^2 + b_{\pi/2}^2}\right)^{1/2}$ being the logarithm of Coulomb and $b_{\pi/2}$ is the impact parameter for a diffusion of $\pi/2$; $\mathrm{v}_{tn} = \left(\frac{8T_n}{\pi m_n}\right)^{1/2}$ is the neutral thermal velocity.

To describe the dust grains charge, we use the orbit motion limited model (OML) [5].

## Numerical results

In order to study the dynamics of dust grains, we calculate the total force acting on a single dust particle which is given by

$$\vec{F}_{tot} = \vec{F}_g + \vec{F}_e + \vec{F}_i + \vec{F}_n, \tag{13}$$

and the dust particle potential energy,

$$E_p = -\int F_{tot} dz. \tag{14}$$

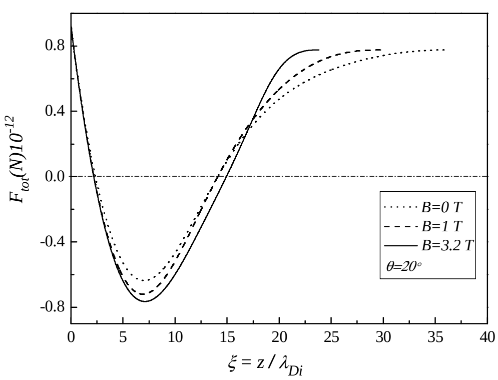


Figure 2

The total force acting on the dust particle versus normalized position

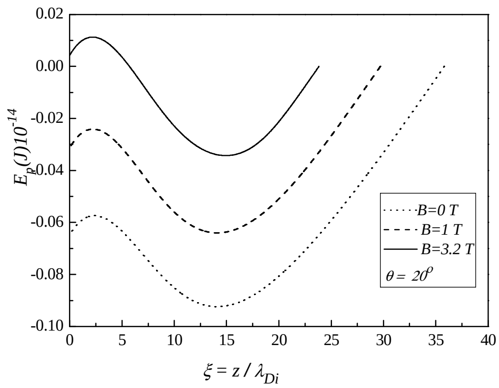


Figure 3

The potential energy of the dust particle versus normalized position

We implement the present model by considering an oxygen plasma with typical parameters of electronegative dusty plasmas, the particle radius $r_d = 1\mu m$, the electrode potential $\phi_0 = -6V$, the electrons temperature $T_e = 1eV$, the ions temperature $T_i = 0.1eV$, the neutral gas temperature $T_n = 0.1eV$, the gas pressure $P_n = 10mTorr$, the equilibrium ions density $n_{i_0} = 10^9 cm^{-3}$, and the mass density of the dust particles $\rho_d = 19.32gcm^{-3}$.

First, we have check numerically that the contribution of the neutral drag force is negligible compared to other forces. Furthermore, only negative dust particles could be trapped in the lower electrode. For the nano-particles, the trapping is due to the compensation between the ion drag force and the electric force. Whenever, for the micro-particles, the trapping is due to the compensation between the electric force and the gravity force. The magnetic field does not directly act on the dust particles but it affects the others forces acting on the particles by charging the sheath variable such as ions' number density and their velocity distribution.

The figures 2 and 3 show the existence of stable and unstable trapping positions of dust particles. Finally, we observe that the presence of magnetic field reduces the sheath thickness.

## References

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