Proc. VI Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008,
Eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev
Publ. Astr. Soc. "Rudjer Bošković", No. 9, 2009, 183-188

ON THE REGULARITIES OF STARK BROADENING PARAMETERS OF Ar I LINES WITHIN A SPECTRAL SERIES

MILAN S. DIMITRIJEVIĆ[1], MAGDALENA CHRISTOVA[2],
ZORAN SIMIĆ[1] and SYLVIE SAHAL-BRÉCHOT[3]

[1]*Astronomical Observatory, Volgina 7, 11060 Belgrade 38, Serbia*
e-mail: mdimitrijevic@aob.bg.ac.yu, zsimic@aob.bg.ac.yu
[2]*Department of Applied Physics, Technical University-Sofia,*
BG-1000 Sofia, Bulgaria
e-mail: mchristo@tu-sofia.bg
[3]*Observatoire de Paris, 92195 Meudon Cedex, France*
e-mail: sylvie.sahal-brechot@obspm.fr

Abstract. The calculated Stark broadening parameters (width and shift) of argon spectral lines within a spectral series $3p^5nd \rightarrow 3p^54p$ (n = 4-7) have been analyzed. The Stark broadening parameters have been calculated using the semi-classical impact theory of Sahal-Bréchot within the perturbation formalism. The dependences of the Stark width and shift due to collisions with perturbers (electrons, protons and helium ions) versus effective quantum number have been presented.

1. INTRODUCTION

When reliable data do not exist, the knowledge on regularities and systematic trends of line broadening parameters can be used for quick acquisition of new data especially when high accuracy of each particular value is not needed. Namely, with the suitable use of the knowledge of regularities and systematic trends, we might use the existing experimental and theoretical values for the interpolation of new data needed in stellar spectroscopy. Such knowledge might be used as well for the critical evaluation of available published data needed for stellar spectra modeling and analysis. One must take into account however, that the validity of systematic trends and line broadening data is limited to the plasma conditions for which they are derrived and extrapolations are of low accuracy.

The aim of this paper is to investigate if regular behavior, enabling interpolation of new data and critical evaluation of published values, exists within the spectral series of $3p^54p\ ^2[5/2]_3 - 3p^5nd\ ^2[7/2]^\circ_4$, n= 5-7, of neutral argon. Moreover, the transition $3p^54p\ ^2[5/2]_3$ - $3p^55d'\ ^2[7/2]^\circ_4$ is included in analysis in order to examine the systematic trend when transitions belonging to the different spectral series within the same transition array are included. For this Ar I 737.2 nm line, calculations of Stark broadening parameters were performed here as well.

2. THEORY

The Stark broadening parameters have been calculated using Sahal-Bréchot theory within the semi-classical perturbation formalism (Sahal-Bréchot, 1969ab), where the full width (*W*) at half maximum and the shift (*d*) of an isolated line originating from the transition between the initial level *i* and the final level *f* is expressed as:

$$W = 2n_e \int_0^\infty v f(v)\, dv \left[\sum_{i' \neq i} \sigma_{ii'}(v) + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_{el} \right] \quad (1)$$

$$d = \int_0^\infty v f(v)\, dv \int_{R_3}^{R_d} 2\pi\rho\, d\rho \sin 2\varphi_p \quad (2)$$

where *i'* and *f'* are perturbing levels, n_e and v are the electron density and the velocity of perturbers respectively, and $f(v)$ is the Maxwellian distribution of electron velocities.

The inelastic cross sections $\sigma_{ii'}(v)$ (respectively $\sigma_{ff'}(v)$) can be expressed by an integration of the transition probability $P_{ii'}$ over the impact parameter ρ:

$$\sum_{i' \neq i} \sigma_{ii'}(v) = \frac{1}{2}\pi R_1^2 + \int_{R_1}^{R_d} 2\pi\rho\, d\rho \sum_{i' \neq i} P_{ii'}(\rho, v) \quad (3)$$

The elastic collision contribution to the width is given by:

$$\sigma_{el} = 2\pi R_2^2 + \int_{R_2}^{R_d} 8\pi\rho\, d\rho \sin^2 \delta \quad (4)$$

$$\delta = \left(\varphi_p^2 + \varphi_q^2\right)^{1/2} \quad (5)$$

The phase shifts φ_p and φ_q are due to the polarization and quadrupole potential respectively. The cut-off parameters R_1, R_2, R_3, the Debye cut-off R_d and the symmetrization procedure are described in Sahal-Bréchot (1969ab).

3. RESULTS

The calculations were performed for particular lines within multiplets (spin-orbital interaction is included). The most appropriate *j-L* coupling scheme for argon atom has been used. The values of the energy levels have been taken from NIST catalogue (NIST, 2008). The oscillator strengths (*j-L* coupling) have been calculated within the Bates & Damgaard approximation. The calculations have been made for a set of temperatures (2.5 – 5.0) $.10^4$ K at a perturber (electrons, protons and helium ions) density of 10^{16} cm^{-3}. The results for Ar I 522.1, 549.6 and 603.2 are given in Dimitrijević et al. (2007), where the calculations are oriented to laboratory plasma. The examined perturbers there are electrons, argon ions and protons.

In this work we present the calculated Stark broadening parameters for Ar I 737.2 nm spectral line. In Table 1 wavelengths of the studied argon lines, the corresponding transitions in *j-L* coupling, the perturbing levels *i'* and *f'*, the energy values and the effective quantum number of the initial level are presented.

Table 1. Basic data on the considered Ar I spectral lines. Here λ denotes wavelength, i and f are initial and final level of the transition (within the frame of *j-L* coupling), i' and f' are the corresponding perturbing levels, E_i and E_f are the energy values and n* is the effective quantum number of the initial level.

λ nm	Transition (i - f)	i' levels	f' levels	E_i cm^{-1}	E_f cm^{-1}	n*
522.1	$3p^57d - 3p^54p$ $^2[7/2]^\circ_4 - ^2[5/2]_3$	5f, 6f, 7f, 8f, 9f, 5p, 6p, 7p, 8p, 9p	4s, 5s, 6s, 3d, 4d, 5d, 6d	124610	105463	6.62
549.6	$3p^56d - 3p^54p$ $^2[7/2]^\circ_4 - ^2[5/2]_3$	4f, 5f, 6f, 7f, 4p, 5p, 6p, 7p	4s, 5s, 6s, 3d, 4d, 5d, 6d	123653	105463	5.63
603.2	$3p^55d - 3p^54p$ $^2[7/2]^\circ_4 - ^2[5/2]_3$	4f, 5f, 6f, 7f, 4p, 5p, 6p, 7p	4s, 5s, 6s, 3d, 4d, 5d, 6d	122036	105463	4.65
737.2	$3p^55d' - 3p^54p$ $^2[7/2]^\circ_4 - ^2[5/2]_3$	4f, 5f, 6f, 4p, 5p, 6p	4s, 5s, 6s, 3d, 4d, 5d, 6d	119024	105463	3.68

For the atmospheres of the main branch stars the total Stark width *W* and shift *d* are approximately:

$$W = W_e + 0.9W_p + 0.1W_{He+} \tag{6}$$

$$d = d_e + 0.9d_p + 0.1d_{He+} \tag{7}$$

where W_e, d_e denote the contribution of electron collisions in the total Stark width and shift, respectively, W_p, d_p – the contribution of proton collisions and W_{He+}, d_{He+} - He^+ ion collisions.

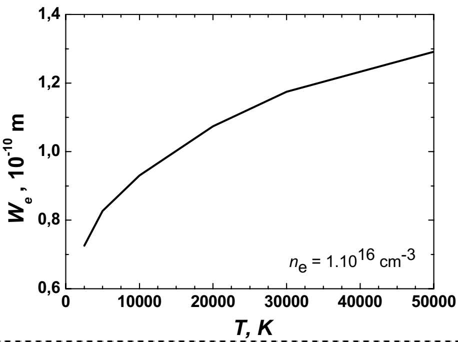

Figure 1: Electron impact width of Ar I 737.2 nm spectral line versus the temperature for the electron density 10^{16} cm^{-3}.

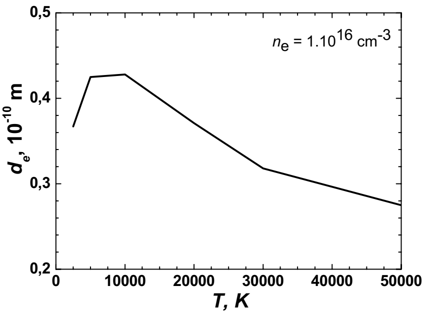

Figure 2: Electron impact shift of Ar I 737.2 nm spectral line versus the temperature for the electron density 10^{16} cm^{-3}.

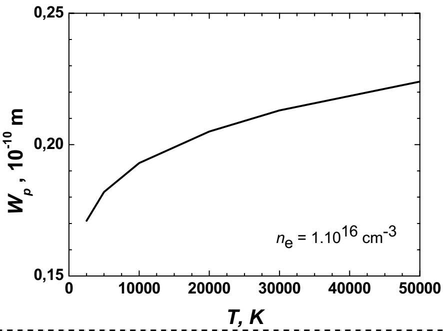

Figure 3: Impact (due to proton collisions) width of Ar I 737.2 nm spectral line versus the temperature for the electron density 10^{16} cm^{-3}.

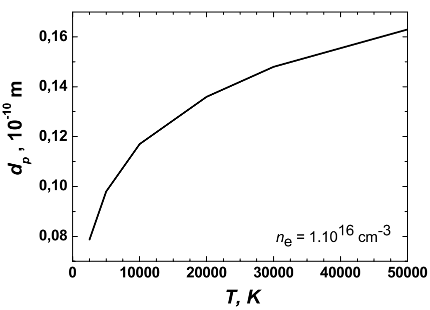

Figure 4: Impact (due to proton collisions) shift of Ar I 737.2 nm spectral line versus the temperature for the electron density 10^{16} cm^{-3}.

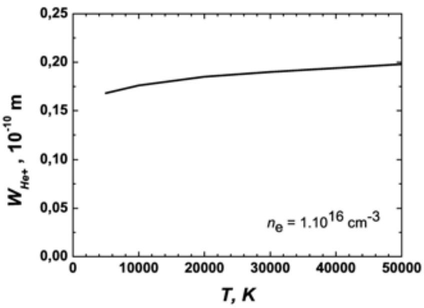

Figure 5: Impact (due to helium ion collisions) width of Ar I 737.2 nm spectral line versus the temperature for the electron density 10^{16} cm^{-3}.

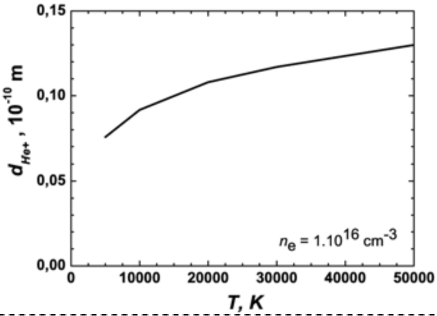

Figure 6: Impact (due to helium ion collisions) shift of Ar I 737.2 nm spectral line versus the temperature for the electron density 10^{16} cm^{-3}.

In Figs. 1-6 the obtained results for electron-, proton-, and helium ion-impact width and shift for Ar I 737.2 nm line are shown respectively as a function of temperature.

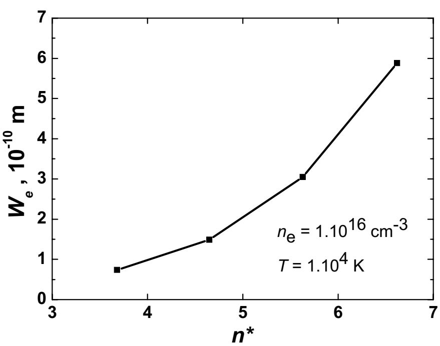

Figure 7: Electron impact widths of Ar I spectral lines within the spectral series versus effective quantum number of the initial energy level.

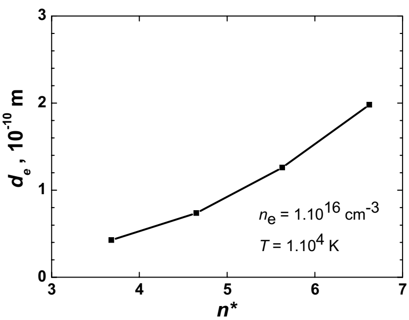

Figure 8: Electron impact shifts of Ar I spectral lines within the spectral series versus effective quantum number of the initial energy level.

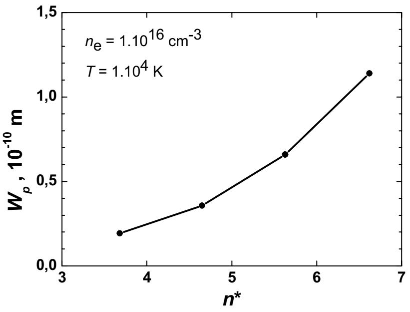

Figure 9: Impact (due to proton collisions) widths of Ar I spectral lines within the spectral series versus effective quantum number of the initial energy level.

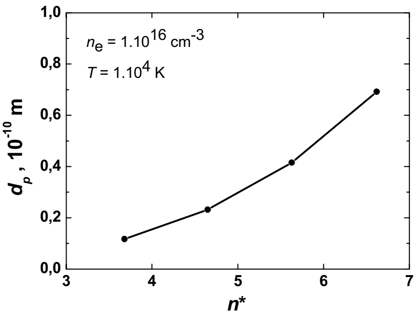

Figure 10: Impact (due to proton collisions) shifts of Ar I spectral lines within the spectral series versus effective quantum number of the initial energy level.

In Figs. 7-10 the electron-, and proton-impact full half widths and shifts for Ar I $3p^54p\ ^2[5/2]_3 - 3p^5nd\ ^2[7/2]°_4$, n= 5-7 spectral lines, together with the transition $3p^54p\ ^2[5/2]_3 - 3p^55d'\ ^2[7/2]°_4$, are presented as a function of the effective quantum number of the upper level of the transition for a temperature of 10 000 K and an electron density of 10^{16} cm^{-3}. We can see a gradual change of Stark broadening parameters within the considered spectral series, enabling the interpolation of new data or critical evaluation of mutual consistency of existing data as in our previous analyses (see e.g. Dimitrijević and Sahal-Bréchot 1996).

Acknowledgments

This work was partially financed by the Technical University – Sofia and is a part of the project 146001 supported by the Ministry of Science and Technological Development of Serbia.

References

Dimitrijević, M. S., Christova, M., Sahal-Bréchot, S.: 2007, *Phys. Scripta*, **75,** 809.
Dimitrijević, M. S., Sahal-Bréchot, S.: 1996, *Phys. Scripta*, **54,** 50.
NIST: 2008, http://physics.nist.gov/
Sahal-Bréchot, S.: 1969a, *Astron. Astrophys.*, **1,** 91.
Sahal-Bréchot, S.: 1969b, *Astron. Astrophys.*, **2,** 322.