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Experimental Stark parameters of Cr II spectral lines

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Abstract. Stark broadening and shift parameters of Cr II lines with wavelengths in the range 2000-3500 Å have been measured by laser-induced breakdown spectroscopy. The plasmas were generated from fused glass samples selected with different chromium concentrations to avoid self-absorption which would lead to distorted line profiles. The spectra have been measured at different instants of the plasma evolution from 0.6 to 3.4 μs, at which the temperature and electron density are in the ranges 12000-16300 K and (0.89-8.2) × 10^{17} cm^{-3}, respectively. The electron density has been obtained from the Stark broadening of the H_α line.

1. Introduction

Stark broadening and shift parameters are essential for the analysis of the astrophysical and laboratory plasmas. In the particular case of chromium, a considerable number of lines have been identified in the spectra of A-type stars [1-2] where the Stark broadening is the most important pressure broadening mechanism. Despite their relevance, there is a need of experimental data for Cr II Stark widths and shifts since only measurements for three lines, performed with a T-tube in 1984 [3], are available. Theoretical data have been calculated for seven Cr II multiplets from the 4s-4p transition [4] using the semiclassical perturbation approach whereas recently nine resonant $3d^5$-$3d^4$4p multiplets have been obtained within the same approach [5]. In the latter work, after having applied the available data for stellar atmosphere modelling, the authors conclude the need of new Stark parameters for the Cr II lines. The aim of this paper is to provide reliable experimental Stark widths and shifts for several multiplets not previously measured and verify the available values in the literature. Our group has performed laser-induced breakdown spectroscopy to measure Stark parameters, see for example [6], with a procedure based on the curve of growth methodology which allows to control the self-absorption of the lines [7]. Recently the use of fused glass samples has been shown to improve the signal-background ratio in these type of measurements [8]. Hence in the present work we utilize this method and report data for Stark widths and shifts of ionized chromium lines with wavelengths in the range 2000-3500 Å.

2. Experiment

The experimental system consists in a Nd:YAG laser (wavelength 1064 nm, pulse energy 60 mJ, pulse width 4.5 ns, repetition rate 20 Hz) focused onto a sample placed in air at atmospheric pressure to

generate the plasma. The focusing lens has 128 mm focal length whereas the lens-to-sample distance is 124 mm. The light emitted from the plasma is collected in a direction forming a small angle with the laser beam by a system of flat and concave mirrors forming an image on the entrance slit of a 0.75 m focal length Czerny-Turner spectrometer. The slit width (20 and 50 μm) and the grating (3600 and 1200 lines mm^{-1}) are selected depending on the spectral resolution needed. Spectra were recorded by a time-resolved intensified CCD (1200 × 256 effective pixels) at different delays from the laser pulse in synchronism with the electronic trigger of the laser Q-switch. For every period of data acquisition the spectrum of 100 laser shots is accumulated while the sample rotates at 100 rev min^{-1}.
In these measurements three fused glass samples have been used with chromium atomic concentrations of 0.05, 0.1 and 0.2 per cent, previously prepared from borate fusion of pure chromium oxide. One extra sample was prepared with low Fe II concentration to measure plasma temperature.

3. Results and discussion
The spectra have been recorded with six time windows centred at instants from 0.6 to 3.4 μs, having widths from 0.06 to 0.6 μs, and with an extra window centred at 10 μs to obtain a negligible line shift. Plasma temperature was determined by the Boltzmann plot of seven well known Fe II spectral lines, whereas the electron density was obtained by using the Stark broadening of the Hα line [9], whose emission arises from the small water content of air surrounding the sample. In order to perform the latter measurements it was necessary to use the grating of 1200 lines mm^{-1} and a spectrometer slit of 50 μm. During the plasma evolution the temperature and electron density decrease from 16300 to 12000 K and from 8.2 to 0.89 × 10^{17} cm^{-3} respectively, as shown in figures 1 and 2.

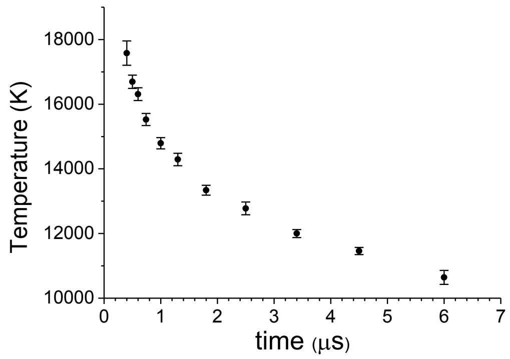

Figure 1. Plasma temperature obtained by Boltzmann plot from seven Fe II spectral lines.

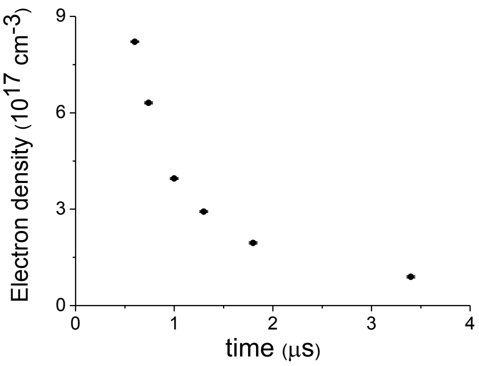

Figure 2. Electron density measured using the H_α broadening.

Self-absorption has been studied with the help of the k_t coefficient as defined in [7], thus atomic data related to the spectral line, plasma temperature and emitter ion density are required together with geometrical factors. For the lines studied, a chromium atomic concentration of 0.05 per cent was needed to ensure self-absorption lower than ten per cent for the more intense lines. Other two samples with 0.1 and 0.2 per cent concentration were used with less intense lines in order to improve the signal-background ratio.

Line widths and shifts have been obtained by fitting the recorded spectral lines to Voigt profiles using home-made software. As is well known, the Lorentzian component corresponds to the Stark width. The Gaussian component has been determined as the combination of the instrumental width and the Doppler width, the first value being measured as 13.5 pm using a low-pressure Hg lamp, and the second one being calculated as 3 pm for a typical temperature of 14000 K. Other broadening mechanisms are negligible in comparison with the electron impact contribution. In figure 3 the fitting of the 2061.575 Å line at the time window centred at 1 μs is shown as an example.

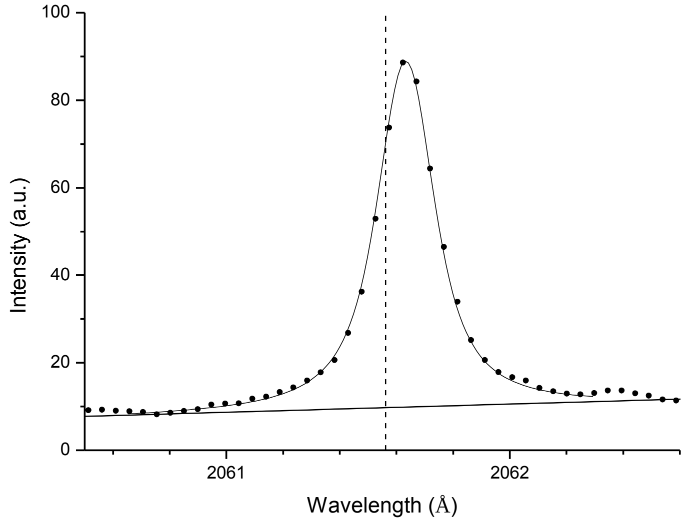

Figure 3. Experimental spectrum of the Cr II line at 2061.575 and fitting to a Voigt profile. The dashed line shows the position of the unshifted line.

The obtained values were proportional to the electron density during the evolution of the plasma, which denotes that the weak dependence of Stark width and shift on temperature is not observed in our range. Therefore, the final value of Stark width (FWHM) and shift at an electron density of 10^{17} cm^{-3} corresponds to the slope of the linear fitting of these magnitudes as shown in figures 4 and 5.

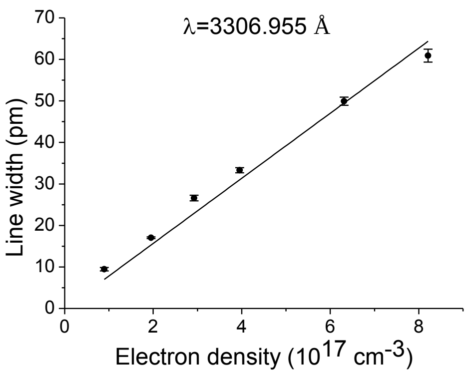

Figure 4. Line width of Cr II line at 3306.955 Å as a function of the electron density.

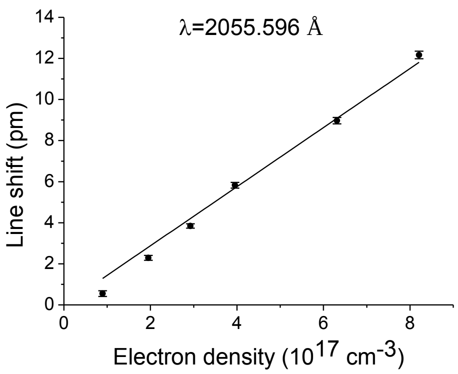

Figure 5. Line shift of Cr II line at 2055.596 Å as a function of the electron density.

The results for transitions belonging to several multiplets, including resonance lines, are presented in table 1 together with previous data from the literature. The complete results, including 83 widths and 49 shifts have been reported in [10].

Table 1. Stark widths *w* (pm) and shifts *d* (pm) at electron density 10^{17} cm^{-3} of Cr II lines.

				Experimental				Theoretical			
Transition	Multiplet	λ(Å)	k_t (10^{-30} m^3)	w	d	w^a	d^a	w^b	w^c	d^b	d^c
$3d^5$ - $3d^4(^5D)4p$	$a\,^6S$ - $z\,^6P^*$	2055.596	6.32	3.7	1.4				3.42		-0.0402
		2061.575	4.76	3.4	1.4				3.42		-0.0402
$3d^4(^5D)4s$ - $3d^4(^5D)4p$	$a\,^4D$ - $z\,^4F^*$	3132.053	7.60	7.2	-0.1	34	-10	27.8		-9.06	
		3124.973	5.47	7.4	-0.1	26	-12	27.8		-9.06	
		3120.359	3.67	7.5	-0.2	22.6	-11	27.8		-9.06	
		3118.646	2.30	7.6	-0.2			27.8		-9.06	
		3147.220	0.832	7.5	-0.2			27.8		-9.06	
		3128.692	0.856	7.1	-0.2			27.8		-9.06	
$3d^5$ - $3d^4(a\,^3F)4p$	$c\,^2F$ - $y\,^2G^*$	3306.955	0.189	7.8	0.0						
$3d^4(^3D)4s$ - $3d^4(^3D)4p$	$b\,^2D$ - $w\,^2F^*$	2941.957	0.418	6.6	0.7						

[a] Temperature 13700 K, experimental [3].
[b] Data interpolated to a temperature of 14000 K, semiclassical perturbation approach [4].
[c] Data interpolated to a temperature of 14000 K, semiclassical perturbation approach [5].

4. Conclusions
We present measurements of Stark widths and shifts of Cr II lines carried out by LIBS, some of them firstly measured. The curve of growth methodology and the use of fused glass samples have allowed to control the self-absorption of the lines.

Acknowledgment
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