PARTICLE CONFINEMENT IN OHMICALLY HEATED ASDEX PLASMAS

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Abstract: The anomalous particle transport in ohmic deuterium and hydrogen discharges is investigated by scans of the plasma current, density and toroidal magnetic field. At smaller current or larger ion mass more peaked density profiles are found. The flux-surface-averaged transport is analysed by computer simulations. It is shown that the inward drift velocity is independent of the poloidal and toroidal magnetic field and the ion mass number but inversely depends on the density and electron temperature. Empirical scaling relations for the electron heat diffusivity and the diffusion coefficient are also presented.

Introduction: Anomalous diffusion and inward drift in ohmically heated (double-null divertor) discharges are investigated in the ASDEX tokamak by extensive parameter studies. For deuterium and hydrogen plasmas the variation of the density profile with plasma current I_p, toroidal magnetic field B_t and line-averaged density $\bar{n}_e$ is explored. Several series of discharges are studied in which only one of these parameters has been scanned. In all cases, data measured during long current and density plateaus are analysed.

Diagnostics: The electron density n_e is measured by a multichannel HCN-laser interferometer /1/ working at a wavelength of 337 µm. Figure 1 shows the arrangement of the viewing chords with respect to the ASDEX plasma. The electron density profile $n_e(r)$ is constructed by a fit procedure for the measured line densities of the horizontal channels. A modified parabola of the form $n_e(r) = n_e(0)\ [1 - (r/a)^{\beta}]^{\alpha}$ describes the profile inside the separatrix while an exponential function with a typical decay length of 2 cm is used outside. For the rather smooth profiles found in ohmically heated discharges, this method yields good accuracy.

The electron temperature T_e is derived from the extraordinary mode of the second harmonic of the electron cyclotron emission (ECE) from the plasma. Its intensity is registered by a four-channel polychromator, constructed to observe simultaneously four slightly different wavelengths between $2.0 \leq \lambda \leq$ 3.0 mm corresponding to four radial positions in the plasma about 6 - 8 cm apart from one another. The complete T_e profile can be established by a sequence of at least two identical discharges with properly varied wave

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length settings of the polychromator. For details of the ECE diagnostic employed see e.g. Ref. /2/.

Analysis of the particle transport by computer modelling: The steady-state particle balance equation with anomalous outward diffusion and anomalous inward convection reads

$$- D \frac{dn_e}{dr} + v_{in} n_e = \Gamma_i, \quad (1)$$

where Γ_i is the flux density due to ionization of cold atoms which mainly takes place near the plasma edge.
The experiments are simulated with the BALDUR transport code /3,4/. For deuterium and hydrogen plasmas the computations fit the measured $n_e(r)$ and $T_e(r)$, the central ion temperature $T_i(0)$ from CX diagnostics and the poloidal beta β_p from the diamagnetic loop. The following expressions for the electron heat diffusivity χ_e and the diffusion coefficient D are to be used for best fits in ohmically heated plasmas:

$$\chi_e(r) = 1.61 \times 10^{16} A_i^{-1/2} B_t n_e(r)^{-1} T_e(r)^{-1} q(r)^{-1} \text{ cm}^2 \text{ s}^{-1} \quad (2)$$

$$D(r) = 0.2 \chi_e(r), \quad (3)$$

where B_t is in kG, n_e is in cm^{-3} and T_e is in keV. A_i denotes the ion mass number. Note that the ion mass dependence given holds under pure deuterium and hydrogen plasma conditions after glow-discharge cleaning. The ion heat diffusivity χ_i used is one time the neoclassical values according to Chang and Hinton. For the anomalous inward drift velocity $v_{in} = \gamma(r/r_w)^2$ is applied instead of the Ware pinch. γ is a factor whose parameter dependences are investigated by scanning I_p and $\bar{n}_e$, and r_w is the wall radius (r_w = 49 cm). As illustrated by Fig. 2, this model yields the measured profile variation, characterized by $n_e(0)/\langle n_e \rangle$, on I_p, where $\langle n_e \rangle$ is the volume-averaged density. For deuterium $v_{in} = -550 (r/r_w)^2$ cm s^{-1} is used while for hydrogen $v_{in} = -710 (r/r_w)^2$ cm s^{-1} is applied. The inward drift velocity is found to be independent of the plasma current. In Figs. 3 and 4, examples of computed density and temperature profiles from these scans are compared with the measured results for deuterium and hydrogen, respectively.

Results of the density scan are presented in Fig. 5. For a given electron temperature the inward drift exhibits an inverse $\bar{n}_e$ scaling. Scanning the toroidal magnetic field (see Fig. 6) yields a weak rise of the measured $n_e(0)/\langle n_e \rangle$ values with increasing B_t which is ascribed to the variation of the q=1 radius. These scans show that v_{in} is independent of the poloidal magnetic field B_p, B_t and A_i but it depends inversely on n_e and T_e. Equations (2) and (3) and $B_t/q = R_o B_p/r$ yield

$$\frac{v_{in}(r)}{D(r)} \simeq - A_i^{1/2} B_p(r)^{-1} f(r) \quad (4)$$

independently of B_t, n_e and T_e. Smaller currents and larger ion mass correspond to higher $|v_{in}|/D$, i.e. more peaked density profiles, in agreement with the measurements. The v_{in} scaling given by Eq. (4) differs from the previously used relation $v_{in}/D \simeq -2\alpha r/a^2$ with α being a constant. An explicit dependence of χ_e, D and v_{in} on Z_{eff} was not identified in the scans.

References

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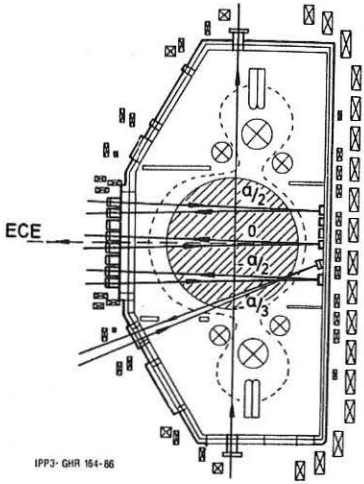


Fig. 1: Cross-section of the ASDEX device, showing the viewing chords of the HCN-laser interferometer (solid lines) and ECE diagnostics (dashed line).

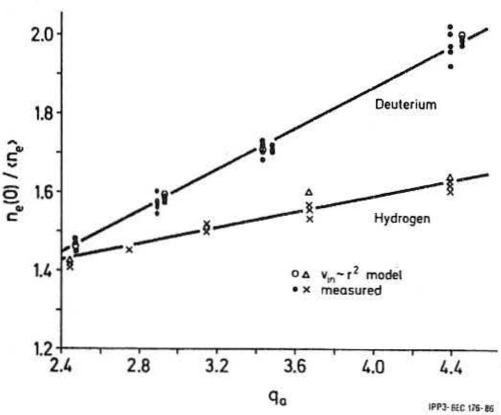
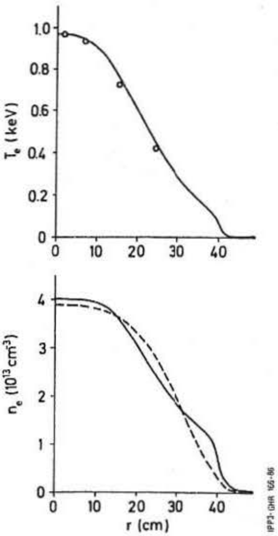


Fig. 2: $n_e(0)/\langle n_e \rangle$ versus q_a by scanning the plasma current between 250 and 450 kA (B_t = 2.25 T, $\bar{n}_e$ = 2.7 x 10^{13} cm^{-3}.



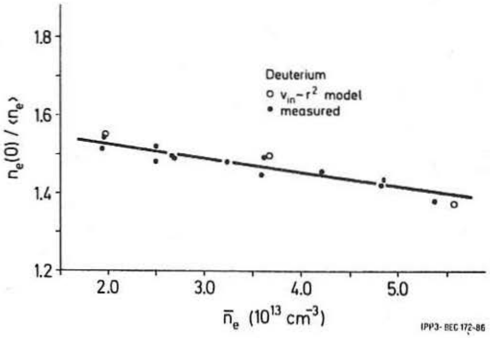
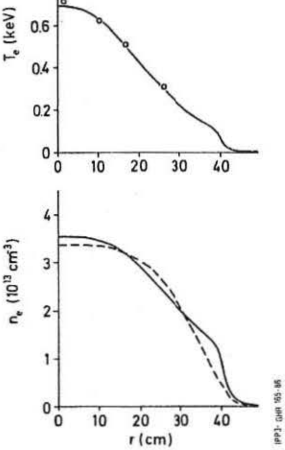


Fig. 5: Measured and computed $n_e(0)/\langle n_e \rangle$ versus $\bar{n}_e$ (I_p = 420 kA, B_t = 2.18 T).

Fig. 3: Measured density (dashed curve) and electron temperature (circles) profiles compared with computed results (solid curves, I_p = 320 kA and deuterium plasma).



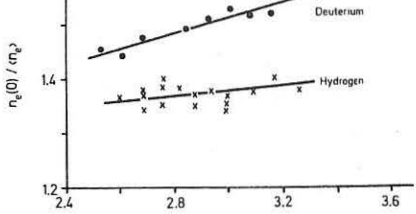


Fig. 6: Measured $n_e(0)/\langle n_e \rangle$ versus q_a by scanning the toroidal magnetic field (I_p = 380 kA).

Fig. 4: As in Fig. 3, but I_p = 350 kA and hydrogen plasma.