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Study on impurity hole plasmas by global neoclassical simulation

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An impurity hole observed in the Large Helical Device (LHD) is a hollow density profile of an impurity ion species, typically carbon, spontaneously formed in the core plasma in which a negative (inward pointing) ambipolar radial electric field exists [1,2]. Local neoclassical models have predicted that the carbon impurity flux flows inwardly under such a condition. Further, the local models have predicted that the sign of the radial electric field in impurity hole plasmas is negative for the entire region. This contradicts an experimental observation of an impurity hole plasma that the radial electric field changes its sign from negative to positive along the minor radius [3].

Since the total particle flux is thought to be given by the sum of the neoclassical flux and turbulent flux, it is reasonable to suspect that the outward turbulent contribution overcomes the inward neoclassical contribution to produce the impurity hole. However, gyrokinetic studies have shown that this scenario is unlikely to be true [4,5], and the results suggest that the neoclassical models need to be extended.

The most common approximations that has been employed in neoclassical models is the radially local approximation. This is the assumption that particles are constrained on a single flux surface. It is also common to assume that electrostatic potential is uniform on each flux surface.

To investigate the impurity hole phenomenon, we have extended a global neoclassical code FORTEC-3D to calculate multiple ion species plasmas including the variation of electrostatic potential, Φ_1 [6,7]. Using this code, we have shown that an ambipolar radial electric field that changes its sign along the minor radius is obtained as a solution of the ambipolar condition and with such a radial electric field profile, the impurity carbon flux can be outwardly directed even where the radial electric field is negative and the carbon density profile is hollow [7] (Figure 1). The global calculation result was also shown to be consistent with a gyrokinetic simulation result [4] in terms of the particle balance.

To investigate what enables the carbon flux to be driven outwardly in the presence of the negative radial electric field, we introduce a new method to evaluate the impacts of each driving force on the neoclassical transport by a single δf simulation [8]. Using the method, we demonstrate that the temperature gradient and negative ambipolar radial electric field contribute to the flux near the magnetic axis in the same level, each in the opposite direction. This means that the large temperature gradient, which characterizes the impurity hole plasmas, can cancel the impact of the negative radial electric field (Figure 2).

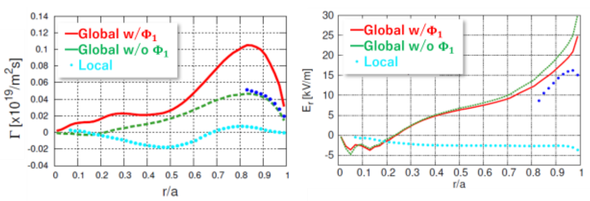

Figure 1. Radial profiles of the radial carbon flux (left) and ambipolar radial electric field (right). The red and green lines represent the results with and without $\mathbf{\Phi_1}$ calculated by the global code FORTEC-3D, respectively, and the cyan lines represent the result calculated by a set of local codes DKES/PENTA

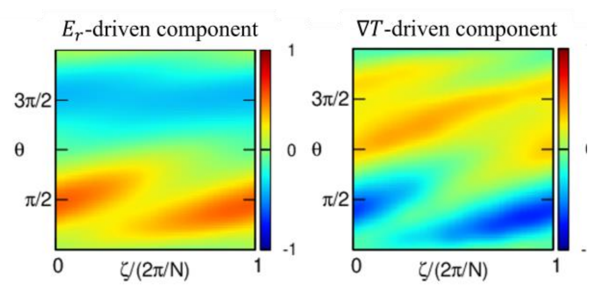

Figure 2. Density variation of carbon on a flux surface produced by the radial electric field (left) and temperature gradient (right). Both have similar amplitudes and the opposite signs.

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