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Kr II TRANSITION PROBABILITIES FOR ANALYSIS OF TRACE ELEMENT LINES IN HIGH RESOLUTION STELLAR SPECTRA

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Abstract. On the basis of the relative line intensity ratio (RLIR) method transition probability value for the spontaneous emission (Einstein's A values) of 14 transitions in the singly ionized krypton (Kr II) spectra have been obtained relatively to the reference A value related to the 435.548 nm Kr II most intensive transition in the Kr II spectra. Mentioned A values have been calculated also using the Coulomb approximation (CA) method taking into account new atomic data for Kr II energy levels.

1. INTRODUCTION

For the analysis and modelling of stellar spectra, abundances determination and stellar plasma analysis, gf values related to the transition probabilities are essential. Moreover, due to development of space born astronomical techniques and devices like Goddard High Resolution Spectrograph on the Hubble space telescope the spectral lines of trace elements like krypton, are observed and the corresponding atomic data are of increasing interest. Thus, it is of interest to know the transition probability values for the spontaneous emission (Einstein's A values).

In this work we present 14 Kr II 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 allow accurate measurements of the line intensities. The well known relative line intensity ratio (RLIR) method was used for A values determination applied already by us in a number of cases (Djeniže & Bukvić 2001, Srećković et al. 2002, Djeniže et al. 2002abc). Kr II A values have been also calculated by using the method on the basis of the Coulomb approximation (CA) taking into account new atomic data in singly ionized krypton spectra (Sugar & Musgrove 1991).

2. EXPERIMENT and RESULTS

Experimental set-up system, plasma source characteristics and diagnostical procedures are described in Milosavljević et al. (2000) and in Djeniže et al. (2003).

All Kr II lines are recorded by experimental arrangement needed for the use of the RLIR method. Total line intensity (I) corresponds to the area under the line profile

Table 1: Our relative (dimensionless) experimental (A^{rel}_{exp}) and theoretical (A^{rel}_{Th}) transition probability values in the Kr II spectrum. 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).

Transition	λ (nm)	E_u	A^{rel}_{exp}	A^{rel}_{Th}	A_{Th}
5s $^4P_{5/2}$ - 5p $^4P^o_{5/2}$	473.900	16.60	$0.83 \pm 9\%$	0.55	0.72
5s $^4P_{5/2}$ - 5p $^4P^o_{3/2}$	465.888	16.65	$0.69 \pm 9\%$	0.37	0.49
5s $^4P_{3/2}$ - 5p $^4P^o_{1/2}$	483.208	16.83	$0.89 \pm 8\%$	0.65	0.85
5s $^4P_{5/2}$ - 5p $^4D^o_{7/2}$	435.548	16.83	$1.00 \pm 3\%$	1.00	1.31
5s $^4P_{3/2}$ - 5p $^4D^o_{5/2}$	476.574	16.87	$0.78 \pm 8\%$	0.57	0.75
4d $^4D_{5/2}$ - 5p $^4D^o_{3/2}$	556.865	17.16	$0.04 \pm 12\%$		
5s $^2P_{3/2}$ - 5p $^2P^o_{1/2}$	484.661	17.24	$0.73 \pm 10\%$	0.27	0.36
5s $^2P_{3/2}$ - 5p $^2P^o_{3/2}$	461.529	17.37	$0.58 \pm 11\%$	0.79	1.04
5s $^2P_{3/2}$ - 5p $^2D^o_{5/2}$	461.917	17.37	$0.72 \pm 11\%$	0.95	1.25
5s' $^2D_{3/2}$ - 5p' $^2F^o_{5/2}$	463.388	18.48	$0.85 \pm 18\%$	0.79	1.03
5s' $^2D_{5/2}$ - 5p' $^2F^o_{7/2}$	457.721	18.56	$1.15 \pm 18\%$	0.82	1.07
5s' $^2D_{5/2}$ - 5p' $^2P^o_{3/2}$	447.501	18.62	$0.92 \pm 19\%$	0.84	1.10
5s' $^2D_{5/2}$ - 5p' $^2D^o_{5/2}$	408.833	18.88	$0.97 \pm 21\%$	1.12	1.47
5p $^4D^o_{7/2}$ - 5d $^4F_{9/2}$	378.310	20.11	$2.97 \pm 30\%$	1.69	2.22
5p $^4D^o_{5/2}$ - 5d $^4F_{7/2}$	377.809	20.15	$2.70 \pm 30\%$	1.43	1.87

(within 3%-5% accuracy).

The used procedures for transition probability measurements and calculations are described in Djeniže et al. (2003, and herewith).

Our results of experimentally and theoretically obtained A^{rel} values are given in Tables 1, 2 and 3.

3. DISCUSSION

At the beginning, it should be remarked that absolute A values, taken from various references, corresponding to our reference 435.548 nm Kr II transition lie in a wide range 1.00 - 1.64 excluding unrealistically high A (9.1 10^8 s^{-1}) value from Levcenko (1971).

Our A_{Th} values calculated on the basis of the Coulomb approximation (CA) confirm ones calculated earlier (Brandt et al. 1982) also on the basis of the CA approximation.

Acceptable agreement between our experimental and calculated relative transition probabilities (within ±15% on the average) exists only in the 5s' - 5p' transition (463.388, 457.721, 447,501 and 408.33 nm). It turns out that similar agreement exists among mentioned A^{rel}_{exp} and A^{rel}_{SG}, A^{rel}_{M} and A^{rel}_{FC} calculated values based on the various theoretical approximations. This might suggest that the simple CA method provides, in the case of the 5s' - 5p' transition, A values with acceptable accuracy.

Table 2: Relative (dimensionless) Kr II transition probability values. A_N denote tabulated values in NIST (2002) where absolute and relative values (normalized to a 435.548 nm transition) are equal. Other relative (dimensionless) experimental transition probability values are: A_K^{rel}, (Keil 1973); A_L^{rel}, (Levcenko 1971); A_D^{rel}, (Donnelly et al. 1975); A_M^{rel}, (Miller et al. 1972); A_B^{rel}, (Brandt et al. 1982); A_{FC}^{rel}, (Fonseca & Campos 1982); A_{BR}^{rel}, (Bertucceli & Di Rocco 1991); A_{SCH}^{rel}, (Schade et al. 1989); A_{MH}^{rel}, (Le Mond & Head 1987); A_F^{rel}, (Fink et al. 1970) and A_{MK}^{rel}, (Mohamed & King 1979). Data in brackets denote absolute A values of the reference 435.548 nm transition (in 10^8 s^{-1}).

λ (nm)	A_{exp}^{rel}	A_{Th}^{rel}	A_N	A_K^{rel}	A_L^{rel}	A_D^{rel}	A_M^{rel}	A_B^{rel}	A_{FC}^{rel}	A_{BR}^{rel}	A_{SCH}^{rel}	A_{MH}^{rel}	A_F^{rel}	A_{MK}^{rel}
473.900	0.83	0.55	0.76	0.72		0.94	1.50	0.64	0.83	1.35	0.88	1.04	1.02	0.92
465.888	0.69	0.37	0.65	0.63	0.84	0.87	1.12	0.63	0.80	1.06			0.80	0.89
483.208	0.89	0.65	0.73		0.55	0.86	1.46		0.87	1.39				0.89
435.548	1.00	(1.31) 1.00	(1.00) 1.00	(1.02) 1.00	(9.1) 1.00	(1.30) 1.00	1.00	(1.15) 1.00	(1.43) 1.00	(1.20) 1.00	(1.39) 1.00	(1.25) 1.00	(1.15) 1.00	(1.38) 1.00
476.574	0.78	0.57	0.67	0.66			1.21	0.65			0.72	0.84	1.14	
556.865	0.04													
484.661	0.73	0.27					1.75	0.78		2.00				
461.529	0.58	0.79	0.54				0.87			1.29				
461.917	0.72	0.95	0.81	0.79		0.94	1.47	0.71	0.87	1.35	0.90		0.98	
463.388	0.85	0.79	0.71	0.70	0.73	0.86	1.24	0.70	0.78	2.17		0.89	0.77	0.84
457.721	1.15	0.82	0.96	0.94	0.76	0.92	1.54	0.69	0.86	2.30		0.96	1.05	
447.501	0.92	0.84				1.22	1.12		1.06				1.14	
408.833	0.97	1.12				1.10	0.84		1.03	0.91			1.16	
378.310	2.97	1.69											1.64	
377.809	2.70	1.43											1.34	

Table 3: Same as in table 2. Relative theoretical transition probability values: A^{rel}_{MRT}, (Marantz et al. 1969); A^{rel}_{KT}, (Koozekanani & Trusty 1969); A^{rel}_{SG}, (Spector & Garpman 1976); A^{rel}_{SC}, (El Sherbini 1976); A^{rel}_{B}, (Brandt et al. 1982) and A^{rel}_{FC}, (Fonseca & Campos 1982).

λ (nm)	A^{rel}_{exp}	A^{rel}_{Th}	A_N	A^{rel}_{MRT}	A^{rel}_{KT}	A^{rel}_{SG}	A^{rel}_{SC}	A^{rel}_{B}	A^{rel}_{FC}
473.900	0.83	0.55	0.76	0.81	0.75	0.76	0.62	0.55	0.76
465.888	0.69	0.37	0.65	0.79	0.65	0.62	0.09	0.37	0.68
483.208	0.89	0.65	0.73	0.74	0.56	0.69	0.45		0.79
		(1.31)	(1.00)	(1.47)	(1.64)	(1.64)	(1.30)	(1.32)	(1.45)
435.548	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
476.574	0.78	0.57	0.67		0.42	0.69	0.31	0.56	
556.865	0.04								
484.661	0.73	0.27				0.64	0.007	0.28	
461.529	0.58	0.79	0.54		0.48	0.45	0.10		
461.917	0.72	0.95	0.81	0.71	0.47	0.75	0.25	0.94	0.84
463.388	0.85	0.79	0.71	0.99		0.71		0.78	0.78
457.721	1.15	0.82	0.96	0.80		0.86		0.87	0.82
447.501	0.92	0.84		0.91		1.12			0.87
408.833	0.97	1.12		1.21		1.04			1.11
378.310	2.97	1.69							
377.809	2.70	1.43							

Fortunately, absolute A value of the reference 435.548 nm Kr II transition tabulated by NIST (2002) is 1.00 10^8 s^{-1} making the absolute and relative NIST A_N values mutually equal (in the case of our experiment). Our A^{rel}_{exp} values agree well (within $\pm$ 12%, on the average) with 8 A_N values, especially in the case of the 465.888, 473.900 and 461.917 nm transitions.

Our A^{rel}_{exp} values show tolerable agreement with previously experimental results by : Keil (1973) (6 transitions within $\pm$ 14% on the average), Donelly et al. (1975) (8 transitions within $\pm$17% on the average), Fonseca & Campos (1982) (8 transitions within $\pm$14% on the average), Brandt et al. (1982) (7 transitions within $\pm$17% on the average).

Our A^{rel}_{exp} values are in good agreement with theoretical values predicted on the basis of the LS coupling approximation performed by Fonseca & Campos (1982) (8 transitions within $\pm$ 12% on the average), Marantz et al. (1969) (8 transitions within $\pm$ 14% on the average), and with A^{rel} values predicted on the basis of the effective operator formalism presented by Spector & Garpman (1976) (11 transitions within $\pm$15% on the average).

It should be pointed out that in the recent work of Rodriguez et al. (2001) the authors have found satisfactory agreement among their experimental A values and calculated Kr II transition probabilities by Spector & Garpmann (1976). Their A data show good agreement with those from Brandt et al. (1982).

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