§55. Impurity Behavior in Long Pulse Discharges on LHD

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Impurity behavior was investigated in long pulse discharges on LHD. In a variety of long pulse discharges, we found that metal impurity accumulation was observed in only hydrogen discharges in a narrow density window of around $2 \times 10^{19} m^{-3}$.

The radial impurity flux was investigated for various collisionality regimes. For the case of low collisionality (low density and high temperature), the impurity flux is given by

$$\Gamma_I = -D_S n_I (n_I'/n_I - Z_I E_r/T_I + \alpha T_I'/T_I) \quad (1)$$

where D_S and E_r is the diffusivity and the radial electric field, respectively, and α is a collisionality dependent factor. If the impurities are in a regime of $1/\nu$ or collisionless detrapping, the flux is dominated by the term due to the electric field, in particular, for high-Z impurities. The formation of E_r is determined from an ambipolarity condition for the radial fluxes of electrons, ions and impurities. If the electron flux is the dominant flux in a very low collisionality regime, the ambipolar electric field becomes positive (electron root). In this case, the impurity flux tends to go outward. When the collisionality increases, the ion flux becomes dominant and the electric field turns to be negative (ion root). Then the impurity flux tends to go inward. For the case where the impurities are in the plateau regime and the ions in the banana regime, the impurity flux is given by

$$\Gamma_I = -D_{BP} n_I (n_I'/n_I + 3T_I'/2T_I - Z_I n_i'/n_i - 3Z_I T_i'/2T_i) \quad (2)$$

based on neoclassical transport for axisymmetric devices. For high-Z impurities, the flux is dominated by the last two terms, which drive the impurities inward because n_i' and T_i' are generally negative. When the plasma density increases, the impurities enter in the Pfirsch-schlüter regime with high collisionality. If only the interaction of heavy impurities with the background ions is important, the impurity flux is written as

$$\Gamma_I = -D_{PS} n_I (n_I'/n_I - T_I'/2T_I - Z_I n_i'/n_i + Z_I T_i'/2T_i) \quad (3)$$

In this regime, the last two terms also dominate the impurity behavior. The density term is directed towards the plasma axis and is responsible for peaking of the impurity density. The temperature term is of the opposite sign and prevents such a peaking, i.e. is responsible for the so-called 'temperature screening'. In LHD, since the density profile is flat or hollow in the discharges with gas puffing and the temperature profile is nearly parabolic, the impurity flux tends to go outward in the plasma core and it leads to a flat profile of the impurity density.

By taking into account the various impurity transport regimes described above, one can see the impurity behavior in a n-T diagram as shown in Fig. 1, where the plasmas with impurity accumulation (closed circles) are distinguished from those without accumulation and with pump-out (squares). The solid line represents the transition between the plateau regime and the Pfirsch-schlüter regime for iron impurity. This boundary was calculated in consideration of the collision with light impurities (C, O), whose concentrations were determined so that Z_{eff} has a typical value of 2.5 obtained in the experiments on LHD. The broken line represents the transition between the electron root and the ion root for background plasma. This indicates a critical point of the specific space where the plasma has multiple solutions for the ambipolar electric field. The point was calculated by an analytical model with typical profiles of temperature and density measured in long pulse discharges. On the whole, the impurity behavior obtained in long pulse discharges is qualitatively in good agreement with the neoclassical impurity transport. In the low density and high temperature region, the high-Z impurities may be expelled by the positive electric field or diffused out because of nearly zero electric field. As indicated in Fig. 1, it is not so easy to obtain the electron root in the plasma core, but it is possible to obtain in the peripheral region. Furthermore, small positive electric fields were observed even in the density range of ion root near the transition to electron root. The boundary of impurity accumulation in the low collisionality regime may be shifted to higher collisionality regime. In the intermediate regime with negative electric field (ion root), the high-Z impurities are accumulated in the central plasma due to the electric field in the $1/\nu$ regime or the temperature gradient in the plateau regime. When the impurities enter in the PS regime, the accumulated impurities are pumped out by the dominant contribution of the temperature gradient term on account of the flat density profile and the parabolic temperature profile. If the plasma density is raised up quickly, impurity accumulation does not occur because of the temperature screening effect in the PS regime.

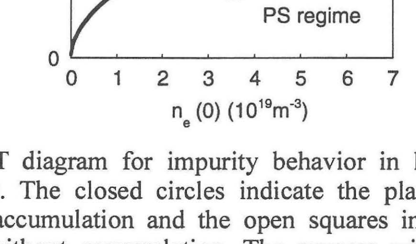

Fig. 1 n-T diagram for impurity behavior in long pulse discharges. The closed circles indicate the plasmas with impurity accumulation and the open squares indicate the plasmas without accumulation. The squares with a cross indicate the plasmas with pump-out or without accumulation.