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ON THE EXPERIMENTAL AND THEORETICAL INVESTIGATIONS OF F II STARK BROADENING

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Abstract. Stark widths (W) and shifts (d) of 5 singly ionized fluorine (F II) spectral lines within the $3s - 3p, 3s' - 3p'$ and $3d - 4f$ transitions have been measured in a linear, low-pressure, pulsed arc discharge created in SF_6 plasma at $30400 - 33600$ K electron temperatures and at $(2.75 - 2.80) \times 10^{23}$ m^{-3} electron densities. The widths and shifts have also been calculated using the semiclassical perturbation formalism (SCPF) (taking into account the impurity of energy levels, i.e. that the atomic energy levels are expressed as a mix of different configurations due to the configuration interaction). Calculations have been performed for temperatures between 5 000 K and 100 000 K for the for electrons, protons and helium ions as perturbers. Our measured and theoretical Stark parameters are compared with existing experimental and theoretical data. Tolerable agreement was found among them.

1. INTRODUCTION

In the last five years fluorine spectral lines have become important for abundance investigations in various astrophysical plasmas (Lodders, 2003; Zhu et al., 2002; Highberger et al., 2001). Only two experiments (Platiša et al., 1977 and Djeniže et al., 1991), deal with investigations of Stark broadening parameters (W, d) of singly ionized fluorine spectral lines.

The aim of this work is to present measured Stark FWHM (full-width at half intensity maximum, W) and shift (d) values at $(30400 - 33600)$ K electron temperatures and at $(2.75 - 2.80) \times 10^{23}$ m^{-3} electron densities for 5 F II spectral lines belonging to the $3s - 3p$, $3s' - 3p'$, and $3d - 4f$ transitions, together with their calculated values using the semiclassical perturbation formalism (SCPF) updated several times (Sahal-Bréchot, 1969ab, see also a review in Dimitrijević, 1996). A unique exception is the transition $3p - 3d$ from the F II spectrum (multiplet No. 3) for which only calculated values are presented. Our measured and calculated Stark parameters are compared with the existing experimental and theoretical data (Griem, 1974; Platiša et al., 1977; Djeniže et al., 1991) elsewhere (Srećković et al., 2004).

Table 1: Measured F II Stark FWHM (W_m in pm) and shift (d_m in pm) at a given T (in 10^4 K) and N (in 10^{23} m^{-3}). Transitions and wavelengths (λ in nm) are taken from NIST (2003). Negative shift is toward the blue.

Ion	Transition Multiplet	λ	T	N	W_m	d_m
FII	$2p^33s - 2p^3\ (^4S^o)3p$ $^5S -\ ^5P$ (1)	385.167	3.36	2.80	64.8	-3.4
	$2p^33s' - 2p^3\ (^2D^o)3p'$ $^3D^o -\ ^3D$ (5)	410.916	3.04	2.75	61.0	-1.8
			3.36	2.80	54.8	
	$^1D^o -\ ^1F$ (7)	429.916	3.04	2.75	74.4	
			3.36	2.80	71.8	-0.6
	$^1D^o -\ ^1D$ (8)	320.276	3.04	2.75	61.0	
			3.36	2.80	57.8	-5.0
	$2p^33d - 2p^3\ (^4S^o)4f$ $^5D^o -\ ^5F$ (9)	424.666	3.04	2.75	381	-1.8
			3.36	2.80	355	4

2. EXPERIMENT

A linear pulsed arc has been used as plasma source. The working gas was SF_6 at 130 Pa filling pressure in a flowing regime (10 ml/min). The complete experimental procedure, plasma diagnostic techniques and set-up of the system used are described in Djeniže et al. (2002).

The measured profiles were of the Voigt type due to the convolutions of the Lorentzian Stark and Gaussian profiles caused by Doppler and instrumental broadening. For the electron density and temperature presented in our experiment, the Lorentzian fraction was dominant.

The standard deconvolution procedure has been applied using the least squares algorithm. The Stark widths were measured with ±12% error at a given N and T. Our measured Stark FWHM (W_m) values are presented in Table 1.

The Stark shifts were measured relative to the unshifted spectral lines emitted by the same plasma using a method established and applied first by Purić and Konjević (1972). Stark shift data are determined with ±0.8 pm error at a given N and T. Measured (d_m) Stark shifts are presented in Table 1.

3. METHOD OF CALCULATION

The semiclassical perturbation formalism used here (Sahal-Bréchot, 1969a,b), has been briefly reviewed e.g. in Dimitrijević (1996).

Table 2: Calculated F II Stark FWHM (W in pm) and shift (d in pm) values for electrons (a), protons (b) and helium ions (c) as perturbers for various plasma temperatures (T in 10^3 K) and 10^{23} m^{-3} perturber density. $< \lambda >$ is the mean wavelength in the multiplet. The negative shift is toward the blue.

Transition Multiplet	$< \lambda >$ (nm)		T (10^3 K)											
			5		10		20		30		50		100	
			W	d	W	d	W	d	W	d	W	d	W	d
$3s\ ^5S - 3p\ ^5P$ (1)	385.01	a	38.5	-0.17	27.9	-0.34	20.4	-0.44	17.6	-0.43	15.3	-0.52	13.7	-0.46
		b	0.64	-0.08	1.12	-0.16	1.58	-0.28	1.75	-0.34	1.92	-0.43	2.15	-0.52
		c	0.91	-0.08	1.14	-0.15	1.75	-0.24	1.89	-0.30	2.05	-0.36	2.22	-0.43
$3s'\ ^3D^o - 3p'\ ^3D$ (5)	411.48	a	44.7	0.08	32.3	-0.45	23.5	-0.62	20.2	-0.61	17.6	-0.74	15.7	-0.64
		b	0.72	-0.11	1.27	-0.24	1.79	-0.39	1.99	-0.48	2.19	-0.60	2.45	-0.71
		c	1.02	-0.11	1.55	-0.22	1.98	-0.34	2.14	-0.42	2.32	-0.49	2.53	-0.59
$3s'\ ^3D^o - 3p'\ ^3P$ (6)	354.08	a	34.0	0.40	24.6	-0.07	18.0	-0.14	15.6	-0.13	13.7	-0.16	12.3	-0.16
		b	0.64	-0.02	1.08	-0.05	1.51	-0.09	1.65	-0.12	1.81	-0.16	2.01	-0.20
		c	0.90	-0.02	1.33	-0.05	1.65	-0.08	1.78	-0.11	1.93	-0.14	2.08	-0.17
$3s'\ ^1D^o - 3p'\ ^1F$ (7)	430.54	a	49.5	-0.06	35.8	-0.56	26.3	-0.61	22.8	-0.66	20.2	-0.78	18.2	-0.73
		b	0.87	-0.13	1.50	-0.26	2.10	-0.44	2.32	-0.53	2.55	-0.66	2.86	-0.79
		c	1.23	-0.12	1.84	-0.24	2.31	-0.38	2.50	-0.47	2.72	-0.54	2.94	-0.66
$3s'\ ^1D^o - 3p'\ ^1D$ (8)	320.65	a	29.8	0.62	21.6	0.43	16.1	0.25	14.1	0.35	12.7	0.40	11.7	0.32
		b	0.70	0.08	1.14	0.17	1.55	0.27	1.68	0.33	1.84	0.41	2.04	0.49
		c	0.96	0.08	1.40	0.15	1.67	0.24	1.80	0.29	1.95	0.34	2.08	0.41
$3p\ ^5P - 3d\ ^5D^o$ (3)	350.54	a	41.4	0.96	30.9	1.00	23.4	0.96	20.6	1.07	18.4	1.14	16.8	1.01
		b	1.50	0.22	2.26	0.42	2.84	0.64	3.07	0.76	3.34	0.88	3.63	1.06
		c	1.90	0.21	2.65	0.38	3.05	0.55	3.27	0.63	3.52	0.73	3.69	0.87
$3d\ ^5D^o - 4f\ ^5F$ (9)	424.70	a	990	-2.01	158	-3.88	129	-3.1	120	-2.75	110	-3.28	99.9	-3.02
		b	11.5	-7.37	15.7	-10.7	19.6	-14.8	21.9	-16.5	24.8	-19.0	28.2	-21.5
		c	11.9	-5.98	15.0	-8.59	18.0	-12.2	19.4	-13.3	21.5	-15.4	23.3	-17.7

Atomic energy levels needed for the calculation have been taken from Bashkin and Stoner (1975). The calculations have been performed for electron temperatures between 5 000 K and 100 000 K.

Calculated W and d values are presented in Table 2.

4. RESULTS AND DISCUSSION

Our measured (W_m and d_m) and calculated (W and d) values at a given electron temperature (T) and density (N) are given in Tables 1 and 2, respectively. For each value given in Table 2, the collision volume multiplied by the perturber density is much less than one and the impact approximation is valid (Sahal-Bréchot, 1969a,b).

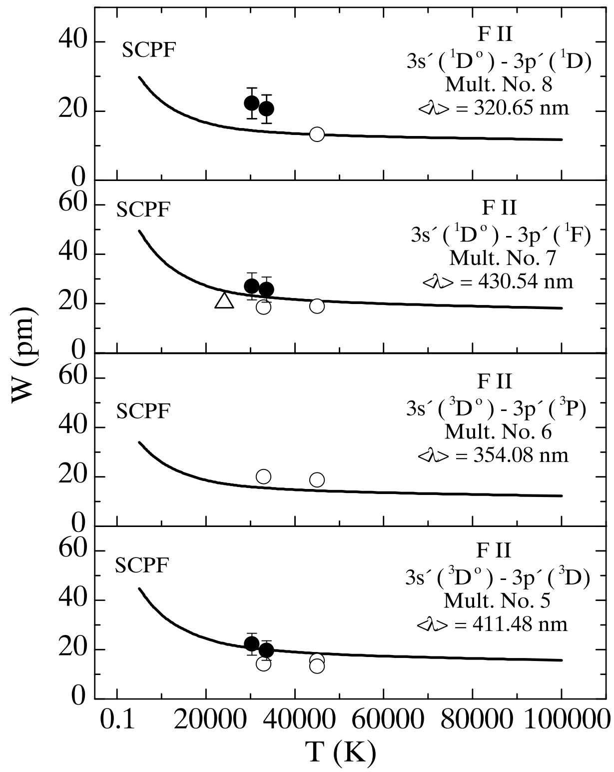

Figure 1: F II Stark widths (W in pm) as a function of the electron temperature (T) in the $3s - 3p$ transition at 10^{23} m^{-3} electron density. •, our experimental results, △, Platiša et al. (1977) and ◦, Djeniže et al., (1991). SCPF (full line) represents our calculations using the semiclassical perturbation formalism. Error bars include the uncertainties of the width and electron density measurements (±20%).

To compare the measured and calculated Stark FWHM values, we have presented in Figs. 3-8 an existing experimental data set including our results, together with our (SCPF) theoretical results and those from Griem (1974) (G).

The F II W values generated by protons and helium ions are up to 5-10 times smaller than the widths generated by electrons and show weak dependence on the temperature (see Table 2). The F II d values generated by electrons, protons and helium ions are very small, except for the multiplet No. 9, and are of the same magnitude.

Very good agreement has been found among our measured and calculated F II W and d values. Existing experimental W values (Djeniže et al., 1991; Platiša et al., 1977) also agree with our calculated values (see Fig. 1). Griem's (1974) W values lie below ours.

On the basis of the obtained W and d values we can conclude that a good agreement is found between our measured and calculated (SCPF) W values (within the experimental accuracy and uncertainties of the calculations) in the case of the F II lines that belong to the $3s - 3p$, $3d - 4f$ and $3s' - 3p'$ transition.

We found that the Stark width generated by electrons is dominant and that the proton and helium ion contributions to the total Stark width can be neglected up to 150 000 K.

Our calculated Stark shift d values are generally very small (< 1 pm) with negative sign in the case of the F II lines belonging to the $3s - 3p$ and $3s' - 3p'$ transitions except for the muliplet No. 8 where the calculated d values have a positive sign. Small d values with positive sign are found for the $3p - 3d$ transition. In the case of the $3d - 4f$ transition the calculated d values are less than 4 pm with a negative sign.

We hope that the results presented in this paper, for Stark broadening parameters of the F II spectral lines, will be of interest for a number of problems in plasma physics and astrophysics.

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