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EXPERIMENTAL TOTAL STARK SHIFTS IN THE Ar I SPECTRUM

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Abstract. The Stark shifts (d) in the 4s'–5p' transitions of neutral argon (Ar I) have been studied in a linear, low–pressure, optically thin pulsed arc discharge. The line shapes are measured in three different plasmas at about 16 000 K electron temperature (T) and about 7.0x10^{22} m^{-3} electron density (N). The separate electron and ion contributions to the total Stark shift (d_t), i.e. d_e and d_i have also been obtained and represent new experimental data in this field.

On the basis of the observed asymmetry of the Stark broadened line profile we have deduced the ion broadening parameters which describe the influence of the ion–static (A) and the ion–dynamical effect (E) to the Stark shift.

1. INTRODUCTION

The presence of the neutral argon (Ar I) spectral lines has been discovered in various cosmic light sources in the last few years. Recently, Weaver et al. (2002) have referred the presence of (Ar I) lines in the spectra of long-period comets. The Ar I absorption lines have been detected in the spectra of the quasar Q0347-3819 and PG 1259 + 593. In the study by Friedman et al. (2000) the absorptions in the Ar I lines were presented. Argon is detected in the spectrum of the damped Ly$_\alpha$ system of IZw 18. Mallouris et al. (2001) refer the presence of Ar I lines in the spectrum of the Wolf–Rayet binary SK 108. Thus, the Ar I spectral line shapes represent important sources of information about the physical conditions in the place of birth of the radiation, especially since the launch of the Hubble space telescope.

In this work we applied the line deconvolution procedure (Milosavljević and Poparić, 2001) to precisely recorded Ar I lines profile. The spectral lines are measured using the step–by–step technique (Milosavljević et al., 2000) for three different plasmas created in a linear, low–pressure, pulsed arc discharge in argon–helium and argon–hydrogen mixtures.

The basic plasma parameters, i.e. electron temperature (T) and electron density (N) have been obtained using well–known, experimental diagnostical techniques, but also using the line deconvolution procedure (Milosavljević and Poparić, 2001).

In this paper we are presenting the measured Stark shift of the 415.86, 416.42 and 426.63 nm Ar I spectral lines (in 4s'–5p' transition, multiplet [3/2]^o-[3/2]) at about 16 000 K electron temperature and at about 7.0x10^{22} m^{-3} electron density. The used T values are typical for many cosmic light sources and laboratory plasmas.

On the basis of the observed Ar I line profile asymmetry, the characteristics of the ion contribution to the total Stark shift ($d_{\rm t}$), has been obtained in function of the ion contribution parameter (A) and ion–dynamical effect (E). Our $d_{\rm t}$, $d_{\rm e}$ and $d_{\rm i}$ quasi–static values have been compared to theoretical and experimental values.

2. EXPERIMENT

The modified version of the linear low pressure pulsed arc (Milosavljević et al., 2000; Djeniže and Bukvić, 2001; Djeniže et al., 2002abc; 2003) 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).

3. THEORETICAL BACKGROUND AND DECONVOLUTION PROCEDURE

The total line Stark shift ($d_{\rm t}$) with the corresponding electron ($d_{\rm e}$) and ion ($d_{\rm i}$) contributions is given as:

$$d_{\rm t} = d_{\rm e} + d_{\rm i} \tag{1}$$

For a non–hydrogenic, isolated neutral atom line the ion broadening is not negligible and the line profiles are described by an asymmetric K function (see Eq. (5)). The $d_{\rm t}$ may be calculated from the equation:

$$d_{\rm t} \approx W_{\rm e}[d_{\rm e}/W_{\rm e} \pm 2AE(1-0.75R)] \tag{2}$$

where $W_{\rm e}$ is electron Stark FWHM and R is the Debye shielding parameter. A is the quasi–static ion broadening parameter, E is a coefficient of the ion–dynamical contribution to the shift, with the established criterion:

$$E = \frac{2.35 \cdot B^{-1/3} - 3A^{1/3} \cdot R}{2 \cdot (1-0.75 \cdot R)} \qquad \text{for} \qquad B < 1;$$

or

$$E = 1 \qquad \text{for} \qquad B \geq 1, \tag{3}$$

where

$$B = A^{1/3} \cdot \frac{4.03 \cdot 10^{-7} \cdot W_e[\rm nm]}{(\lambda[\rm nm])^2} \cdot (N[\rm m^{-3}])^{2/3} \cdot \sqrt{\frac{\mu}{T_{\rm g}[\rm K]}} < 1; \tag{4}$$

is the factor with atom–ion perturber reduced mass μ (in amu) and gas temperature $T_{\rm g}$. When $E = 1$ the influence of the ion–dynamic is negligible to the width and shift respectively, and the line shape is treated using the quasi–static ion approximation, described by Milosavljević and Poparić (2001) and references therein:

Table 1: The Stark shift characteristics for Ar I lines. Measured: $d_{\rm t}^{\rm exp}$, $d_{\rm e}^{\rm exp}$ and $d_{\rm i}^{\rm exp}$ (in pm) within 12% accuracy at measured electron temperature ($T^{\rm exp}$ in 10^3K) and electron density ($N^{\rm exp}$ in $10^{22}{\rm m}^{-3}$). Ref. represents sources of experimental data. Tw denotes our data. Other notations: Bu, Bues et al. (1969); Po, Powell (1969); Mo, Morris and Morris (1970); Ge, Gericke (1961); Gr, Griem (1962); Ch, Chapelle et al. (1967). $A^{\rm exp}$ denotes our quasi–static ion broadening parameters.

Multiplet	λ (nm)	$T^{\rm exp}$	$N^{\rm exp}$	$A^{\rm exp}$	$E^{\rm exp}$	$d_{\rm t}^{\rm exp}$	$d_{\rm e}^{\rm exp}$	$d_{\rm i}^{\rm exp}$	Ref.
$[3/2]^{\rm o}_2$-$[3/2]_2$	415.86	15.6	6.7	0.143	1.46	57	41	16	Tw
		16.0	7.0	0.146	1.93	68	46	22	Tw
		16.2	7.1	0.147	1.91	71	48	23	Tw
		9.75–12.7	1.2–9.4			13–94			Bu
		14.0	1.0			9.9			Po
		13.5	12.8			142			Mo
		11.4	4.6			50			Ge
		9.72–14.83	1.7–18.0			16–172			Gr
$[3/2]^{\rm o}_2$-$[3/2]_1$	416.42	15.6	6.7	0.140	1.51	55	40	15	Tw
		16.0	7.0	0.142	1.97	65	44	21	Tw
		16.2	7.1	0.142	1.97	68	47	21	Tw
		9.75–12.7	1.2–9.4			11–79			Bu
		14.0	1.0			10			Po
		11.4	4.6			42			Ge
		13.8	14.5			75			Ch
$[3/2]^{\rm o}_1$-$[3/2]_2$	426.63	15.6	6.7	0.132	1.55	60	45	15	Tw
		16.0	7.0	0.132	2.06	71	51	20	Tw
		16.2	7.1	0.134	2.02	72	51	21	Tw
		14.0	1.0			9			Po
		13.5	12.8			129			Mo
		11.4	4.6			50			Ge

$$K(\lambda) = K_{\rm o} + K_{\rm max}\int_{-\infty}^{\infty} exp(-t^2)\cdot[\int_0^{\infty} \frac{{\rm H_R}(\beta)}{1+(2\frac{\lambda-\lambda_{\rm o}-\frac{\rm W_G}{2\sqrt{\ln 2}}\cdot {\rm t}}{\rm W_e}-\alpha\cdot\beta^2)^2}\cdot d\beta]\cdot dt. \quad (5)$$

Here $K_{\rm o}$ is the baseline (offset) and $K_{\rm max}$ is the maximum intensity (for λ=$\lambda_{\rm o}$) (Milosavljević and Poparić, 2001). $H_{\rm R}(\beta)$ is an electric microfield strength distribution function of normalized field strength β=$F/F_{\rm o}$, where $F_{\rm o}$ is the Holtsmark field strength. A (α=$A^{4/3}$) is the static ion broadening parameter and represents the measure of the relative importance of ion and electron broadenings. R is the Debye shielding parameter and $W_{\rm e}$ is the electron width (FWHM) in the $j_{\rm A,R}$ plasma broadened spectral line profile (Griem, 1974). The $W_{\rm G}$ is the Gaussian FWHM width (Eq.(2.3) in Milosavljević and Poparić (2001)).

More details, about deconvolution procedure, it can be find in Milosavljević and Poparić (2001).

On the end it is important to point out that, taking into account the uncertainties of the line profile measurements and mentioned in Milosavljević and Poparić (2001), we estimate errors as ±12% for the $d_{\rm e}$ and $d_{\rm i}$, ±15% for the A parameter and ±20% for E.

4. RESULTS AND DISCUSSION

The plasma broadening parameters ($d_{\rm t}^{\rm exp}$, $d_{\rm e}^{\rm exp}$, $d_{\rm i}^{\rm exp}$, $A^{\rm exp}$, $E^{\rm exp}$) obtained using our deconvolution procedure of the recorded line profiles at measured $N^{\rm exp}$ and $T^{\rm exp}$ values are presented in Table 1 together with those of the other authors.

In order to facilitate the comparison among the measured total (electron + ion) Stark shift ($d_{\rm t}^{\rm exp}$) values and the well-known theoretical one ($d_{\rm t}^{\rm G}$), due to Griem (1974), the dependence of the ratio $d_{\rm t}^{\rm exp}$ / $d_{\rm t}^{\rm G}$ on the electron temperature is presented graphically in Fig. 1.

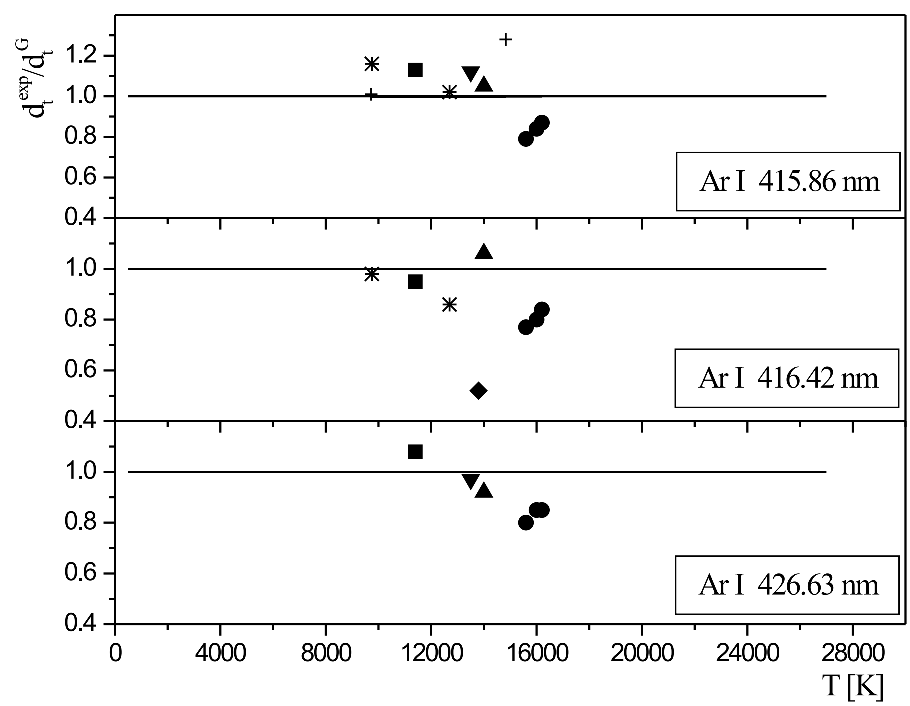

Figure 1: Ratios of the experimental total Stark shift ($d_{\rm t}^{\rm exp}$) to the theoretical ($d_{\rm t}^{\rm G}$) predictions (Griem, 1974) vs. electron temperature for three Ar I spectral lines. ∘, our experimental results and those of other authors: ∗, Bues et al. (1969); □, Gericke (1961); △, Powell (1969); ∇, Morris and Morris (1970); +, Griem (1962) and ♢, Chapelle et al. (1967).

5. CONCLUSION

Our d_t values lie below Griem's (1974) at about 20%. We have found that the ions contribute about 30% to the investigated Ar I Stark shifts at our plasma conditions.

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References

Bues, L., Haag, T. and Richter, J.: 1969, *Astron. Astrophys.*, **2**, 249.
Chapelle, J., Cabonne, Sy.A., Cabannes, F. and Blandin, J.: 1967, *JQSRT*, **8**, 1201; 1967, C.R.H. *Acad. Sci. Ser. B*, **264**, 853.
Djeniže, S. and Bukvić, S.: 2001, *Astron. Astrophys.*, **365**, 252.
Djeniže, S., Milosavljević, V. and Dimitrijević, M.S.: 2002a, *Astron. Astrophys.*, **382**, 359.
Djeniže, S., Srećković, A. and Bukvić, S.: 2002b, *Eur. Phys. J. D*, **20**, 11.
Djeniže, S., Dimitrijević, M.S., Srećković, A. and Bukvić, S.: 2002c, *Astron. Astrophys.*, **396**, 331.
Djeniže, S., Milosavljević, V. and Dimitrijević, M.S.: 2003, *Eur. Phys. J. D*, **27**, 209.
Friedman, S.D., Howk, J.C., Andersson, B–G, et al.: 2000, *Astrophys. J. Lett.*, **538**, L39.
Gericke, W.E.: 1961, *Z. Astrophys.*, **53**, 68.
Griem H. R.: 1962, *Phys. Rev.*, **128**, 515.
Griem, H.R.: 1974, Spectral Line Broadening by Plasmas, New York: Acad. Press.
Mallouris, C., Welty, D.E., York, D.G. et al.: 2001, *Astrophys. J.*, **558**, 133.
Milosavljević, V., Djeniže, S., Dimitrijević, M.S. and Popović, L.Č.: 2000, *Phys. Rev. E*, **62**, 4137.
Milosavljević, V. and Poparić, G.: 2001, *Phys. Rev. E*, **63**, 036404.
Morris, J.C. and Morris, R.U.: 1970, *Aerospace Research Laboratories Report*, **No. ARL 70-0038**.
Powell, W.R.: 1969, *Diss. Abstr.*, **B29**, 3030.
Weaver, H.A., Feldman, P.D., Combi, M.R. et al.: 2002, *Astrophys. J.*, **576**, L95