Publ. Astron. Obs. Belgrade No. 75 (2003), 93 - 96 *Poster*

TRANSITION PROBABILITIES IN Kr III SPECTRUM, OF INTEREST FOR HIGH RESOLUTION STELLAR SPECTRA ANALYSIS

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Abstract. Using the relative line intensity ratio (RLIR) method, transition probability values of the spontaneous emission (Einstein's A values) of 7 transitions in the doubly ionized krypton (Kr III) spectra have been obtained relatively to the reference A value related to the 324.569 nm Kr III, most intensive transition in the Kr III spectra. Our Kr III transition probability values are the first data for this ion obtained experimentally using the RLIR method. Values have been calculated also using the Coulomb approximation (CA) method taking into account new atomic data for Kr III energy levels.

1. INTRODUCTION

On the basis of the recent investigation of the Planetary Nebulae spectra (Dinerstein 2001) it was found that krypton is one of the most abundant elements in the universe with Z > 32. Krypton has been detected also in the spectra of the interstellar medium (Cardelli & Meyer 1997). Moreover, krypton is present in many light sources and lasers as the working gas. Thus, doubly ionized (Kr III) krypton spectral lines are of interest for plasma diagnostical purposes. For the modelling or diagnostics of cosmic and laboratory plasmas it is useful to know the transition probability values (Einstein's A values) for considered transitions (Zeippen 1995).

The aim of this work is to present 7 Kr III A values obtained on the basis of the precisely measured spectral line intensities using the step–by–step technique for the line profile recording (Milosavljević et al. 2000) and deconvolution procedure (Milosavljević & Poparić 2001) which allows accurate measurements of the line intensities. The well–known relative line intensity ratio (RLIR) method used for A values determination has been already applied by us in the cases of the Ar III , Ar IV, O II, Ne II, N III, N IV, N V and Si III spectra (Djeniže & Bukvić 2001, Srećković et al. 2002, Djeniže et al. 2002abc). We also calculated Kr III A values on the basis of the Coulomb approximation (CA) method (Bates & Damgaard 1949) taking into account atomic data in doubly ionized krypton spectra (Sugar & Musgrove 1991).

The experimental A^{exp} values are obtained relatively to the reference A value related to the 324.569 nm Kr III line. Our Kr III transition probability values are the first data for this ion obtained experimentally using the RLIR method. Experimental and calculated A values have been compared only to the transition probabilities from references which contain A data corresponding to our chosen reference Kr III transition.

2. EXPERIMENT

The modified version of the linear low pressure pulsed arc (Milosavljević et al. 2000, Djeniže & Bukvić 2001, Djeniže et al. 2002abc) has been used as an optically thin plasma source. A pulsed discharge was driven in a quartz discharge tube of 5 mm inner diameter and plasma length of 7.2 cm. The tube has end-on quartz window. Experimental set-up system, line profile recording technique and plasma diagnostical procedures are described in Milosavljević et al. (2000) and in Djeniže et al. (2003).

One can notice that the investigated spectral lines are well isolated while the continuum is very close to zero within the wavelengths range of interest. These facts are important for an accurate determination of the total line intensities and correspondingly, for a reliable determination of A values.

3. TRANSITION PROBABILITY MEASUREMENTS

In the case when plasma remains LTE the well–known formula

$$(I_1/I_2)_{EXP} = (A_1 g_1 \lambda_2 / A_2 g_2 \lambda_1) exp(\Delta E_{21}/kT) \tag{1}$$

can be used for a comparison between measured relative line intensity ratios and corresponding calculated values, taking into account the validity of the Boltzmann distribution for the population of excited levels in emitters. In this expression I denotes the measured relative intensity, λ the wavelength of the transition, A the transition probability of the spontaneous emission, E the excitation energy from the ground energy level, and g the corresponding statistical weight. T is the electron temperature of the plasma in LTE and k is the Boltzmann constant. On the basis of the measured relative line intensity ratio and determined electron temperature the Eq. (1) affords possibility to obtain ratio of the corresponding transition probabilities or possibility of the determination of particular transition probability value relatively to the selected reference A value. As reference A values the transition probability corresponding to the 324.569 nm Kr III transition have been chosen. Namely, this line is the most intense and has the highest reproducibility among the investigated Kr III spectral lines. Our experimental relative A values (A_{exp}^{rel}) are presented in Table 1 with estimated accuracies which contain the uncertainties of the line intensity and electron temperature determinations and the uncertainties of the calibration procedure. A_{exp}^{rel} represent averaged values obtained during plasma decay in time interval for which the criterion of the existence of the LTE is fulfilled. Our A_{exp}^{rel} values provide possibility for future comparison with absolute as well as with data presented in relative form.

Table 1: Our relative (dimensionless) experimental (A^{rel}_{exp}) and theoretical (A^{rel}_{Th}) transition probability values in the Kr III spectrum and those of other authors: A^{rel}_{F}, (Fink et al. 1970); A^{rel}_{KPA}, (Kernahan et al. 1987) and A^{rel}_{R}, (Raineri et al. 1998). A_{Th} (in 10^8 s^{-1}) represent our calculated values using the Coulomb approximation (CA) method. Wavelengths, transitions and upper-level energies (E_u in eV), are taken from NIST (2002) and Striganov & Sventickij (1966). Data in brackets denote absolute transition probability values of the 324.569 nm Kr III reference transition.

Transition	λ (nm)	E_u	A^{rel}_{exp}	A^{rel}_{Th}	A_{Th}	A^{rel}_{F}	A^{rel}_{KPA}	A^{rel}_{R}
5s $^5S^o_2$ - 5p $^5P_1$	335.193	21.76	$0.94 \pm 6\%$	0.91	1.99	0.86	1.11	0.89
5s $^5S^o_2$ - 5p $^5P_2$	332.575	21.79	$0.98 \pm 6\%$	0.93	2.03	0.90	1.02	0.89
				(2.19)		(1.59)	(3.33)	(2.80)
5s $^5S^o_2$ - 5p $^5P_3$	324.569	21.88	$1.00 \pm 3\%$	1.00	2.19	1.00	1.00	1.00
5s $^3S^o_1$ - 5p $^3P_2$	350.742	22.32	$1.22 \pm 9\%$	0.86	1.88	1.16	0.85	0.75
5s' $^3D^o_2$ - 5p' $^3D_2$	343.946	23.89	$1.68 \pm 18\%$	0.66	1.45	1.34	0.86	1.13
5s' $^3D^o_1$ - 5p' $^3F_2$	326.848	24.03	$1.59 \pm 20\%$	0.74	1.61	1.10	0.97	0.08
5s' $^3D^o_3$ - 5p' $^3F_4$	326.481	24.26	$1.60 \pm 21\%$	1.01	2.22	0.92	0.92	0.88
5s' $^3D^o_3$ - 5p' $^3P_2$	302.445	24.56	$1.02 \pm 23\%$	1.07	2.34		1.32	0.80

4. TRANSITION PROBABILITY CALCULATIONS

Due to its simplicity, the Coulomb approximation (CA) method of Bates & Damgaard (1949) and Oertel & Shomo (1968) for the calculation of the Einstein's A values (oscillator strengths) is often used in spite of the existence of more sophisticated methods. It is used particularly for complex calculations of e.g. line broadening parameters or stellar opacity. It is of interest therefore, to compare oscillator strengths calculated within Coulomb approximation, with experimental values, as well as with theoretical ones obtained by sophisticated methods. This is particularly interesting for Kr III, since many of the known terms in this spectrum are affected by configuration interactions.

The Kr III calculations of configuration mixing in Bredice et al. (1996) show that results for 5s-5p transitions are obtained with best accuracy, depending of the unknown purity of 5p levels. The purity of 5s'^{3}D^o levels is 77% for 5s'^{3}D$^o{}_1$, 66% for 5s'^{3}D$^o{}_2$, and 93% for 5s'^{3}D$^o{}_1$. The worse case is for 4d"^{3}D$^o{}_2$. The results in Bredice et al. (1996) show that this configuration is present with only 25% and that the leading configuration with 39% is 4d'^{3}D$^o{}_2$, so that authors changed even the notation of this term. Since there are no results for the composition of 5p"^{3}D$_3$ term, it is difficult to estimate the reliability of the obtained value, but it is obviously low.

5. RESULTS AND DISCUSSION

The results of experimentally and theoretically obtained A^{rel} values are given in Table 1.

First of all, it must be remarked that absolute A values, taken from various references, corresponding to our reference 324.569 nm Kr III transition lie in a wide range (1.59 - 3.33).

Acceptable agreement between our experimental and calculated relative transition probabilities (within ±15% on the average) exist only for the 5s - 5p Kr III transition (335.19 and 332.575 nm). This could suggest that the simple CA method provides, in the case of the 5s - 5p Kr III transition, A values with acceptable accuracy.

Evident disagreement between our A^{rel}_{exp} and A^{rel}_{Th} values exists in the case of the 343.946, 326.848 and 326.481 nm Kr III transitions where CA approximation provides about 2 times smaller A^{rel} values.

The best agreement was found with A^{rel}_{F} values (6 transitions within ±26% on the average).

6. CONCLUSION

On the basis of the precisely obtained spectral line intensities we have obtained 7 Kr III transition probability values relatively to the reference 324.569 nm transition. The comparison among available A^{rel} values (except extremely high or small values) and here presented data show agreement (within ±15%) for A^{rel} values corresponding to the 335.193 and 332.575 nm Kr III transitions. Thus, they can be recommended as useful atomic data with accurate A^{rel} values related to the chosen Kr III reference transition.

Acknowledgments. This work is a part of the projects "Determination of the atomic parameters on the basis of the spectral line profiles" and "Influence of collision processes on astrophysical plasma lineshapes" supported by the Ministry of Science, Technologies and Development of the Republic of Serbia.

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