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§16. 1D Fluid Model of Plasma Profiles in the LHD Divertor Leg

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The core plasma of LHD is surrounded by the ergodic layer characterized by stochastic magnetic field lines. Outside the ergodic layer, a plasma is carried along magnetic field lines toward a divertor plate. This intermediate region is called divertor leg and plays essential roles in impurity transport. The plasma profiles such as density and temperature are necessary to determine the charge state and movement of impurity atoms. We present a divertor leg model of 1D flux tube to determine the plasma profiles from input parameters such as energy flux coming from the ergodic layer.

The following assumptions and notations are employed in this work. The spatial coordinate variable is denoted by s and the origin of the coordinate, $s = 0$, is chosen at the boundary between the ergodic layer and the divertor leg. The other end, $s = l_c$, is located at the boundary between the collisional presheath and the magnetic presheath[1], which is a very thin layer in front of the divertor plate. The boundary condition at the magnetic presheath entrance is given by equality of the Bohm criterion and the sheath transmission factors. The plasma includes neutral hydrogen atoms n_n and the collisions between the plasma and the neutrals cause electron impact ionizations and charge exchanges. Their rate coefficients are denoted by $\langle\sigma_{iz}v\rangle$ and $\langle\sigma_{cx}v\rangle$ respectively, and calculated by Lotz model[2] and Freeman-Jones model[3].

1D stationary fluid equations describing the divertor plasma are given by the following five equations. i) and ii) Density and momentum conservations:

$$\frac{dm_i nv}{ds} = \langle\sigma_{iz}v\rangle\, m_i n_n n, \qquad (1)$$

$$\frac{d}{ds}\left[m_i n v^2 + n(T_e + T_i)\right] = -\langle\sigma_{cx}v\rangle\, m_i n_n n v, \qquad (2)$$

where the electron and ion masses and temperatures were denoted by m_e, m_i, T_e and T_i. iii) and iv) Energy conservations for electrons and ions:

$$\frac{d}{ds}\left[\frac{5}{2}nvT_e - \kappa_{e0}T_e^{5/2}\frac{dT_e}{ds}\right]$$
$$= env\frac{d\phi}{ds} - \frac{3m_e n}{m_i}\nu_{eq}(T_e - T_i) - 25e\langle\sigma_{iz}v\rangle\, n_n n - Lnn_{imp} \qquad (3)$$

$$\frac{d}{ds}\left[\frac{m_i n v^3}{2} + \frac{5}{2}nvT_i - \kappa_{i0}T_i^{5/2}\frac{dT_i}{ds}\right]$$
$$= -env\frac{d\phi}{ds} + \frac{3m_e n}{m_i}\nu_{eq}(T_e - T_i)$$
$$-\langle\sigma_{cx}v\rangle\, n_n n\left(\frac{3}{2}T_i + \frac{1}{2}m_i v^2\right), \qquad (4)$$

where the potential was denoted by ϕ. The heat conduction coefficients and temperature equilibration coefficient are denoted by κ_{i0}, κ_{e0} and ν_{eq}. The density of impurities and the radiative cooling rate coefficient were denoted by n_{imp} and $L(T_e)$. For simplicity, the impurity density is assumed to be proportional to the plasma density, i.e. $n_{imp}/n = r_{imp} = \text{const.}$
v) electron force balance :

$$e\frac{d\phi}{ds} = \frac{1}{n}\frac{dnT_e}{ds} + 0.71\frac{dT_e}{ds}. \qquad (5)$$

For simplicity, the flow velocity of the neutrals is treated as a constant in this work. The decrease in the number of the neutrals is given by the ionizations and thus, the neutral density n_n is determined by the equation of the flux conservation:

$$\frac{dv_n n_n}{ds} = -\langle\sigma_{iz}\rangle\, n_n n, \qquad (6)$$

where the flow velocity of neutrals was denoted by v_n. The average flow velocity of atoms is estimated from the Frank-Condon energy; $v_n \simeq -\sqrt{3e/\pi m_i} \simeq 1\times10^4$ m/s.

We have developed a computational code to solve the fluid equations (1) – (6). They are integrated numerically from the wall side, $s = l_c$, by the fourth order Runge-Kutta method.

We show plasma profiles for typical parameters in Fig. 1. The parameters used in the calculation are as follows; l_c = 3m, R = 0.9, r_{imp} = 0, $n_0 = 5\times10^{18}/\text{m}^3$ and $Q_0 = 10\text{MW/m}^2$. We use a fixed recycling coefficient in the calculations here. The profile of the plasma density is plotted in Fig. 1(a). A collisional presheath is formed in front of the wall and its width is approximately 0.3m in this case. The gradual increase in the region, $s < 2.7$m, is caused by the ion temperature gradient shown in Fig. 1(b). Since the neutral density is very low compared with n_{n1}, the energy is conserved and thus the pressure $n(T_e + T_i)$ is constant. Therefore, the temperature drop, $d(T_e + T_i)/ds < 0$, yields the density rise, $dn/ds > 0$. The temperature drop sustains the energy flux by the heat conduction. The gradient of T_e is smaller than that of T_i because the heat conductively of electrons is much higher than that of ions. These mechanisms cause the density peaking near the wall and its sharpness increases for the plasma of higher density.

1) D. Tskhakaya and S. Kuhn, Plasma Phys. Control. Fusion, **47**, A327 (2005)
2) W. Lotz, Astrophys. J. Suppl., **14**, 207 (1967).
3) R. L. Freeman and E. M. Jones, *Atomic Collision Processes in Plasma Physics Experiments*, Culham Laboratory, Abingdon, England, Report CLM-R 137 (1974).

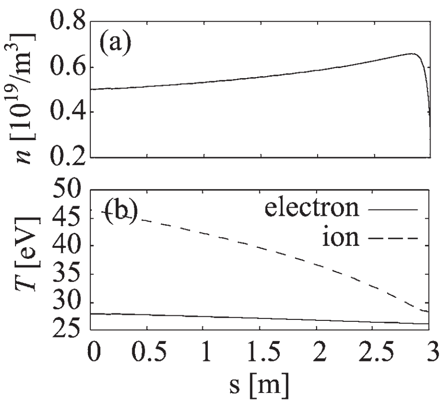

Fig. 1: Spatial profiles along a field line of (a) plasma density n and (b) temperatures T_e, T_i.