§45. Dynamics of a Dust Particle in Sheaths

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In the present work, the motion of a single dust particle that started from the wall is analyzed including charging dynamics on wide range of dust radii and masses in both sheath and presheath, which were simulated with particle model of plasma [1].

The motion of a spherical dust particle in the simulated system is described by momentum and charging equations:

$$m_d \frac{d^2x}{dt^2} = F(x,t), \qquad \frac{dQ_d(x,t)}{dt} = I(x,t). \tag{1}$$

We consider the motion of a dust particle that initially placed at the wall with zero velocity and the charge that corresponds to the wall surface charge density $Q_d(t=0) = -4\pi\varepsilon_0 E_w R_d^2$. Total force acting on the dust particle $F(x,t) = F_E(x,t) + F_d(x,t)$ includes the electrostatic force $F_E(x,t) = Q_d(x,t)E(x)$ and the ion drag force due to the absorption of ions $F_d(x,t)$, here $E(x)$ is the local electric field. The charging current on the dust particle is the sum of electron current and ion current $I(x,t) = I_e(x,t) + I_i(x,t)$. Using approach of the monoenergetic ions and Maxwellian electrons with the OML theory the ion drag force and the currents to the dust particle can be expressed as

$$F_d(x,t) = \pi R_d^2 m_i n_i(x) V_i^2(x)\left(1 - \frac{Q_d(x,t)e}{2\pi\varepsilon_0 R_d m_i V_i^2(x)}\right), \tag{2}$$

$$I_e(x,t) = -\pi R_d^2 e n_e(x)\sqrt{\frac{8T_e(x)}{\pi m_e}}\exp\left[\frac{Q_d(x,t)e}{4\pi\varepsilon_0 R_d T_e(x)}\right], \tag{3}$$

$$I_i(x,t) = \pi R_d^2 e n_i(x) V_i(x)\left(1 - \frac{Q_d(x,t)e}{2\pi\varepsilon_0 R_d m_i V_i^2(x)}\right), \tag{4}$$

where $n_i(x)$, $n_e(x)$ and $V_i(x)$ are the local ion and electron densities and the ion flow velocity, respectively..

The dependencies of the farthest positions x_{max} that a dust particle reaches moving off the wall in the simulated system on its radius are shown in Fig. 1 for various masses of the dust particle. There are two types of motion of the heavy dust particles sharply discriminated by the second critical radius R_{c2} between short and long-range trajectories. Existence of such trajectories for heavy dust particles, which oscillation frequencies are much lower than charging frequencies, can be described with effective potential energy $E_{eff}(x) = \int_0^x F(x')dx'$, Fig.2. Dust particles smaller that the critical radius R_{c2} have positive gradient of the effective energy near the wall and potential minimum around which they oscillate reaching far from the wall positions. Dust particles bigger that R_{c2} have no minimum of potential energy or separated from it with potential barrier that does not allow them to move far off the wall. The delayed charging effect leads to increasing of the second critical radius with decreasing of the dust mass due to gradual relaxation during motion of the large initial dust charge (Fig. 1).

Some results of the present study were reported at ITC-13 [2] and will be further developed accounting additional forces and charging processes for better understanding of dust particles motion that is kind of impurity transport.

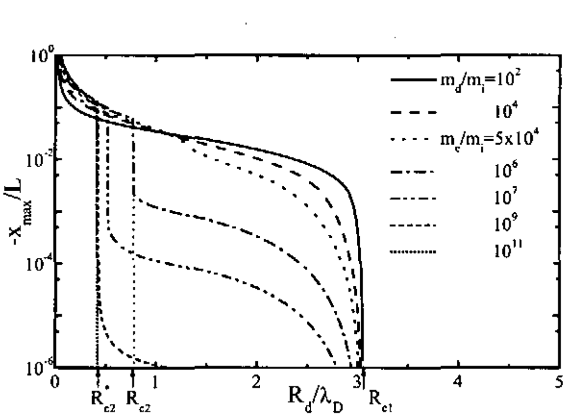

Fig. 1. Dependencies of the farthest position that dust particles reach moving off the wall on their radii for various masses of the dust particles.

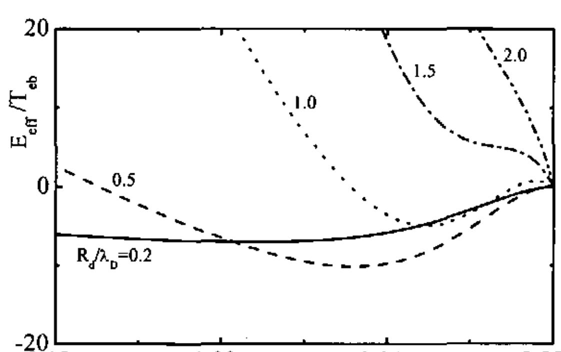

Fig. 2. Spatial profiles of effective potential energy for heavy dust particles with different radii.

Reference

1) Smirnov, R.D. et al., "Statics of a dust particle in sheaths and at walls" (this issue)
2) Smirnov, R.D. et al., JPFR Series **6**, (2004) (to be published)