Investigation of Ion Dynamics in the ASDEX Upgrade Divertor by High Resolution Spectroscopy: First Results on Ion Drift Velocities

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1 Introduction

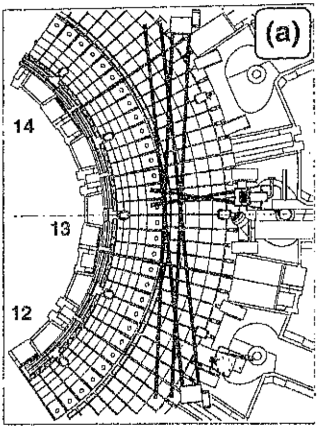
Divertor physics studies turn out to be one of the most important tasks in fusion research using magnetically confined plasmas. The divertor is necessary for dispersion of the plasma power, for fuel gas and helium ash control, for reduction of impurity production at the boundary and for screening these impurities from the plasma core. Hence detailed investigations of the plasma parameters and of the ion dynamics in the divertor region and their modelling have high priority.

Optical spectroscopy with high spectral, temporal and spatial resolution in different directions to the magnetic field lines is a key to deducing a variety of these important divertor parameters and mechanisms. The highly resolved emission spectra are dominated by Doppler shift and broadening as well as by the Zeeman pattern, integrated along the line of sight. Hence, measured with high resolution, the spectra are — in terms of ion temperature and ion drift velocity distributions — a sensitive probe for the ion dynamics.

2 Experimental

In ASDEX Upgrade the emission profiles of several spectral lines are measured using high resolution spectroscopy. There are 30 lines of sight in a poloidal plane [1] and 44 lines of sight viewing tangentially to the toroidal magnetic field, half of them in the field direction and half of them opposite to it. This scheme of sight lines is illustrated in Fig. 1a as viewed from the top and in Fig. 1b as a projection into a poloidal plane (for some selected chords in Sector 14 of ASDEX Upgrade). The various lines of sight viewing from opposite directions cover the area from the outer divertor tiles beyond the X-point and thus allow for probing of both sides of the X-point region. This special matrix-like arrangement of the chords was chosen to diagnose the ion dynamics in the outer as well as in the inner divertor fan.

Quartz lenses and optical quartz fibers are used to couple the light collected along the lines of sight into the 1.5 m Echelle spectrometer, whose spectral resolution is about 10^5. The spectra are recorded by an intensified 2D CCD camera. For simultaneous data acquisition up to 32 chords can be selected via fiber coupling out of the 74 chords available. For an unambiguous determination of line shifts selected poloidal chords are always taken as an internal reference.



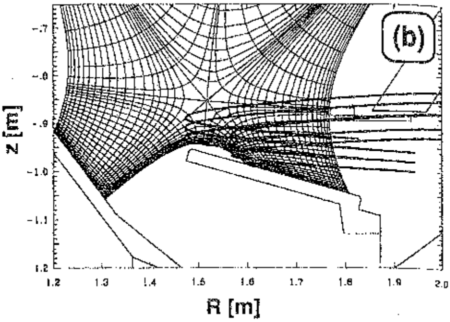


Fig. 1: Schematic representation of the poloidal and toroidal lines of sight in ASDEX Upgrade seen from the top (a) and as a projection into a poloidal plane (b, selected toroidal chords in Sector 14)

3 Zeeman Effect of Spectral Lines

As an example for a measurement we show the HeI singlet line at 667.815 nm, which has a simple Zeeman pattern and thus is suitable for demonstrating some characteristic features. In Fig. 2 the profile of the HeI-line for a radial (poloidal) chord (a) is compared to a profile measured with a tangentially oriented (toroidal) chord viewing in the direction of the toroidal magnetic field (b). While for the poloidal case the π-component clearly dominates, the tangential orientation is governed by the two σ-components. There is no significant Doppler shift observable for these HeI-spectra. The fit curves overlayed on the spectra were obtained by non-linear least squares fits to a convolution of the theoretical Zeeman-pattern with the instrumental function and a Gaussian describing the thermal broadening. Fig. 3 gives the results for the parameters of interest in this context as a function of time. The wavelength positions (relative to the poloidal case) shown in Fig. 3a for the poloidal and toroidal sight lines from Fig. 2 are the same within the error margin which is mainly given by the pixel resolution of the CCD camera. Similar results of the dependence on the chord direction are obtained for the magnetic field strength B (Fig. 3b) and for the ratio of the π- and σ-components (Fig. 3c). The magnetic field strength values are in very good agreement with the magnetic measurements. These values and the π/σ-ratio are used for calculating the

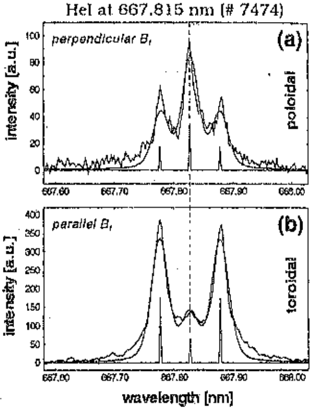


Fig. 2: Example of the HeI singlet line spectra for a chord viewing in the poloidal direction (a) and parallel to the toroidal magnetic field (b)

Zeeman-profiles of the other (ionic) lines observed for the identical lines of sight in similar discharge scenarios. As this procedure is only justified if the (spatial) emission profiles along the lines of sight are similar, this situation is checked by additional measurements with the boundary layer spectrometer [2] and the divertor spectrometer [3] at ASDEX Upgrade.

4 Drift Velocities of Ions

In contrast to the atomic line HeI the ionic spectral lines of all impurities in the plasma boundary show pronounced Doppler shifts for the toroidal observation. These ionic lines are, e.g., CII (doublet at $\lambda \approx 658$ nm), CIII (triplet at $\lambda \approx 465$ nm and singlet at $\lambda = 229.687$ nm), BII (singlet at $\lambda = 345.141$ nm), BIV (triplet line at $\lambda = 282.168$ nm) and HeII (doublet at $\lambda \approx 468.6$ nm).

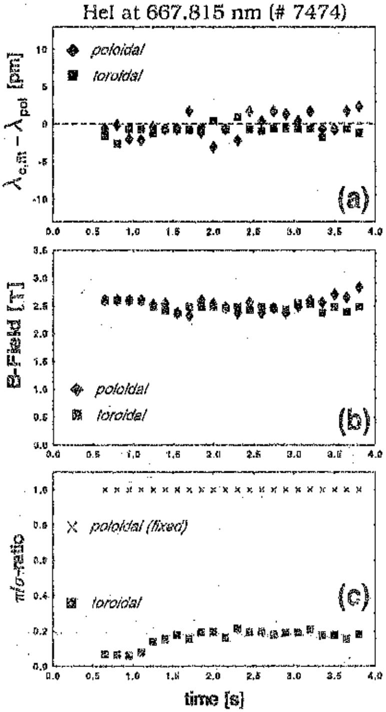


Fig. 3: Time dependence of (a) line shifts (relative to λ_{pol}), (b) magnetic field strength and (c) π/σ-ratio determined by fits to the HeI spectra of # 7474

Fig. 4 shows the CIII-singlet line spectra that were recorded under high recycling conditions (2 time ranges in # 8057: $P_{NI} = 2.0$ MW/7.5 MW, $\bar{n}_e \approx 6{\cdot}10^{19}$ m^{-3}/$8{\cdot}10^{19}$ m^{-3}) for the poloidal (b) and two toroidal chords (a, c) viewing into opposite directions. The shifts (relative to the average poloidal position λ_{pol}) deduced from these spectra are plotted as a function of time in Fig. 5a, clearly demonstrating the opposite Doppler shifts for the parallel and antiparallel (to $\vec{B}$) toroidal observation. These Doppler shifts result in (sight line averaged) drift velocities v_D of the order of $1.1{\cdot}10^4$ m/s that are given in Fig. 5b. Taking a C^{2+}-ion temperature of about 6 eV obtained from the Doppler width of the CIII-spectra the corresponding Mach numbers are in the range of 0.4 - 0.5. It should be noted that the observation volume is well above the high recycling region which is located close to the divertor plates. As to compare these experimental results with model calculations the distribution of C^{2+}-drift velocities along the appropriate lines of sight (for a typical L-mode discharge with $\bar{n}_e = 6{\cdot}10^{19}$ m^{-3}) was calculated using the B2-EIRENE code [4]. The v_D-values obtained from this simulation and from the spectroscopic data presented here (chord integrated) agree within about 50 %.

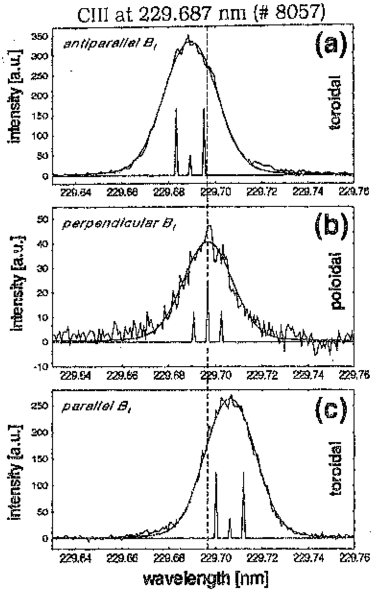


Fig. 4: Example of the CIII singlet line spectra for a poloidal (b) and two toroidal chords, one viewing in the direction of (c) and one opposite to (a) the toroidal magnetic field

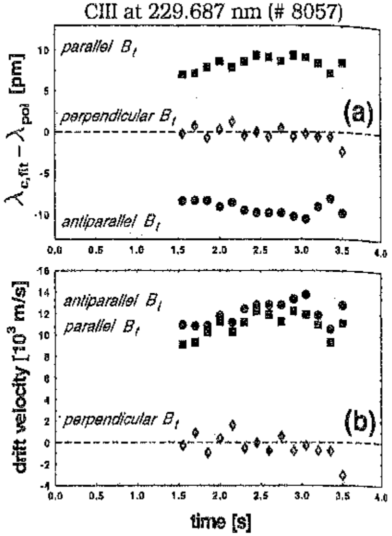


Fig. 5: (a) Doppler shifts (relative to the averaged poloidal position λ_{pol}) determined by non-linear least squares fits to the CIII spectra of # 8057 and (b) the resulting drift velocities towards the outer divertor plates as a function of time

Due to the matrix-like arrangement of the lines of sight mentioned above, the spectra are measured as a function of the radial position and thus yield information on drift velocities in both the outer and the inner divertor. By choosing appropriate chords it is possible to deduce ion drift speeds to the outer as well as to the inner divertor plates. This allows for a comparison of the ion dynamics in both divertor areas. As an example, the BII-spectra (λ = 345.141 nm) of an ohmic discharge (# 7193, $\bar{n}_e \approx 3.7\cdot10^{19}$ m^{-3}) yield v_D-values of about $1.1\cdot10^4$ m/s (towards the outer divertor) and of about $1.5\cdot10^4$ m/s for the drift of B^+ towards the inner divertor well above the divertor plates.

These first experimental results clearly demonstrate that the determination of drift velocities via the Doppler shift of emission lines is a suitable technique for investigating the drift dynamics of impurities in the ASDEX Upgrade divertor.

References

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[3] Lieder, G. et al., Europhys. Conf. Abstr. **17C**, Part II, 579–582 (1993).
[4] Schneider, R. et al., J. Nucl. Mater. **196–198** 810 (1992).