

Effect of electron temperature on magnetized plasma sheaths contaminated by multi-sized impurities

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Abstract

In the present work, the effect of electron temperature on magnetized electrostatic sheaths structure is investigated. A three dimensional and stationary theoretical model is established. Electrons are considered in thermodynamic equilibrium whereas ions are described by fluid equations. The impurities are spherical dust grains with different sizes, which are also modeled by fluid equations. The grain size distribution is described by a Gaussian law ^{1,2} and the charge variation is described by the orbit motion limited model ^{3,4}. Numerical results show that the increase of electron temperature induces the increase of the electrostatic sheath thickness. Indeed, the increase of the electron temperature increases their probability of attachment to dust grains and so the charge separation. Consequently, the electrostatic sheath thickness is enlarged. The presence of the magnetic field reduces the electrostatic sheath thickness. The effect of the other parameters are examined and discussed.

Introduction

When plasma is in contact with a solid wall, such as an electrode in discharge plasmas, it acquires a negative potential with respect to the bulk plasma, due to the high mobility of the electrons. An electrostatic sheath that is a boundary layer where the plasma departs from quasi neutrality gets formed.

In the present work, we focus on the effect of electron temperature on magnetized plasma sheaths contaminated by multi-sized impurities.

Theoretical Model

The electrons (e) are assumed to be in thermal equilibrium thus, their number densities n_e satisfy the Boltzmann relation.

$$n_e = n_{e0} \exp(e\phi / T_e), \quad (1)$$

where T_e is the electron temperature and ϕ is the electrostatic potential.

The positive ions and dust grains are described by fluid equations ⁵,

$$\frac{\partial n_i}{\partial t} + \nabla \cdot (n_i \vec{v}_i) = k_i n_i n_e, \quad (2)$$

$$\frac{\partial \vec{v}_i}{\partial t} + \vec{v}_i \cdot \nabla \vec{v}_i = \frac{\vec{F}_c}{m_i} + \frac{e}{m_i} (\vec{E} + \vec{v}_i \times \vec{B}) - \frac{\vec{\nabla} p_i}{n_i m_i}, \quad (3)$$

$$\frac{\partial n_{dk}}{\partial t} + \nabla \cdot (n_{dk} \vec{v}_{dk}) = 0, \quad (4)$$

$$m_{dk} \left(\frac{\partial \vec{v}_{dk}}{\partial t} + \vec{v}_{dk} \cdot \nabla \vec{v}_{dk} \right) = \vec{f}_{ek} + \vec{f}_{gk} + \vec{f}_{idk} + \vec{f}_{ndk}. \quad (5)$$

where B is magnetic field making an angle θ with the vertical axis Oz , n_i , v_i and m_i are the density, the fluid velocity and the mass of the ions respectively, q_d , m_d and v_d are the charge, the mass and the fluid velocity of dust grains respectively, g being the acceleration of gravity. The forces actives on the dust grains are the electromagnetic force f_{ek} , the gravitational force f_{gk} , the ion drag force f_{idk} and the neutral drag force f_{ndk} respectively.

Their expressions are given by:

$$\vec{f}_{ek} = q_{dk} (\vec{E} + \vec{v}_{dk} \times \vec{B}), \quad (6)$$

$$\vec{f}_{gk} = m_{dk} \vec{g} = \frac{4}{3} \pi r_{dk}^3 \rho_d \vec{g}, \quad (7)$$

$$\vec{F}_{idk} = \pi m_{ik} n_{ik} r_{dk}^2 v_{sk} \vec{v}_{ik} \left(1 - 2b_{\pi/2k}^2 / r_{dk} + 4\Gamma_k b_{\pi/2k}^2 / r_{dk}^2 \right), \quad (8)$$

where $b_{\pi/2k} = e q_{dk} / m_{ik} v_{sk}^2$ is the orbital impact parameter, Γ is the Coulomb logarithm and $v_{sk} = (v_{ik}^2 + 8T_i / \pi m_i)^{1/2}$ is total ion velocity.

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

$$\Delta\phi = -\frac{1}{\epsilon_0} \left(n_i e - n_e e + \sum_k n_{dk} q_{dk} \right). \quad (9)$$

The dust grains charge is described by the orbit motion limited model (OML) ³⁻⁴

$$\vec{v}_{dk} \cdot \nabla q_{dk} = I_{ek} + I_{ik} \quad (10)$$

Finally, the dust size distribution is modeled by a Gaussian Law ¹⁻²,

$$f(r_d) = D \exp\left(-\mu(r_d - r_{dm})^2\right), \quad \text{for } r_{d\min} \leq r_d \leq r_{d\max}, \quad (11)$$

otherwise, the distribution has zero value, where r_{dm} is average dust radius, D is the normalization constant and the constant μ is given by

$$f(r_{d\min}) = f(r_{d\max}) = 0.01 f(r_{dm}), \quad (12)$$

$r_{d\min}$ and $r_{d\max}$ being the lower and the upper limits of the dust grains radius.

Numerical results

In this section, we present the numerical results of our theoretical model. We have used a non reactive gas flow, i.e., argon as background gas and neglected any gas flow ($v_n = 0$).

The physical parameters used are $T_i = 0.01 \text{ eV}$, $T_n = 0.01 \text{ eV}$, $n_{i0} = 10^9 \text{ cm}^{-3}$, $P_n = 10 \text{ mTorr}$, $B = 1 \text{ T}$, $\theta = 20^\circ$, $\delta_d = 10^{-4}$, $\rho_d = 2 \text{ g cm}^{-3}$, $r_{d\min} = 0.01 \mu\text{m}$, $r_{d\max} = 5 \mu\text{m}$, $u_{i0} = 1.5$ and $u_{d0} = 2.5$.

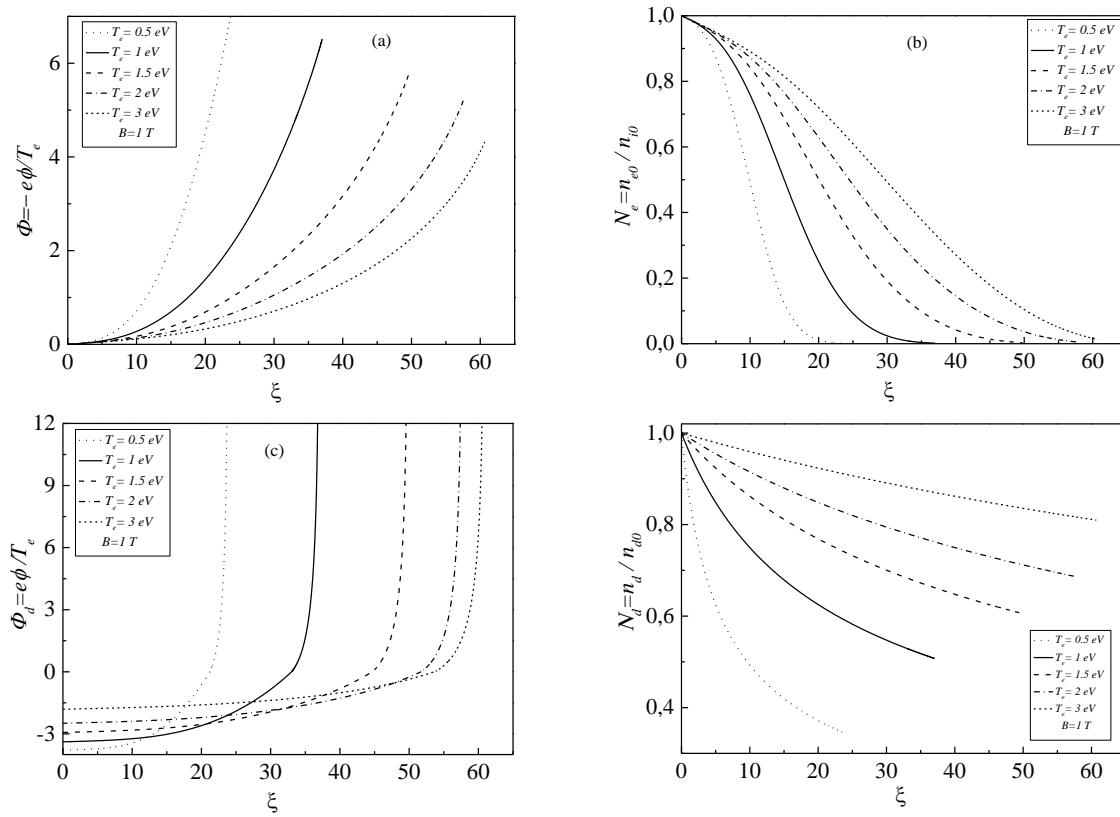


Figure1: Normalizes electrostatic potential (a), normalized electron density (b), normalized dust grains surface potential (c) and normalized dust grains density (d) as function $\xi = z / \lambda_{Di}$.

The numerical results show that the increase of electrons temperature induces the increase of the electrostatic sheath thickness. Indeed, the increase of the electron temperature increases their probability of attachment to dust grains and so the charge separation. Consequently, the electrostatic sheath thickness is enlarged. On the other hand figure (c) shows that the dust charge remains negative even for distances too close to wall and then changes sign abruptly just before the wall is reached. This is due to the fact that the density of electrons falls faster than that of ions in the sheath.

References

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