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RMPを加えた領域における不純物輸送シミュレーションコード開発
Drift-kinetic simulation of heavy impurity transport in the edge affected by RMPs

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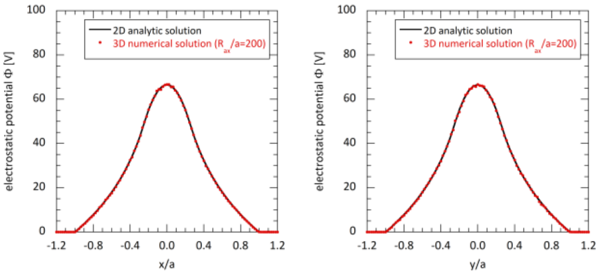
Based on the drift-kinetic equation, we develop a model of collisional transport of a heavy impurity like tungsten in the edge of a quasi-steady tokamak plasma. It is known in recent tokamak experiments that resonant magnetic perturbations (RMPs) are effective at controlling the impurity transport in the edge, simultaneously at mitigating or suppressing edge localized modes. In such a case, electromagnetic fluctuation is presumed to be generated by, for example, turbulence in the edge, in which magnetic field lines are ergodized by the RMPs. The distribution function of the impurity in the edge is also assumed to be fluctuating. The computational cost of a kinetic simulation of the impurity transport including the electromagnetic fluctuation is expected to be quite-high. Under considering that the behavior of the distribution function of the impurity is probabilistic, it is helpful to evaluate time-evolution of an ensemble-averaged distribution function of the impurity for understanding how the distribution function of the impurity becomes quasi-steady. The modeling shows that the electromagnetic fluctuation can be ignored in the drift-kinetic equation of the ensemble-averaged distribution function, if it is appropriate that effect of the electromagnetic fluctuation on the impurity transport is interpreted as a noise, which has zero expectation and is bounded, on the equation of motion of an impurity guiding center. We are preparing a drift-kinetic simulation code according to the above idea.

In solving the drift-kinetic equation, next problem is how to evaluate electrostatic potential in the ergodized edge, when the vector potential is assumed to be fixed in time. The required performance of the Poisson solver is complex as the solver is applied to the complicated structure of the charge density, which is caused by the ergodized edge. We develop a new simulation code for solving the Poisson equation. To reduce the computational cost of solving the Poisson equation in the complicated three-dimensional magnetic structure, it is desirable that the electrostatic potential is calculated only in the edge. In this work, we propose a basic idea for evaluating a potential of the following Poisson equation in only part of the domain in curvilinear coordinates (u^1, u^2, u^3), based on Monte Carlo methods.

$$\frac{1}{\sqrt{g}}\frac{\partial}{\partial u^k}\left\{\sqrt{g}\,g^{kl}\frac{\partial}{\partial u^l}\Phi\right\} = -\frac{1}{\varepsilon_0}\rho$$

For benchmarking the Poisson solver, calculation of a potential Φ is discussed in the case that the charge density $\rho = 1.0 \times 10^{-8}$ [C/m^3] if r=sqrt{$(u^1)^2+(u^2)^2$} < r_0 and ρ =0 otherwise, where r_0 is set to $r_0/a=0.25$ and r(u^1, u^2) = a = 1 [m] is the boundary at which Φ=0. Here, the 3D coordinates (u^1, u^2, u^3) satisfy the following relation that $X=(R_{ax}+u^1)\cos(u^3)$, $Y=-(R_{ax}+u^1)\sin(u^3)$, and $Z=u^2$. The difference between the 3D numerical solution evaluated by the solver and the 2D analytic solution becomes smaller if the torus is slender. It should be noted that the 2D analytic solution is derived under the assumption of cylindrical symmetry. This tendency is confirmed in the figure below, where $x=u^1$ and $y=u^2$ in this figure. When the major radius is set to $R_{ax}/a = 200$, the 3D numerical solution is almost identical to the 2D analytic solution.



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