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Kinetic simulation studies on particle transport of multi-species plasma

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In magnetic confined systems, the transport of particles and heat of multi-species plasmas are demanded to be accurately predicted for understandings of the burning plasma in the ITER, future reactors, and also stellarators such as the Large Helical Device (LHD) [1]. For the purposes, large scale numerical simulations based on the first principle of the kinetic frameworks are extremely powerful. Indeed, by means of the flux-matchings, it becomes able to validate the kinetic simulation results against the experimental observations for the plasma temperature and density profiles with the experimental errors taken into account [2, 3]. In LHD experiments, we often observe the extremely hollow impurity density profiles called *impurity hole* [4] in high ion temperature plasma heated by neutral beam injection (NBI). The hollow profile has a great advantage to avoid impurity accumulation which deteriorates the performances of the confinement. Therefore, the clarification of its generation mechanism is one of the critical issues for high performance of magnetically confined plasmas. In these plasmas which consist of multi-species, the particle transport fluxes of each species should be quantitatively evaluated by kinetic simulations for the neoclassical and anomalous contributions, where the particle balances for each species should be determined by the total particle transport fluxes including the both contributions.

In the micro-instability analyses for the LHD impurity hole plasma, it was found that the ion temperature gradient (ITG) mode is the dominant instability mode, and the nonlinear gyrokinetic turbulence simulations are performed to evaluate anomalous contributions. Figure 1 shows the impurity carbon density gradient dependences of the turbulent contributions of the radial transport fluxes of particles for all species satisfying the ambipolar conditions. It is newly found that there are quite different dependencies between each species while the main ion (hydrogen) density gradient has little effects on the fluxes. Furthermore, the impurity carbon particle flux remains the negative (radially inward directed) for wide ranges of the gradients. Therefore, if the system is in the steady state with negligible auxiliary particle sources or sinks, the outward neoclassical carbon particle flux should be expected for balancing with the inward turbulent flux.

On the other hand, in order to evaluate the neoclassical contributions, we solve the drift-kinetic equation and evaluate the ambipolar radial electric field by the neoclassical simulations. Since the neoclassical particle fluxes can be affected by the external momentum torque by NBI heating through the radial electric field (E_r) generation, co-injected external torque can cause not only negative E_r but also positive one. Although the negative E_r is often observed in the core region of the LHD plasmas, if there exists the positive one, the neoclassical particle flux of carbon can be outward directed which is consistent with the expectation that the outward directed neoclassical particle fluxes for balancing with turbulent one. In addition, if there exist sufficient direct inward contributions of the injected beam to the total ion particle flux, the carbon particle fluxes can be outward directed because each ion particle flux should be shifted outward due to the additional contribution for satisfying ambipolar condition.

References

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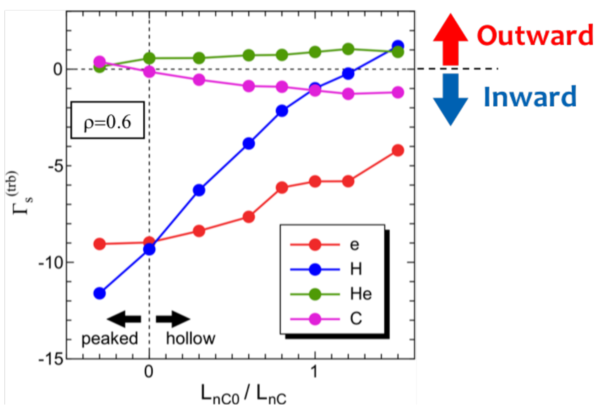

Figure 1: Carbon density gradient dependences of turbulent transport fluxes of particles for each particle species in the LHD impurity hole plasma.