TRANSPORT ANALYSIS OF THE L-TO-H TRANSITION IN ASDEX BY COMPUTER SIMULATION

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ABSTRACT: The transport properties and ideal ballooning stability during the L-phase and a burst-free period at the beginning of the H-phase are explored by computer modelling. It is found that the diffusivities χ_e and D are reduced in the steep gradient zone by a typical factor of six a few ms after the H-transition. Local transport in the inner plasma improves at an early stage by a factor of about two. Prior to and after the H-transition both electrons and ions are in the banana regime. Ideal ballooning modes are shown to be stable everywhere, including the edge zone.

INTRODUCTION: The first H-regime studies /1, 2, 3/ already revealed that the L-to-H transition starts at the plasma edge and that processes near the separatrix are of crucial importance. At present, the roles of the divertor chamber, scrape-off layer and steep gradient zone in the H-mode transition are still poorly understood. In order to get more insight, simulations of ASDEX discharges are carried out by modified versions of the BALDUR predictive transport code /4, 5/. The code is appropriate for analysing edge processes since it includes a scrape-off layer model and runs with a non-equidistant radial grid capable of resolving the very steep density and temperature gradients close to the separatrix (r_s = 40 cm). Anomalous energy and particle fluxes are modelled by local (flux-surface-averaged), empirical electron heat diffusivities χ_e, diffusion coefficients D and inward drift velocities v_{in}. The conditions and processes prior to and at the H-transition are studied, with special attention being paid to the plasma periphery. Computed time developments of electron density and temperature profiles and beta poloidal are compared with measured results. The search for critical parameters which might trigger the H-mode /6/ is being continued. Self-consistent modelling of the processes in the divertor and scrape-off plasmas /7/ is not attempted, since sufficient reliable information is lacking.

TRANSPORT BEHAVIOUR OF THE INTERIOR AND EDGE PLASMA: An H-discharge with line-averaged density $\bar{n}_e = 3.3 \times 10^{13}$ cm^{-3}, plasma current I_p = 320 kA, toroidal magnetic field B_t = 1.85 T and neutral injection power P_{NI} = 3.45 MW ($H^0 \rightarrow D^+$) is analysed (see Fig. 1). The discharge shows a relatively late L-to-H transition at t^* = 1.229 s succeeded by a burst-free period of 35 ms. Both $\bar{n}_e$ and β_p^{dia} almost reach a saturated L-state and quickly rise during the quiescent H-phase. The time developments of electron temperature and density profiles measured by periodic multichannel Thomson scattering (circles) are presented in Figs. 2 and 3. The solid curves are modelled with the $\chi_e(r)$ given in Fig. 4, $D(r) = 0.5\ \chi_e(r)$ and $v_{in} = 233\ r/r_W$ cm s^{-1}

The results presented in Fig. 4 were obtained with the Spitzer resistivity, which yields better agreement with the measured loop voltage and the expected q value on axis than the neoclassical resistivity. In the L-phase and the quiescent H-phase, the plasma is everywhere stable to ideal ballooning modes even in the steep gradient zone. At 1.261 s, i.e. a few ms prior to the first burst, the stability limit is not reached at the edge if the 25% higher $(\partial p/\partial r)_c$ due to small aspect ratio is taken into account.

Earlier analyses /13, 14/ are confirmed by the present result that the pressure gradient in the pre-transition L-phase is everywhere smaller than the critical value for ideal ballooning modes. This finding is incompatible with the model assumption made for the L-phase in Ref. /15/.

The profile parameter $\eta_e = d \ln T_e / d \ln n_e$, which is important for drift instabilities, does not change much in the L- and H-phases (see Fig. 4).The modest variation even at the edge results from raising both the density and temperature gradients in the zone Δ. In the initial phase of the H-transition particle flow blocking at the separatrix should yield transiently flat density profiles. The corresponding higher η_e or η_i values possibly trigger the reduction of the diffusivities in the steep gradient zone.

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with wall radius r_W = 49 cm. The density and temperature gradients near the separatrix were determined on ASDEX on a shot-to-shot basis by an edge Thomson scattering device /8/. The steep gradient zone Δ extends over about 2.5 cm and persists throughout the H-phase. A few ms after t^* the electron temperature measured by the ECE diagnostics begins to rise, indicating reduced diffusivities in the edge zone at this very early stage. In the simulations reduced values of χ_e and D in the zone Δ are thus applied for $t \geq t^*$. It is found that the electron heat diffusivity has to be diminished by a factor of about six (see Fig. 4) in order to obtain the measured temperature pedestal.

The scrape-off region is modelled by classical $\chi_{e\parallel}$, subsonic flow Mach number $M = v_\parallel/v_s = 0.11$ with $v_s = [2(T_e + T_i)/m_i]^{1/2}$ and cross-field diffusivities $\chi_{eSOL} = 1.2 \times 10^4\ cm^2s^{-1}$ and $D_{SOL} = 2 \times 10^3\ cm^2s^{-1}$, yielding the measured decay lengths $\lambda_{Te} \simeq 1$ cm and $\lambda_n \simeq 1.5$ cm.

Figure 4 shows that χ_e^H in the inner plasma is reduced by a typical factor of two in relation to χ_e^L, which agrees with earlier transport analyses /9, 10/. The results of Fig. 2 are obtained with $\chi_e = \chi_e^H$ for $t \geq t^*$. Obviously, the modelling fits the measured T_e profiles. In addition, good fits to the measured β_p^{dia} and ion temperature profiles are obtained with ion heat diffusivities three times the neoclassical values /11/. The conclusion that both χ_e and D in the zone Δ drop immediately after the H-transition agrees with results on DIII-D, where the density and temperature gradients inside the separatrix were found to rise steeply within a few ms after t^*.

It is obvious from Fig. 3, however, that the transport model fails to simulate the measured high edge density and the density shoulder in the initial burst-free H-phase. Extensive studies have shown that a further reduction of D in the zone Δ raises the density gradient. A higher edge density is only obtained by strongly reducing the particle flow across the separatrix. This process seems to be crucial for the L-to-H transition.

The electron collisionality factor $\nu*_e$ (see Fig. 4) and the ion collisionality factor ($\nu*_i < 0.6$) do not change a lot in the L- and H-phases. The plasma at the periphery does not proceed to a different collisionality regime. At the edge, both electrons and ions are in the banana regime ($\nu*_{e,i}<1$) already in the L-phase. It is concluded that a different collisionality regime is not reached, which contradicts the assumption in Ref. /12/ concerning the ion energy transport mechanism across the separatrix.

Ideal ballooning stability is studied by the transport code, which evaluates the local criterion for large aspect ratio

$$- \frac{2R_0q^2}{B_t^2} \left(\frac{\partial p}{\partial r}\right)_c = f(s) \qquad (1)$$

where $(\partial p/\partial r)_c$ is the critical pressure gradient and f(s) is a known function of the dimensionless shear $s = (r/q)\partial q/\partial r$. At finite aspect ratio (A = 4.2) critical pressure gradients are obtained which are typically 25% higher. The profiles of j_t, q and s result from solving the diffusion equation for B_p. Both the thermal pressure and the anisotropic beam pressure are included.

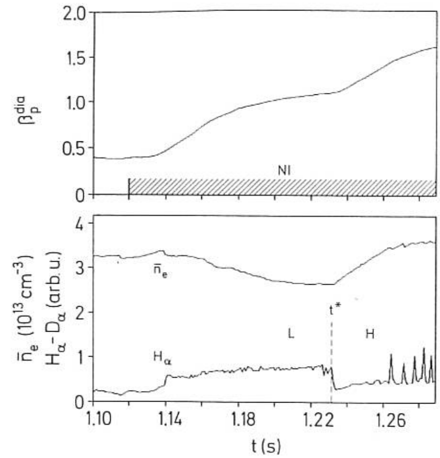

Fig. 1:

Time evolution of $\bar{n}_e$, H_α intensity and β_p^{dia} in an H-discharge.

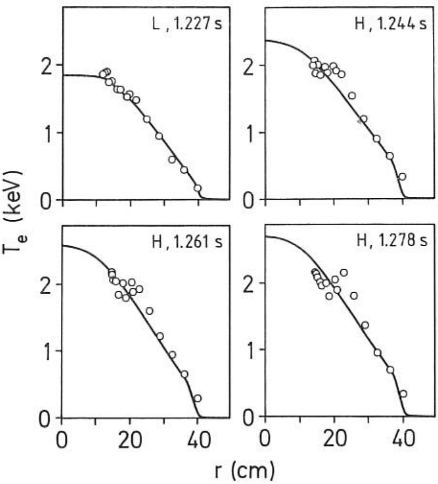

Fig. 2:

Comparison of measured (circles) and computed (solid curves) electron temperature profiles.

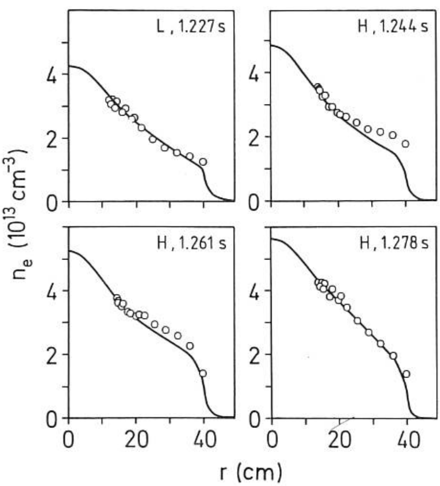

Fig. 3:

As in Fig. 2, but electron density profiles.

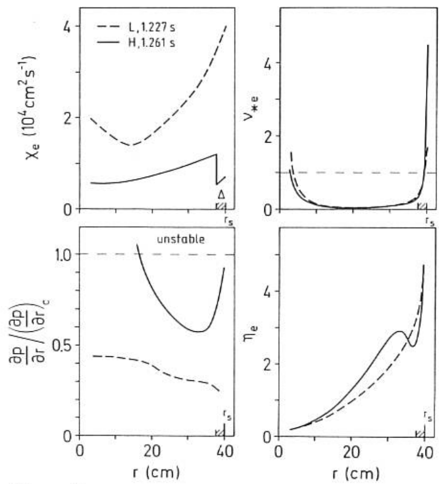

Fig. 4:

Profiles of χ_e, electron collisionality factor ν_{*e}, ideal ballooning stability parameter $\partial p/\partial r/(\partial p/\partial r)_c$ and η_e=d ln T_e/d ln n_e in L- and H-phases.