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モンテカルロ２体衝突モデルを用いた新しい熱力モデルによる核融合プラズマ中のテスト不純物粒子輸送シミュレーション

Impurity test particle transport simulation in fusion plasmas using a new thermal force model based on the Monte Carlo Binary Collision model

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To realize stable energy production by nuclear fusion plasmas, the impurity particles have to be well controlled. It is desirable that the impurities do not enter the core, but at the same time, do remain in the edge region because they can cool down the peripheral plasma leaking from the core, to reduce the plasma-wall interactions at divertor plates. To this end, correct understanding of impurity transport processes in fusion plasmas is one of the most important research subjects to develop sustainable fusion devices.

The importance to model the transport processes which are particular in the edge region (SOL + divertor regions) of Tokamak plasma, has been more and more recognized. Our group is developing such impurity transport modeling in the edge, by checking each process step by step. Here, we present our recent progresses, especially on the modeling of thermal force caused by background plasma temperature gradient which is perpendicular to magnetic field.

It has been considered that the impurity transport process in the edge plasma may be different from the traditional classical / neo-classical transport model. Because the following large differences between the core and the edge plasma are not completely taken into account in the actual transport modelings:

1. In the edge, the magnetic field is open. The passing particles and a part of trapped particles are lost in the edge, because they soon end up running into the divertor. In addition, relatively stronger parallel temperature gradient exists before the divertor plates when we consider the high-recycling or the detached plasma. The consequent parallel thermal force can be greater than the frictional drag force due to background plasma flow.

2. Steep radial gradient of background plasma density exists in the edge. It may transport impurities along the direction of the gradient, i.e. from lower to higher density region. This effect can lead to impurity accumulation in the dense core, but is not appropriately included in the actual impurity transport simulations. Recently, Y. Sawada has developed a new numerical kinetic model to simulate such impurity inward diffusion in the classical diffusion limit. The detail will be reported in the presentation.

3. Strong radial gradient of background plasma temperature exits in the edge. The thermal force caused by such perpendicular temperature gradient drives the guiding center drift of impurities, called *temperature screening effect (TSE)*[1]. This drift by thermal force can transport impurities in a direction opposite to the gradient, i.e. from hotter core to colder edge region across the magnetic field. After rough estimation, this drift velocity may be non-negligible compared with the anomalous diffusion supposed in the actual impurity simulations. The TSE has to be included in the impurity transport simulation in the edge.

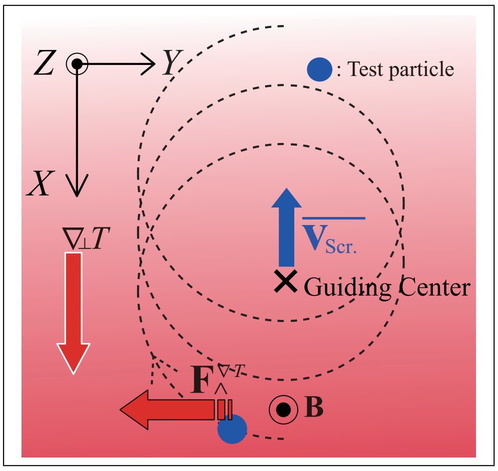

Fig. 1.: Thermal force $\mathbf{F}^{\nabla T}_{\wedge}$ due to perpendicular temperature gradient $\nabla_{\perp}T$ is depicted. The magnetic field $\mathbf{B}$ is in the Z-direction and a perpendicular plasma temperature gradient $\nabla_{\perp}T$ is along the X-axis. The consequent thermal force acting on a test particle is oriented to the $(\nabla_{\perp}T \times \mathbf{B})$-direction, i.e. along $(-Y)$-direction. Such thermal force drives the guiding centre drift toward $(\mathbf{F}^{\nabla T}_{\wedge} \times \mathbf{B})$-direction, i.e. along $(-\nabla_{\perp}T)$-direction.

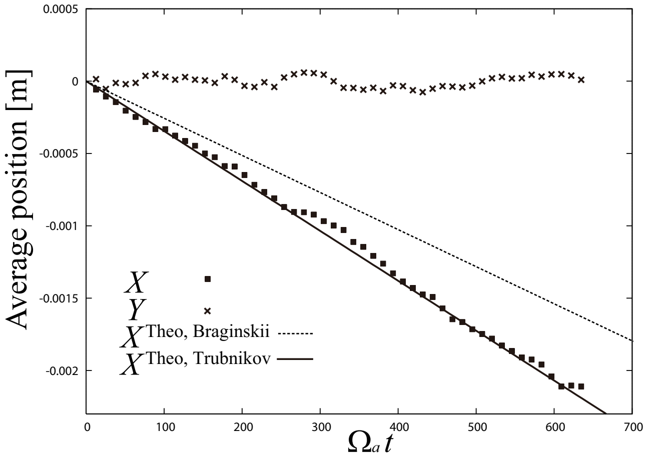

Fig. 2.: A simulation result on the temperature screening effect (TSE) is shown. Sufficiently large number of test particles started moving from the coordinate origin. As in the Fig. 1, the magnetic field $\mathbf{B}$ is in the Z-direction and the perpendicular temperature gradient $\nabla_{\perp}T$ is along the X-axis. Time evolution of test particle's ensemble-averaged position has been calculated. Its X-, and Y-component are shown, respectively, by ■ and ×. The vertical axis means the travel distance and the horizontal axis represents the time normalized to the Larmor gyration time of test particle $\Omega^{-1} := (q|\mathbf{B}|/m)^{-1}$. The simulated results agree well with their theoretical values: $Y^{Theo.} = 0$ and $X^{Theo.}$ has been estimated from the drift velocity of TSE.

We have developed a new numerical model of thermal force for the test-impurity particle transport simulation in fusion plasmas. Our model is able to correctly simulate the thermal force caused by not only the parallel temperature gradient but also the perpendicular gradient, which is very steep in the edge. Coulomb collision simulation by the Monte-Carlo Binary Collision model[2], and the random sampling of the background plasma ion velocity from a distorted Maxwellian distribution[3, 4] play the key role in the model.

In our previous paper[4], we have performed a test simulation for the model validation with limited patterns of plasma parameters. In this presentation, we will show the results of test simulation on the TSE effect with wider range of the plasma parameters. We have varied the magnitude of the radial temperature gradient, the magnetic field, and the background plasma density, as well as the impurity ion's mass and electric charge. In addition, the limit length of valid simulation time step has been checked to investigate the numerical efficiency of the model.

Then, we would like to discuss the effects of radial density/temperature gradient on the impurity transport and compare them with the anomalous diffusion under realistic Tokamak conditions.

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