

## §18. Transport Analysis of High Density Plasmas with Internal Diffusion Barrier in Toroidal Helical Plasmas

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The understanding of the turbulence-driven transport and the improved confinement (transport barriers) is the key issue in fusion research. Many kinds of the improved confinement mode in the core plasma of toroidal helical plasmas have been reported; e.g., the e-ITB with the strong positive radial electric field. The radial transition of  $E_r$  was predicted to induce the internal transport barrier due to the shear of the radial electric field in the helical plasmas. The transition of  $E_r$  was found on the Compact Helical System (CHS), and the improvement of confinement was found inside of the transition point for  $E_r$ . Observations on Wendelstein7-AS (W7-AS), LHD and the other experiments followed. On the other hand, the Internal Transport Barrier (ITB) in LHD was recently discovered with the strong gradient of the density in a super dense core (SDC) plasma when a series of the pellet is injected. We present the transport model to explain the ITB. The theoretical model for the ITB observed in LHD is shown. The mechanism, which is based on the transport reduction due to the shear of the radial electric field, is newly examined in the formation of the ITB. In the case of the particle fuelling, the density rapidly increases. Therefore, the ion temperature temporally decreases and the positive gradient in the  $T_i$  profile is found to appear. From the ambipolar condition to determine the  $E_r$  profile, the positive  $E_r$  is found. As the result, the strong gradient of  $E_r$  and the reduction of the anomalous particle diffusivity can be shown.

For the case of the ITB plasma, the transport modeling is done. The one-dimensional transport analysis for the LHD-like plasma has been performed. To simulate the pellet injection, we use the parameter  $S_p$  of the particle source. This parameter  $S_p$  has a distribution as  $S_p = S_{p0} \exp(-(r/(0.2a))^2)$  and is set to have a value from the initial time  $t=0$  to 1ms. We set the pulse of the particle source as  $S_{p0} = 10^{23} \text{m}^{-3} \text{s}^{-1}$  for  $0 < t < 1 \text{ms}$  and  $S_{p0} = 0 \text{m}^{-3} \text{s}^{-1}$  for  $t > 1 \text{ms}$ . The rapid change of the gradient in the density profile at  $t=10 \text{ms}$  can be found at  $\rho = \rho_T (\approx 0.2)$  in Fig. 1, where  $\rho = r/a$ . The parameter  $\rho_T$  represents the location of the transition from the positive  $E_r$  to the negative  $E_r$  at 10ms. When the value of the density increases with the particle fuelling in Fig. 1, the value of the ion temperature decreases because the value of the pressure is temporally constant. We can show the much steeper gradient ( $|E_r| \sim 100 \text{kV m}^{-2}$ ) of the radial electric field at the point  $\rho_T$  at  $t=10 \text{ms}$  than that at  $t=1 \text{ms}$ . The time 10ms is roughly the typical time scale during which the radial transition of  $E_r$  is formed in the parameter regime examined here. A clear reduction of the anomalous particle diffusivity  $D_a$  is found at the transition point  $\rho = \rho_T$  due to the strong gradient of  $E_r$  compared with

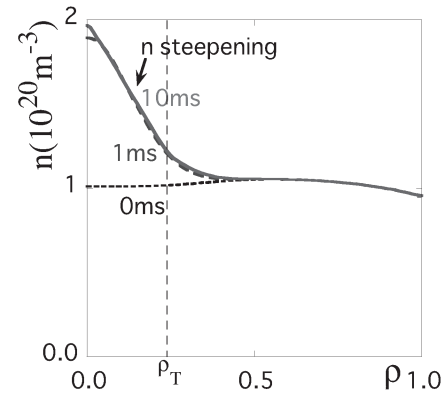


Fig. 1 Temporal evolution of the density profile

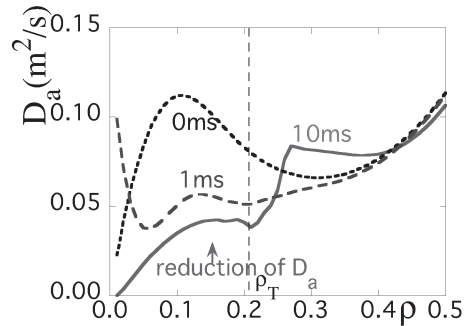


Fig. 2 Temporal evolution of the anomalous particle diffusivity  $D_a$

the region  $\rho > \rho_T$  at 10ms in Fig. 2. In the region  $\rho < 0.3$  at the time 10ms, the neoclassical diffusivity  $D_{\text{NEO}} (= -\Gamma^{\text{na}}/n')$  is found to be much smaller than the absolute value of the effective anomalous particle diffusivity and is  $|D_{\text{NEO}}| < 0.01 \text{m}^2 \text{s}^{-1}$ , where  $\Gamma^{\text{na}}$  is the neoclassical particle flux. In the core region, the slightly negative value for the effective neoclassical particle diffusivity  $D_{\text{NEO}}$  and the particle neoclassical pinch are obtained at the time 10ms. The value of  $E_r$  can be roughly derived by the equation  $E_r = T_i (n'/n + C_i T_i'/T_i) / e$  in the parameter region examined here ( $T_e \approx T_i$ ). Note that the contributions to  $E_r$  from the gradients of  $n$  and  $T_i$  are different by the factor  $C_i$ , where  $C_i \approx 3$ . The positive  $E_r$  can be obtained because of the sufficient positive  $T_i'$  in the region  $\rho < \rho_T$ . Therefore, the strong gradient of  $E_r$  can be obtained. It is emphasized that the barrier formation still occurs after the particle fuelling. If we set much smaller value for  $S_{p0}$ ,  $S_{p0} = 2 \times 10^{22} \text{m}^{-3} \text{s}^{-1}$  than that ( $S_{p0} = 10^{23} \text{m}^{-3} \text{s}^{-1}$ ) in this calculation, we can not find the steepening in the density gradient, because the gradient of  $E_r$  after the pellet fuelling is not large enough. It is shown that there is a threshold value for  $S_p$  to form the barrier with respect to the particle confinement in the density profile.

1) S. Toda and K. Itoh: Plasma and Fusion Research, in press.