Extension and optimization of lithium beam diagnostic methods

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Introduction

Lithium beam diagnostics are a multi-facetted technique for investigating fusion edge plasmas. While the determination of electron densities by lithium impact excitation spectroscopy (Li-IXS) has already reached a satisfying standard on both large fusion experiments at IPP Garching [1,2], a neutral lithium beam can also be used to determine local concentrations as well as temperatures of impurity ions by charge exchange spectroscopy (Li-CXS) [3,4]. In order to achieve simultaneous Li-IXS and Li-CXS measurements, both existing IPP setups for electron density measurements have been extended. First results prove the feasibility of Li-CXS in W7-AS plasmas.

In order to check the modelling of the lithium beam we have also investigated the population of higher LiI energy levels.

Experimental setup on W7-AS

The existing lithium beam diagnostic on the stellarator W7-AS has been extended by a 14 channel CXS observation system. Two achromats ($\Omega/4\pi \approx 2.9\text{x}10^{-4}$sr) are used to image the light onto 14 bundles of quartz fibers, each bundle consisting of 8 single fibers (400μm). The detection region covers a radial range of about 13cm from the plasma center to the last closed flux surface of standard plasma configurations. For these investigations the bundles are coupled one by one to the entrance slit of a monochromator (ACTON, Czerny-Turner, f=0.75m). A two-dimensional detector (Proscan CCD camera, 512x512 pixels, each 19x19μm^2) is directly connected to the monochromator exit. The spectral resolution is up to 0.018nm/pixel using a 1800g/mm holographic grating. An additional system of photomultipliers equipped with interference filters (λ=529.0nm) has been introduced, which can be coupled to the same light guides for simultaneous measurements at 14 radial locations. We used the improved extraction geometry of the ion source [1,2] to inject a beam ($I_{Li}\leq$3mA) in the energy range of 20-66keV.

Experimental setup on ASDEX Upgrade

On the ASDEX Upgrade tokamak the lithium beam diagnostic has a new location 33cm above midplane. It is equipped with a completely rebuilt 35 channel electron density optics, a 16 channel charge exchange optics and a 3 channel neutral density monitoring system (fig. 1). At the new position of the ion gun, which is similar to the one on W7-AS, the magnetic field is weaker. There is also additional μ-metal shielding around the ion beam. Thus, we expect magnetic field effects on the lithium beam (E=35keV, I=1.2mA) to be reduced considerably.

Electron density measurement setup

In the former optical system each spatial channel consisted of three 400μm fibers. The light collection/transmission efficiency varied drastically from fiber to fiber and the system was sensitive to the beam position [5]. To overcome these difficulties, a new head for the fiberguides was built with each spatial channel corresponding to a bundle of 35 quartz fibers (100/130μm). The light from each bundle is coupled to a 48m long, 600μm monofiber (N.A.=0.37) that carries the light to the detection units. About seven percent of the incoming light can be detected this way. A new BK7 optical system -a wedge and two lenses- was built to gather light into 35 channels from about 16cm along the beam path. The observation region can be radially shifted by a couple of centimeters, allowing it to be adjusted to different plasma scenarios. Each detection unit is equipped with an interference filter (T>40%, FWHM≤0.7nm) followed by a photomultiplier. We expect 5 to 10 times more signal with the new detection system which will permit increased temporal resolution and investigations of density fluctuations outside the separatrix.

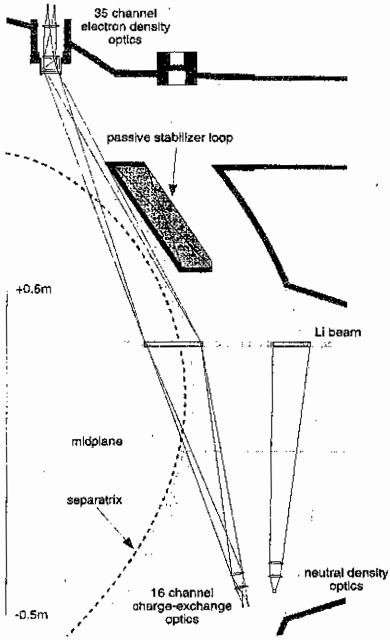

Fig. 1: Optical observation systems of extended lithium beam diagnostics on ASDEX Upgrade.

CXS measurement setup

Two quartz lenses ($\Omega/4\pi \approx 1.5\text{x}10^{-3}$sr) focus the light onto an array of 16 quartz fibers (400μm) enabling the radial distribution of the emitted light in a 16cm region around the separatrix to be measured with 1cm spatial resolution. The fibers are coupled to the entrance slit of the same CXS spectroscopic system as described for W7-AS. Temporal resolution is limited by the readout time of the CCD detector for 16 channels (13 ms).

Neutral density measurement setup

Two BK7 lenses ($\Omega/4\pi \approx 1.8\text{x}10^{-3}$sr) focus the light onto an array of 21 quartz fibers (400μm) that are grouped into three bundles. The light is gathered from a region far from the separatrix where lithium excitation by collision with neutrals is the dominant process [2]. Each channel is equipped with an interference filter (T>40%, FWHM≤0.7nm) to select the Li(2p→2s) line.

Results

Lithium beam composition

Because of highly different cross sections for charge exchange processes, depending on the excitation state of the donor atom, the composition of the lithium beam is an important parameter for evaluating CXS data. We have therefore investigated several LiI spectral lines (2p→2s, 3d→2p, 4s→2p, 4d→2p) in W7-AS discharges. While the measurements of the most relevant line Li(2p→2s) at λ=670.8 nm were performed for calibrating the CXS setup relatively to the Li-IXS photomultiplier setup, all other LiI lines were investigated to check the attenuation model of the lithium beam [6]. Measured intensities of emission from higher levels were found to differ considerably (30-60%) from corresponding theoretical values. We observed no dependence on magnetic field strength and beam energy, whereas changing plasma densities had strong effects on the conformity of experimental and theoretical values with the deviation becoming larger at higher densities.

Inadequate scaling relations for excitation and ionization processes involving protons and impurity ions in the underlying database [7] have been identified as the major reason for these disagreements. These are now being recalculated by more advanced means. First results for the Li(3l→2l) transitions show a significant decrease of theoretical values of Li(3d)/Li(2p) ratios (fig.2) when using the improved cross section data. However, since the relative population of the Li(3d) level in the lithium beam is in the range of 1% only, with populations of all other Li(nl) levels (n>2) even smaller, the influences on electron density calculations remain below 10%.

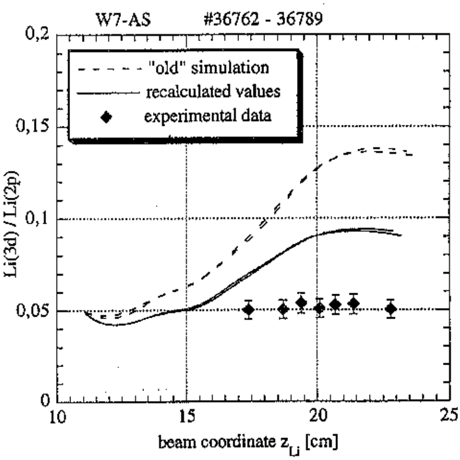

Fig.2: Population ratios of the Li(3d) and Li(2p) energy levels. Comparison of experimental data and beam simulation results for a series of similar W7-AS discharges. Plasma center at z_{Li}≈26cm.

Furthermore, recent simulations have suggested that the population of higher excited states depends on Z_{eff}. Thus, the measurement of only one additional line besides the resonance line offers a possibility to determine an estimate for Z_{eff} -under the assumption of a reasonable radial charge state distribution of the impurities and if the present disagreement for n=3 populations between simulation and experiment further diminishes as a consequence of more accurate cross sections.

CXS investigations

Measurements of spectral lines of impurity ions have proven the feasibility of charge exchange spectroscopy on W7-AS plasmas with the extended setup. The photomultiplier system has been introduced for simultaneous measurements of C^{6+} concentrations at 14 radial locations, while the spectrometer system has been used for the determination of temperature profiles of C^{6+} ions (fig. 3).

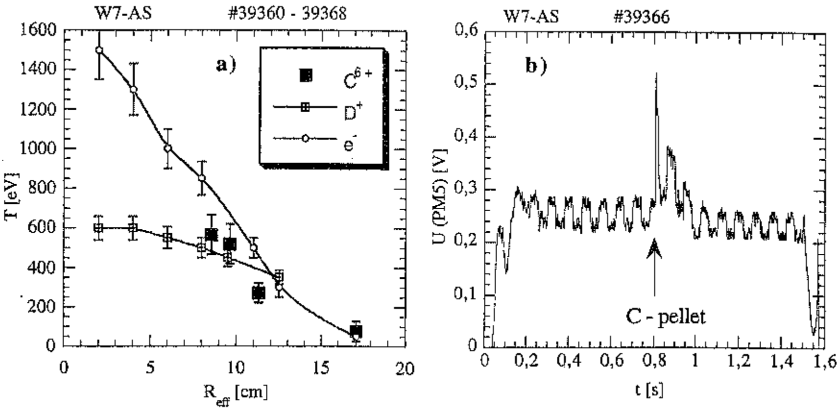

Fig. 3: a) Radial temperature profiles of C^{6+} compared to e^- [8] and D^+[9]. All data were obtained during a series of similar W7-AS discharges. b) Raw photomultiplier signals for concentration evaluation at R_{eff}=12.3cm. Injection of a carbon pellet at t=0.8s increases the charge exchange induced signal significantly. Injected lithium current I_{Li} ≈2mA at E≈48kV.

Temperature values, which were corrected for line broadening effects such as Zeeman splitting and l-level mixing [10], are similar to proton/deuteron as well as electron temperature profiles. Evaluation of impurity ion concentration values requires extension of the charge exchange cross section database, which is presently being carried out.

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