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EDGE ION TEMPERATURE GRADIENTS IN H-MODE DISCHARGES

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Introduction

Understanding the processes that sustain the edge transport barrier (ETB) in H-mode plasmas is necessary for reliable scaling to next step tokamaks. In particular, the temperature at the top of the barrier sets the boundary condition for the level of turbulent transport in the plasma core. Moreover, the mechanisms that connect particle and heat transport in the electron channel and the ion channel are not yet completely clear. In this investigation experimentally determined electron and ion edge temperature gradients of H-mode discharges are compared. Selected experimental results are modelled with the 2D fluid code B2.5 to gain insight into the transport processes within the ETB.

Experimental setup and results

Ion temperature (T_i) profiles in the ETB region of H-mode discharges in the ASDEX Upgrade tokamak have been measured by means of Lithium beam charge exchange spectroscopy [1]. Here a 40 keV neutral Lithium beam serves as electron donor for the charge exchange process with fully stripped He impurity ions: $He^{2+} + Li^0 \rightarrow He^{+*} + Li^+$. The subsequent radiation of the HeII (4-3) transition is measured with two Czerny Turner spectrometers coupled to frame transfer CCD cameras via up to 18 lines of sight. From the Doppler width of the line T_i is derived. The data cover a region of normalised poloidal radius between $\rho_{pol} = 0.9$ and $\rho_{pol} = 1.01$ with a spatial resolution of 6 mm. The frame rate of the CCD cameras was set to 4 ms. During ELMs the intensity of the passive HeII line increases by a factor of 2 to 3 due to the increased He recycling, disturbing the weak active charge exchange contribution. Therefore, the CCD frames containing such high passive signals during ELMs have to be omitted from evaluation. In order to retain enough useful frames in between ELMs, the measurements are restricted to type I ELMy H-modes with ELM frequencies less than 100 Hz and a constant phase for about 2 seconds. Because of the small active CX-signal, weak He gas fuelling was applied to some of the discharges, leading to a He concentration (n_{He2+}/n_e) of ~10%. Figure 1 shows the ion temperature profiles of both the core CXRS system using the CVI (8-7) transition and the edge Li-beam CXRS system using the HeII (4-3) transition for discharge #21160, t=5-7 s.

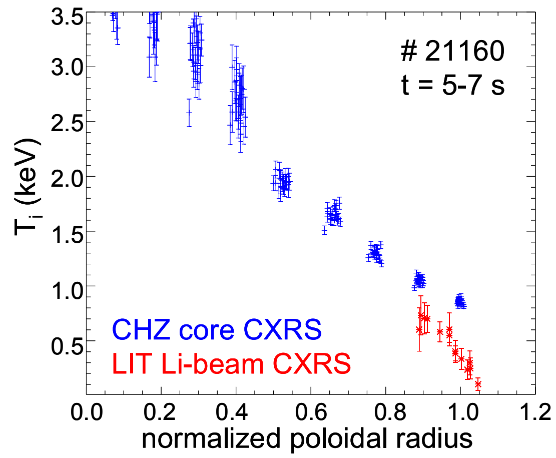

Figure 1: Measured ion temperature profile for shot #21160, t=5-7 s. The blue data points are from the core CXRS diagnostic, the red points from Li-beam CXRS edge diagnostic.

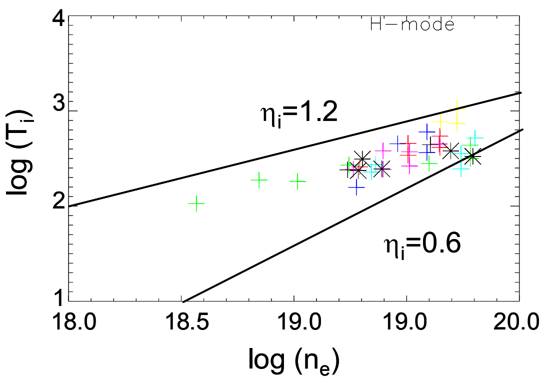

Figure 2: Double logarithmic plot of T_i vs n_e for 6 different H-mode discharges. Only data in the ETB, $0.96< \rho_{pol}<1.01$ are taken. The solid lines show gradients of 0.6 and 1.2 to guide the eye to the values determined as minimum and maximum for η_i.

While there is still a discrepancy between the outermost channels of the core system and the innermost channels of the edge system, the T_i gradient is considerably steeper in the ETB region than in the core. The typical H-mode edge structure, the so-called pedestal, can thus also be seen in the T_i profiles. For a variety of such discharges with the pedestal top densities varying between 5 to 8 10^{19} m^{-3}, edge profile data have been collected from various diagnostics, i.e. edge Thomson scattering for electron temperature (T_e) and electron density (n_e), ECE for T_e and the Lithium beam diagnostic for n_e. In the steep edge gradient region, i.e. between ρ_{pol}=0.96 and ρ_{pol}=1.01, the ratio of density gradient length and temperature gradient length, η, has been determined for electrons and ions. With the gradient length L_x being defined as $L_x = |1/x\ dx/dr|^{-1}$, we can write $\eta = L_n/L_T = d(\ln T)/d(\ln n)$. By fitting a straight line to a double logarithmic plot of T versus n, η can be determined in a simple way. Figure 2 shows such a plot for 6 different discharges, where the ion density (n_i) is replaced by n_e, assuming that there is a constant factor between n_e and n_i. While η_e is found to be about 2 in agreement with previous results [2] at ASDEX Upgrade, η_i is determined to be between 0.6 and 1.2 in the investigated discharges. The two lines marked η_i = 0.6 and 1.2 are not fits to the data, but are meant as a guide to the eye, marking the minimum and maximum η_i derived. As the onset of ion temperature gradient (ITG) modes is expected to occur for η_i = 1-2 [3], no significant anomalous transport is expected for ions in the ETB region.

Modelling

In order to investigate whether neoclassical transport is sufficient to explain the measured gradients, the 2D fluid code B2.5 [4] has been applied to model discharge #21160. A version of the code with neoclassical transport coefficients is used [5] in an interpretative way. Great care has been taken to match the particle fluxes across the inner (core) boundary to the particle flux due to neutral beam heating. Also pump fluxes at the outer boundary were carefully matched to experimental values. In addition to the neoclassical transport coefficients, a profile of anomalous transport coefficients is determined [6], so that experimental outer midplane profiles are reconstructed. In figure 3 the modelled mid-plane profiles (black lines) are compared with experimental profiles of electron density, electron temperature, ion temperature and He^{2+} ion density. As can be seen a successful match was found for all profiles within the error bars of the measurements.

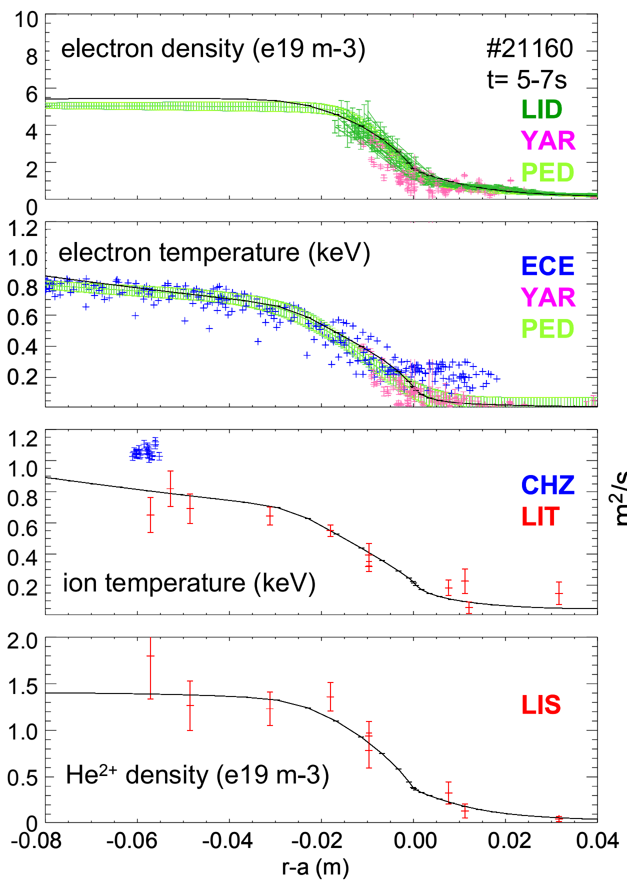

Figure 3 (left): Mid-plane profiles from various diagnostics (symbols: LID = Lithium beam, YAR= Thomson scattering, ECE = electron cyclotron emission, CHZ = core charge exchange, LIT = Li-beam CXRS, LIS = Li-beam CXRS, PED = 'tanh' fit to n_e and T_e profiles) in comparison with the model (black lines).

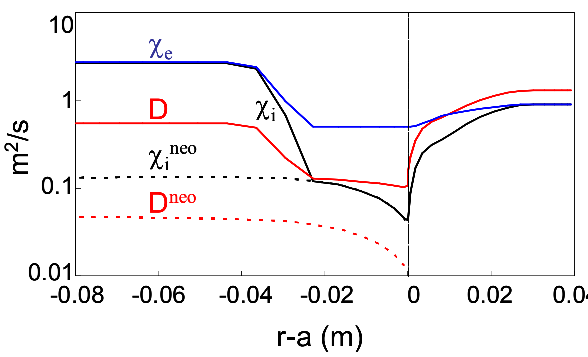

Figure 4: Profiles of particle and heat transport coefficients used for the best match. Also indicated are neoclassical values for D and χ_i.

To achieve this excellent match between experiment and modelling, profiles for particle and heat transport coefficients are used, which are shown in figure 4. While for the particle diffusion coefficient D and electron heat transport coefficient χ_e anomalous values across the whole radial region are necessary to model the experiment, the ion heat transport coefficient χ_i can be set to neoclassical values in the ETB region. As can be seen in figure 4, the barrier region extends 2.5 cm inwards from the separatrix. Also in this region, the ratio of the banana width to the minimum gradient length of all profiles stays well below one, which is a condition for the validity of neoclassical transport models. Although the neutrals are simply treated as a fluid, i.e. no kinetic treatment is applied, the modelled data match the measured H_α and CIII radiation in the divertor within a factor of 2, being in surprisingly good agreement.

Conclusions

In ASDEX Upgrade H-mode discharges with ELM frequencies < 100 Hz the ion and electron temperature gradient lengths differ by around a factor of 2. While η_e is found to be around 2, η_i is between 0.6 and 1.2. Therefore it is unlikely that ion temperature gradient driven modes occur. This is supported by B2.5 modelling of such an H-mode discharge, because the mid-plane profiles can be simulated with the ion heat transport coefficient set to neoclassical values in the ETB region.

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