§11. Gravitational Effect on Release Conditions of Dust Particle from Plasma-Facing Wall —Acting Force on Dust—

Tomita, Y.,
Smirnov, R. (UCSD), Takizuka, T. (JAEA),
Tskhakaya, D. (Univ. of Innsbruck)

In order to analyze the release conditions of the spherical dust particle on the conducting wall analytically, a one-dimensional model is applied. The balance between pushing forces and repelling forces determines the release condition of the dust particle. The pushing forces in this case are the ion drag force due to absorption of plasma ions by the dust, the Coulomb scattering force by plasma ions, and the electrostatic image force caused by the interaction of the dust charge with the mirror charge of itself. The drag force due to absorption of plasma ions is estimated by applying the OML (Orbit Motion Limited) model [5, 6], where the absorption cross section is given by

$$\sigma_{iab} = \pi R_d^2 \left(1 - \frac{q_d Z_i e}{2\pi\varepsilon_0 R_d m_i v_i^2}\right), \qquad (1)$$

where R_d and q_d are the radius and the charge of the dust particle, and Z_i, m_i, and v_i are the atomic number, mass, and incident speed of a plasma ion, respectively. As the plasma ions are sufficiently accelerated by the presheath and Debye sheath potential drops, we assume the ions at the wall have the monoenergetic velocity distribution. The dust charge q_d is expressed by its radius R_d and the electric field at the wall E_w according to the relation between the surface charge density and E_w.

$$q_d = -\xi_d \pi \varepsilon_0 R_d^2 E_w, \qquad (2)$$

where we introduced the form factor ξ_d for charging of the dust particle, which is equal to $2\pi^2/3 = 6.58$ in the case of the spherical dust in the uniform electric field [7]. In order to estimate the forces on the dust particle, the flow velocity of ions u_{iw} and the electric field E_w at the wall are necessary. The ion flow velocity at the wall is obtained as a function of the electrostatic potential at the wall ϕ_w from the conservations of particle flux and energy inside the collisionless sheath

$$u_{iw}(\phi_w) = V_{ise}\sqrt{1 - \frac{2Z_i e\phi_w}{m_i V_{ise}^2}} = \sqrt{\frac{T_e}{m_i}\left(1 - \frac{2Z_i e\phi_w}{T_e}\right)}. \qquad (3)$$

Here we assume the monoenergetic ion flow velocity at the sheath entrance V_{ise} is the ion sound speed $\sqrt{Z_i T_e / m_i}$, where T_e is the uniform electron temperature. The electric field at the wall is calculated by integration of Poisson equation combined with the electron density with the Boltzmann distribution and the ion density, which are expressed by the local electrostatic potential.

$$E_w^2(\phi_w) = \frac{2n_{se}T_e}{\varepsilon_0}\left[\exp(e\phi_w/T_e) - 1 + \frac{1}{Z_i}\left(\sqrt{1 - \frac{2Z_i e\phi_w}{T_e}} - 1\right)\right] \qquad (4)$$

where n_{se} is the plasma density at the sheath entrance. These quantities are used to evaluate a force balance acting on the spherical dust particle on the conduction wall. According to the analytical model and forces in the previous section, one can obtain the total force divided by πR_d^2 has a form of a quadratic equation with respect to the dust radius R_d.

$$F/\pi R_d^2 = a_0(\phi_w)R_d^2 + a_1(\phi_w)R_d + a_2(\phi_w), \qquad (5)$$

where the coefficients a_j depend on the macroscopic plasma quantities such as the particle flux, ion flow velocity at the wall and electron temperature as well as the wall potential ϕ_w

$$a_0(\phi_w) = \frac{Z_i^2 e^2 \xi_d^2 \Gamma_i \ln\Lambda E_w^2(\phi_w)}{4 m_i u_{iw}^3(\phi_w)}, \qquad (6)$$

$$a_1(\phi_w) = \frac{Z_i e \xi_d \Gamma_i E_w(\phi_w)}{2u_{iw}(\phi_w)}[1 + \delta_g(\phi_w)], \qquad (7)$$

$$a_2(\phi_w) = m_i \Gamma_i u_{iw}(\phi_w) + \frac{\xi_d^2 \varepsilon_0 E_w^2(\phi_w)}{16} - \xi_d \varepsilon_0 E_w^2(\phi_w), \qquad (8)$$

where δ_g indicate the effect of the gravitational force, which is defined as

$$\delta_g(\phi_w) \equiv \frac{8 g \rho_d u_{iw}(\phi_w)}{3 Z_i e \xi_d \Gamma_i E_w(\phi_w)}. \qquad (9)$$

The normalized threshold potential $-e\phi_w^{th}/T_e$ is shown as a function of the form factor ξ_d for $Z_i = 1$, 2, and 18 in Fig.1. As the all terms in the coefficient a_2 have the same dependence on the plasma quantities as $n_{se}T_e$, the normalized threshold potential depends on only the form factor ξ_d. At the region between $\xi_d \sim 4$ and ~ 12 the threshold potential is almost independent of the form factor ξ_d, especially in the case of the low atomic number.

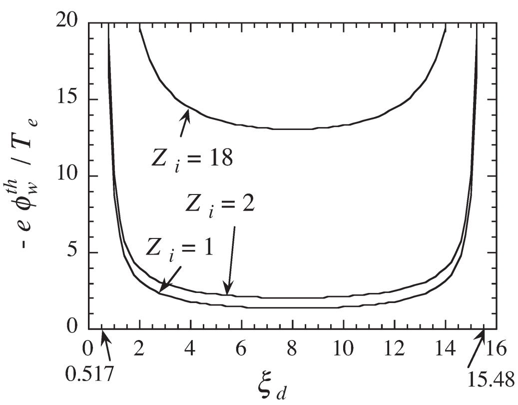

Fig.1 Threshold wall potential as a function of the form factor ξ_d for $Z_i = 1$, 2, and 18. The deeper wall potential than the threshold makes the dust release.