LIF MEASUREMENTS ON AN ATOMIC HELIUM BEAM IN THE EDGE OF A FUSION PLASMA

MACIEJ KRYCHOWIAK[1)], PH. MERTENS[2)], B. SCHWEER[2)], S. BREZINSEK[2)], R. KÖNIG[1)], O. SCHMITZ[2)], M. BRIX[3)], T. KLINGER[1)] AND U. SAMM[2)]

[1)] *Max-Planck-Institut für Plasmaphysik, EURATOM-Association, Greifswald, Germany*

[2)] *Institut für Plasmaphysik, FZ Jülich, EURATOM-Association, TEC, Jülich, Germany*

[3)] *UKEA, JET- Experimental Department, EURATOM-Association, Culham Science Centre, ABINGDON, Oxfordshire, OX14 3DB, U.K.*

1. INTRODUCTION

A method for diagnosing the edge region of high-temperature plasmas is the use of line radiation from atomic helium puffed radially into the plasma [1]. Intensity ratios of selected line pairs provide information about the electron density and temperature. In order to derive the plasma parameters from intensity ratios a comparison with a collisional-radiative (cr) model calculation of the population densities of corresponding levels is required. Therefore, the accuracy of the model based to a large extent on collisional rate coefficients for excitation and ionisation, often known only from calculations, is crucial for a reliable data analysis. The LIF spectroscopy can be used to validate some model predictions for the level populations. Both metastable levels $2^{1,3}$S as well as the $2^{1,3}$P^o states are in principle accessible with this method and the results of such measurements are presented in the paper. They were performed on the tokamak TEXTOR at the Forschungszentrum Jülich in Germany where an appropriate LIF set-up has been prepared allowing measurements in the plasma edge [2].

2. ABSOLUTE POPULATIONS OF THE LEVELS 2^3S AND 2^3P^o

Interaction of helium atoms with the surrounding plasma results in establishing a certain population distribution among excited levels relative to the ground state depending on the plasma parameters. For the theoretical prediction of the relative level populations cr models are used. The populations of non-radiating levels such as the metastables can be validated experimentally by resonant laser excitation of the levels. Detecting the maximum fluorescence light intensity during a laser pulse by using an absolutely calibrated observation system provides the absolute population density of the excited level. The knowledge of the number of ground state atoms in the observation volume allows the determination of relative populations which can be compared with model predictions. However, the derivation of the absolute population of a level from the fluorescence light is in our case not straightforward. This is because of the narrow spectral width of the laser light and complicated the Zeeman structure of the excited transitions due to the magnetic field in the plasma [2]. On the other hand, the number of ground state atoms in the observation volume is difficult to access due to the beam divergence and attenuation in the course of the plasma penetration. The latter effect can be modelled theoretically by considering beam particle losses due to ionisation processes. However, we quantify both effects experimentally by means of camera pictures of the beam emission because of an earlier observation of lower beam penetration depth than resulting from the model calculation [3].

In Figure 1 the results of relative population densities calculated by the cr model and measured at TEXTOR of two triplet levels 2^3S and 2^3P^o are summarised. In the model electron excitation cross sections between the levels of the shells $n = 1 - 4$ recommended by Ralchenko et. al. [4] are used. Levels of the $n = 5$ shell are also included by use of an electron excitation data set compiled by Brix [3]. Electron impact ionisation cross sections from the ground state and both metastables recommended by Kato & Janev [5] and from other excited states based on semi-empirical formulas by Fujimoto [6] are used. Non steady state population distributions due to the beam penetration into the plasma are allowed for in the model calculation. Other effects such as excitation collisions with background plasma ions, impurity ions and helium atoms themselves, recombination, wave function mixing due to the break down of the LS coupling scheme, radiation trapping and photoionisation by the strong laser radiation play no considerable role for the measurements shown in this paper and are neglected.

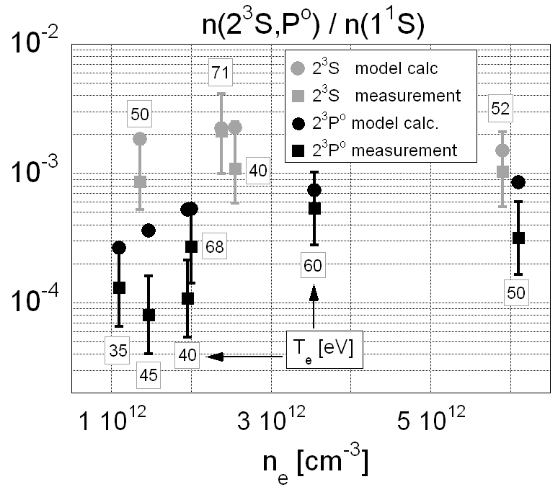

FIGURE 1. Calculated and measured relative populations of the levels 2^3S and 2^3P^o.

The measurements were obtained by exciting helium atoms from the mentioned levels to levels of the $n = 3$ shell, 3^3P^o ($\lambda = 388.9\,\mathrm{nm}$) and 3^3D ($\lambda = 587.6\,\mathrm{nm}$), respectively. The measurement points were obtained from signals recorded at two different radial observation positions (at the minor plasma radius $r = 47$ and $r = 45.5$ cm) during several discharges. The overall measurement accuracy roughly amounts to a factor of two. This is mainly a consequence of the uncertainties in the absolute calibration of the observation system, the errors in the derivation of the number of observed helium atoms from the camera pictures and the calibration of the gas flow through the nozzle, uncertainties in the plasma parameters at the observation points, uncertainties on the laser spectral width and the strong scattered laser light intensity.

The measured populations of the triplet metastable level 2^3S lie below the model prediction, in the range of 0.5-0.95 of that and within the error bars. A similar result of 0.4-0.7 of the model prediction is obtained for the population density of the level 2^3P^o apart from two measurement points at $n_\mathrm{e} = 1.47 \times 10^{12}\,\mathrm{cm}^{-3}$ and $n_\mathrm{e} = 1.96 \times 10^{12}\,\mathrm{cm}^{-3}$ for which the measured population is five times smaller than the model prediction. The deviations of these two measurement points is not understood yet. They seem also not reasonable in view of one other measurement at a very similar density of $n_\mathrm{e} = 2 \times 10^{12}\,\mathrm{cm}^{-3}$ delivering a higher 2^3P^o population by a factor of 2.5 compared to a measurement at $n_e = 1.96 \times 10^{12}\,\mathrm{cm}^{-3}$. The measurement point at $n_e = 3.55 \times 10^{12}\,\mathrm{cm}^{-3}$, providing a population of this level lying only 30% below the model prediction originates from the same discharge as one of the measurement points in question (at $n_e = 1.47 \times 10^{12}\,\mathrm{cm}^{-3}$) – they were obtained by simultaneous light detection at the two mentioned radial observation positions (the same is true for the measurement points at $n_e = 1.96 \times 10^{12}\,\mathrm{cm}^{-3}$ and $n_e = 6.1 \times 10^{12}\,\mathrm{cm}^{-3}$). Thus, the remarkably low measured population at $n_e = 1.47 \times 10^{12}\,\mathrm{cm}^{-3}$ cannot be explained e.g. by a failure of the gas injection, of the laser or of the observation system which would rather affect measurements at both radial points in the same manner. The only explanation which could hold are imprecise values of the electron densities at the observation points (this could arise due to inaccuracy of the horizontal plasma shift derived from the magnetohydrodynamic equilibrium calculation or due to some errors in the n_e derivation with the helium beam diagnostic). A change of the value of n_e affects the calculated population of triplet levels stronger in the case of our observation point at the radial position of $r = 47\,\mathrm{cm}$ than of the one at $r = 45.5\,\mathrm{cm}$ because of the lack of beam relaxation at the outer observation channel. A method to avoid the uncertainty connected to the mapping of the radial positions could be a simultaneous n_e and T_e derivation from helium line intensity ratios by using the line emission of our helium beam at the same radial positions as used for the LIF measurements.

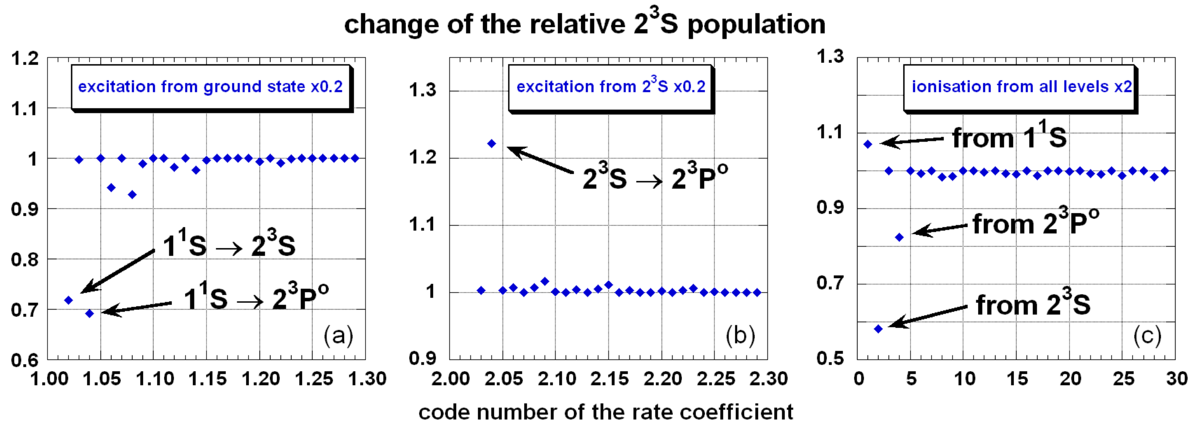

FIGURE 2. Calculated population changes of the level 2^3S induced by (a-b): separate doubling of rate coefficients for electron excitation from the ground state and the metastable level 2^3S by the factor of five, (c): separate enhancing the ionisation rate coefficients from all levels. The rate coefficients are coded with the number – in ascending order of the level energy – of the corresponding levels. The calculation is done for $n_e = 2 \times 10^{12}\,\mathrm{cm}^{-3}$ and $T_e = 50\,\mathrm{eV}$.

In Figure 2 it is shown how the model prediction of the relative population of the level 2^3S changes upon separate variation of some excitation and ionisation rate coefficients. In plot (a) the effect of lowering the excitation from the ground state by a factor of five is shown. Only the excitation to the levels 2^3S and 2^3P^o causes a considerable 2^3S population drop by $\sim 30\%$. Among the excitation from all other (excited) levels we find only one rate coefficient $\langle \sigma v \rangle_{2^3\mathrm{S} \rightarrow 2^3\mathrm{P}^o}$ which changes (enhances in this case) the 2^3S population by more than 2% (shown in plot (b)). Analogue calculations for the level 2^3P^o provide very similar results except for the lowering of the rate coefficient $\langle\sigma v\rangle_{2^3\mathrm{S}\rightarrow 2^3\mathrm{P^o}}$ which, of course, has the opposite effect (drop of population) since in this case the population is just shifted from the level 2^3P^o to the metastable level. By changing this rate coefficient no simultaneous population drop in both levels can be achieved which would be consistent with the measurement. Hence, only a decrease of the excitation rate coefficients from the ground state to both considered levels can result in a significant drop of the calculated population of these levels (quantitatively similar results were obtained for the density of $n_\mathrm{e} = 6\times 10^{12}\,\mathrm{cm}^{-3}$). The factor five by which the rate coefficients were lowered was chosen such as to decrease the calculated populations by up to $\sim 50\%$ which follows from the measurements. However, the available excitation data from the ground state, based on calculations and measurements, are believed to have a much higher accuracy of $\sim 30\%$ [4] and the lowering of the rate coefficients in the model by a factor of five does not seem reasonable.

Another possibility to reduce the model prediction of the populations of the two measured levels is an increase of the loss rate of the beam atoms from these levels, e.g. due to enhanced ionisation. The calculated influence of the enhancement of all ionisation rate coefficients one by one by a factor of two on the relative population of the level 2^3S is presented in Figure 2 (c). The population decreases by around 40% upon the change of the rate coefficient from the level 2^3S and of 20% in the case of the rate coefficient from the level 2^3P^o (the population of the level 2^3P^o is affected in a similar way). Changing any other rate coefficient does not entail a significant population decrease. Simultaneous doubling of both mentioned rate coefficients results in a population drop of both levels 2^3S and 2^3P^o by 50% and hence is equivalent to the average deviation between the measured populations and those calculated with our standard model (Figure 1). Owing to the overall discrepancies between calculated ionisation rate coefficients from excited levels (see e.g. the discussion in [5]) and owing to the lack of corresponding measurements the assumption of enhanced ionisation from the level 2^3P^o could be justified. In contrast, the rate coefficient for the ionisation from the triplet metastable level used in our model is based on measurements by different authors providing the same results in the overlapping energy range. However, enhanced loss rates of excited atoms in the beam could also be caused by charge exchange collisions with the background plasma ions, which are a current subject of investigation [7].

REFERENCES

[1] B. Schweer et. al., J. of Nucl. Mater. **196-198** (1992) 174-178.

[2] M. Krychowiak et. al., Proc. 33rd EPS Conf. on Plasma Physics (Roma) **30I** (2006) P-2.125.

[3] M. Brix, Messung von Elektronentemperatur und -dichte mittels Heliumstrahldiagnostik im Randschichtplasma eines Tokamaks, Jülicher Report Jül-3638

[4] Yu.V. Ralchenko et. al., Rep. NIFS-DATA-59, NIFS, Nagoya (2000).

[5] T. Kato and R.K. Janev, in: Atomic and Plasma-Material Interaction Data for Fusion, R.K. Janev, **Vol. 3**, IAEA, Vienna (1992).

[6] T. Fujimoto, Semi-empirical cross-sections and rate coefficients for excitation and ionization by electron collisions and photoionization of helium, IPPJAM-8, Institute of Plasma Physics, Nagoya, Japan (1978).

[7] M. Brix, private communication.(1998).