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Neoclassical Transport in the Plasma Edge at ASDEX Upgrade with B2

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1 Introduction

In tokamak plasmas, like at ASDEX Upgrade, electron and ion thermal and particle transport in the edge are generally dominated by anomalous transport. At the presence of an edge transport barrier, however, the transport coefficients for electrons and ions are strongly reduced. Therefore, neoclassical transport can become important in certain H-mode scenarios where the anomalous ion thermal conductivity χ_i in the pedestal falls well below $0.5\,\mathrm{m^2s^{-1}}$. In such cases, the neoclassical contribution to the ion thermal conductivity and impurity diffusivity can reach levels comparable to anomalous transport.

2 Implementation into B2

In our contribution, the neoclassical contribution to thermal and particle transport for such an ASDEX Upgrade scenario is studied. A one-dimensional model for the neoclassical transport for ions (fuel and impurities) and electrons has been implemented into the multifluid code B2 [1]. The heat and particle fluxes of every species are calculated by solving a set of multiple species fluid force balance equations, following a matrix formalism by Hirshman and Sigmar [2] and using the reduced charge state formalism [3, 4]. The thermodynamic forces $F^{\mathrm{p}}_{aj} = \frac{\partial \ln p_{aj}}{\partial \rho}$ for the pressure gradient and $F^{\mathrm{T}}_{aj} = \frac{\partial \ln T_a}{\partial \rho}$ for the temperature gradient (where ρ is a flux label and a and j denote the species and the charge state, respectively), together with an external electric field E, determine the particle and heat fluxes in a simple linear form

$$\begin{aligned} \Gamma_{aj} &= -D_{aj}\nabla n_{aj} + v_{aj} n_{aj} && (1) \\ q_{aj} &= -\kappa_{aj}\nabla T_a + w_{aj} T_a \,. && (2) \end{aligned}$$

Here D_{aj},κ_{aj}, v_{aj}, and w_{aj} denote the particle and heat diffusion coefficients and the particle and heat pinch velocities, respectively. The transport matrices have been approximated by their diagonal forms by summarizing off-diagonal contributions to the fluxes into the respective pinch velocities.

Then, the contributions from classical transport and for the Banana plateau and the Pfirsch-Schlüter regimes are calculated on closed flux surfaces (i.e. inside the separatrix) by the code `NEOART` by A.G. Peeters.

We employ a 1D model. Therefore, flux surface averages of the appropriate quantities are used. We furthermore assume that ion thermalization is fast, i.e. all ions have a common temperature T_{i}.

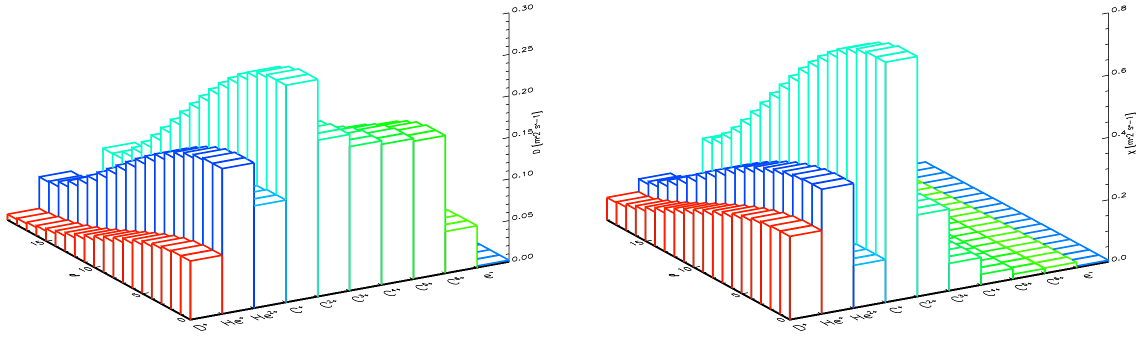
We study the neoclassical contribution for a Deuterium plasma with Helium and Carbon impurities. Calculation of the collisionalities ν_* show that impurities are well in the Pfirsch-Schlüter regime while Deuterium ions and electrons are marginally in the Banana Plateau regime.

A comparison of the width of the Banana orbit $w_{\mathrm{B}} = q\rho_{\mathrm{L}}/\sqrt{\epsilon}$ (safety factor q, inverse aspect ratio ϵ, and Larmor radius ρ_{L}) with the gradient lengths of the densities and temperatures, as well as a check of the strong magnetic field limit $\nu/\omega_{\mathrm{c}} \ll 1$ (collision frequency ν, cyclotron frequency ω_{c}) and the assumption of uniform (along a flux surface) density approximation shows that electrons and ions with low and high charge states may well be treated in a 1D-model while this model is only marginally valid in the plasma edge for impurities with intermediate charge states.

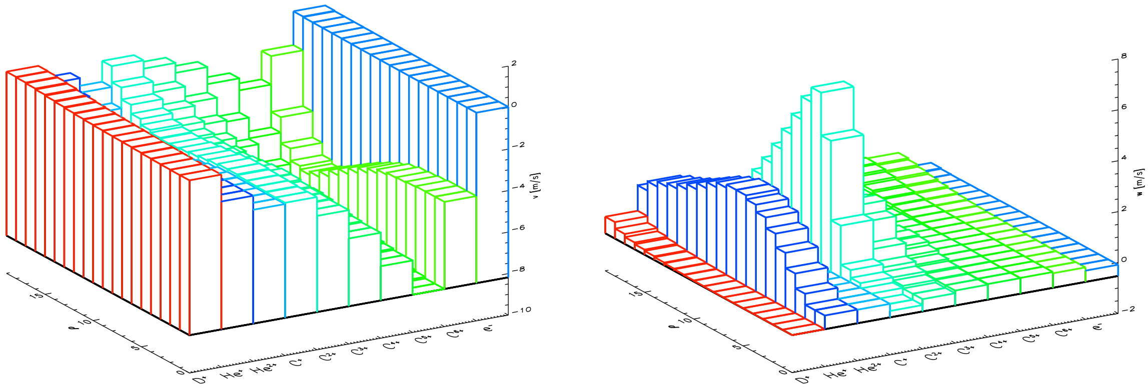
3 Results

We calculate the neoclassical contribution to the heat and particle transport for a constant background level of anomalous transport with $D_{\mathrm{i}} = \chi_{\mathrm{i}} = 0.05\,\mathrm{m}^2\,\mathrm{s}^{-1}$ and $\chi_{\mathrm{e}} = 0.1\,\mathrm{m}^2\mathrm{s}^{-1}$ inside the separatrix and $D_{\mathrm{i}} = \chi_{\mathrm{i}} = \chi_{\mathrm{e}} = 0.1\,\mathrm{m}^2\,\mathrm{s}^{-1}$ in the scrape-off layer, the private flux region, and the divertor regions.

Fig. 3 shows that the particle diffusivities D lie in a range $< 0.3\,\mathrm{m}^2\,\mathrm{s}^{-1}$ while the heat diffusivities χ can reach levels of $0.8\,\mathrm{m}^2\,\mathrm{s}^{-1}$ for the C^+ ions. The pinch velocities also reach levels which are comparable to anomalous transport levels. A closer analysis shows that the electron particle pinch is directed outward while the ions feel an inward pinch which is especially strong for the impurities. This leads to the well-known accumulation of impurities in the core plasma. The quasi-neutrality of the plasma remains guaranteed

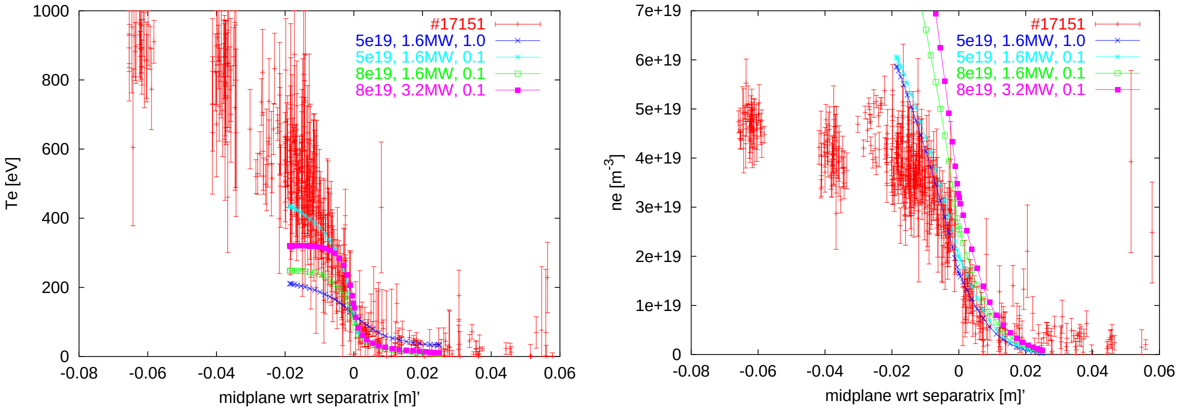


(a) particle diffusivities D ($\mathrm{m^2\,s^{-1}}$) (b) heat diffusivities χ ($\mathrm{m^2\,s^{-1}}$)



(c) particle pinch v ($\mathrm{m\,s^{-1}}$) (d) heat pinch w ($\mathrm{m\,s^{-1}}$)

Figure 1: diffusivities and pinch velocities for ions and electrons vs. index ρ of the flux surface ($\rho = 0$ is the core boundary, i.e. 2 cm inwards from the separatrix, $\rho_{\max}$ the separatrix)



(a) T_e (eV) (b) n_e ($\mathrm{m^{-3}}$)

Figure 2: comparison with experimental data

through the outward diffusion of the ions. We furthermore find an inversion of the D^+ heat pinch in the pedestal close to the separatrix which contributes to a steepening of the temperature profile. Overall, we can conclude that even in the pedestal neoclassical transport coefficients for the impurities can become important in cases of reduced anomalous transport.

We finally compare our results for various levels of background anomalous transport ($0.1\,\mathrm{m}^2\,\mathrm{s}^{-1}$ and $1.0\,\mathrm{m}^2\,\mathrm{s}^{-1}$), various input powers (1.6 MW and 3.2 MW), and various D^+ particle densities ($5 \cdot 10^{19}\,\mathrm{m}^{-3}$ and $8 \cdot 10^{19}\,\mathrm{m}^{-3}$) at the core boundary to the experimental electron temperature and density profiles for AUG shot #17151 (Fig. 2). We find the best agreement for an anomalous transport level of $0.1\,\mathrm{m}^2\,\mathrm{s}^{-1}$, $n_{\mathrm{D}+} = 5 \cdot 10^{19}\,\mathrm{m}^{-3}$, and $P_{\mathrm{t}} = 1.6\,\mathrm{MW}$. Therefore, anomalous transport in the pedestal clearly was reduced in the shot #17151.

4 Discussion

Application of a 1D-model for the neoclassical transport on B2 runs for realistic tokamak configurations shows that diffusivities and pinch velocities of the impurities can reach levels which are comparable to levels of reduced anomalous transport. However, the 1D-model remains limited in its applicability to regions close to the separatrix and cannot be applied in the scrape-off layer. We therefore envision a future quasi-2D model which treats neoclassical effects in the scrape-off layer through direct calculation of the fluid drift velocities [5] and uses the 1D-model for the core and the pedestal top.

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