TRANSPORT MODELLING OF NEUTRAL BEAM HEATED L AND H DISCHARGES IN ASDEX

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Abstract. Local transport of divertor plasmas in the L and H regimes is analyzed by a prediction code. In the L regime two types of discharges with different local confinement are distinguished and studied. It is found that the observed decrease of the τ_E with increasing neutral injection power is due to an enhancement of the electron heat diffusivity. In L discharges with $\beta_p << 1$ there are indications that transport results from drift-wave turbulence, while for $\beta_p \gtrsim 1$ pressure-driven modes could be involved. With I_p = 300 and 380 kA transport in the H phase is characterized by flat $\chi_e \cong 2$ to 3×10^4 cm^{2}s^{-1}, $D = 0.2\ \chi_e$ and neoclassical χ_i. The observed improvement of τ_E and τ_p compared with the L phase is due to a reduction of χ_e and D by a factor of two in the whole plasma. The diffusivities χ_e and D in L and H discharges do not depend on density and decrease with increasing plasma current.

Introduction. As in divertor discharges in ASDEX very clean plasmas have been achieved with ohmic (OH) and neutral injection (NI) heating /1/, they are particularly suitable for studying particle and energy transport. With neutral-beam injection two types of discharges with different confinement behaviour denoted as L (low β_p) and H (high β_p) have been found in ASDEX /2/. Local transport analysis is preferable to the study of global confinement times, since it is more selective with respect to the type of theory to be adopted. Thus, our main objectives are to investigate local transport in the L and H regimes and to find the scaling laws of the diffusion coefficient D and of the thermal diffusivities of electrons and ions χ_e and χ_i. The computer simulations are carried out with modified versions (BALDI09R) /3/ of the BALDUR prediction transport code.

Local transport in L discharges. Extensive studies of L discharges have shown that larger χ_e values are obtained by reducing the plasma current (I_p) and by increasing the beam power (P_{NI}). Local transport is found to change from flat $\chi_e(r)$ and $D = 0.2\ \chi_e$ (LI type) to steep $\chi_e(r)$ and flat D(r) (LII type), if χ_e is raised above a value of about 5×10^4 cm^{2}s^{-1}.

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The results obtained in an earlier work /3/ (LI type) have been confirmed by a series of L discharges with $I_p = 380$ kA, $B_t = 1.9$ T and $\bar{n}_e = 2.7 \times 10^{13}$ cm^{-3}, in which P_{NI} was scanned. Hydrogen is injected tangentially into a deuterium target with co-beam power P_{NI} between 0.3 and 2.5 MW. Compared with OH plasmas there is a change in scaling, which suggests that a different transport mechanism is present with NI /3/. The enhanced diffusivities with NI appear and disappear with time delays relative to the beginning and end of NI and are found to be correlated with $\eta_e = d \ln T_e / d \ln n_e$, which is an important parameter for collisionless drift instabilities.

In both the ohmic and L phases the velocity of the anomalous inward flux $v_{in} = 245\ r/r_w$ cms^{-1} /3/ with wall radius $r_w = 49$ cm and without Ware pinch is consistent with the experimental data. Good agreement with measured $n_e(r)$, $T_e(r)$, $T_i(o,t)$, τ_E and $\beta_p(t)$ is reached, if flat $\chi_e(r)$, $D = 0.2\ \chi_e$ and 1 to 3 times neoclassical χ_i values are applied. The increase of the homogeneous χ_e in the range $r_{q=1} < r < 0.9a$ with P_{NI} is shown in Fig. 1. The circles result from simulations, while the crosses are $\chi_e(a)$ values derived from the experimental variation of τ_E with P_{NI} by assuming $\tau_E(a) \sim 1/\chi_e(a)$. Obviously, the observed decrease of τ_E with increasing P_{NI} is due to enhanced electron heat diffusivities.
Even at the smallest absorbed beam power (P_b=0.3 MW < P_{OH}=0.4 MW) the scaling for OH plasmas is no longer applicable. Here, β_p (= 0.3) is not raised by NI but the quantity η_e has changed indicating that for $\beta_p \ll 1$ the turbulent state responsible for the enhanced χ_e and D is not due to pressure-driven modes but rather due to drift instabilities.
Scanning P_{NI} at 300 kA can raise χ_e above 5×10^4 cm^{2}s^{-1} and results in a transition to the LII regime with steep $\chi_e(r)$ (see Fig. 2). A practically time independent χ_e profile of this shape yields the measured peaked $T_e(r,t)$ (see Fig. 3). Agreement with measured $n(r)$, $T_i(o)$, τ_E and β_p is obtained for flat $D(r)$ that are no longer coupled to χ_e. Such a situation is indicative of transport in stochastic magnetic fields /4/. According to this model electron thermal transport is enhanced by conduction $\parallel$ B in braided magnetic fields, while mass transport remains unchanged, since it is limited by ambipolar potentials. In the collisionless case of ASDEX $D/\chi_e = v_s/v_{Te} \simeq 0.02$ results, where v_s is the ion sound speed and v_{Te} the thermal velocity of the electrons.
The transition to the LII regime coincides with $(\beta_p)_{tot}$ (sum of thermal and beam contributions) becoming larger than unity. According to theory pressure-driven modes could be involved, which are capable of producing the B_r-fluctuations necessary for magnetic braiding. For $\beta_p \gtrsim 1$ resistive ballooning instabilities with high wave numbers m and n are expected to be dominant. These modes occur, if the ratio S of resistive and Alfvén time scales amounts to typically 10^5 to 10^6. As the high central T_e values reached in ASDEX correspond to $S \approx 10^8$, ideal pressure-driven modes are more likely.

Local transport in H discharges. The H phase is always found to develop from an L discharge and to return to an L phase after turning off neutral-beam injection. Modelling typical H discharges in double-null divertor configuration with $I_p = 380$ kA and $P_{NI} = 2.5$ MW yields flat $\chi_e = 4.7 \times 10^4$ cm^{2}s^{-1} and $D = 0.2\ \chi_e$ during the L phase and flat $\chi_e = 2 \times 10^4$ cm^{2}s^{-1} and $D = 0.2\ \chi_e$ during the H phase. The ion heat diffusivity is again approximately neoclassical. It is found that the improvement of energy and particle confinement in the H regime is due to a clear reduction of χ_e and D over the whole plasma cross-section.
Scans of $\bar{n}_e$ in the H regime show that τ_E and the diffusivities are indepen-

dent of density as in L discharges. In the H regime $\tau_E \sim I_p$ is observed as in both L regimes. These results prove that in H discharges the transport scaling of OH plasmas in not recovered.
In simulations of H discharges with 300 kA and 2.5 MW flat $\chi_e = 3\mathrm{x}10^4\ \mathrm{cm}^2\mathrm{s}^{-1}$ and $D = 0.2\ \chi_e$ have to be applied in the H phase, while the χ_e profile is steep during the L phase. Here, the reduced χ_e values in the H phase should correspond to smaller fluctuation levels, which seem to be insufficient for magnetic braiding.
These conclusions are confirmed by discharges with $I_p = 200$ kA for which the electron heat diffusivity exceeds $5 \times 10^4\ \mathrm{cm}^2\mathrm{s}^{-1}$ both in the L and in the H regime. Here, the corresponding higher fluctuation level leads to steep χ_e profiles even during the H phase. The improvement of τ_E in the H phase can be explained again by the reduction of the electron thermal diffusivity in the whole plasma.

Conclusions. In the L regime two types of discharges LI and LII with different local confinement can be distinguished. The decrease of τ_E observed with higher P_{NI} is explained by increased electron heat diffusivities. In the L regime there are indications that for $\beta_p << 1$ drift-wave turbulence is present, while for $\beta_p \gtrsim 1$ pressure-driven modes could be involved. With $I_p = 300$ and 380 kA transport in the H phase is characterized by flat $\chi_e \approx 2$ to $3 \times 10^4\ \mathrm{cm}^2\mathrm{s}^{-1}$, $D = 0.2\ \chi_e$ and neoclassical χ_i. Compared with L discharges χ_e and D are reduced by a factor of about two in the whole plasma. In both the H and L regime χ_e and D decrease with increasing I_p, but are independent of n_e. These parallels in scaling should reflect the influence of the saturated microturbulent state.

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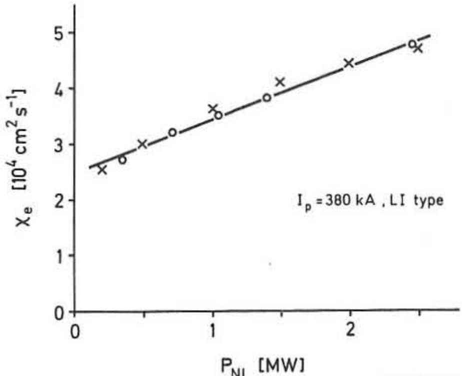

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Fig. 1: Electron thermal diffusivity from simulations (circles) vs. neutral injection power. For comparison $\chi_e(a)$ (crosses) derived from τ_E scaling are shown.

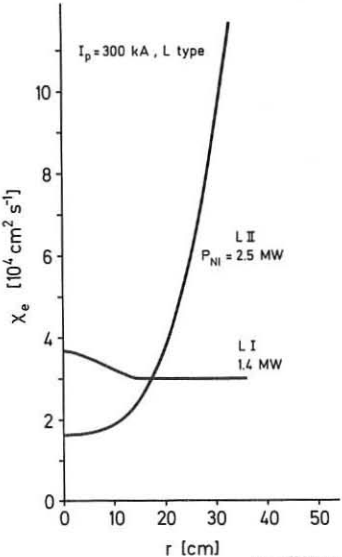

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Fig. 2: Different local transport behaviour in the LI (P_{NI} = 1.4 MW) and LII regime (2.5 MW) shown by $\chi_e(r)$.

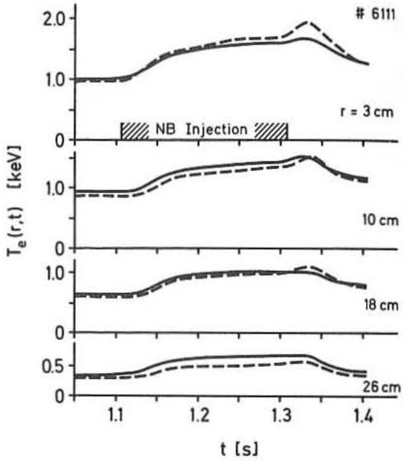

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Fig. 3: $T_e(r,t)$ in an LII discharge with 300 kA and 2.5 MW computed with $\chi_e(r)$ from Fig. 2 (solid curves) compared with ECE measurements (dashed curves).