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Tungsten Spectroscopy for the Measurement of W-Fluxes from Plasma Facing Components

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Introduction

Tungsten is foreseen for the full divertor of JET and also ITER operation is planned to be carried out with tungsten as one of the first wall materials. Therefore, high-Z materials moved into the scope of plasma surface engineers because of their high melting temperature, short penetration depths and high redeposition probabilities. Moreover, since it was discovered that carbon (from carbon based PFCs) buries high amounts of tritium simultaneously with its redeposition [1], the use of high-Z materials could be a solution for these problems. For the characterization of the accompanying plasma surface interaction a thorough diagnostic of the W influx into the plasma and the W content in the plasma is of utmost importance. These quantities are generally determined spectroscopically, however, theoretical data are scarce or even missing. Thus, a comprehensive effort has been started at the tokamak TEXTOR to compare experimental spectroscopic results with those from model calculations in order to provide reliable data for the determination of tungsten particle fluxes from emission lines. At the moment, a W I transition ($5d^5 6s\ ^7S_3 – 5d^5 6p\ ^7P_4$) at 4008 Å is used for this purpose, but an extension of the method to other lines with (preferably longer) wavelengths is highly desirable, especially because the wavelength of this line does not allow a long transfer via optical fibres. This has experimentally been carried out and accompanied by calculations.

Experiment and theoretical background

The experiments have been performed in the tokamak TEXTOR (R=1.75m and r_a=0.46m) The two discharges #98035 and #100133 used for the measurements are characterized by the following data: #98035 (#100133): I_p=355kA, B_{tor}= 1.71(2.25)T, P_{NBI}=2.66(1.57)MW, $\bar{n}_e(0)=2.5\times10^{19}$ $(5\times10^{19})m^{-3}$, $n_e[47cm] = 6\times10^{18}$ $(1.4\times10^{19})m^{-3}$, T_e[47cm]= 70(48)eV. Later we will refer to them as exp1 and exp4 respectively. The lines emitted from tungsten atoms which were released from tungsten plates and limiters in the TEXTOR edge plasma were observed with a CCD camera equipped with interference filters with a bandwidth of 15 Å for the respective impurity line, an image intensified CCD spectrometer and different spectrometers within the wavelength range 2200 Å – 7000 Å to study both their intensity distributions and their Zeeman pattern in order to identify possible influences of nearby interfering plasma lines. The spectrometers were calibrated with an integrating sphere in the visible and with a deuterium lamp in the UV spectral region.

The lines considered and their characteristics are given in the table 1.

λ / A	*E / cm^{-1}*		*g_L*		*Transition*		*A / s^{-1}*	*br*
	low	*Up*	*low*	*Up*	*Low*	*Up*		*%*
2551.35	0.00	39183.20	0.0	1.00	a_$^5D_0$	x_J=1	1.8e+8	86
2681.42	2951.29	40233.97	1.98	1.50	b_$^7S_3$	x_J=4	7.4e+7	86
4008.75	2951.29	27889.68	1.98	1.70	b_$^7S_3$	d_$^7P_4$	1.6e+7	99
4294.61	2951.29	26229.77	1.98	1.84	b_$^7S_3$	d_$^7P_2$	1.2e+7	94
4886.90	6219.33	26676.48	1.50	1.46	a_$^5D_4$	c_$^7F_5$	8.1e+5	100
4982.59	0.00	20064.30	0.0	1.54	a_$^5D_0$	c_$^7F_1$	4.2e+5	79
5053.28	1670.29	21453.90	1.51	2.51	a_$^5D_1$	c_$^7D_1$	1.9e+6	52

Table 1: *Designations: a=5d^4(^{5}D)6s^2, b=5d5(^{6}S)6s, c=5d^4(^{5}D)6s6p, d= 5d5(^{6}S)6p, x means unidentified, g_L is the Lande factor, br is the branching ratio.*

All data are from the NIST database [2]. For the modelling of the line intensities the ionization cross-sections were calculated by the code ATOM [3] in the Born and Born-Ochkur approximations. Our results for ionization of the 6s and 5d electrons from the configuration 5d^{4}6s^2 agree quite well with the ones calculated by the distorted wave method [4]. Concerning the excitation rates for many lines the experimental data for radiative transition probabilities can be found in the NIST tables. However, for most levels the identification is unknown. Therefore, the calculation of the excitation cross sections is difficult and we restricted our discussion to the dipole transitions exploiting the semiempirical van Regemorter formula [5].

k_0:	1	2	3	4	5	6
Config.	5d^4(^{5}D)6s^2					5d^5(^{6}S)6s
Level	$^5D_0$	$^5D_1$	$^5D_2$	$^5D_3$	$^5D_4$	$^7S_3$
E / cm^{-1}	0.00	1670.29	3325.53	4830.00	6219.33	2951.29

Table 2. *List of the "ground" levels.*

The coronal approximation was used with excitation from the group of the "ground" levels 5d^4(^{5}D)6s^2 ^5D_J and 5d^5(^{6}S)6s $^7S_3$ only (table 2) as kinetic model for the population of the levels. From these rates one can calculate the so-called S/XB value (ionization rate / (excitation rate $\times$ br), which then in the case of an ionizing plasma (ionizations $\propto$ number of particles) connects the measured photon flux from a line to a particle flux (see e.g.[6]). It was assumed that the population of the ground levels is described by the Boltzmann formula with a virtual temperature T_W. The real distribution is not known and here T_W was considered as free parameter (independent of T_e). The calculated values of S/XB for a set of T_W and T_e are

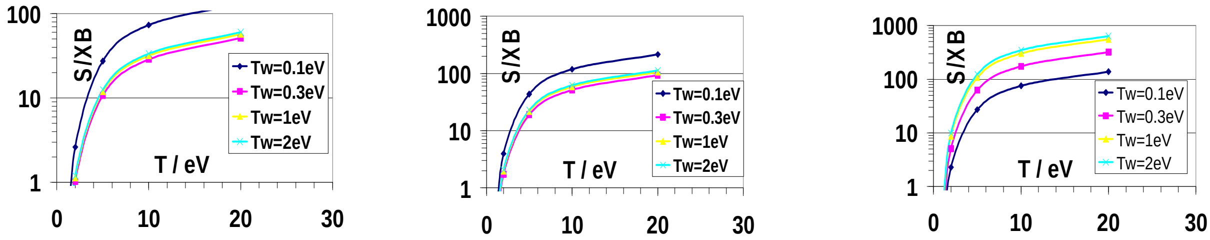

Fig.1: *S/XB for 4008.75 Å*   *for 4294.61 Å*   *for 5053.28 Å*

displayed in fig.1 for 3 selected lines. Values for more lines will be found in a forthcoming paper [7]. The influence of the value for T_W can be intensively studied for the 2551 Å, 5053 Å and 4982 Å lines as these are excited from the lowest configurations of the ground state ($^5D_{0,1}$) which are continuously depopulated for increasing T_W.

Comparison with experimental data

In fig.2 the Zeeman splitting and the line shapes are shown for 2 lines. The angle between the magnetic field (B=2.3T) and the line of sight was assumed to be 90^0 according to the experimental set-up. One can see that observed and calculated shapes are in good agreement. The two lines illustrate different cases: 1) unresolved shape with one central maximum, 2) two-maxima with a gap in the centre of line and an absence of the central component. Fig.3 displays the S/XB values (for T_W=0.3eV) for the most frequently used line at 4008.75 Å together with all experimental data published so far. The calculations fit surprisingly well. Some slight deviations at low and indicate some unknown population mechanisms.

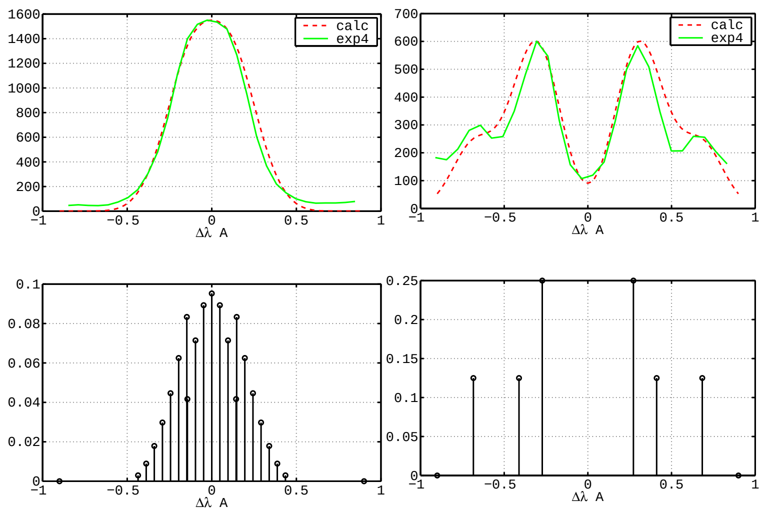

Fig.2: *Splitting for 4008.75 Å*   *5053.28 Å*

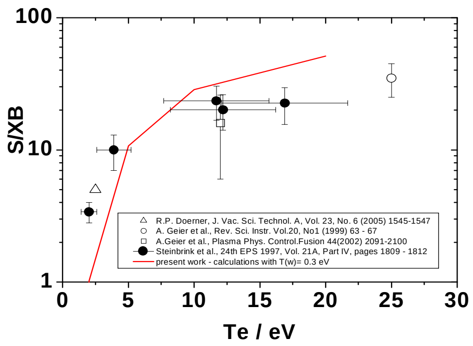

Fig.3: *Calc. & exp. S/XB for 4008.75 Å*

The influences of the plasma (T_e) and the population of the ground state (T_W) on the different line ratios can be seen in fig. 4. The I(2681)/I(4008) intensity ratio is independent of T_W (excitation from the same ground level $^7S_3$) whereas I(2681)/I(2551) is nearly independent of T_e (similar upper levels). From the experimental values one can deduce $T_W \approx$ 0.2-0.3eV and $T_e \approx$1 eV. Whereas the value for T_W seems reasonable, T_e is much different from the plasma data measured at this radial position (see above). These values seem to become additionally confirmed when one plots the measured inverse line intensities versus the calculated S/XB values (fig.5). Because of Γ_{part}=S/XB $\times$ Φ_{photon} (see above) the data should show a linear dependence. Fig.5, which also includes some rough estimates for cascading from higher levels into the upper line levels, displays the best result for T_W = 0.3 eV and T_e = 1 eV.

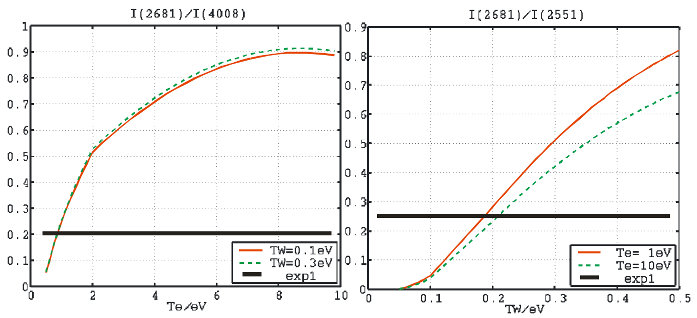

Fig.4:*Line intensity ratios with different dependencies*

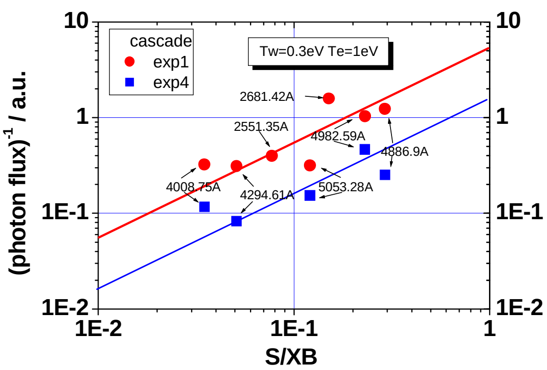

Fig.5: *Measured versus calculated values*

Conclusions

The results are not always consistent with the experimental data. Especially the reason for the low T_e which had to be assumed is unknown. The agreement for the 4008 Å line is quite good for all experiments and the calculations so far. For wavelengths longer than 4000 Å only 4294 Å and 5053 Å can be recommended. Measurements are presently performed in order to study in more detail the influences of T_W, T_e and cascading.

References

[1] J.P. Coad, N. Bekris, J.D. Elder, S.K. Erents, D.E. Hole, K.D. Lawson, G.F. Matthews, R.-D. Penzhorn and P.C. Stangeby, J.Nucl.Mater. **290-293** (2001) 224

[2] NIST Atomic Spectra Database, ver. 3.0.3, http://physics.nist.gov/PhysRefData/ASD/index.html

[3] V.P. Shevelko and L.A. Vainshtein, 1993, Atomic Physics for Hot Plasmas (Bristol: IOP Publishing)

[4] M.S. Pindzola, D.C. Griffin, 1992 Phys. Rev. **A 46** 2486

[5] H.van Regemorter, Astrophys. J. **136** (1962) 906

[6] A. Pospieszczyk, *Diagnostics of Edge Plasmas by Optical Methods,* in Atomic and Plasma-Material Interaction Processes in Controlled Thermonuclear Fusion, R.K. Janev and H.W. Drawin *edd.*, Elsevier (1993) 213-242

[7] I.Beigman, A.Pospieszczyk, G.Sergienko, I.Yu.Tolstikhina, L.Vainshtein, submitted to Plasma Physics and Controlled Fusion (2007)