§ 21. Theoretical Approach to Potential Formation near Divertor Plate

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The potential formation near divertor plate was investigated by using one-dimensional kinetic analysis. The plasma flow injected from the position of $x = 0$ into the collisionless and sourceless region where the divertor plate is installed at the position $x = L$. In this system the plasma velocity distribution function is expressed from Boltzmann equation in (x, ε) space, where ε is the total energy of a plasma particle $m_j v_x^2/2 + q_j \phi(x)$ which is one of the constants of motion :

$$v_x(x,\varepsilon,\mu)\frac{\partial f_j(x,\varepsilon)}{\partial x} = 0. \tag{1}$$

The quantity ϕ denotes the electrostatic potential which is 0 at the injection point and monotonically decreasing to the wall. In this case there is no particles with $v_x = 0$ inside the system. This Boltzmann equation of eq.(1) gives the local distribution function is expressed by the injected one. In this analysis we consider the plasma is injected from $x = 0$ with the half-Maxwellian distribution:

$$f_j(x,\varepsilon) = f_j(0,\varepsilon) = 2n_{js}\sqrt{\frac{m_j}{2\pi T_j}}\exp(-\varepsilon_j/T_j). \tag{2}$$

In the decreasing potential ions has positive velocity to the wall, the density n_i is

$$n_i(x) = n_{is}\exp[-q_i\phi(x)/T_i]\,\mathrm{erfc}\,[\sqrt{-q_i\phi(x)/T_i}], \tag{3}$$

where erfc is a complementary error function: $\mathrm{erfc}\, z = (2/\sqrt{\pi})\int_z^{\infty} e^{-t^2}dt$. On the other hand electrons have positive and negative velocities due to the reflection of the wall potential which is negatively charged. These densities are

$$n_e^{(+)}(x) = n_{es}\exp[e\phi(x)/T_e], \tag{4}$$

for particles with positive velocity,

$$n_e^{(-)}(x) = n_{es}\exp[e\phi(x)/T_e]\,\mathrm{erf}\,\{\sqrt{e[\phi(x)-\phi_w]/T_e}\} \tag{5}$$

for negative velocity, where erf is a error function: $\mathrm{erf}\, z = (2/\sqrt{\pi})\int_0^z e^{-t^2}dt$. Here ϕ_w is the potential at the divertor wall, which is determined by the condition of the equal flux there:

$$\phi_w = -\frac{T_e}{2e}\ln\left[\left(\frac{n_{es}}{n_{is}}\right)^2\frac{m_i}{m_e}\frac{T_e}{T_i}\right]. \tag{6}$$

Other local physical quantities are able to obtain from the local velocity distribution functions, eq. (2). The densities and flow velocities are shown in Fig. 1 as a function of potential for a case of $T_e/T_i = 10$, $m_i/m_e = 1836.0$. Here the injection density ratio n_{es}/n_{is} is selected 0.507, which corresponds the density at the injection position is neutral. The electron sheath ($n_e > n_i$) is formed in front of injection region ($\phi \sim 0$). On the other hand the ion sheath ($n_i > n_e$) is generated in front of wall ($\phi = \phi_w$). Near wall ions are decelerated by the negative wall potential and their density increase because of the flux conservation.

These analyses could give the physical base for the sheath formation near divertor plate where the collisions between particles are able to be neglected.

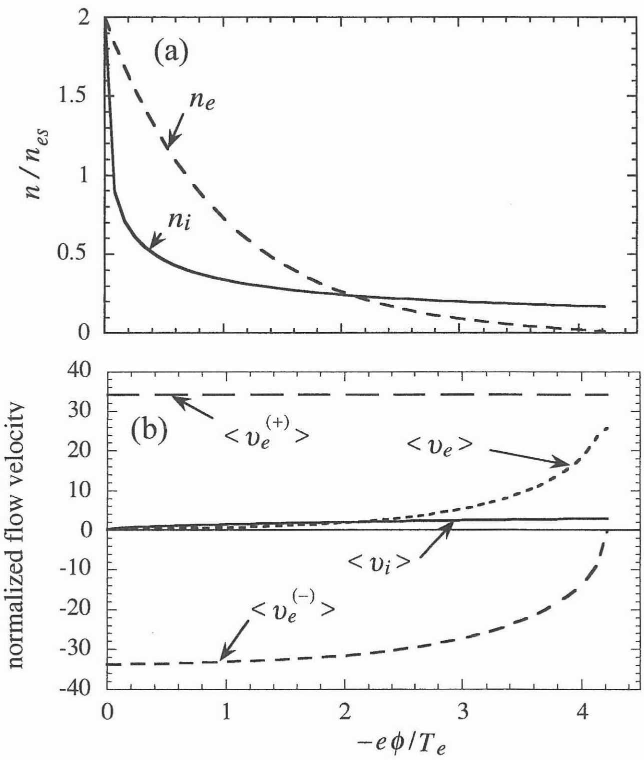

Fig. 1. Densities (a) and flow velocities (b) as a function of electrostatic potential in case of $T_e/T_i = 10$, $m_i/m_e = 1836.0$, where the normalized wall potential is 4.22. Here densities and flow velocities are normalized by n_{es} and $(T_e/m_i)^{1/2}$, respectively.