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ドリフト運動論方程式に基づいた不純物輸送モデル開発
Development of an impurity transport model based on the drift-kinetic equation

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Based on the drift-kinetic equation, we are developing a model of collisional transport of a heavy impurity like tungsten in a quasi-steady three-dimensional edge plasma [1, 2]. Here, the impurity is assumed to be sufficiently rarefied in the edge plasma and does not contribute to electromagnetic field in the edge. In recent tokamak experiments [3], resonant magnetic perturbations (RMPs) are effective at controlling the impurity transport in the edge, and 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, and 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 such an electromagnetic fluctuation is expected to be high. Under considering that the behavior of the distribution function of the impurity is probabilistic, it may be helpful to interpret effect of the electromagnetic fluctuation as a noise in the impurity transport.

It is known that in general such a probabilistic fluctuation in equations of motion of a guiding center affected by the Coulomb collisions does not change the probability density given by the motion in the velocity space, as shown, for example, in Fig.1. This fact is also mathematically confirmed by Theorem 8.4.3 in [4], where the theorem gives the necessary and sufficient condition for an Ito process to coincide in law with a given diffusion process. On the other hand, when effect of the probabilistic fluctuation is considered in the drift kinetic equation of the impurity, role of the effect has not been explained.

We evaluate the 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. The difference between the mathematical result in [4] and the result of applying to the drift-kinetic equation can be explained by the stochastic processes with and without the martingale. Here, a martingale is one of the properties of a stochastic process, which is represented as $\mathrm{E}[X_t|F_s] = X_s$, where X_t is a stochastic process, i.e., a random variable at time t, $t > s$, F_s is the σ-algebra generated by $\{X_\tau\,;\,\tau \leq s\}$, and $\mathrm{E}[\cdot\,|F_s]$ is the conditional expectation operator. The developed model will be applied firstly to a weakly three-dimensional toroidal plasma.

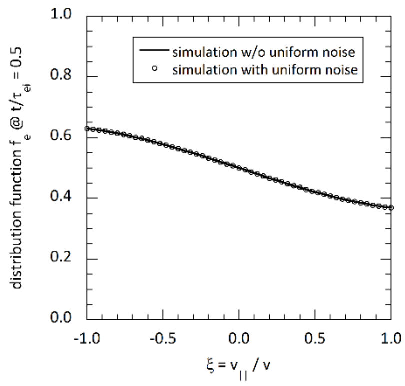

Figure 1; The distribution function in the velocity space $f_e = \mathrm{E}^{\xi}[\Phi(\xi_t)]$ at time $t/\tau_{ei} = 0.5$, where the initial distribution is set to be $\Phi(\xi)$. Here, open circles and solid line are given by the equation of motion with and without the noise, respectively.

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