PROGRESS IN IMPURITY TRANSPORT STUDIES ON TEXTOR USING NEW VUV SPECTROMETERS WITH HIGH TIME RESOLUTION

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Introduction and overview. Argon impurity transport in ohmic discharges has been studied at TEXTOR using new VUV spectrometers with high time resolution (1 ms). In these experiments short argon puffs were injected into the discharges and the time evolution of spectroscopic signals from many different ionisation stages was recorded. The time evolution of normalised line intensities is used to determine the radial profile of the argon diffusion coefficient by STRAHL code modelling [1].

New VUV spectrometers at TEXTOR. At the limiter tokamak TEXTOR (major radius $R_0 = 1.75$ m, minor radius $a_0 = 0.46$ m, circular plasma shape) new VUV spectrometers with high time resolution have been installed at sightlines located near the horizontal midplane. These systems have been optimised with respect to efficiency and time resolution and each of these spectrometers collects 1000 full spectra per second continuously over each TEXTOR discharge. In total a wavelength range of more than one order of magnitude within the VUV range is covered (see table 1), where all of the first 30 elements of the periodic table have strong emission lines.

VUV spectrometer system	wavelength range / nm	wavelength resolution / nm
Seya-Namioka	57 – 130	0.3
SPRED-A	15 – 110	0.4
SPRED-B	11 – 33	0.1

Table 1: *Data of the new VUV spectrometers at TEXTOR*

In particular, the covered wavelength range comprises intense spectral lines from H-like and He-like states of low-Z impurities (from He to carbon) as well as strong Mg-like, Na-like, B-

like, Be-like and Li-like lines from medium-Z impurities (up to Cu). Thus these spectrometers are well suited to conduct impurity injection experiments.

Argon injection experiments. A fast piezo-electric valve was used to inject short argon puffs (FWHM 2 ms) into the flat top phase of a series of OH discharges. Using the new VUV spectrometers, spectral lines from the ionisation stages Ar-VII (58 nm), Ar-VIII (70 nm), Ar-X (17 nm), Ar-XII (15 nm), Ar-XIV (18 nm), Ar-XV (22 nm) and Ar-XVI (35 nm) are measured simultaneously. In the plasma centre, the Ar-XVI and Ar-XVII signals at $\lambda = 0.4$ nm are collected by means of a high-resolution x-ray spectrometer [2] installed in the horizontal mid-plane, while SXR cameras equipped with 100 μm Be foils monitor the central SXR radiation at different sightlines. All spectroscopic signals are recorded with high time resolution (≤ 1 ms). In fig. 1 the measured VUV spectra are shown for different times after an argon puff at t = 3.7 s. In fig. 2 the normalised line intensities are displayed for discharge conditions with mean electron density $\overline{n}_e = 3.5 \cdot 10^{13}$ cm^{-3}, together with a STRAHL code simulation. In order to improve the signal-to-noise ratio for the Ar-X, Ar-XII and x-ray (0.4 nm) signals, the experimental data are averaged over 4 equal discharges (#88709, 10, 27, 28).
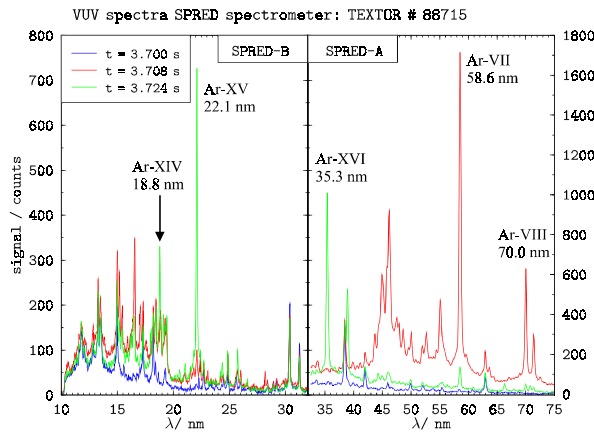

Fig. 1: *VUV spectra measured after argon puffing in an OH discharge with discharge conditions $I_P = 350$ kA, $T_e(0) = 1.6$ keV, $\overline{n}_e = 2.0 \times 10^{13}$ cm^{-3}*
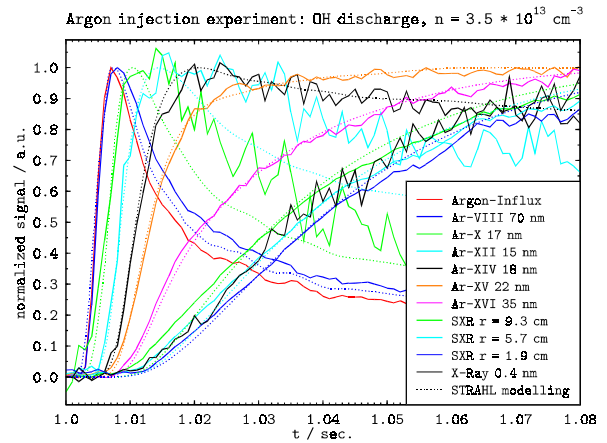
Fig. 2: *Measured line intensities (coloured lines) and STRAHL results (dotted lines) for OH discharge conditions $I_P = 350$ kA, $T_e(0) = 1.2$ keV, $\overline{n}_e = 3.5 \times 10^{13}$ cm^{-3}*

All measured line intensities show a fast increase, followed by a slower decay phase. The signals from the higher ionisation stages are delayed with respect to the lower stages by only 5 to 50 ms, showing that the bulk of the argon ions moves quite fast from the plasma edge towards the plasma centre.

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 ionisation stages of argon in a

spatially one-dimensional geometry (flux surface averages). Radial profiles of the time-averaged profiles of n_e and T_e as measured by interferometry, ECE, Thomson scattering and helium beam spectroscopy are used as input parameters, while the relevant atomic processes as ionisation, recombination, line excitation and charge exchange between argon ions and the hydrogen neutral particle background are described using data from ADAS. The hydrogen neutral particle density profile $n_H(r)$ is taken from a self-consistent RITM-code modelling of the discharges. In these calculations we take into account the radial transport contributions by neoclassical diffusion D_{neocl} and radial drift velocity v_{neocl} as well as the radial profile of the anomalous diffusion coefficient D_{an}, which is varied iteratively until we find agreement between the measured and the calculated spectroscopic signals (see fig. 2). As the technique described here is not sufficiently sensitive for determining the magnitude of the anomalous pinch velocity v_{an}, 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 same discharge as given above are shown in fig. 3. In fig. 4 the radial profiles of D are displayed.
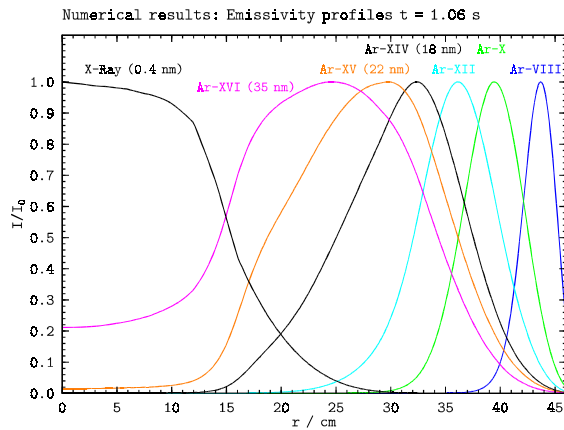

Fig. 3: *Radial profiles of normalised argon emissivities calculated by STRAHL (same discharge conditions as in fig. 1)*
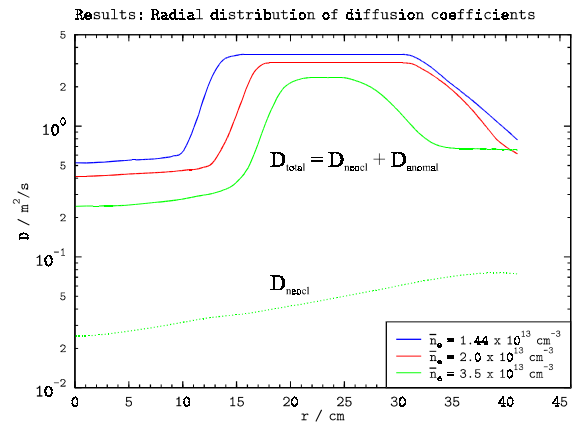
Fig. 4: *Radial profiles of argon diffusion coefficients for OH discharges with different electron densities*

The emissivity shells of the measured VUV lines cover the radial region r = 15...45 cm, while the emissivity of the SXR radiation is restricted to the plasma centre (r = 0...15 cm), since the 100 μm Be foils practically suppress all argon radiation besides the 0.4 nm resonance lines of Ar-XVII and Ar-XVI. All emissivity shells are significantly broadened compared to the corona model. The dense coverage of the radial region with emissivity shells allows to derive the detailed radial profiles of D(r) from the STRAHL modelling, see fig. 4. For the plasma conditions investigated here we obtain values of $D_{core} \approx 0.2...0.5$ m^2/s for the plasma centre, $D_{max} \approx 2...4$ m^2/s in the radial region near half minor radius (r $\approx$ 25 cm) and a decrease of D
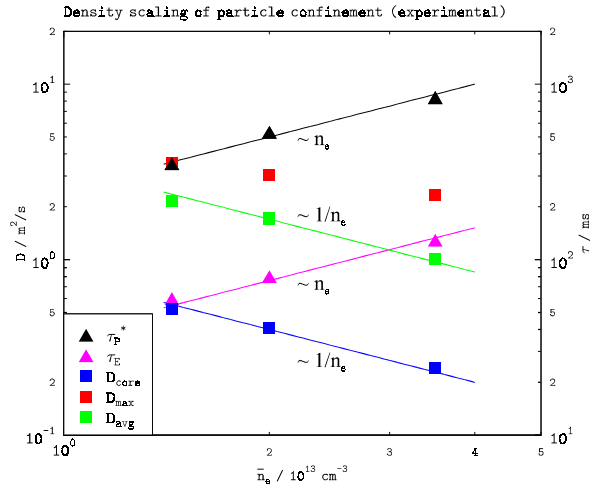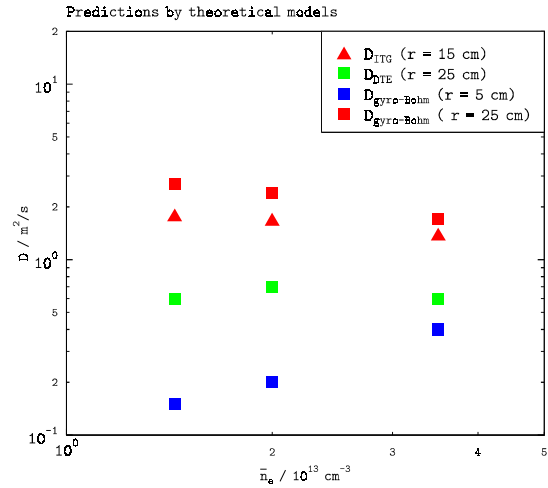
Fig. 5: *Density scaling of argon transport properties*

Fig. 6: *Predictions for anomalous diffusion coefficients D_{an} by theoretical models*

towards $D \approx 0.5 \ m^2/s$ near the plasma edge. The absolute figures exceed the neoclassical values by more than one order of magnitude in both the plasma centre and in the outer plasma region. With increasing line-averaged electron density the diffusion coefficient decreases, see fig. 5. We find that both the central value D_{core} as well as the mean value D_{avg} show an Alcator-like scaling $D \propto 1 / \bar{n}_e$. Simultaneously, both the effective particle confinement time τ_P^* and the energy confinement time τ_E increase linearly with density, where the latter relation indicates that the discharges follow the linear ohmic confinement regime (LOC).

The results for the anomalous diffusion coefficients are compared to predictions by theoretical models for the dissipative trapped electron (DTE) and the ion temperature gradient driven (ITG) instabilities [3] as well as to a simple gyro-Bohm formula, see fig. 6. We find that both the ITG diffusion coefficient as well as the gyro-Bohm value fit to the experimental figures for D_{max} in the radial region $r = 15...25$ cm.

Summary and conclusions. New VUV spectrometers with high time resolution have been used in argon injection experiments on TEXTOR to determine the impurity diffusion coefficient in OH discharges. The simultaneous measurement of spectral lines from many different ionisation stages allows to determine the detailed radial profile of D by STRAHL code modelling. It is found that $D >> D_{neocl}$ and $D_{core} << D_{max}$ ($r = 15...25$ cm), where both quantities show an Alcator-like scaling with mean density $D \propto 1 / \bar{n}_e$.

References:

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