§26. Fast Ion Driven Neoclassical Parallel Flows and Radial Fluxes in Non-symmetric Toroidal Plasmas

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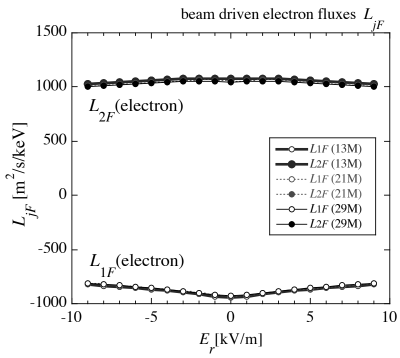
Though many applications of a method to obtain the neoclassical transport matrix in general non-symmetric toroidal plasmas [1] have been performed especially for quantitative predictions of neoclassical parallel flows and/or currents, only the inductive parallel electric field is taken into account there as the external driving force for the parallel flows. In this study, we investigate parallel plasmas flows driven by tangentially injected neutral beams in non-symmetric toroidal plasmas. Then the Onsager symmetric transport matrix is now extended to include (1) Ohkawa current, (2) fast ion driven radial fluxes, and (3) parallel momentum.

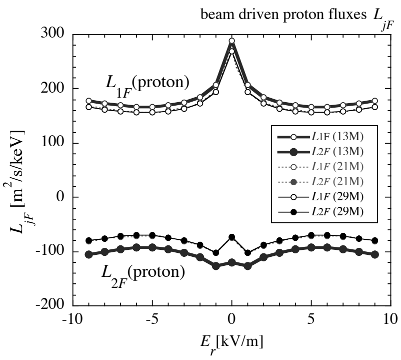
An important aspect of this problem (fast ion driven flows and fluxes) clarifying a relation between tokamak and stellarator/heliotron studies [2] can be found when considering the quasi-steady-state charge neutrality. As already pointed out in Ref.[3], there is a severe confliction in considering the beam driven flows and fluxes in symmetric configurations such as tokamaks. A phenomenological damping term for the flows was introduced in Ref.[3]. This is also one of backgrounds of recent discussions on the momentum transport in various tokamak experiments [4]. In contrast to it, the flows and fluxes in non-symmetric stellarator and heliotron configurations, where the parallel viscosity and the non-ambipolar particle diffusion are not directly connected to each other, can be consistently determined by the neoclassical procedure without any phenomenological damping terms. In the present study, the thermalized particles' kinetic and moment equations for general multi-ion-species plasmas [5] are extended to include the fast ion friction term, which is obtained by applying the eigenfunction method in Ref.[6]. Then the radial particle and heat diffusions are derived by using the [$\mathbf{N}_a$, $\mathbf{L}_a$] matrices defined in Ref.[1].

Figure 1 shows the newly generated non-diagonal coefficients $L^a_{jF} = -L^a_{Fj}$ in a part of the extended Onsager symmetric transport matrix including the fast ions' parallel friction (momentum loss) moment $\langle \mathbf{B}\cdot\mathbf{F}_{f1}\rangle$

$$\begin{bmatrix} \langle \Gamma^{\rm bn}_a \cdot \nabla s \rangle \\ \langle \mathbf{q}^{\rm bn}_a \cdot \nabla s \rangle / \langle T_a \rangle \end{bmatrix} = \sum_b \begin{bmatrix} L^{ab}_{11} & L^{ab}_{12} \\ L^{ab}_{21} & L^{ab}_{22} \end{bmatrix} \begin{bmatrix} X_{b1} \\ X_{b2} \end{bmatrix} + \begin{bmatrix} L^a_{1E} \\ L^a_{2E} \end{bmatrix} \frac{\langle \mathbf{B}\cdot\mathbf{E}^{(\mathrm{A})} \rangle}{\langle B^2 \rangle^{1/2}} + \begin{bmatrix} L^a_{1F} \\ L^a_{2F} \end{bmatrix} \frac{\langle \mathbf{B}\cdot\mathbf{F}_{f1} \rangle}{\langle B^2 \rangle^{1/2}}$$

for an impure plasma (e^-+H^++Ne^{10+}, $Z_{\rm eff}$=5.74). The assumed magnetic configuration is that with a magnetic axis position of $R_{\rm ax}$=3.6m in the LHD (B=2.45T, r/a=0.5). Positive values $L^a_{1F} > 0$ correspond to the outward particle fluxes driven by counter-injected neutral beams. An application to recent Heliotron-J experiments [7] is now being conducted.





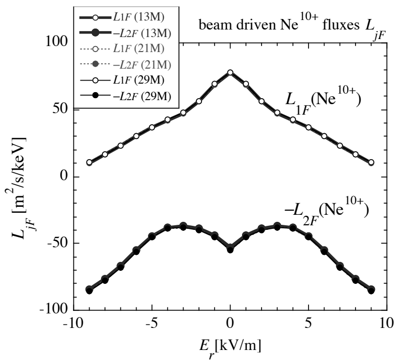


Fig.1 The non-diagonal transport coefficients $L^a_{jF} = -L^a_{Fj}$ in the extended transport matrix describing the beam induced radial particle and heat transport. (LHD, $R_{\rm ax}$=3.6m, B=2.45T, r/a=0.5, $T_{\rm e}$=2.0keV, $T_{\rm i}$=1.0keV, $n_{\rm e}$=10^{18}m^{-3}, $Z_{\rm eff}$=5.74)

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