§ 4. Neoclassical Transport Calculation for the N-ITB in CHS

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The parallel and radial plasma transports in multi-species plasmas in non-symmetric toroidal configurations are the important application of a recently developed neoclassical transport formulation[1]. In CHS, the toroidal flow of the fully ionized carbon in the counter direction and the reduction of the bootstrap current in the co-direction were observed when the neoclassical internal transport barrier (N-ITB) with the strong positive radial electric field($E_r\sim$ 10kV/m at the minor radial position of $r/a\sim0.3$) was formed in spite of the momentum input due to the co-injected heating neutral beam[2]. This phenomenon was qualitatively interpreted as the well-known mechanism making the flow in the viscosity-minimum direction that generates the counter-direction bootstrap current in the collisional regimes of the conventional helical configurations. Figure 1 shows the energy dependent pitch-angle-scattering collision frequency ν of each particle species in the particle velocity range of $v_{th}/10<v<5v_{th}$, where v_{th} is the thermal velocity, evaluated using the measured plasma parameters and the radial electric field at minor radial position of r/a=0.5 (T_e=0.5keV, T_i=0.20keV, $n_e=2.5\times10^{12}\mathrm{cm}^{-3}$, E_r=2.7kV/m). Here, a hydrogen plasma having fully ionized carbon with the density ratio of 10% as an impurity (Z_{eff}=3) is assumed. The curves in Fig.1 give the integration paths to make energy-integrated viscosity and transport coefficients from the mono-energetic coefficients given as the function of ν/v and E_r/v. As shown in the figure, the collisionality of each particle species cover the wide range from the Pfirsch-Schlueter to the super banana regimes. Furthermore, the low energy components of the distributions of ions suffer the effect of so-called toroidal resonance ($E_r/B\sim vB_p/B_t$) and thus their viscosity and transport coefficients have strong dependence on the radial electric field even in the plateau regime. An connection formula is used to connect the numerically obtained $1/\nu$ regime mono-energetic diffusion coefficients to the analytical formula of the super banana regime mono-energetic diffusion coefficients[3]. The mono-energetic coefficients under the toroidal resonance can be obtained from the poloidal and toroidal viscosity coefficients in Ref.[4] using the procedure in Appendix B of Ref.[1].

Figure 2 shows the parallel flows and radial diffusion fluxes obtained for the N-ITB condition in CHS (at r/a=0.5) obtained by the procedure in Ref.[1]. The ambipolar condition $\Sigma_a e_a\Gamma_a=0$ is attained at $E_r\sim$8kV/m. Under this radial electric field strength, the parallel flows of the ions turn to counter direction with the velocities of 20km/s (C^{6+}) and 50km/s (H^+) and the bootstrap current $\Sigma_a\Sigma e_a n_a < Bu_{//}>/<B^2>^{1/2}$ in the co-direction is strongly reduced. These results qualitatively coincide with the experimental results.

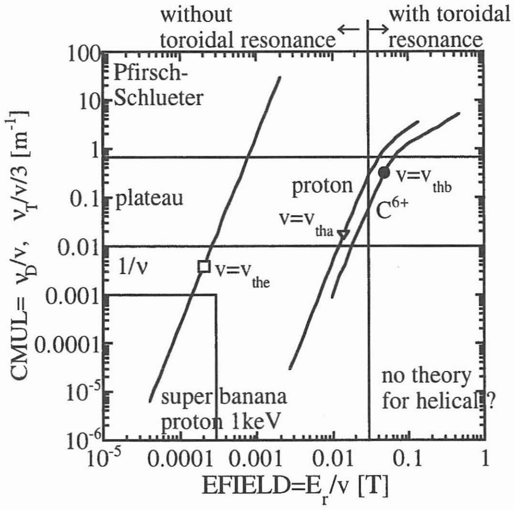

Fig.1 The energy integration path for the mono-energetic transport coefficients in ν/v-E_r/v plane. □, ▽, and ● denote the values for the thermal velocities.

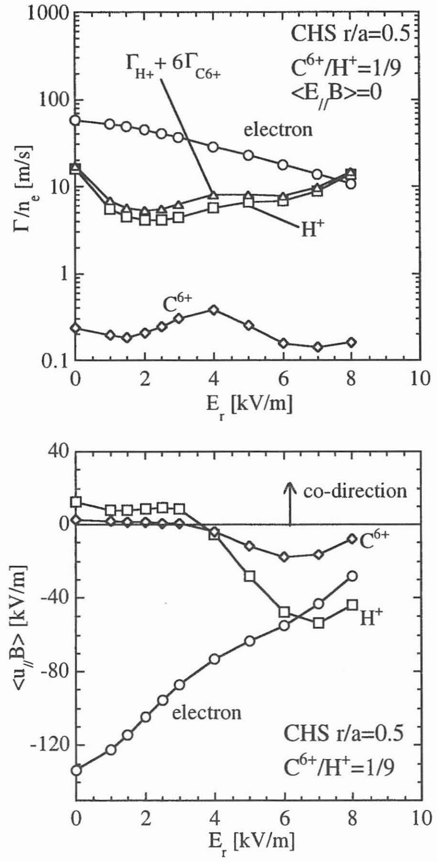

Fig.2 The parallel flows $u_{//}$ and radial diffusion fluxes Γ calculated for the N-ITB condition in CHS (at r/a=0.5).

References

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