Radial profiles of the neutral gas density and the transport coefficient from imaging X-ray spectroscopy at TEXTOR

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Abstract

The K_α-spectrum of He-like argon is commonly used for plasma temperature diagnostics. Nevertheless it has repeatedly been in the focus of discussions as the observed line ratios significantly deviate from the coronal expectations. X-ray imaging revealed that these deviations are most severe for emission from the outer plasma regions rather than from the center. But up to now the mechanisms behind this could not be exactly identified or quantified.

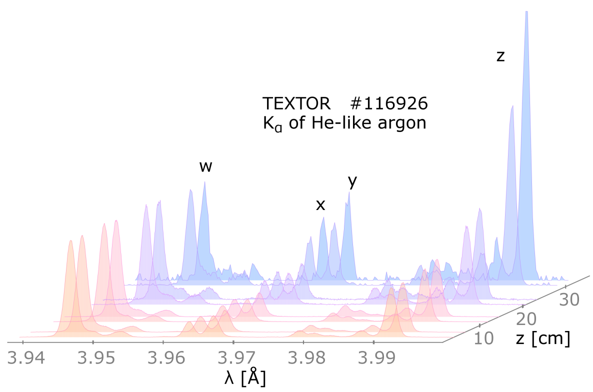
In this paper we present radially resolved K_α-spectra of He-like argon measured at the tokamak TEXTOR. The line ratios can consistently be described with charge exchange and impurity transport over the whole radial field of view. Both processes are well separable and the method allows to deduce radial profiles of the neutral particle density $n_0(r)$ and the diffusion coefficient $D_\perp(r)$. A high transport zone is found to be essential for a consistent reconstruction of the spectra. Yet there is also need for an adequate density of neutral particles causing charge exchange recombination at the plasma edge.

Our results introduce imaging K_α-spectroscopy as diagnostic for impurity transport and the neutral particle density in hot fusion plasmas.

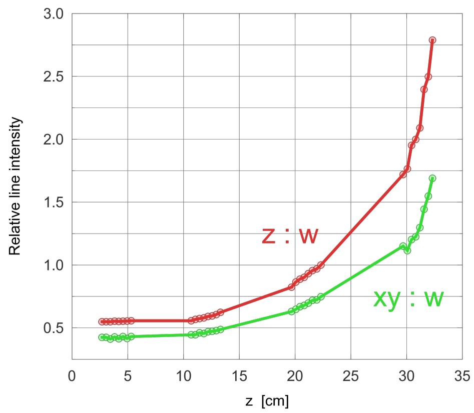
Experimental setup

The compact imaging Bragg spectrometer for the stellarator W7-X [1] was installed at the tokamak TEXTOR for a short commissioning phase. Developed to measure the K_α-emission of He-like argon in radial resolution the device features an array of six 2-dim. CCD chips each covering ca. 3 cm of vertical height in the plasma vessel. This allows to simultaneously observe the K_α-emission over a major part of the minor TEXTOR radius (47 cm). The vertical position of each line of sight has been precisely determined via ray tracing. Each of them enters the torus tilted by 20° towards the major plasma radius. Due to technical reasons the time resolution of the device was limited to 700 ms. Only data well within the flat top phase of a discharge was

*retired



(a)



(b)

Figure 1: **(a)** K_α-scan of He-like argon measured at the tokamak TEXTOR (a=47 cm). The line labels follow Gabriel [2]. **(b)** Line intensities of the triplet lines **x**, **y**, **z** relative to the singlet line or reference line **w**. The line intensities shown are raw data including superposed satellites.

used for further analysis.

Spectra were recorded during several ohmic and beam heated discharges in argon seeded hydrogen and helium plasmas. While this paper briefly demonstrates the principle method the results as a whole will soon be published elsewhere.

Experimental data

Figure 1(a) shows a typical K_α-scan of He-like argon measured during an ohmic TEXTOR discharge with a line averaged electron density of $\overline{n_e} = 2.5 \cdot 10^{13} cm^{-3}$. Most remarkable are the changing line ratios between the singlet line (**w**) and the triplet lines (**x**, **y**, **z**). ***Figure 1(b)*** illustrates that the **w**-line clearly dominates the emission from the hot plasma center but is exceeded by the **z**-line by a factor of two to three on the outermost channels. This picture is in qualitative agreement with findings from ALCATOR-C [3, 4].

The increasing triplet lines indicate the dominance of recombination processes in the colder edge region. However, up to now the radial behavior was not understood quantitatively. Especially the influences of radiative recombination and charge exchange recombination could not be identified. Despite from this any recombination process necessitates significant amounts of radial impurity transport as in the TEXTOR edge region at temperatures of ca. 0.5 keV no H-like argon should exist.

Data processing

As e.g. described in [5, 6] the K_α-spectrum allows to determine several plasma parameters. The electron temperature T_e is determined from the dielectronic **k**-satellite in reference to the **w**-line.

The argon ion ratio $Ar^{15+} : Ar^{16+}$ follows from the **q**-satellite compared to the **w**-line while the argon ion ratio $Ar^{17+} : Ar^{16+}$ can be deduced from the recombination contributions on the He-like lines (**w**, **x**, **y**, **z**). The latter then depends on the assumed neutral particle density $n_0(r)$ due to charge exchange contributions. In addition the ion temperature T_i can be deduced from the Doppler broadening. To take account of the line integrated signals the fit routine integrates over all relevant plasma profiles given as input data. These profiles include $n_e(r)$, $T_e(r)$, $T_i(r)$, the densities of H-like, He-like and Li-like argon as well as $n_0(r)$.

As mentioned above the found ion ratios deviate strongly from the coronal values. To reproduce them a 1-D transport model was applied including charge exchange recombination as well as diffusive and convective ($v \propto \frac{r}{a} D_\perp$) impurity transport. Based on profiles of $n_0(r)$ and the diffusion coefficient $D_\perp(r)$ it calculates the radial distribution of all argon ion stages. While diffusive transport generally reduces gradients in the argon ion balance charge exchange as additional recombination channel tends to shift the balance towards the lower stages.

Once $n_0(r)$ and $D_\perp(r)$ are found to reproduce the fitted quantities $Ar^{17+} : Ar^{16+}$ and $Ar^{15+} : Ar^{16+}$, new fits are carried out basing on the newly calculated argon ion profiles leading to slightly changed results. An iterative procedure is necessary to achieve self consistency between the transport calculations and the fitted line intensities. The final set of $n_0(r)$ and $D_\perp(r)$ as well as the argon ion balance are considered as experimental results.

We would like to emphasize that charge exchange and transport effects in the K_α-spectrum are well separable. The cascade contributions due to charge exchange do not affect the doubly excited Li-like collisional satellites (**q**, **r**) as the low density limit is well fulfilled. Therefore only the singly excited He-like lines feature direct contributions from charge exchange. In contrast the slow transport processes only act on the argon ground states and cause indirect contributions for any line intensity.

Results

A representative result of the procedure described above is shown in ***figure 2***. Both argon ion ratios can be reproduced over the whole field of view. The dominant process is diffusive transport. Particularly a high transport zone (HTZ) is indispensable to reconstruct the measured line ratios. This confirms earlier results from VUV-spectroscopy at TEXTOR [7]. However, especially in the edge region also charge exchange contributions are not to be neglected.

The errors in the transport coefficient mainly arise from the fragmentary radial coverage and could be significantly reduced with a continuous one piece detector. The neutral particle density can be determined by a factor of 2 or better as long as it does not fall below the detection limit which can happen in the plasma center. Beyond the outer most channel no distinct statements

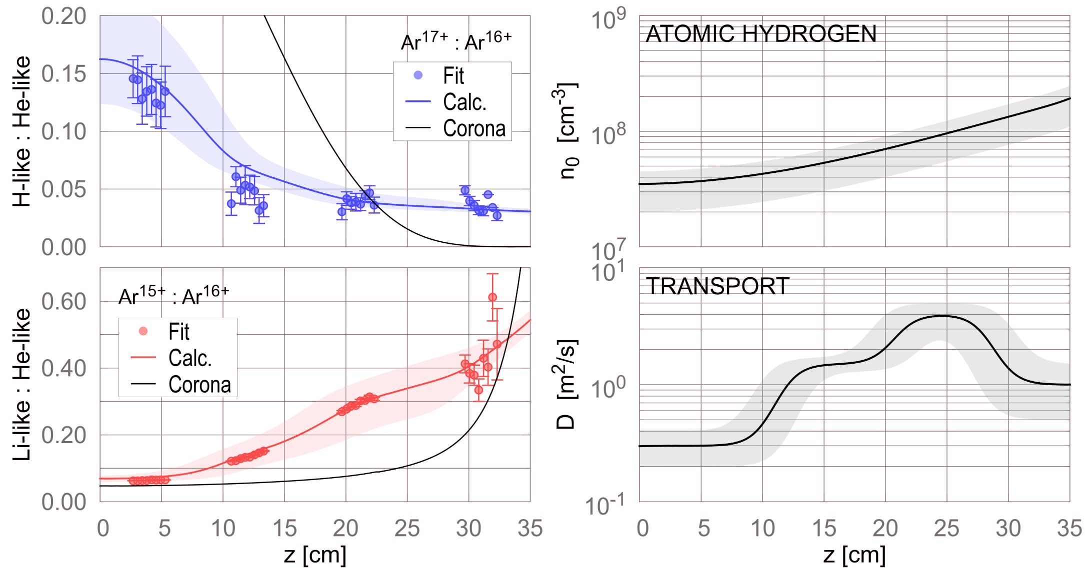


Figure 2: Self consistent reconstruction of the argon ion density ratios and the deduced profiles of $n_0(r)$ and $D_\perp(r)$. The shaded areas indicate the errors in the resulting profiles, the error bars show the fit errors. (TEXTOR discharge #116924, ohmic, $\overline{n_e} = 2.0 \cdot 10^{13} cm^{-3}$)

can be made.

Conclusions

We presented the first radially resolved measurements of the K_α-emission of He-like argon in TEXTOR and described a method to simultaneously deduce profiles of n_0 and $D_\perp$. The results for $n_0(r)$ state not only the first measurements of the neutral particle density profile in the TEXTOR core plasma. The method presented rather makes X-ray imaging the only diagnostic for neutral particle density measurements in the plasma core available today.

References

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