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Effect of radial electric field on collisional transport in toroidal plasma affected by resonant magnetic perturbations

共鳴摂動磁場を印加したトロイダルプラズマの衝突輸送に対する径電場の効果

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We develop a drift-kinetic simulation code for calculating the radial particle and energy fluxes of electron and ion in a perturbed region affected by resonant magnetic perturbations (RMPs). Here, the perturbed region is assumed to be generated on and near the resonance surfaces, and is wedged in between the regular closed magnetic surfaces. In this proceedings paper, we show a benchmark test of evaluating the particle flux affected by a self-consistent electric field in regular closed magnetic surfaces, and preliminary calculate the particle and energy fluxes in the perturbed region; the electron particle flux is extremely larger than the ion particle flux under an assumption of zero electric field, and thus a positive radial-electric-field is expected because of the ambipolar condition.

1. Introduction

To understand properties of plasma transport in a perturbed magnetic field is important for control of fusion plasma by employing resonant/non-resonant magnetic perturbations (RMPs/non-RMPs) [1]. In the recent tokamak experiments [2,3], RMPs/non-RMPs are used to suppress edge localized modes. It has been found simultaneously with the suppression that the theoretical estimates of radial transport in the perturbed region, which are based on the field line diffusion derived by Rechester-Rosenbluth [4], are too large compared to the experimental results [2]. The purpose of the present study is set to check the fundamental properties of the plasma transport. In order to approach the “puzzle” of plasma transport in a perturbed region, we have started from the step to examine the dependences of the radial thermal diffusivity on several important parameters (e.g., the strength of RMPs, collisionality, and so forth) by using the drift-kinetic simulation code, KEATS. In the previous simulation studies under an assumption of zero electric field [5,6], we have found that 1) the radial thermal diffusivity in an ergodic region is close to the theoretical one derived by [4] if the diffusivity is estimated at $t \ll \omega_{\mathrm{t}}^{-1}$, where t is time and ω_{t} is the transit frequency, 2) the diffusivity is extremely small compared with the theory of [4] in a quasi-steady state (i.e., $t \gg \omega_{\mathrm{t}}^{-1}$), and 3) the dependence of the diffusivity on the parameters is approximately same as in the formula of [4]. At the present, the study is progressing for investigating effects of radial electric field E_{r} on the plasma transport.

2. Simulation Results

2.1 *Magnetic configuration affected by RMPs*

To investigate the transport in a perturbed region, we use a magnetic field **B** that is formed by adding an RMP field δ**B** to a circular tokamak field $\mathbf{B}_0$ having concentric circular flux surfaces, where the major radius of the magnetic axis R_{ax}=3.6 m, the minor radius of the plasma a=1 m, and the magnetic field strength on the axis B_{ax}=4 T. The unperturbed magnetic field $\mathbf{B}_0$ is given by $B_{0\mathrm{R}} = -B_{\mathrm{ax}}Z/qR$, $B_{0\varphi} = -B_{\mathrm{ax}}R_{\mathrm{ax}}/R$, and $B_{0\mathrm{Z}} = B_{\mathrm{ax}}(R - R_{\mathrm{ax}})/qR$:

$$\mathbf{B}_0 = B_{0\mathrm{R}}\hat{R} + B_{0\varphi}\hat{\varphi} + B_{0\mathrm{Z}}\hat{Z}. \quad (1)$$

The RMPs causing resonance with the rational surfaces of q=3/2, 10/7, 11/7, 13/9, 14/9, 16/11, 17/11, 19/13, 20/13, 22/15, 23/15, 25/17, 26/17 are given as the perturbation field $\delta\mathbf{B}=\nabla\times(\alpha\mathbf{B}_0)$ and the total magnetic field is $\mathbf{B}=\mathbf{B}_0+\delta\mathbf{B}$. Details of the RMP field are explained in [5].

2.2 *Benchmark of KEATS code with electric field*

It is well known that the drift-kinetic equation in regular closed magnetic surfaces satisfies the following relation: $E_{\mathrm{r}} = (T/e)(1/n)(\mathrm{d}n/\mathrm{d}r)$ or $n = n_0\exp(-e\Phi/T)$ if $u_{\|} = 0$ and $\nabla T = 0$ [7,8], where the Maxwellian background is assumed, T is the temperature, n the density (n_0 the density at the magnetic axis), e the elementary charge, Φ the electric potential, and $u_{\|}$ the parallel flow velocity.

The neoclassical transport with a self-consistent electric field E_r, which satisfies $E_r = (T/e)(1/n)(dn/dr)$, is confirmed by using KEATS code, as shown in Fig.1, and is compared to the case without E_r. In the case without E_r, a self-collision-driven ion flux is seen, see also [7].

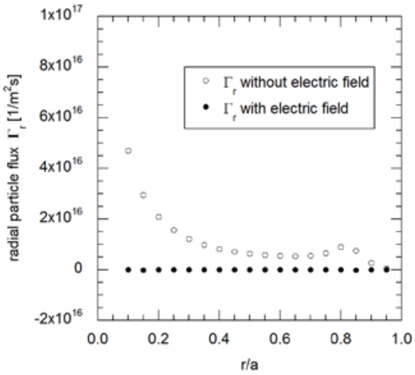

Fig.1. Radial particle fluxes Γ_r of ion with/without E_r in the unperturbed field $\mathbf{B}_0$, where $\delta f\,(t=0)=0$.

2.3 *Magnetic configuration affected by RMPs*

The electron and ion particle fluxes in the perturbed region under an assumption of zero electric field are shown in Fig. 2. The peaks of the particle fluxes in the perturbed region ($r/a \approx 0.4$~0.8) appear around the center $r/a \approx 0.6$. In the perturbed region, the electron particle flux is extremely larger than the ion particle flux, and thus a positive radial-electric-field is expected because of the ambipolar condition: $\Gamma_r^{\text{electron}}(E_r) = \Gamma_r^{\text{ion}}(E_r)$.

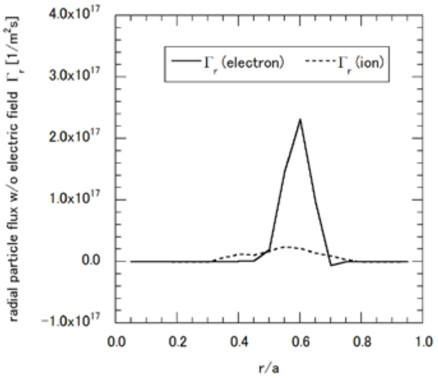

Fig.2. Radial particle fluxes Γ_r of electron and ion in the perturbed field $\mathbf{B}$ without E_r, where $\delta f\,(t=0)=0$.

The contour map of the integrand in the radial energy flux Q_r in the velocity space ($v_\parallel$, $v_\perp$), which is represented by $\delta Q_r(r, v_\parallel, v_\perp)$, are shown in Fig. 3, where the energy flux Q_r is given as follows:

$$Q_r = \left\langle \nabla r \cdot \int d^3 v \frac{mv^2}{2} \mathbf{v}\, \delta f \right\rangle. \tag{2}$$

Here, $\langle \cdot \rangle$ means the average over a flux surface of $\mathbf{B}_0$, and a distribution function of guiding centers in five dimensional phase space, $f(t, \mathbf{x}, \mathbf{v})$, is separated into the Maxwellian background f_M and a kinetic part δf, i.e., $\delta f = f - f_M$. While the important contribution to the radial energy flux of electron originates mainly from the un-trapped particles affected by the RMP field, the contribution to the flux of ion originates from not only the un-trapped particles but also the trapped particles, which are affected by the RMP field. Details of the results are shown in the poster.

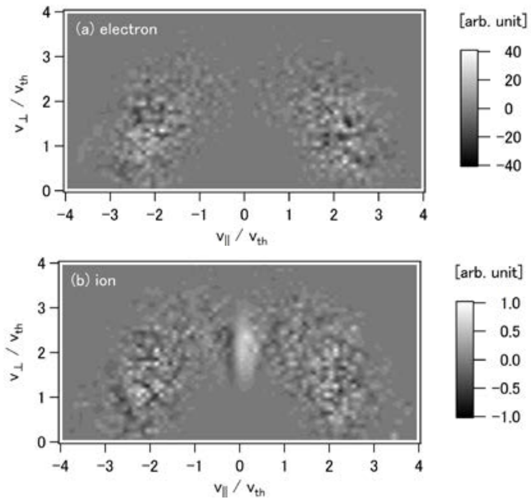

Fig.3. The contour maps of δQ_r in ($v_\parallel/v_{th}$, $v_\perp/v_{th}$) at $r/a \approx 0.6$ in case of Fig.2, where v_{th} is the thermal velocity.

Acknowledgments

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