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Dependence of Thermal Diffusivity on Plasma Parameters in Perturbed Magnetic Field in Toroidal Plasma

トロイダルプラズマの摂動磁場領域での熱輸送シミュレーション

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We consider the modeling of radial heat transport under effects of both the Coulomb collision and resonant magnetic perturbations (RMPs) in toroidal plasma. It is found in the previous study that the radial thermal diffusivity χ_r in the perturbed region is represented as $\chi_r = \chi_r^{(0)}\{1+c|\delta B_r/B_t|^2\}$, where $|\delta B_r|$ is the strength of RMPs in the radial directions, $|B_t|$ is the strength of toroidal magnetic field at the magnetic axis, $\chi_r^{(0)}$ is the diffusivity when $\delta\mathbf{B}=0$, and c is an unknown coefficient. In the present study, dependence of the coefficient c on plasma parameters is investigated by a Monte-Carlo simulation code KEATS. We find that the dependence of c is given as $c \propto \omega_b/\nu$ in the banana regime, where ω_b is the bounce frequency and ν is the collision frequency.

1. Introduction

Essentially, energy transport phenomenon in perturbed magnetic field under conditions of n=constant, $\mathbf{V}=0$ and $\mathbf{E}=0$ in the radial directions (i.e., the radial heat transport in the perturbed region) is one of diffusive phenomena caused by the Coulomb collision [1], where n is the density, $\mathbf{V}$ is the mean velocity, and $\mathbf{E}$ is an electric field. The radial heat flux after a sufficient time is represented by using the following model of radial thermal diffusivity: $\chi_r = \chi_r^{(0)}\{1+c|\delta B_r/B_t|^2\}$; see [1].

The present study is devoted to investigate dependence of the unknown coefficient c in χ_r on collision frequencies and particle species by using a δf simulation code KEATS [2].

2. δf simulation for estimating radial thermal diffusivity

We investigate dependence of the coefficient c on plasma parameters in the modeling of radial thermal diffusion, where the radial heat flux is estimated by using a guiding center distribution function. The radial thermal diffusivity can be evaluated by the δf simulation code KEATS [1, 2].

In the simulation, a toroidal magnetic configuration is formed by adding RMPs to a simple tokamak field having concentric circular flux surfaces and an ergodic region is bounded radially on both sides, where the major radius of the magnetic axis is set as R_{ax}=3.6 m, the minor radius of the plasma is a=1 m, and the magnetic field strength on the axis is B_{ax}=4 T. The Poincare plot of magnetic field lines with RMPs on a poloidal cross section is shown in Fig.1. Details of magnetic field including RMPs used in the simulations are described in [1]. The temperature profile is fixed as $T(r) = T_{ax} - (T_{ax}-T_{edge})(r/a)$ with T_{ax}=1.137 keV and $T_{edge}=0.8T_{ax}$, and the density n is assumed to be a constant, where $r=\{(R-R_{ax})^2+Z^2\}^{1/2}$ is the label of magnetic flux surfaces if neglecting the RMPs in cylindrical coordinates (R, φ, Z). Comparison between the results of the δf simulation of KEATS and previous studies including the field-line diffusion theory is discussed in detail in [1].

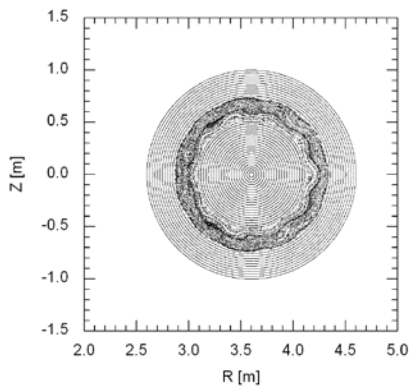

Fig.1. Poincare plot of the magnetic field lines on a poloidal cross section in coordinate space.

As shown in Fig.2, the radial thermal diffusivity is proportional to the square of the strength of RMPs in the radial directions, $|\delta B_r|^2$, and also depends on the collision frequency, ν, where the collision frequency is proportional to the density n.

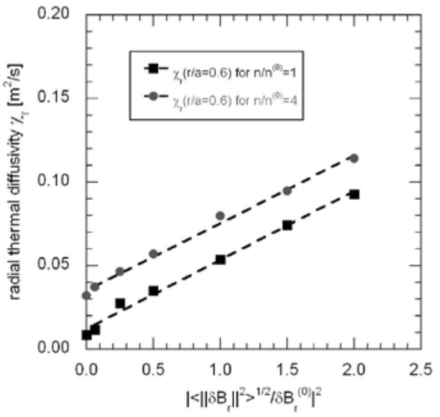

Fig.2. The radial thermal diffusivity of ion (proton) at r/a=0.6 depends on both the strength of RMPs in the radial directions and the density n, where $n^{(0)}=1\times10^{19}$ m^{-3}, $|\delta B_r| = <||\delta B_r||^2>^{1/2}$ is given as the averaged value of δB_r on a reference surface of r/a=0.6, and $|\delta B_r^{(0)}|$ is the strength of δB_r at r/a=0.6 in Fig.1.

The dependence of χ_r on the collision frequency in the configurations with and without RMPs is shown in Fig.3, where the radial thermal diffusivity in the plateau regime is close to the one given by the neoclassical theory in the plateau regime, i.e., χ_r = 0.3 m^2/s [3]. We see that difference between the diffusivities with and without RMPs is negligibly small in the plateau regime, and that one of the key parameters is ω_b/ν, where ω_b is the bounce frequency. As shown in Fig.4, the dependence of χ_r on ν is represented as $c \propto 1/\nu$ from the results calculated by using data in Fig.3. Therefore, the diffusivity in the perturbed magnetic field is formulated as $\chi_r = \chi_r^{(0)}\{1+c'(\omega_b/\nu)|\delta B_r/B_t|^2\}$, where c' is a coefficient.

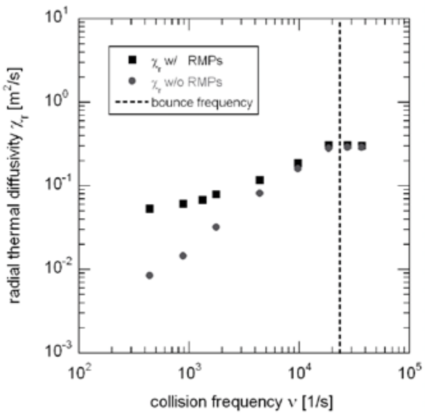

Fig.3. The radial thermal diffusivity of ion (proton) at r/a=0.6 in the configuration with and without RMPs.

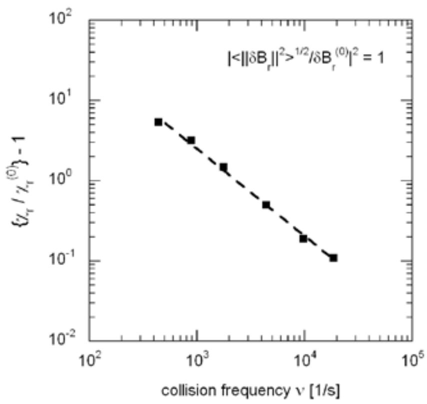

Fig.4. The radial thermal diffusivity of ion (proton) at r/a=0.6 depends on the collision frequency ν, where $|\delta B_r| = <||\delta B_r||^2>^{1/2}$ is given as the averaged value of δB_r on a reference surface of r/a=0.6 and $|\delta B_r^{(0)}|$ is the strength of δB_r at r/a=0.6 in Fig.1.

As shown in Fig.5, the radial thermal diffusivity also depends on the particle mass, i.e., c' should be a function of the particle mass. We are investigating the dependence of c' on particle species in detail, and will report on it in the near future.

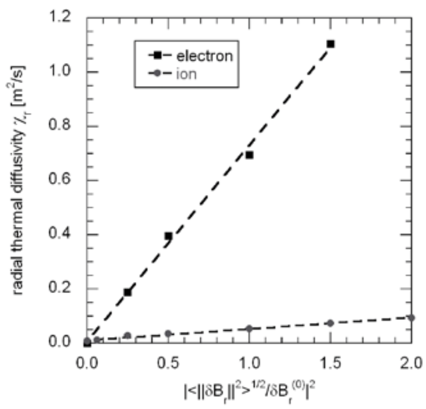

Fig.5. The radial thermal diffusivities of electron and ion (proton) at r/a=0.6.

Acknowledgments

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