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Influence of impacts with charged particles on Cd I and F III spectral lines in stellar plasma

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Abstract. We have calculated within the semiclassical perturbation approach the Stark broadening parameters of 11 Cd I singlets and 13 triplets in ultra-violet and visible, and 24 Cd I triplets in infra red spectral ranges, for temperatures between 2500 K and 50000 K, and for perturber density of $10^{16}cm^{-3}$. Also, we have calculated within the same approach Stark broadening parameters for the F III $2p^3$ $^4S^o$ - 3s ^4P resonant line. Moreover, for 10 F III multiplets, Stark line widths have been obtained within the modified semiempirical approach, for temperatures between 10000 K and 300000 K, and for perturber density of $10^{17}cm^{-3}$. Our results for neutral cadmium Cd I and doubly ionized fluorine F III have been analyzed with existing experimental data and other theoretical results, also we investigated here the regularity within a spectral series of Cd I $5s^2$ ^1S - np $^1P^o$ and finally have been analyzed the influence of Stark broadening mechanism of neutral cadmium and doubly ionized fluorine in comparison to the Doppler one for an A type star atmosphere.

Key words. Line:profiles - atomic data - atomic processes - line:formation - stars: atmospheres

1. Introduction

Stark broadening data for neutral cadmium and doubly ionized fluorine are of interest not only for laboratory but also for astrophysical plasma research as e.g. for stellar spectra analysis and synthesis, for cadmium and fluorine abundance determination and opacity calculations. Abundance analysis for A type stars showed the presence of neutral cadmium in stellar spectra of e.g. 68 Tauri (Adelman 1994a,b) and V816 Centauri (Cowley et al. 2000), in distinction from fluorine which cosmic abundance is smaller.

Stark broadening of cadmium lines is also of interest for the consideration of regularities and systematic trends, and the corresponding results may be of interest in astrophysics for interpolation of new data and critical evaluation of existing ones.

The particularity of neutral cadmium is that the line 6438.4696 Å, 5p $^1P^o_1$ - 5d $^1D_2$ is the fundamental wavelength standard on which other standards are based.

The main goal of this work is twofold: firstly, to determine Cd I spectral line widths and shifts, particularly for the cases when Stark broadening parameters are not known well, and secondly, to obtain results applicable for an analysis of Stark broadening influence on mentioned element lines in stellar spectra. In order

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to analyze the difference between neutral and ion emitters we included F III lines particularly because their Stark broadening was not investigated enough, so that the obtained results can be useful from this point of view, as well.

2. Results and discussion

We have calculated within the semiclassical perturbation approach (Sahal−Bréchot 1969a,b) the Stark broadening parameters of 11 Cd I singlets and 13 triplets in ultra-violet and visible, and 24 Cd I triplets in infra red spectral ranges, for temperatures between 2500 K and 50000 K, and for perturber density of $10^{16}\mathrm{cm}^{-3}$ (Simić et al. 2005; Simić 2004). Also, we have calculated within the same approach such parameters for F III $2p^3\ ^4S^o$ - 3s ^4P resonant line (Simić et al. 2005; Simić 2004). Moreover, for 10 F III multiplets, line widths have been obtained within the modified semiempirical approach (Dimitrijević and Konjević 1980), for temperatures between 10000 K and 300000 K, and for perturber density of $10^{17}\mathrm{cm}^{-3}$ (Simić et al. 2005; Simić 2004). Atomic energy levels needed for calculations have been taken from Moore (1971). The oscillator strengths have been calculated within the Coulomb approximation (Bates & Damgaard 1949; Oertel & Shomo 1968). For higher levels, the method of van Regemorter et al. (1979) has been used.

We compared our results (see Table 1) for Cd I 5p $^3P^o$ - 6s $^3S^o$ multiplet with existing experimental data (Kusch & Oberschelp 1967). In this experiment Stark widths were determined by using spark discharge in tube with $Cd(CH_3)_2$ and $Cd(C_2H_5)_2$ for perturber density normalized at value of $10^{17}\mathrm{cm}^{-3}$ and for temperature of 11 100 K. Also, for the same multiplet there are theoretical results obtained within GBKO approach (Griem et al. 1962) by Dimitrijević & Konjević (1983). Both theoretical results are in disagreement with experimental results. In (Konjević et al. 1984) the selfabsortion is indicated as a possible reason for this.

In the case when there are no reliable data for Stark broadening, investigation of regularities and systematic trends can provide fast estimate of missing values, especially if it is no necessary to have the high accuracy for each particular line, and a good average accuracy for large number of lines is sufficient. We investigated here the regularity within a spectral se-

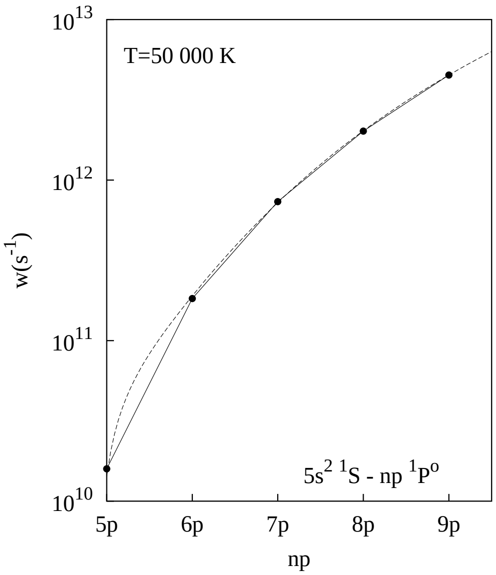

Fig. 1. Electron-impact widths for Cd I $5s^2\ ^1S$ - np $^1P^o$ spectral series in angular frequency units as a function of main quantum number n for the upper atomic energy level (Simić et al. 2005; Simić 2004).

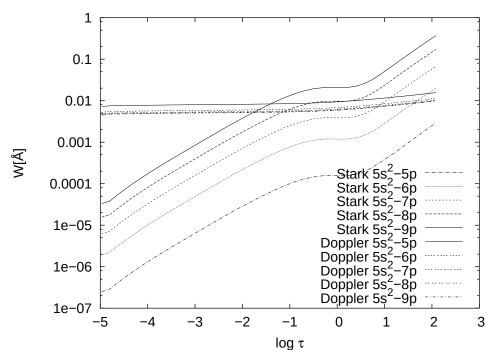

Fig. 2. Thermal Doppler and Stark widths for Cd I singlet spectral lines: $5s^2\ ^1S$ - 5p $^1P^o$ (2288.7 Å), $5s^2\ ^1S$ - 6p $^1P^o$ (1669.3 Å), $5s^2\ ^1S$ - 7p $^1P^o$ (1526.9 Å), $5s^2\ ^1S$ - 8p $^1P^o$ (1469.4 Å), $5s^2\ ^1S$ - 9p $^1P^o$ (1440.2 Å) as a function of Rosseland optical depth (Simić et al. 2005; Simić 2004).

Table 1. Experimental Stark widths - W_m, our theoretical results - W_{th}, theoretical results of Dimitrijević & Konjević (1983) obtained within GBKO (Griem et al. 1962) approach - $W_{th'}$.

TRANSITION	λ (Å)	W_m(Å)	W_m/W_{th}	$W_m/W_{th'}$
CdI	5085.8	3.67	6.41	6.34
	4799.9	3.84	7.53	6.63
5p $^3P^o$ - 6s $^3S^o$	4678.2	1.74	3.59	3.00

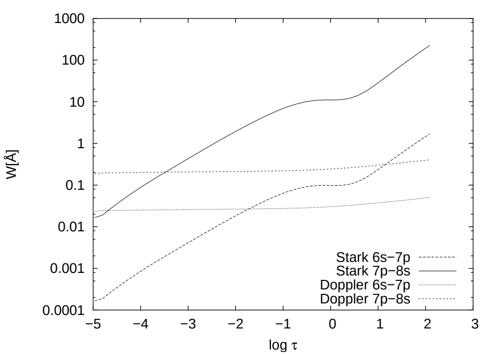

Fig. 3. Thermal Doppler and Stark widths for Cd I triplet spectral line: 6s $^3S^o$ - 7p $^3P^o$ (7400.9 Å) and 7p $^3P^o$ - 8s $^3S^o$ (59346.5 Å) as a function of Rosseland optical depth (Simić et al. 2005; Simić 2004).

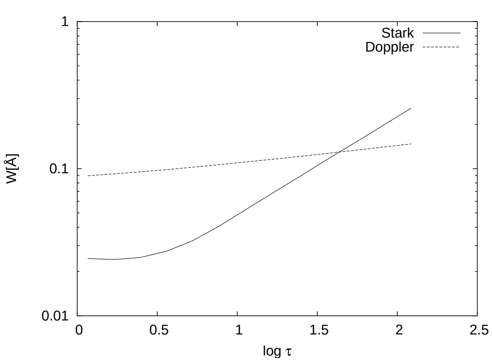

Fig. 4. Stark and Doppler widths for F III 4s 4P - 4p 4D^o (8890 Å) as a function of Rosseland optical depth, for an A type stellar atmosphere model with T_{eff}= 10,000 K and log g = 4 (Simić et al. 2005; Simić 2004).

ries of Cd I 5s^2 ^{1}S - np $^1P^o$ and we confirmed such behavior.

In Fig. 1 electron-impact full half widths - W in angular frequency units, for Cd I 5s^2 ^{1}S - np $^1P^o$ lines as a function of quantum number - n, for T=50,000 K at N_e=10^{16} cm^{-3} are shown. We can see gradual change of Stark widths within 5s^2 ^{1}S - np $^1P^o$ spectral series. Such regular behavior of Stark widths is the consequence of the gradual change of the energy separations between the initial (upper) level and the principal perturbing levels. This function $W(n)$ has been interpolated by third power polynomial (Simić et al. 2005; Simić 2004)

$$W(n) = an^3 + bn^2 + cn + d.$$

Here W is a full width at half maximum (FWHM) expressed in rad/s per electron, and constants are a=6.83417× 10^{10}, b=-1.05083×10^{12}, c=5.15558×10^{12} and d=-9.83561×10^{12}. Polynomial function is represented by dotted line in Fig.1. Using the previous expression, it is estimated the Stark width for Cd I 5s^2 ^{1}S - 10p $^1P^o$ spectral line for which there is no enough atomic data and we obtained a value of W=8.564 10^{12} s^{-1} i.e. W=0.911 Å.

We have analyzed the influence of Stark broadening mechanism on neutral cadmium and doubly ionized fluorine spectral lines in comparison to the Doppler one (Simić et al. 2005; Simić 2004) for an A type star atmosphere. Stark widths within 5s^2 ^{1}S - np $^1P^o$ spectral series have been compared in Fig. 2 with Doppler widths for a model (T_{eff}=10,000 K, log g= 4) of A type star atmosphere

(Kurucz 1979), close to the conditions for 68 Tauri (T_{eff}=9,025 K, log g=3.95) where Stark broadening is of interest for the atmosphere modelisation (Adelman 1994a,b). We note also that one of the line (2288.7 Å) within the first member of this series, the multiplet $5s^2$ ^1S - 5p $^1P^o$, has an intensity of 1500 according to the NIST Atomic Spectra Database. Our results are presented as a function of Rosseland optical depth. As one can see, with an increase of the principal quantum number the importance of Stark broadening in comparison to the Doppler one increases as well. For lines with higher initial quantum number Stark broadening is more than one magnitude larger than Doppler mechanism. The mentioned model for the stellar atmosphere has been used for two other spectral lines, the first (7400.9 Å) in optical range and the second (59346.5 Å) in IC range (see Fig. 3.) In Fig. 4 are compared line widths due to Stark and thermal Doppler broadening mechanisms as functions of optical depth corresponding to 10,000-30,000 K temperature range, for an A type star atmosphere model (T_{eff}=10,000 K, log g= 4). One should take into account that due to differences between Lorentz (Stark) and Gauss (Doppler) line intensity distributions, Stark broadening may be more important on line wings in comparison with the thermal Doppler one, even when it is smaller in the central part.

Our results show that Stark broadening data for neutral cadmium and doubly ionized fluorine lines are needed for an adequate description of stellar spectra and plasma modelisation.

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