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Influence of metal macroparticles to the electron density in a dusty plasma

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Abstract. We obtained the equation, which describes electron density in an equilibrium dusty plasma taking into account parameters of the electron gas inside the dust particles. The inclusion of these parameters performed on the basis of the model of "solid-state plasma," considering the condensed particle system as the ion core and the free electron gas. The shape of potential barrier at the particle surface assumed as a rectangular.

1. Introduction

Dust particles in a plasma acquire an electric charge and are an additional charged component of the plasma. The properties of dusty plasmas are much richer than those of ordinary multi-component plasma of electrons and ions of various sorts [1]. In technological processes of plasma and flame spraying the powder particles are entered into the hot gas stream. Heated particles emit electrons into the surrounding gas or plasma and acquire a positive charge forming dusty plasma as a result [2-8]. The presence of charged dust particles has a strong influence on the characteristics of the flow. Intensive work is being done in the physics of dusty gas clouds in the atmosphere. The presence of charged dusty particles in the lower ionosphere radically affect its ionization properties.

In connection with the above description experimental and theoretical studies of the dusty plasmas properties are of great interest.

We consider dusty plasma at low temperatures, where thermal ionization of the gas can be neglected.

2. Theoretical background and results

We assume that the macroparticles are spheres of radius R , their concentration is equal to n_r , the concentration of electrons in the conduction band of dusty particles before emission is equal to n_{e0} , the average concentration of electrons in a gas or plasma, n_e , one dusty particle emits N electrons, the electron gas and dusty particles are in a state of statistical of equilibrium [9-12].

The following equation [12] equilibrium condition of the electron gas

$$\mu_1 + e\varphi_1 = \mu + e\varphi, \quad (1)$$

where μ_1 - the Fermi energy for an electron within the dusty particle and μ - is the Fermi energy for an electron outside of the dusty particle, φ_1 and φ - potentials of the electric field inside and outside of the



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dusty particle, e - charge of an electron. We assume that the $\varphi=0$ and inside of the dusty particle $\varphi_1=const$, $|e|=q$. With this in mind, equation (1) can be written as

$$\mu_1 - \mu = q\varphi_1. \quad (2)$$

Here h - Planck's constant, m_e - mass of the electron, n_e - electron density.

The potential energy of an electron within the dusty particle with a charge equal to Nq , is determined by the known equation

$$W_n = -q\varphi_1 = -\frac{q^2 N}{4\pi\epsilon\epsilon_0 R}. \quad (3)$$

where ϵ - relative dielectric permittivity, ϵ_0 - electric constant.

The concentration of free electrons in a gas or plasma is usually low, and therefore as μ it necessary to use the Fermi energy of a nondegenerate electron gas

$$\mu = \theta \ln(an_e), \quad a = \frac{1}{2} \left(\frac{h^2}{2\pi m_e \theta} \right)^{\frac{3}{2}}. \quad (4)$$

Here, h - Planck constant, θ - statistical temperature, equal to kT , k - Boltzmann constant, T - absolute temperature, m_e - mass of the electron.

Depending on temperature and concentration of electrons in dusty particles are two possibilities. For large n_{e0} and small T the electronic gas in a dusty particle is degenerate, while for small n_{e0} and large T it is nondegenerated. Lets consider first case in more detail. The Fermi energy of the electronic gas in a dusty particle is defined by

$$\mu_1 = \frac{h^2}{2m_e} \left(\frac{3n_{e1}}{8\pi} \right)^{\frac{2}{3}}. \quad (5)$$

where n_{e1} - concentration of the electrons in a dusty particle after emission.

Substituting expressions (3), (4) and (5) in (2) gives

$$\frac{h^2}{2m_e} \left(\frac{3n_{e1}}{8\pi} \right)^{\frac{2}{3}} - \theta \ln(an_e) = bN, \quad b = \frac{q^2}{4\pi\epsilon\epsilon_0 R}. \quad (6)$$

Due to the absence of the thermal ionization of the gas we have

$$n_r N = n_e. \quad (7)$$

From (6) we find

$$\frac{h^2}{2m_e} \left(\frac{3 \left(n_{e0} - \frac{3N}{4\pi R^3} \right)}{8\pi} \right)^{\frac{2}{3}} - \theta \ln(an_r N) = bN. \quad (8)$$

The figure shows the dependence of n_e from R when $\epsilon = 1$, $n_{e0} = 10^{24} \text{ m}^{-3}$, and different values of temperature (curve 1 - $T = 1000 \text{ K}$, curve 2 - $T = 1500 \text{ K}$, curve 3 - $T = 2000 \text{ K}$). As can be seen, a decrease of R and increase of T leads to an increase of the electrons concentration in a dusty plasma.

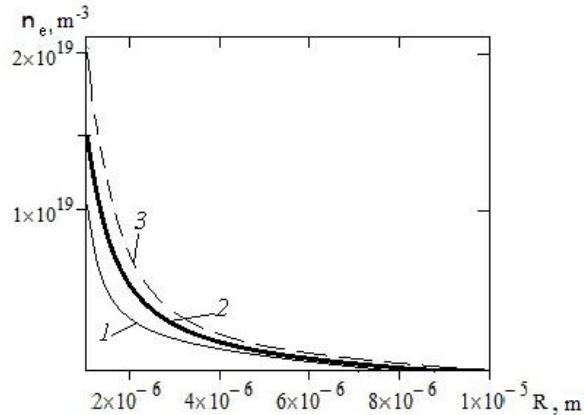


Fig.

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