## §7. Transport Phenomena in the Ergodic Region Having Magnetic Islands

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To understand fundamental transport properties of a low-collisionality toroidal plasma with the ergodic region bounded radially on both sides, we have applied the drift kinetic equation solver KEATS to ion (proton) energy transport in the magnetic field disturbed by resonant magnetic perturbations (RMPs) under the assumption of neglecting effects of an electric field, impurities and neutrals. Here the perturbed magnetic field is given as $\boldsymbol{B} = \boldsymbol{B}_0 + \delta\boldsymbol{B}$, the unperturbed magnetic field $\boldsymbol{B}_0$ is the simple tokamak field having concentric circular flux surfaces, the RMPs is $\delta\boldsymbol{B} = \nabla \times (\alpha \boldsymbol{B}_0)$, and the function $\alpha$ is used to represent the structure of the perturbed magnetic field. We have evaluated the ion thermal diffusivity as a constant with respect to time from the radial energy flux given by the guiding centre distribution function in five dimensional phase space and have found that the diffusivity depends on both the strength of the RMPs and the collision frequency.

From the simulation results of KEATS code (the results of the KEATS computation) illustrated in Fig. 1, the thermal diffusivity in the perturbed magnetic field $\boldsymbol{B} = \boldsymbol{B}_0 + \delta\boldsymbol{B}$ in low-collisionality cases is presumed to be formulated as

$$\chi_{\mathrm{i}\,r} = \chi_{\mathrm{i}\,r}^{\mathrm{NCT}} \left\{ 1 + \tilde{c} \left( \frac{\tilde{\omega}}{\nu_{\mathrm{col}}} \right)^{\tilde{\gamma}} \frac{\langle \|\delta B_r\|^2 \rangle}{{B_\mathrm{t}}^2} \right\} \qquad (1)$$

under the assumption of neglecting an electric field. Here

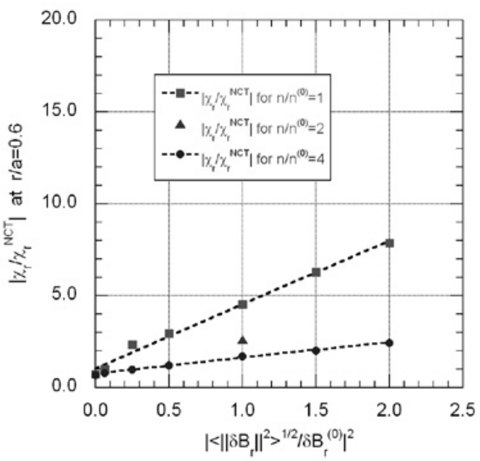


Fig. 1: Ratio of the ion thermal diffusivity in the perturbed magnetic field to the neoclassical thermal diffusivity in the simple tokamak. Here $n$ means the density.

$\chi_{\mathrm{i}\,r}^{\mathrm{NCT}} = 1.35{\epsilon_\mathrm{t}}^{1/2} T_\mathrm{i}/(m_\mathrm{i}\Omega_{\mathrm{i}\theta}^2 \tau_{\mathrm{ii}}) \approx \sqrt{\epsilon_\mathrm{t}}\,\rho_{\mathrm{i}\theta}^2 \nu_{\mathrm{col}}$ is the neoclassical thermal diffusivity in the banana regime, and $\tilde{c}$, $\tilde{\omega}$ and $\tilde{\gamma}$ are unknown parameters. The parameters $\tilde{c}$, $\tilde{\omega}$ and $\tilde{\gamma}$ should be independent of the density $n_\mathrm{i}$, then the parameter $\tilde{\gamma}$ is evaluated as $\tilde{\gamma} \approx 1$ in Fig. 1.

We should pay attention to the result that the ion thermal diffusivity $\chi_{\mathrm{i}\,r}$ estimated by the KEATS computations in the magnetic configuration is extremely small compared to the one predicted by the theory of field-line diffusion (the FLD theory), as shown in Fig. 2. Here the

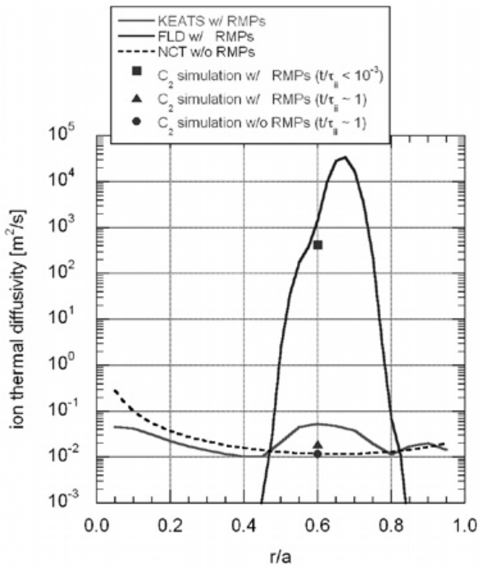


Fig. 2: Radial profiles of ion thermal diffusivity. KEATS: $\chi_{\mathrm{i}\,r}$, FLD: $\chi_{\mathrm{i}\,r}^{\mathrm{FLD}}$, NCT: $\chi_{\mathrm{i}\,r}^{\mathrm{NCT}}$, $C_2$ simulation: $\chi_{\mathrm{i}\,r}^{C_2} = (1/\Delta t)\{C_2(t+\Delta t) - C_2(t)\}$ where $C_2(t)$ is the 2nd cumulant of radial displacements of guiding center orbits starting from $r/a = 0.6$, $t$ is time and $\tau_{\mathrm{ii}}$ is the ion-ion collision time.

diffusivity predicted by the FLD theory, $\chi_{\mathrm{i}\,r}^{\mathrm{FLD}}$, is given by

$$\chi_{\mathrm{i}\,r}^{\mathrm{FLD}} = \pi q R_{\mathrm{ax}} v_{\mathrm{i\,th}} \frac{\langle \|\delta B_r\|^2 \rangle}{{B_\mathrm{t}}^2}, \qquad (2)$$

where $v_{\mathrm{i\,th}}$ is the ion thermal velocity. The dependence of $\chi_{\mathrm{i}\,r}$ on $\langle \|\delta B_r\|^2 \rangle / {B_\mathrm{t}}^2$ in the KEATS computations has been expected in the FLD theory. The value of $\chi_{\mathrm{i}\,r}$ in Eq. (1), however, is extremely small compared to $\chi_{\mathrm{i}\,r}^{\mathrm{FLD}}$ given by the FLD theory. The thermal diffusivity $\chi_{\mathrm{i}\,r}$ also depends on the collision frequency (or the density); see Fig. 1. The dependence on the collision frequency (or the density) is not considered in the prediction (2) of the FLD theory in low-collisionality cases.

These differences of the thermal diffusivity estimated by the KEATS computation from the prediction of the FLD theory are caused by the matter that the ergodic region is bounded radially on both sides and is not sufficiently broad for observing the effect of the field-line diffusion during several collision times.