Publ. Astron. Obs. Belgrade No. 68 (2000), 81 - 85

TRANSITION PROBABILITIES IN THE 4s-4p TRANSITION IN Ar IV SPECTRUM

S. DJENIŽE and S. BUKVIĆ

Faculty of Physics, University of Belgrade,
P.O.B.368, 11000 Belgrade, Serbia, Yugoslavia
E-mail: steva@rudjer.ff.bg.ac.yu

Abstract. Using the relative line intensity ratios method between four strongest Ar IV spectral lines in $4s - 4p$ ($^4P - ^4D^0$) transition their existing transition probability values (A) have been controlled. These A values, within $\pm 10\%$ accuracy, have been confirmed in the case of the 280.944 nm and 278.896 nm spectral lines. Contrary, for transitions with 283.025 nm and 277.626 nm necessity for correction of the A value was found. Beside, the A values, not known before, are determined for the 251.328 nm, 252.569 nm and 259.947 nm Ar IV lines relative to the 280.944 and 278.896 nm transitions.

1. INTRODUCTION

Transition probability of spontaneous emission (A) plays an important role in plasma and laser investigation and, also, in astrophysics. Namely, various kinetic processes appearing in plasma modeling need reliable knowledge of A values (Griem 1964, 1974, 1997). However, the existing A values (Wiese et al. 1966, 1969; Lide 1994), for number of emitters, are given with high uncertainties. These values are calculated on the basis of the Coulomb approximation (Allen 1973) or by using the Self-Consistent Field (SCF) method (Hartree 1956). In the case of ionized emitters (doubly or triply ionized, as example) the expected uncertainties are 50% or higher (Wiese et al. 1969). On the other hand, known experimental techniques show various difficulties (Wiese et al. 1966, Rompe & Steenbeck 1967) which limit accuracy of the measured A values.

In this work the transition probabilities of spontaneous emission of seven transitions in Ar IV spectrum have been obtained using the relative line intensity ratios method. Two among them (280.944 nm and 278.896 nm) are strongest in the Ar IV spectrum and they are frequently applied in different sort of investigations. As a source of radiation plasma of optically thin linear pulsed arc has been used. The total line intensities (I) were calculated from line profiles measured with high accuracy (3% - 5%) using the step-by-step technique. Four researched transitions belong to the $^4P - ^4D^0$ multiplet with upper energy levels (E) within narrow energy interval, so, correction to the electron temperature (T) of the measured line intensity ratios can be neglected. This fact allows us to establish a simple relation between measured line intensity ratios and ratios of the products of the spontaneous emission probabilities and the corresponding statistical weights (g) of the upper levels of the lines. This relation is expressed as:

$$(I_1/I_2)_{exp} \simeq g_1 A_1 / g_2 A_2 \qquad (1)$$

and give us possibility to check the existing A values.

2. EXPERIMENT AND RESULTS

The modified version of the linear low pressure pulsed arc (Djeniže et al. 1991, 1998, 2000ab) has been used as a plasma source. A pulsed discharge was driven in a quartz discharge tube of 5 mm inner diameter and effective plasma length of 7.2 cm (Fig. 1 in Djeniže et al. (1991,1998)). The tube has end-on quartz windows. The working gas was argon-helium mixture (72% Ar +28%He) at 130 Pa filling pressure in constant flux flowing regime. Spectroscopic observation of isolated spectral lines were made end-on along the axis of the discharge tube. The line profiles were recorded using a step-by-step technique with a photomultiplier and a grating spectrograph system. The system was calibrated by using the standard lamp (EOA-101). The spectrograph exit slit (10 μm) with the calibrated photomultiplier was micrometrically traversed along the spectral plane in small wavelength steps (0.0073 nm). The averaged photomultiplier signal (five shots at each position) was digitized using an oscilloscope, interfaced to a computer. All spectral line profiles have been recorded at the same detection conditions. A sample spectrum is shown in Fig.1.

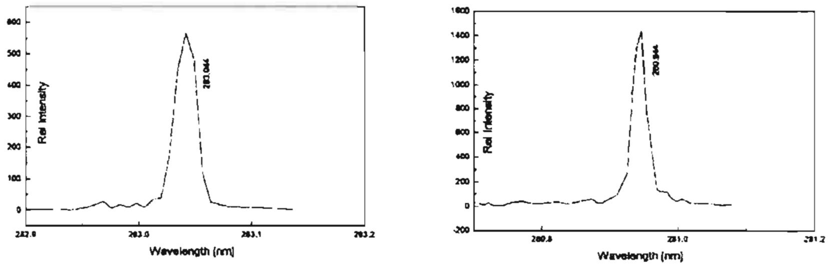

Fig.1. Recorded Ar IV spectrum with researched 280.944 nm and 283.025 nm spectral lines.

Plasma reproducibility was monitored by the Ar III and Ar IV lines radiation and, also, by the discharge current (it was found to be within $\pm$ 3%). Recorded line profiles can be fitted to the Voigt function as a convolution of the Gauss (instrumental and Doppler broadening) and Lorentz (Stark broadening) functions. The standard deconvolution procedure (Davies & Vaughan 1963) was computerized using the least square algorithm. Total line intensity (I) represent the area under the line profile. On the basis of the recorded Ar IV spectrum (as can be see in Fig.1) follow that these lines are well isolated from the other Ar I, Ar II, Ar III and Ar IV lines and, practically lie on the continuum which is equal to zero. These facts are important for determination of the total line intensity and these conveniences lead to the increase of reliability of the results.

The plasma parameters were determined using standard diagnostic methods (Rompe & Steenbeck 1967). Thus, the electron temperature was determined from the Boltzmann-slope on seven Ar III lines with a corresponding upper-level energy interval of 8.32 eV with an estimated error of $\pm$ 7%, assuming the existence of LTE, according to criterion from Griem (1974). All necessary atomic data were taken from Wiese et al. (1969) and Striganov & Sventickii (1966).The electron density decay was measured using a well known single laser interferometry technique for the 632.8 nm He-Ne laser wavelength with an estimated error of ±7%. The electron density and temperature decay's are presented in Fig. 4 in Djeniže et al. (2000b).

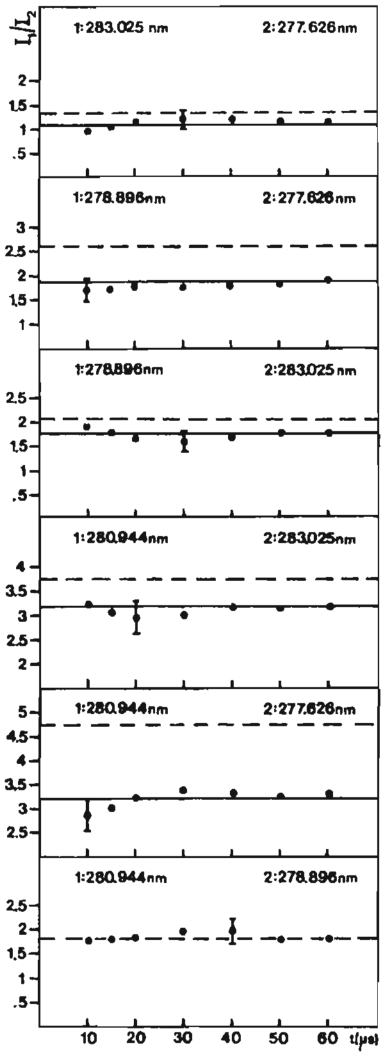

Fig.2. Relative line intensity ratios (I_1/I_2) during the plasma decay. •, our experimental values within 10% accuracy. - - -, theoretical ratios by using the existing transition probability values from Wiese (1969) and Lide (1994) within estimated uncertainties of 50%. Solid lines represent theoretical intensity ratios after the correction of the transition probabilities. All four lines belong to the same multiplet (4UV).

In order to make direct estimation of the influence of the self-absorption on the line intensity, method of the relative line intensity ratios have been applied. Ratios $(I_1/I_2)_{exp}$ were monitored in a wide range of the decaying plasma up to 60th μs after beginning of the discharge when the line intensity maximum dropped down to 10% of its maximal value. Experimental points are presented in the Fig.2. These experimental ratios are constant within $\pm 6\%$, during the plasma decay.

From this fact follows that for employed experimental conditions (spatial distribution, discharge characteristics, gas pressure etc.) our plasma can be treated as optically thin. On the other hand, Stark width values of these lines measured by Djeniže et al. (2000 a, b) in the same plasma conditions agree well with existing experimental and theoretical Stark width values testifying, also, the absence of the self-absorption. This suggest that the comparison between measured and calculated relative line intensity ratios can be employed as a method for estimation of the transition probabilities relatively to the selected referent A values.

Therefore, we suppose that there is at least one pair of lines, belonging to the same multiplet, for which measured and calculated relative line intensity ratios are in agreement during the whole plasma decay period. If such agreement really exist one can accept these lines with corresponding transition probabilities as the referent A values. Among the lines that we have investigated, see Fig.2., described behavior is found for the 278.896 nm and 280.944 nm transitions, while existing A values of the 283.025 nm and 277.626 nm transitions have to be corrected in according to the experimental I_1/I_2 values. These corrected values are presented in Tab.1.

On the basis of the known transition probabilities it is possible to determine unknown A values by using the relative line intensity ratio dependence on the electron temperature (Griem 1964, 1974, 1997):

$$I_1/I_2 = (g_1 A_1 \lambda_2 / g_2 A_2 \lambda_1) exp(\Delta E_{21}/kT) \quad (2)$$

This relation allow the mutual comparison between relative intensities of the spectral lines that origin from the highly different parent energy levels. Using the Eq. (2) A values for the 251.328 nm, 252.569 and 259.947 nm transitions have been obtained relative to the 280.044 nm and 278.896 transitions.

Transit.	Multipl.	λ(nm)	E(eV)	g	$A_w(10^8 s^{-1})$	$A_{exp}(10^8 s^{-1})$
$4s-4p$	$^4P-^4D^0$	283.025	35.49	4	1.4	1.65±10%
	4(UV)	277.626	35.49	4	1.1	1.60±10%
		278.896	35.55	6	1.9	1.90±10%
		280.944	35.65	8	2.6	2.60±10%
	$^4P-^4S^0$	251.328	36.17	4	—	2.25±15%
	$^2P-^2P^0$	252.569	36.66	2	—	2.00±15%
		259.947	36.67	4	—	2.50±15%

Table 1. Atomic data for the seven researched Ar IV spectral lines. E and g denote the upper level energy and the corresponded statistical weights. A_w is the existing transition probability (Wiese et al. 1969) and A_{exp} is the new value obtained by us.

References

Allen C.W., 1973, *Astrophysical Quantities*, 3rd ed., The Athlone Press, London.

Davies, J.T., Vaughan J.M.,1963, Astrophys. J. **137**, 1302.

Djeniže S., Srećković A., Labat J.,Konjević R., Popović L.Č.: 1991, Phys. Rev. A., **44**, 410.

Djeniže S., Milosavljević V., Srećković A.: 1998, JQSRT, **59**, 71.

Djeniže S., Bukvić S., Mišković D.: 2000a, Publ. Astron. Obs. Belgrade, **67**, 53.

Djeniže S., Bukvić S., Mišković D.: 2000b, A& A Supp.Series (submitted).

Griem H.R.: 1964, *Plasma Spectroscopy*, Mc Graw-Hill, New York.

Griem H.R.: 1974, *Spectral Line Broadening by Plasmas*, Acad.Press, New York.

Griem H.R.: 1997, *Principles of Plasma Spectroscopy*, Cambridge Univ. Press. Camb.

Hartree D.R.: 1956, *The Calculation of Atomic Structures*, J. Willey & Sons, New York.

Lide D.R. (Editor-in-Chief): 1994, *CRC Handbook of Chemistry and Physics*, 74^{th} edition (CRC Press, Boca Raton, USA).

Rompe R., Steenbeck, M.: 1967, *Ergebnisse der Plasmaphysik und der Gaselektronik*, Band 1, Akademie Verlag, Berlin.

Striganov R.A., Sventickii N.S.: 1966, *Tablici Spectralnjih Linii*, Atomizdat, Moscow.

Wiese W.L., Smith M.W., Glennon B.M.: 1966, *Atomic Transition Probabilities*, Vol. I NSRDS-NBS 4 (DC.V.S.Government Printig Office, Washington).

Wiese W.L., Smith M.W., Miles B.M.: 1969, *Atomic Transition Probabilities*, Vol. II NSRDS-NBS 22 (DC.V.S.Government Printig Office, Washington).