§11. Plasma and Potential at Plasma-facing Wall —Effects of Truncation of Electron Distribution—

Tomita, Y., Nakamura, H.,
Smirnov, R. (UCSD), Zhu, S. (ASIPP),
Takizuka, T. (JAEA), Tskhakaya, D. (Univ. Innsbruck)

In order to evaluate the forces on the dust particle, the particle flux, the ion flow velocity and the electric field at the wall are necessary. In this study the collisionless Debye sheath is considered to obtain these quantities, where the electrostatic potential and the electric field at the Debye sheath entrance are vanishing and the charge neutrality is satisfied at the sheath entrance. In this model the particle flux is conserved. The ion flow velocity at the wall is obtained as a function of the electrostatic potential drop at the wall ϕ_w and the electron temperature from the particle flux and energy conservations inside the collisionless Debye sheath,

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

Here V_{ise} is the monoenergetic ion flow velocity at the Debye sheath entrance, which is equal to the ion sound speed $c_s = \sqrt{Z_i T_e / m_i}$ from the Bohm criterion. The electric field at the wall is given by integration of Poisson equation combined with the local ion and electron densities. The local ion density is expressed by the local electrostatic potential ϕ,

$$n_i(\phi) = n_{ise} / \sqrt{1-\frac{2Z_i e\phi}{T_e}} . \quad (2)$$

In this system, where there are no particle sources, sinks and collisions, the local energy distribution function of electrons, $f_e(\varepsilon_e)$, is the same as at the sheath entrance, $f_{e0}(\varepsilon_e)$,. Here ε_e is the total particle energy $(= m_e v^2/2 - e\phi)$ in the local electrostatic potential ϕ. The local macroscopic quantities inside the system are easily calculated by using the local energy distribution function. Inside the Debye sheath there are electrons with positive and negative velocities due to the reflection by the monotonically decreasing potential.

$$n_e(\phi) = n_e^{(+)}(\phi) + n_e^{(-)}(\phi) ,$$
$$= n_{ese}^{(+)} \exp(e\phi / T_e)[1+\mathrm{erf}\sqrt{e(\phi-\phi_w)/T_e}] \quad (3)$$

where the quantity $n_e^{(+)}$ is the local density of electrons with positive velocities, which obeys the Boltzmann relation:

$$n_e^{(+)}(\phi) = n_{ese}^{(+)} \exp(e\phi / T_e) , \quad (4)$$

and $n_e^{(-)}$ is that with negative velocities:

$$n_e^{(-)}(\phi) = n_{ese}^{(+)} \exp(e\phi / T_e)\mathrm{erf}\sqrt{e(\phi-\phi_w)/T_e} . \quad (5)$$

It is reasonable to see that there are no electrons with negative velocities at the wall. Here $n_{ese}^{(+)}$ is the density of electrons with positive velocities at the Debye sheath entrance, which is expressed by the total electron density at the Debye sheath n_{ese}

$$n_{ese} = n_e(\phi=0) = n_{ese}^{(+)}(1+\mathrm{erf}\sqrt{-e\phi_w/T_e}) . \quad (6)$$

This gives the local electron density as a function of local potential ϕ

$$n_e(\phi) = n_{ese}\exp(e\phi/T_e)\frac{1+\mathrm{erf}\sqrt{e(\phi-\phi_w)/T_e}}{1+\mathrm{erf}\sqrt{-e\phi_w/T_e}} . \quad (7)$$

The local ion density, Eq.(2), and electron density, Eq.(7), give the electric field at the wall by solving the Poisson's equation:

$$E_w^2(T_e,\phi_w) = \frac{2n_{se}T_e}{\varepsilon_0}\{\frac{1}{1+\mathrm{erf}(\sqrt{-e\phi_w/T_e})}[e^{e\phi_w/T_e}-1$$
$$-\mathrm{erf}(\sqrt{-e\phi_w/T_e}) + \frac{2}{\sqrt{\pi}}e^{e\phi_w/T_e}\sqrt{-e\phi_w/T_e}]$$
$$+\sqrt{1-\frac{2e\phi_w}{T_e}}-1\} . \quad (8)$$

The first term of RHS of Eq.(8) is the effect of truncated electron distribution and the last two terms come from the ion density. These quantities are used to evaluate a force balance acting on the spherical dust particle on the conducting wall. In the case of electrons with the Maxwellian velocity distribution, the electric field at the wall obtained from Poisson equation is

$$E_w^2(T_e,\phi_w) = \frac{2n_{se}T_e}{\varepsilon_0}[\exp(e\phi_w/T_e)-1$$
$$+\sqrt{1-\frac{2e\phi_w}{T_e}}-1] \quad (9)$$

In Fig.1 the electric field at the wall is shown for both cases, where for the potential drops ~1 the electric field with truncation is stronger by around 50% than that without truncation.

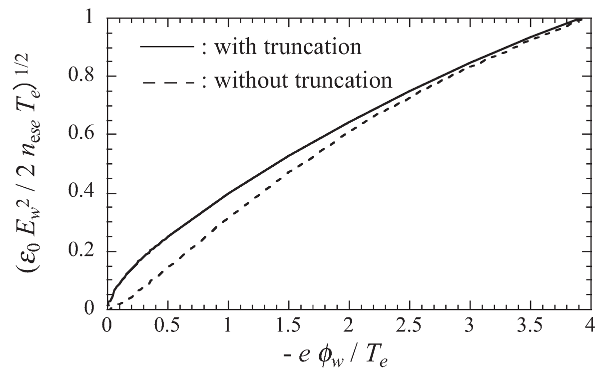

Fig.1 Electric field at the wall as a function of normalized wall potential drop for cases with and without truncation.