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トロイダルプラズマの不純物輸送に対する運動論的モデリング
Kinetic modeling of heavy impurity transport in toroidal plasma

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Evaluation of radial particle flux of tungsten (W) impurity in the core edge of mixed-collisionality toroidal plasma is required for estimating the impurity accumulation. Here, the number density of W impurity should be 10^4-10^5 times smaller than the number density of background ion. In this work, a drift-kinetic simulation code is developed for the evaluation in the quasi-steady state of the edge plasma. In the code, the impurity is set to W^{4+} and the background ion is D^+ (deuteron). The code is a solver of the drift-kinetic equation of W^{4+} impurity under the two effects caused by the Coulomb collision between the impurity and the background ion: neoclassical inward pinch (NC IWP) and temperature screening effect (NC TSE), which are based on Homma's fluid model [1]. Specifically, the model is implemented in the drift-kinetic δf simulation code KEATS [2], where $\delta f = f - f_{\mathrm{M}}$ and f_{M} is the local Maxwellian function. As shown in Fig.1, it is confirmed in the benchmark of the code that the radial particle flux in a circular tokamak is consistent with the theoretical estimate derived in [1], when the parallel flow velocity of the impurity is assumed to be the Pfirsh-Schüter flow velocity. Here, this assumption is used in the theoretical estimate. The radial particle fluxes in Fig.1 are evaluated as

$$\langle \Gamma_r^{(0)} \rangle = \langle \int \mathrm{d}^3 v\, (\boldsymbol{v}\cdot\nabla r)\, f_{\mathrm{M}} \rangle \quad \text{and}$$
$$\langle \Gamma_r^{(1)} \rangle = \langle \int \mathrm{d}^3 v\, (\boldsymbol{v}\cdot\nabla r)\, \delta f \rangle,$$

where $\langle \cdots \rangle$ is the flux surface average. On the other hand, it should be noted that the parallel flow velocity $V_{\parallel}$ is also given by δf and is estimated as

$$V_{\parallel} = (1/n) \int \mathrm{d}^3 v\, v_{\parallel}\, \delta f,$$

where n is the number density. In such an estimation, it is found that effect of the boundary condition is not negligible in the evaluation of the radial particle flux, as shown in Fig.2. We also see that the radial particle flux is affected by the NC IWP and the NC TSE through the parallel flow velocity of the impurity. From the above results, KEATS code with Homma's fluid model is useful for investigating the collisional impurity transport in the quasi-steady state of the edge plasma.

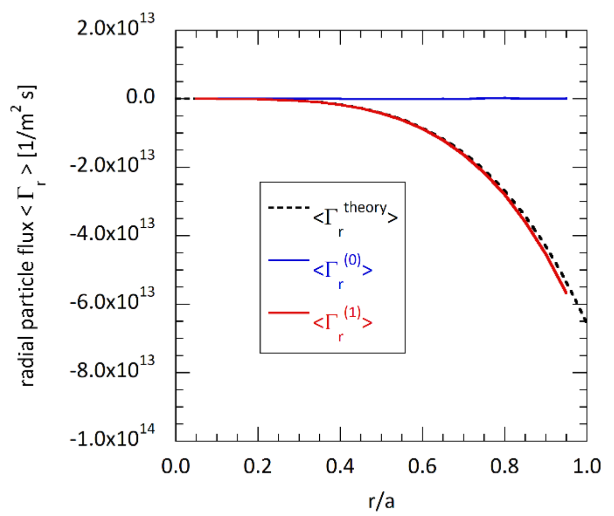

Fig.1: The radial particle flux $\langle \Gamma_r^{(1)} \rangle$ is consistent with the theoretical estimate $\langle \Gamma_r^{\mathrm{theory}} \rangle$.

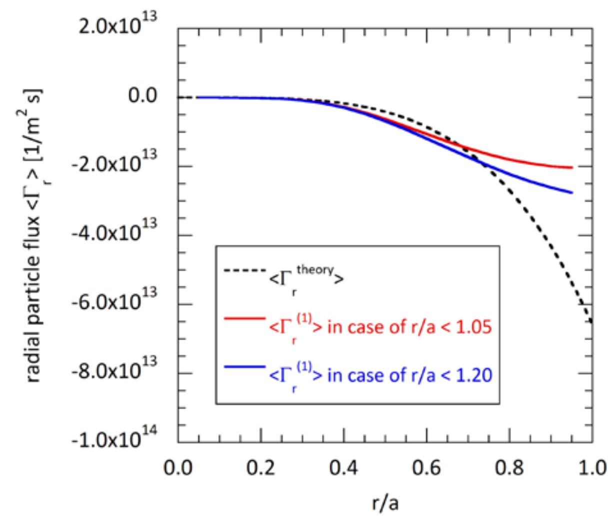

Fig.2: The radial particle flux $\langle \Gamma_r^{(1)} \rangle$ is affected by the boundary condition. The fluxes in the cases where the boundary of the core region is set at r/a=1.05 and at 1.20 are illustrated by the red and blue lines, respectively.

[1] Y.Homma *et al.*, Nucl. Fusion **56** (2016) 036009.
[2] R.Kanno *et al.*, Nucl. Fusion **58** (2018) 016033.