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Investigation of Argon Impurity Transport at TEXTOR-94

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Introduction and overview

Argon impurity transport in neutral-beam heated L-mode discharges has been studied at the tokamak experiment TEXTOR-94 using a fast gas puffing technique. In these experiments the time evolution of spectroscopic signals from different ionization stages of argon (Ar I, Ar VIII, Ar XV, Ar XVI and Ar XVII) was recorded with high time resolution (0.3...1 ms). The measured time traces show a fast increase followed by a slower decay phase, where the signals from the higher ionized states are delayed with respect to the low ionization states by typically 3 to 30 ms. From the time evolution of the measured signals the radial distribution of the diffusion coefficient D is determined using the spatially one-dimensional transport code STRAHL [1]. For the discharge conditions investigated here, we obtain values in the order of $D \approx 0.3...1.2\ m^2/s$ for the plasma centre (r = 0) and $D \approx 3...20\ m^2/s$ in the outer plasma region, respectively. These numbers are significantly (about one order of magnitude) above the figures predicted by neoclassical theory for the respective radial regions.

Experimental technique

At the limiter tokamak TEXTOR-94 (major radius R = 1.75 m, minor radius a = 0.46 m, circular plasma shape) a fast piezo-electric valve was used to inject short argon puffs into the flat top phase of a series of discharges. The temporal shape of these gas puffs is monitored by a fast (0.1 ms) infrared Ar I radiation detector directed towards the gas inlet, yielding a duration of the gas puffs of only 2 ms (FWHM). The Ar VIII (Na-like) line radiation at a wavelength of λ = 70 nm, Ar XVI (Be-like, 22 nm) and Ar XVI (Li-like, 35 nm) are measured using three VUV/XUV monochromators mounted at radial ports near the horizontal midplane of TEXTOR-94. The Ar XVI (Li-like) and Ar XVII (He-like) signals at λ = 0.4 nm are collected by means of a high-resolution x-ray spectrometer [2], which is installed in the horizontal midplane. All spectroscopic signals are recorded with high time resolution (0.3 ms ... 1 ms). The data are averaged over 10 - 20 identical gas puffs performed at equal plasma conditions in order to improve the data statistics. These time-averaged line intensities and all subsequently derived quantities (like the diffusion coefficients) represent averages over the sawtooth periods, because the gas puffs are applied with random phase relation to the sawtooth activity.

Typical experimental results

Argon impurity transport was investigated in a series of sawtoothing neutral-beam heated discharges (co-injection) for different mean electron densities and plasma currents. Small traces of argon were puffed into the flat-top phase of these discharges, keeping the total argon concentration in the plasma well below 0.1 percent of the electron density. Thus the electron density and temperature as well as the loop voltage are not significantly disturbed by the gas puffs, while small peaks are visible in the radiated power signal [3]. As an example, the measured time traces of the normalized line intensities from different argon ionization stages are shown in fig. 1 for the plasma conditions of TEXTOR shot # 80664 (I = 330 kA, B = 2.25 T, $\bar{n}_e$ = 3.1 × 10^{13} cm^{-3}), together with the time traces of the numerical results from the STRAHL code simulation.

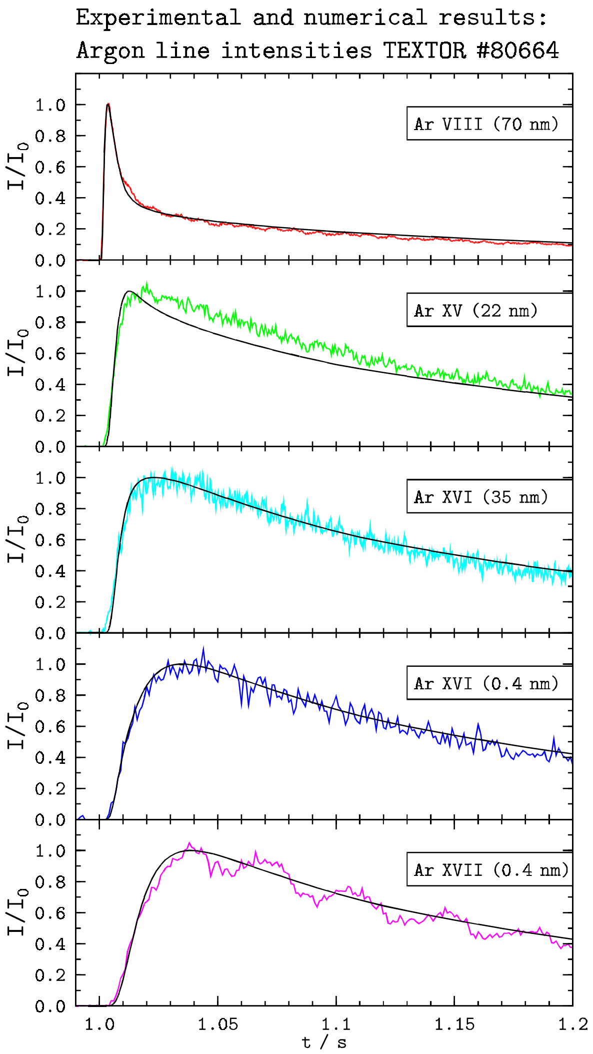

Fig. 1: *Measured line intensities (coloured lines) and STRAHL results (black solid lines) for TEXTOR #80664*

All measured line intensities show a fast increase, followed by a slower decay phase. The signals from the higher ionization stages are delayed with respect to the lower stages by typically only 3 to 30 ms, showing that the bulk of the argon ions moves quite fast from the plasma edge towards the plasma centre. From the decay phase of the signals from the higher ionization stages the effective particle confinement time τ_p^* (including recycling) can be estimated to be between 70 ms and 200 ms for the plasma conditions investigated here, which is about a factor of 2 to 7 above the respective energy confinement times ($\tau_E \approx$ 25...40 ms for all discharges investigated here). The temporal shape of the Ar VIII line burning near the plasma edge differs from the higher ionization stages by displaying an additional fast decay phase which is caused by the short duration of the argon gas puff and the related argon density peak located at the plasma edge shortly after the gas puff.

STRAHL code simulation of the experiments

The experiments are evaluated by simulating the gas puff experiments using the predictive impurity transport code STRAHL [1], solving the system of time-dependent continuity equations for all ionization stages of argon in a spatially one-dimensional geometry (flux surface averages). Radial profiles of n_e and T_e as measured by interferometry, ECE and helium beam spectroscopy are used as input parameters, while the relevant atomic processes as ionization, recombination, line excitation and charge exchange between argon ions and the hydrogen neutral particle background are described using data from ADAS. The time evolution of the argon influx is taken proportional to the Ar I signal measured at the gas inlet. The radial transport contributions by diffusion D and convection v are treated as follows: The neoclassical contributions D_{neocl} and v_{neocl} are taken into account as calculated by a STRAHL subroutine. The radial profile of the anomalous part of the impurity diffusion coefficient D_{an} (assumed to be equal for all ionization stages) as well as the particle removal at the plasma edge are varied iteratively until we find agreement between the measured and the calculated spectroscopic signals at both the increase phase as well as the decay phase of these signals (see fig. 1). In these simulations it is found that the resulting radial profiles of the diffusion coefficient do not change significantly if an additional anomalous inward pinch velocity v_{an} in the range of up to some 10 m/s is assumed. In fact the technique described here is not sufficiently sensitive for determining the magnitude of the anomalous pinch velocity, so that all results presented below refer to simulations where the anomalous radial drift velocity is neglected ($v_{an} = 0$).

Results

Radial profiles of the emissivities of the argon lines for the plasma conditions of TEXTOR # 80664 are shown in fig. 2.

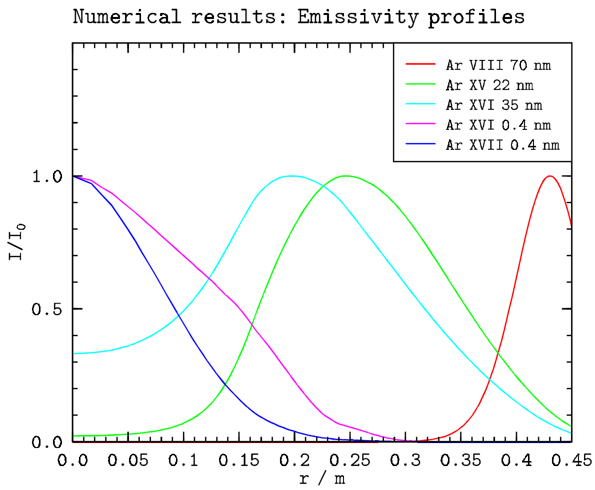

Fig. 2: *Radial profiles of normalized argon emissivities calculated by STRAHL for TEXTOR #80664 ($T_e(0)$ = 1.6 keV, $n_e(0) = 4.5\times10^{13}$ cm^{-3})*

The maximum of the Ar VIII line emissivity is found near the LCFS at 0.46 m, while the XUV Ar XV and Ar XVI lines radiate at about half minor radius. The emissivity of both x-ray lines is restricted to the plasma centre (r = 0...0.15 m) due to their high excitation energy of about 3.3 keV. Due to the limited number of measured lines and due to the broad emissivity profiles the achievable space resolution of radial profiles of D_{an} is limited. Thus we restrict ourselves on determining an effective value for the central diffusion coefficient D_{core} (adjusting the time delay between the increase phases of the two x-ray lines and the Ar XVI XUV line), an effective value for the diffusion coefficient for the outer radial region D_{out} (determined from the time evolution of the Ar VIII line together with the Ar XV line) as well as the position and slope of D in the transition region between D_{core} and D_{out}, which is found to be at about half minor radius. The results for the radial profiles of D = D_{an} + D_{neocl} are displayed in fig. 3 for a series of L-mode shots with the same current and NBI heating power (co-injection).

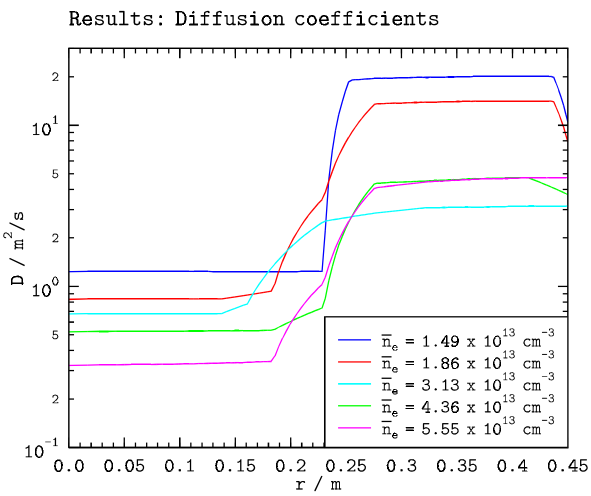

Fig. 3: *Radial profiles of diffusion coefficients (I = 330 kA, B = 2.25 T, NBI power p = 1.34 MW)*

We observe that for all plasma conditions investigated here $D_{core} << D_{out}$, where the absolute figures of these sawtooth-averaged impurity diffusion coefficients exceed the neoclassical values by typically more than one order of magnitude in both the plasma centre and in the outer plasma region. Similar results have been reported from other experiments, see e.g. [4,5]. With increasing mean electron density the diffusion coefficient decreases. The scaling of the diffusion coefficient with the mean electron density is shown in fig. 4.

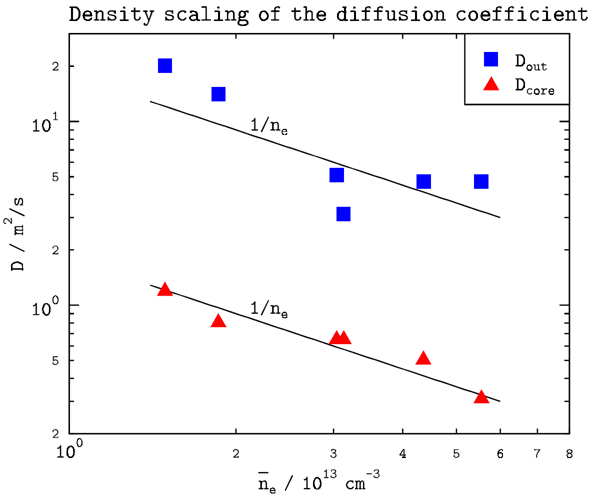

Fig. 4: *Scaling of the diffusion coefficient with mean electron density for constant current I = 330 kA and NBI heating power p = 1.34 MW*

We find that the values for both D_{core} and D_{out} show an Alcator-like scaling $D \propto 1 / \bar{n}_e$, which is in agreement with other experiments, see e.g. [6,7]. In a similar way a scan of the plasma current I was performed at constant mean electron density. While the values for D_{core} show nearly no dependence on I, the values for D_{out} decrease remarkable with increasing I, see fig. 5.

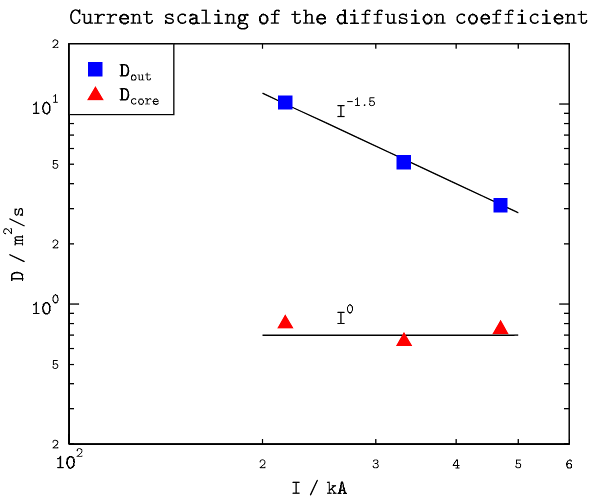

Fig. 5: *Scaling of the diffusion coefficient with plasma current at constant electron density* $\bar{n}_e = 3 \times 10^{13}\ cm^{-3}$ *and NBI heating power*

Summary and conclusions

Argon impurity transport was studied in neutral-beam heated L-mode discharges at TEXTOR-94 by means of a fast gas puffing technique. Evaluating the measured spectroscopic data using the STRAHL code, the radial profiles of the sawtooth-averaged impurity diffusion coefficient are derived. In general it is found that $D_{core} << D_{out}$, where both quantities are more than one order of magnitude above the figures predicted from neoclassical theory valid for the respective radial regions. Varying the mean electron density at constant plasma current and heating power, we find an Alcator-like scaling of the diffusion coefficient $D \propto 1 / \bar{n}_e$. Changing the plasma current at constant density and heating power does not change the central diffusion coefficient significantly, but a remarkable decrease of the outer diffusion coefficient with increasing plasma current is observed. For the future, it is planned to extend these investigations towards other impurity species like Si, Ni, Fe and towards other discharge conditions. Furthermore, we plan to measure radial profiles of highly ionized impurities with high time resolution (by CXRS) in order to derive both the diffusive and the convective parts of the radial impurity transport.

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