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ON THE STARK WIDTH REGULARITIES ALONG THE ARGON ISONUCLEAR SEQUENCE

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SUMMARY: Recent values of the measured spectral lines Stark widths (since 1988) for neutral and ionized argon atoms, have been compared to the values previously predicted by us. These were found from the established regularities of the Stark widths along the argon isonuclear sequence for 4s-4p and 4s′-4p′ types of transitions. Using new experimental Stark width values we have established trends for 4p-4d, 4p′-4d′ and 4p-5s type of transitions which enables predictions of the Stark width values for the Ar III and Ar VIII spectral lines, that have not been calculated or measured before, but are of a considerable astrophysical interest.

1. INTRODUCTION

The existence of the ionized argon spectral lines in a great number of various hot stars spectra makes them interesting for diagnostic purposes. They are transmitters of information about the physical conditions on the place of their birth. Knowledge of the Stark broadening parameters (the width and the shift) of the spectral lines enables modelling various physical processes in the hot star plasmas where the Stark broadening is the principal pressure broadening mechanism. The role of Stark broadening in astrophysics is explained by Griem (1974) and Dimitrijević (1989).

Extensive studies of the star atmospheres (effective temperature ≈ 10^3-10^5 K) on the basis of the shape and position of spectral lines emitted by atomic or ionic emitters, have prompted an effort to develope a fast and reliable method to find the Stark widths of spectral lines. When the Stark broadening is the principal pressure broadening mechanism, in plasmas with 10^{22}-10^{27} m^{-3} electron concentration (Dimitrijević 1989), on the basis of Stark HWHM (half-width at half intensity maximum, w) values it is possible to obtain other basic parameters e.g. electron temperature (T) and density (N), important in the modelling of the star atmospheres.

The simplest way to estimate the values of w is to use the established regularities of w along the isonuclear sequences for a given type of quantum transition (Djeniže *et al.* 1988 for carbon; 1990 for nitrogen, oxygen, neon and silicon; 1992 for silicon; 1996b for carbon, nitrogen and oxygen; Purić *et al.* 1988a,b for fluor, neon, chlorine and argon; 1991 for krypton and xenon; Srećković *et al.* 1990 for phosphorus and sulfur; Labat *et al.* 1991 for bromine). In the case of the argon atoms and ions, the simple trend has been established from experimental and theoretical w data for spectral lines from neutral (Ar I) and ionic spectra (Ar II, Ar III and Ar IV) obtained for various plasmas with the electron temperature not exceeding 60 000 K (see Purić *et al.* 1988a,b and references therein). In the meantime, the results of new experiments have been published (Djeniže *et al.* 1989 for Ar II; Hey *et al.* 1990 for Ar

IV; Kobilarov and Konjević 1990 for Ar III and Ar IV; Dzierżega and Musiol 1994 for Ar II; Djeniže *et al.* 1996a for Ar III; Pellerin *et al.* 1997 for Ar II) since 1988.

The main objective of this study is to compare the recent experimental Stark HWHM results with the values that follow from previously established regularities and establishing, also, new regularities on the basis of measured Stark HWHM values for 4p-4d, 4p′-4d′ and 4p-5s type of transitions in a argon isonuclear sequence.

2. REGULARITIES

On the basis of the experimental and theoretical results of a Stark HWHM (w) of spectral lines from the argon isonuclear sequence (Ar I, Ar II, Ar III and Ar IV) it was found (Purić *et al.* 1988a) that simple analitical relationship exists between w and corresponding upper-level ionization potential (I) of a particular spectral line for the same type of the transitions. The found relationship, normalized to a $N = 1 \times 10^{23}$ m^{-3} electron density, is of the form:

$$w = az^2T^{-1/2}I^{-b} \quad \text{(rad/s)} . \qquad (1)$$

The upper-level ionization potential I (in eV) and the net core charge z (z = 1,2,3,... for neutral, singly, doubly, ...ionized atoms, respectively) specify the emitting ions, while the electron temperature T (in K) characterizes the assembly. The coefficients a and b are independent of I, z and T. In the case of the argon isonuclear sequence the following form for the 4s-4p and 4s′-4p′ transition (Purić *et al.* 1988a) was found:

$$w_{4s-4p} = 5.88 \times 10^{14}z^2T^{-1/2}I^{-1.27} \quad \text{(rad/s)} . \qquad (2)$$

$$w_{4s'-4p'} = 5.59 \times 10^{14}z^2T^{-1/2}I^{-1.32} \quad \text{(rad/s)} . \qquad (3)$$

The results of the new Stark HWHM have been published, since 1988, for the various ionization states of the argon. These allow establishment of the trend of the Stark HWHM values along the argon isonuclear sequence for the other transitions like: 4p-4d, 4p′-4d′ and 4p-5s. The following forms were found:

$$w_{4p-4d} = 1.51 \times 10^{14}z^2T^{-1/2}I^{-1.46} \quad \text{(rad/s)} . \qquad (4)$$

$$w_{4p'-4d'} = 6.31 \times 10^{14}z^2T^{-1/2}I^{-1.0} \quad \text{(rad/s)} . \qquad (5)$$

$$w_{4p-5s} = 2.00 \times 10^{14}z^2T^{-1/2}I^{-1.53} \quad \text{(rad/s)} . \qquad (6)$$

for the 4p-4d, 4p′-4d′ and 4p-5s transitions, respectively.

In Figs 1-5 we present (in log-log scale) reduced Stark widths ($wz^{-2}T^{1/2}$ in rad K$^{1/2}$/s) vs inverse value of the upper-level ionization potential (I^{-1} in eV^{-1}) for the argon isonuclear sequence for: 4s-4p, 4s′-4p′, 4p-4d, 4p′-4d′ and 4p-5s transitions, respectively. The solide lines, in Figs. 1 and 2, present predicted values on the basis of previously established regularities [Eqs. (2,3)], while the new experimental values (not included before in the regularities) are given by various symbols. The solide lines in Figs. 3,4 and 5 represent the new established regularities on the basis of the Eq. (4-6) including all experimental results obtained up to date.

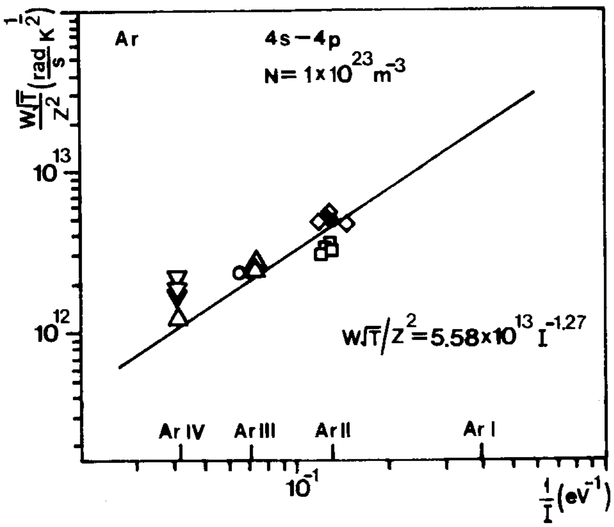

Fig. 1. *Reduced Stark HWHM ($wT^{1/2}z^{-2}$) vs inverse values of the upper level ionization potential for the 4s-4p transition at an electron density of* 1×10^{23} m^{-3}. •, *Djeniže et al. (1989);* □, *Dzierżega and Musiol (1994);* ∇, *Hey et al. (1990);* ∆, *Kobilarov and Konjević (1990);* ○, *Djeniže et al. (1996a);* ◇, *Pellerin et al. (1997).*

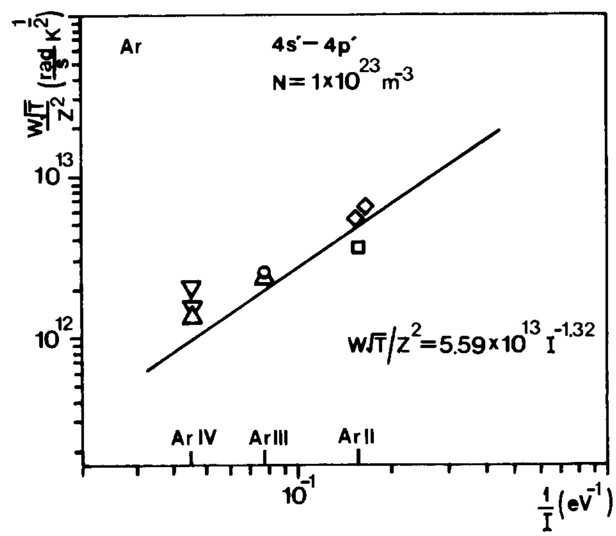

Fig. 2. *Reduced Stark HWHM ($wT^{1/2}z^{-2}$) vs inverse values of the upper level ionization potential for the 4s′-4p′ transition at an electron density of* 1×10^{23} m^{-3}. *The symbols are the same as in Fig. 1.*

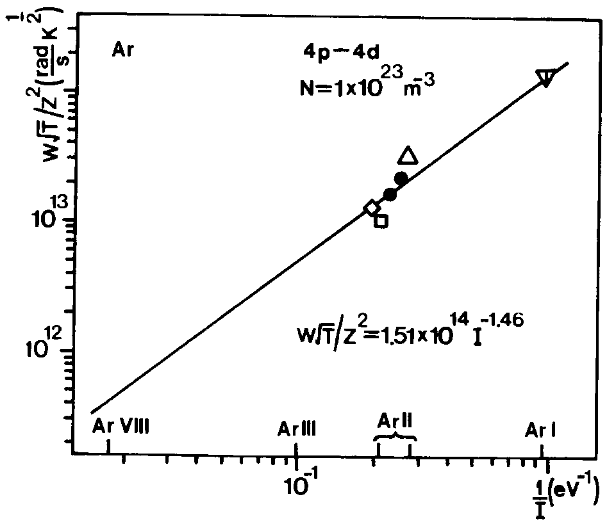

Fig. 3. *Reduced Stark HWHM ($wT^{1/2}z^{-2}$) vs inverse values of the upper level ionization potential for the 4p-4d transition at an electron density of* 1×10^{23} m^{-3}. ∇, *Bues et al. (1969);* ⊕, *Behringer and Thoma (1978);* Δ, *Pittman and Konjević (1986);* •, *Djeniže et al. (1989);* □ , *Dzieržega and Musiol (1994);* ◇, *Pellerin et al. (1997).*

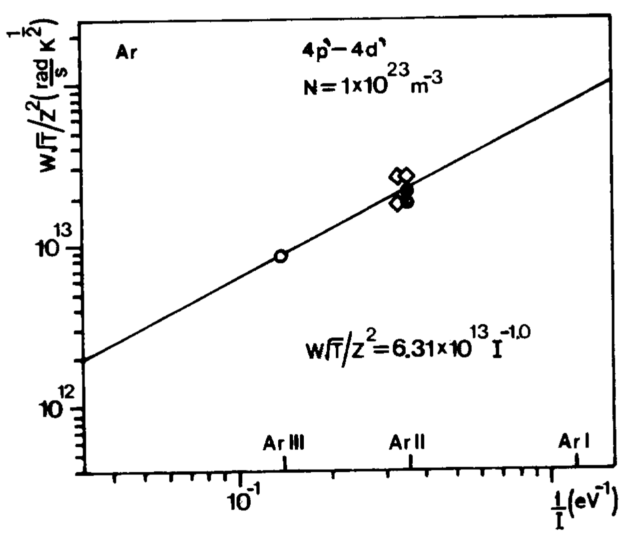

Fig. 4. *Reduced Stark HWHM ($wT^{1/2}z^{-2}$) vs inverse values of the upper level ionization potential for the 4p′- 4d′ transition at an electron density of* 1×10^{23} m^{-3}. ◒, *Lhuissier (1987);* •, *Djeniže et al. (1989);* O, *Djeniže et al. (1996a);* ◇ *Pellerin et al. (1997).*

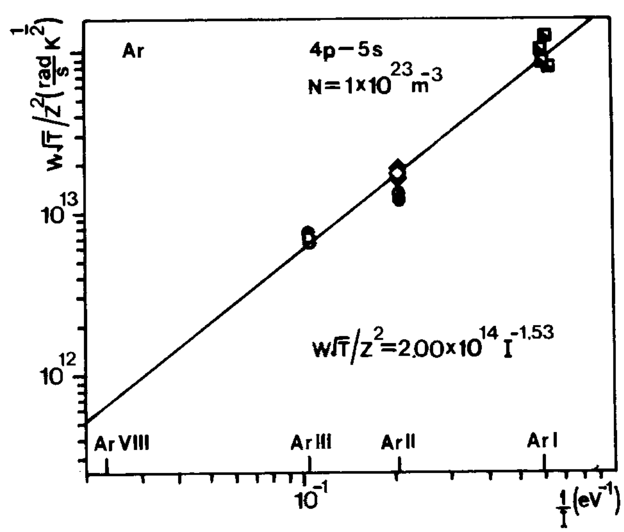

Fig. 5. *Reduced Stark HWHM ($wT^{1/2}z^{-2}$) vs inverse values of the upper level ionization potential for the 4p-5s transition at an electron density of* 1×10^{23} m^{-3}. ◪, *Assous (1968);* ◒ , *Lhuissier (1987);* O, *Djeniže et al. (1996a);* ◇ *Pellerin et al. (1997).*

3. DISCUSSION

Experimental Stark HWHM values published recently for 4s-4p and 4s′-4p′ transitions in Ar II, Ar III and Ar IV ions are in agreement (within ±25% on the average) with the values implied by Eqs. (2,3). However, the results from Hey *et al.* (1990) for the Ar IV lie above the predicted values up to the factor 1.8 in both cases of the transitions.

On the basis of the established regularities for 4p-4d, 4p′-4d′ and 4p-5s transitions given by Eqs. (4, 5,6), respectively, we have evaluated Stark HWHM values for electron temperature at wich this ion is expected to exist. Results are given in Table I. The necessary atomic data were taken from Bashkin and Stoner (1978) and Wiese *et al.* (1969).

Table I Predicted Stark HWHM values for various electron temperatures (T) at $N = 1\times10^{23}$ m^{-3} electron density, with estimated accuracy (Acc) of the prediction.

Transition	Emitter	Multiplet	λ (nm)	T (10^3 K)	w (nm)	Acc. (%)
4s-4p	Ar VIII	^{2}S-^{2}P^0	187.52	150	0.0009	25
4p-4d	Ar III	^{5}P-^{5}D^0	241.16	40	0.007	25
	Ar VIII	^{2}P^0-^{2}D	146.39	150	0.0008	30
4p-5s	Ar VIII	^{2}P^0-^{2}S	54.590	150	0.0002	30

4. CONCLUSION

On the basis of experimental and theoretical values published after 1988, previously found regularities of the Stark HWHM values have been confirmed for the isonuclear sequence of argon for transitions of 4s-4p and 4s′-4p′ type. On the basis of new established trends for Stark HWHM values for spectral lines, that belong to 4p-4d, 4p′-4d′ and 4p-5s type of transitions, we have predicted Stark HWHM values for spectral lines from Ar III and Ar VIII spectrum, that have not been yet found experimentally or theoretically. The wavelength range of these lines lies in the far UV and are attainable to the orbital telescopes, and their Stark HWHM values should be liable to measurment at the electron densities higher than 10^{24} m^{-3}.

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РЕГУЛАРНОСТ ШТАРКОВИХ ШИРИНА ДУЖ ИЗОНУКЛЕУСНОГ НИЗА АРГОНА

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Оригинални научни рад

Постојеће вредности мерених Штаркових ширина спектралних линија (од 1988. год.) из спектра неутралног и јонизованог атома аргона упоређене су са нашим раније предвиђеним вредностима које су нађене на основу утврђених регуларности Штаркових ширина дуж изонуклеусног низа аргона за прелазе типа 4s-4p и 4s′-4p′. Користећи најновије експерименталне податке за Штаркове ширине спектралних линија из спектра неутралног и јонизованог атома аргона, утврдили смо постојање регуларности тих ширина и за прелазе типа: 4p-4d, 4p′-4d′ и 4p-5s. На основу тих регуларности смо, затим, проценили Штаркове ширине неких спектралних линија из спектра двоструко (Ar III) и седмоструко (Ar VIII) јонизованог аргона, које су од интереса за астрофизику, а које до сада нису мерене или рачунате.