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Self-consistent modelling of supersonic He beam attenuation in the TJ-II Edge Plasmas.

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Introduction

Atomic beams represent an excellent tool for the parametric characterization of the plasma periphery in fusion devices. In particular, the use of supersonic He beams, even with average velocities in the thermal range, allows for the sampling of a significant part of the edge/SOL region due to the high ionisation potential of the injected atoms. Furthermore, the low divergence and narrow velocity distribution of this type of beams strongly simplify the interpretation of the data. In the TJ-II stellarator one of these sources has been installed and it is used as a routine diagnostic for the electron temperature and density profile reconstruction, based on the line ratio method [1]. In the present work, the validation of the collisional-radiative model required for this purpose by using the beam attenuation is described. The observed beam penetrations, which are around 4cm under most conditions, are well reproduced by the model without any major changes in the rate constant values assumed for the profile reconstruction, A critical analysis of the collisional processes involved in the beam attenuation and broadening is made, with particular attention paid to the possible effect of elastic collisions, likely dominated by the plasma peripheral molecular neutral particles.

Experimental set-up

In the actual upgraded version of the supersonic helium beam diagnostic, described in detail in [1], a repetition rate up to 200Hz can be achieved. A systematic characterization of the beam was performed [2] and its application to the TJ-IU torsatron pioneered the use of supersonic beams in hot plasma diagnostics [3]. The source consists of a fast, pulsed piezoelectric valve with a nozzle of 0.3mm diameter and a parabolic profile skimmer with a diameter of 0.5mm. For the experiments in TJ-II a nozzle-skimmer distance of 25mm was chosen defining a divergence of 1.4º. The mean beam velocity is 1300-1750m/s depending on the source pressure and the density of He atoms at the measurement region is estimated to be of the order of $10^{11}cm^{-3}$.

The three He lines used for reconstruction of the edge temperature and density profiles (667.2, 706.5 and 728.1 nm) are simultaneously detected by means of a beam-splitter system and a set of three 16-channel photomultiplier arrays with interference filters (FWHM=1nm). The complete He emission radial profile is projected into the 16 channels of the array using a single lens with vertical displacements in order to adjust the observation region to the different TJ-II plasma configurations. A typical toroidal resolution of 20 mm is given by a slit placed in front of the arrays. A radial resolution of 4 mm is chosen with a suitable object/image ratio. This corresponds to a residence time of ~3 μs of the He atoms in the observation volume, which according to the collisional-radiative model estimates enables the full local equilibration of all the relevant excited levels for values of n_e greater than $\sim 1 \cdot 10^{12}$ cm^{-3}. The spectral response of the whole system and the effect of vignetting in the extreme channels were calibrated in-situ by using the TJ-II He glow discharge cleaning. The 48 output signals from the arrays, after passing through a set of preamplifiers are sampled and recorded with a PCI extensions for instrumentation (PXI) acquisition system at a 10KHz rate.

Collisional-radiative model validation.

Uncertainties in the relevant cross sections, the lack of inclusion of all the implied plasma species and the fact that the approximation on which is based the collisional radiative (c-r) model is not fulfilled, typically make the model itself the source of the largest errors in the electron density and temperature profile reconstruction. Of particular interest for the validation of the c-r model are the supersonic He beams as it is mentioned above. Although only the line ratios are needed to obtain local values of plasma parameters, self-consistency of the c-r model can be checked through the simulation of the full propagation of the beam into the plasma.

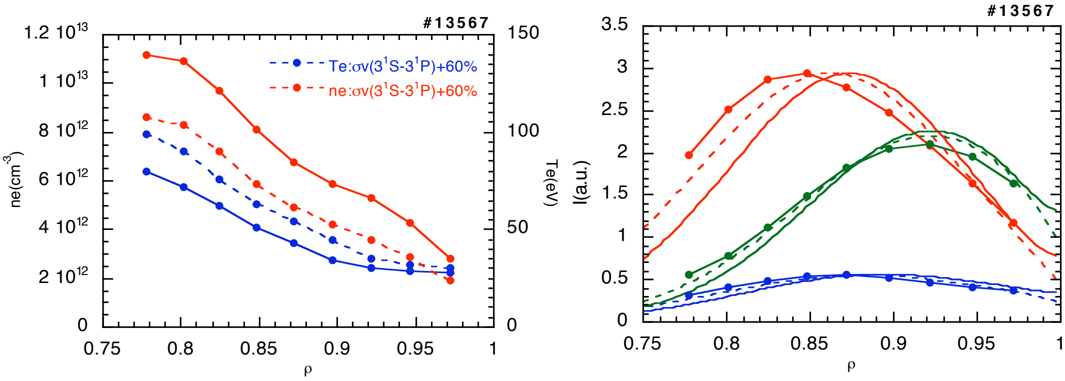

Figure 1. Density and temperature profiles obtained by the C-R model and by the same model using a 60% higher value of the 3^1S-3^1P transition rate coefficient (left). Experimental and simulated lines intensity profiles corresponding to both couple of profiles (solid and discontinuous lines respectively) on the right.

The experimental profiles for the three lines involved (16 points) are first smoothed and the electron density and temperature profiles are reconstructed by using the steady state approach of the C-R model. Then, these profiles are fed back into the simulation of the spatial profile of the emission lines taking into account the actual propagation of the beam. No lateral spreading, i.e. divergence, is considered in the model. As shown the example on figure 1 a fair agreement between the experimental and reconstructed profiles exist. The rates constants used in our C-R model are those recommended by Brix [4], but the Johnson and Hinnov value [5] for the transitions between levels having the same principal quantum number was used instead. A study on the sensitivity of the population calculations to typical uncertainties in the electron impact excitation rate coefficients has been developed by Andrew and O'Mullane [6]. Examples of the effect of such modifications in the reconstructed profiles are also shown in figure 1. For instance, an increase of 60% in the value of the 3^1S-3^1P rate coefficient leads only to an slight improvement of the fitting between the experimental and simulated lines. However, this change leads to reconstructed density and temperature profiles significantly different and a worse agreement with the complimentary diagnostics as the Li beam and Thomson Scattering.

As mentioned above, the lack of inclusion of other collisional processes can also become an important source of errors. We have performed a study about the way that some of these processes affect in the electronic density and temperature profiles reconstruction and in the beam penetration simulation. For the conditions of ECRH plasmas, which include low ion temperatures and relatively low densities, we conclude that none of the analysed processes (proton impact excitation and ionisation, charge exchange) needs to be taken into account in the C-R model.

Moreover, the possible contribution of non-thermal electrons to the excitation lines has been checked. If suprathermals are not taken into account the electron temperature would be overestimated, but again this effect seems to be negligible.

In spite of the fact that the approximation of the model C-R is not fulfilled in the points of measurement corresponding to densities $\leq 1 \cdot 10^{12} cm^{-3}$, it must be noted that the effective ionisation rate constant for typical edge densities in TJ-II is basically insensitive to these finer details of the model. Only the emission of the 706 line depends on them, and we have developed a method to correct the temperature values.

Helium beam width in presence of plasma

Experimental observations show a beam width which is systematically higher than expected from geometrical considerations, at least in the presence of plasma (see figure 2). Although this effect has no significant influence on the beam attenuation simulation, its presence could be a proof of some collisional processes not included in the model. Thus, this beam widening might be explained by considering the elastic scattering of He atoms due to H_2 peripheral molecules. Although this effect has not yet been experimentally observed, the attenuation of the He beam signal with the molecular H_2 density (associated to the peripheral Hα emission) has been deduced (see figure 3). This opens the possibility to a new neutral density diagnostic, and comparative studies with the TJ-II fast manometer are presently underway.

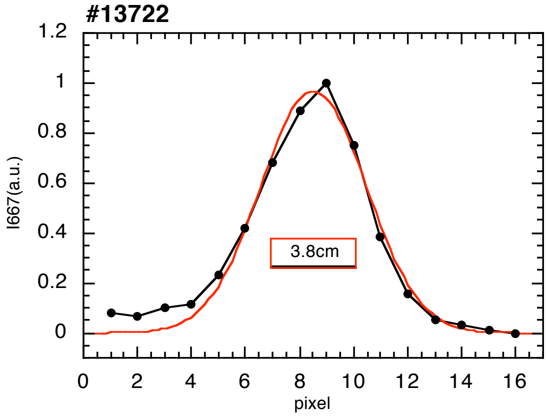

Figure 2. The recorded toroidal profile of 667nm line (11.2cm span) shows a beam FWHM when it propagates into the plasma. This is ~2x the beam width in vacuum.

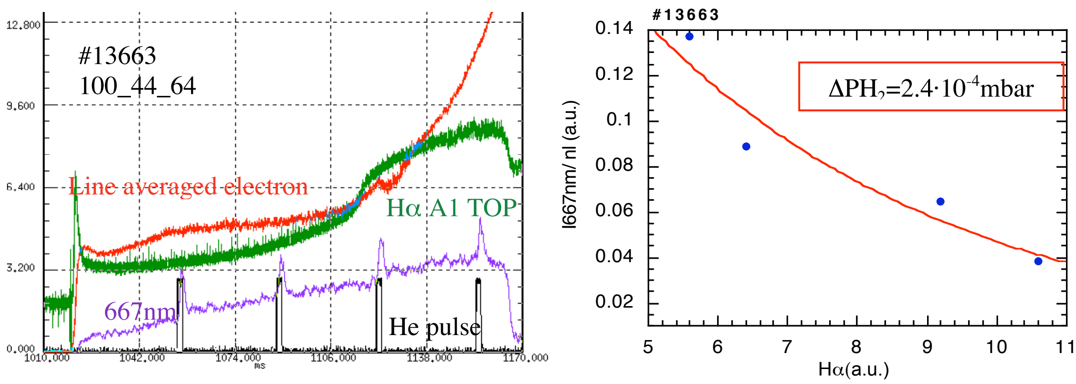

Figure 3 Attenuation of the He beam with the molecular neutral density.

Acknowledgments

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