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STARK WIDTH AND SHIFT DEPENDENCE ON THE REST CORE CHARGE OF THE EMITTERS FOR MULTIPLY CHARGED IONS SPECTRAL LINES

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Abstract. Stark width and shift simultaneous dependence on the upper level ionization potential and rest core charge of the emitter has been evaluated and discussed. It has been verified that the found relations, connecting Stark broadening parameters with upper level ionization potential and rest core charge of the emitters for particular electron temperature and density, can be used for prediction of Stark line width and shift data in case of ions for which observed data, or more detailed calculations, are not yet available. Stark widths and shifts published data are used to demonstrate the existence of other kinds of regularities within similar spectra of different elements and their ionization stages. The emphasis is on the Stark parameter dependence on the upper level ionization potential and on the rest core charge for the lines from similar spectra of multiply charged ions. The found relations connecting Stark widths and shift parameters with upper level ionization potential, rest core charge and electron temperature were used for a prediction of new Stark broadening data, thus avoiding much more complicated procedures.

1. INTRODUCTION

Almost three decades have passed since the first monograph (Griem, 1974) on Stark broadening of spectral lines was published, and the first attempt was undertaken to find possible types of Stark width and shift regularities (Purić and Ćirković, 1973; Purić *et al.*, 1974). Along width the development of the theory of the Stark broadening, numerous experiments were performed to provide new Stark broadening data and to check the theoretical predictions. During last twenty years a large number of experimental and theoretical papers were published. Only a limited number of these, concerning Stark broadening and shift regularities, has been reviewed here. A substantial addition to the theoretical and experimental investigation of the Stark broadening and shift of numerous spectral lines from different atoms and ion represents the search for possible types of regularities of the Stark parameters. According to the approach to the problem of regularities all relevant published papers can be divided into two groups. The first group of papers (see Purić, 1996 and references therein) is concerned with evaluation of different types of regularities, such as dependence on the atomic charge number, ionization potential, atomic polarizability, principal quantum number and rest core charge of the emitter (as "seen" by an electron undergoing transition), based on the Stark width and shift theoretical formulas obtained in different approximations: semiclassical, semiempirical and adiabatic.

In the second group of papers (Wiese and Konjević, 1976, 1992) regularities were searched among the experimental results and conclusions were drawn on the bases of the analyses of the configuration of the atomic energy levels and transition probabilities, the expected regularities were discussed within a multiplet, supermultiplet, spectral series, transition arrays, homologous and isoelectronic sequences without an attempt to find a certain functional relation between Stark parameters and particular atomic structure parameter.

So far, the regularities have been found within: multiplet and spectral series (Wiese and Konjević, 1976, 1992), supermultiplet (Konjević and Dimitrijević, 1981; Wiese and Konjević, 1992), transition array (Wiese 1982, 1992; Purić, 1996 and references therein), isoelectronic sequence, isonuclear sequence, homologous sequence, particular transition along the Periodic system of the elements (Purić, 1996 and references therein) within one stage of the ionization or within several ionization stages (Purić *et al.*, 1991), as far the influence of the atomic structure is concerned. Stark parameters dependence on the plasma parameters-the electron density and temperature has been investigated in great number of published papers (Purić, 1996 and references therein) theoretically and experimentally. It was found that Stark widths and shifts of nonhydrogenic atoms and ions lines linearly depend on the electron density, and they are just the weak functions of the electron temperature. However, Stark parameters temperature dependence for particular spectral line can be far from being weak function.

Some recent reviews (Lanz and Artru, 1987; Smith, 1989) indicate that the experimentally determined Stark widths, as well as the existing theoretical data, cannot satisfy the need for all observed stellar lines, although it is an active field of research. Therefore, it is of interest to exploit any possible theoretical approach that might provide simple relations, for example, from the systematic trends found in the Stark broadening data. Several simple empirical formulas have been used in stellar studies, which take into account the dependence of the Stark width on the electron density, and on the excitation energy of the transition. For example, using the semiempirical approach (Griem, 1968) it was found that the width is proportional to n^{*4} (n^* is the effective quantum number of the upper level). Similarly, after using the modified semiempirical approach the Stark broadening parameters dependence on n^* (leading term proportional to n^{*4}) and the angular quantum number l, was obtained (Dimitrijević, 1987). Another approach (Kurucz, 1979) gave width proportional to n^{*5}. A different approach, based on the systematic trends found in Stark broadening parameters has been developed in series of articles (Purić, 1996 and references therein), in the case of neutral atoms and singly charged ion resonances and off-resonances (ns-np transitions: $\Delta n=0$ or 1 for resonances and $n=n_o+1$ for off-resonances; n_o is the main quantum number of the ground energy level of a corresponding emitter). Similar regularities were found for the isoelectronic sequences (see e.g. Purić *et al.*, 1988a; Djeniže *et al.*, 1992), for the isonuclear sequences (the same type of transition within several stages of ionization of a particular emitter (see e.g. Purić *et al.*, 1988b; Djeniže *et al.*, 1988)); and for the same type of transition within homologous groups of atoms or ions (see e.g. Purić *et al.,* 1988ab; Djeniže *et al.,* 1991ab). In recently published paper (Purić *et al.,* 1991) the same method was applied to doubly and triply charged ion resonances and off-resonances. The proposed method is based on the fact, that the Stark widths and shifts in wavelength or angular frequency units exhibit a systematic dependence on the ionization potential, upper or lower energy level of the corresponding transition when measured from the ionization limit and not from the ground level. In order to avoid misunderstanding the positive value of such quantity (χ) is called the upper or lower level ionization potential, respectively. Moreover, a systematic dependence has been found also on the rest core

charge (Z_c) of the emitter as seen by the electron undergoing transition. Since the simple relations based on such trends may be useful in astrophysics, when Stark broadening data for many lines are needed, it was tried to obtain and analyse such relations. Therefore, the Stark parameter dependencies on χ and Z_c were deduced form the large-scale semi-classical (Griem, 1974) or semiempirical (Griem, 1968) and modified semiempirical (Dimitrijević and Konjević, 1987) calculations. The obtained relations were checked using the existing experimental and theoretical data (Purić, 1996).

Despite continuous acquisition of Stark broadening data (Purić, 1996 and references therein) little is known about lines of heavy and multiply ionised emitters. This paucity of data particularly hampers opacity modelling of stellar atmospheres. Line widths, assumed when analysing or synthesizing the majority of stellar spectra involve either unreliable approximations or outright ignoring of Stark broadening (even though it may exceed natural broadening several times). In Purić *et al.* (1991) it was shown that physically based interpretation of the broadening regularities could provide Stark parameters with a useful combination of reliability and computational simplicity. The approach focused on the strong connection between Stark width and shift and the energy required to ionise the emitter from the transition's upper state. Theoretically derived functional relations for line width and shift, successfully fitted to a number of spectral lines as shown in a series of articles (Purić *et al.,* 1991), are of the form:

$$\omega = N_e f(T) a_1 Z_c^{c_1} \chi^{-b_1} \tag{1}$$

$$d = N_e f(T) a_2 Z_c^{c_2} \chi^{-b_2} \tag{2}$$

where ω and d are the line width and shift, χ is the corresponding upper state ionization potential, and $a_{1,2}$ and $b_{1,2}$ are coefficients independent of temperature, electron density and ionization potential for particular transition, and Z_c is the rest core charge of the emitter, as "seen" by the electron undergoing transition.

Equations (1) and (2) can be used (i) in the case of the lines originating from the same type of transitions (e.g., resonances or off-resonances) within one stage of ionization (Dimitrijević, 1982), or within several stages of ionization (Purić, 1991); (ii) within particular isoelectronic sequences (see e.g. Purić *et al.*, 1988ab; Djeniže *et al.,* 1991a), and (iii) within a given isonuclear sequence (see e.g. Purić *et al.,* 1988ab; Labat *et al.*, 1991; Djeniže *et al.,* 1991a).

In the case of a particular transition within a given homologous group of atom or ions, it is more convenient to use the slightly different relations in the function of the nuclear charge number of the emitter Z ($Z=Z_c+1$, Z_c+2, etc. for neutral, singly charged ions... respectively) (Purić *et al.,* 1988ab):

$$\omega = N_e f(T) a_1 Z^{c_1} \chi^{-b_1} \tag{3}$$

$$d = N_e f(T) a_2 Z^{c_2} \chi^{-b_2} \tag{4}$$

For the same plasma conditions and for the exactly analogous transitions within the different atomic spectra, corresponding a and b constants are similar. Consequently, one can determine empirically, from experiment or more sophisticated calculations, averaged empirical values for $A=aN_ef(T)$ and b.

For lower temperatures of astrophysical interest, $f(T)$ tends to be $f(T)=T^{-1/2}$ in the case of ionised emitters, and one can scale different theoretical and experimental Stark parameters values to other temperatures by using $T^{-1/2}$ dependence (for validity conditions see e.g. Griem, 1974) when using in the regularity studies. In the case of higher temperatures the dependence on the temperature is weaker. In some cases, when only an

estimated value is needed and temperature does not vary too much, one can use an averaged empirical value for a temperature range taking into account that the accuracy gets lower.

In the semiclassical (Griem, 1974) or the semiempirical (Griem, 1968) and modified semiempirical (Dimitrijević and Konjević, 1987) formulas, ionization potentials are included through the expression for effective quantum number, Stark broadening functions (see Griem, 1974), and the wavelength; therefore one can always find an appropriate, more or less approximate, expression for ω and d satisfying mathematical conditions for a series expansion:

$$f(x) = \sum k_n x^n \tag{5}$$

where $f(x)$ stands for ω and d and x for the ionization potential. Moreover, one can always try to fit ω and d with an $f(x)=\alpha x^{\beta}$ expression. In astrophysics ω is sometimes successfully represented as $\omega = \alpha T^{\beta}$ in order to make easier the use of data for the whole temperature range within a model of the stellar atmosphere. The expressions given by Eqs. (1)-(4), all of the same type,

$$\omega, d = A\chi^{-b} \tag{6}$$

are suitable for the calculations of new data by an interpolation or extrapolation, if the necessary coefficients from the known Stark parameter values for particular case mentioned above are determined.

One can try to obtain the coefficients A and b (see Eq.(6)) or k_n, n (see Eq.(5)) analytically and investigate the series expansion convergence and the quality of $f(x)=\alpha x^{\beta}$ fit. For instance, in the case of $np^{k-1}(n+1)s$-np^k resonance transitions of singly ionised emitters the analytical expressions for the corresponding coefficients of the series expansion were obtained (Dimitrijević, 1982) starting from the semiempirical formula (Griem, 1968). Such procedure may provide usable analytical expressions only with additional approximations and for special cases. Another way, used in a large number of papers is to try to obtain the proposed simple relations from a lot of the existing experimental data or more sophisticated calculations, in order to prove that Stark broadening parameters may be fitted with proposed relations and to obtain the corresponding α and β coefficients.

Accuracy of the obtained data using the described procedure is expected to be comparable with accuracy of the data used in verification of Stark width and shift dependencies on the upper level ionization potential. Therefore, it is very important for this method to have a set of data, calculated or measured, for the same plasma conditions, in particular the electron temperature and density. This makes it possible to avoid the influence of density and temperature scaling, Debye screening effect and different ion broadening contributions to the Stark widths and shifts used in the trends analyses.

The approach based on the Stark parameters dependence on the upper level ionization potential differs from earlier Stark broadening trend analyses primarily in the choice of the variable conveying atomic structure information. Prior work of several authors was based on the hydrogenic model. Consequently, it used integer principle quantum numbers instead of the upper state ionization potential χ chosen here. Both variables take into account the density of states perturbing the emitting state. Advantages of the present method are: (i) χ-based trend analyses achieve better fits; (ii) in χ values the lowering of the ionization potential (Inglis and Teller, 1939) is taken into account, predicting merging with continuum when the plasma environment causes a line's upper

state ionization potential to approach zero; and (iii) the χ dependence on ω, d is theoretically expected as shown in the following part of this review.

2. THEORY

Stark broadening and shift result from perturbations of the states of optically active electrons. Accordingly, Stark parameters are expressed in terms of atomic matrix elements as follows (Griem, 1974):

$$\begin{aligned}\omega + id = 2\pi N \cdot \int_{\rho_{\min}}^{\infty} \rho d\rho \Bigg[\frac{2}{3} iB\left(\frac{\hbar}{m\rho v}\right)^2 \sum_{l_{i',f'}} \left(\left\langle l_{i',f'} \left| \frac{r}{a_0} \right| l_{i',f'} \right\rangle \right)^2 \frac{\max(l_{i',f'}, l_{i,f})}{2l_{if}+1} \cdot \\ \cdot \left[A(z_{i'f'}) + iB(z_{if}) \right] + \frac{2}{15}\left(\frac{\hbar a_0}{m v \rho^2}\right) \sum_{l_{i',f'}} \left(\left\langle l_{i',f'} \left| \frac{r}{a_0} \right| l_{i,f} \right\rangle \right)^2 \cdot (2l_{i'f'}+1) \begin{pmatrix} l_{i',f'} & 2 & l_{i,f} \\ 0 & 0 & 0 \end{pmatrix} \cdot \\ \cdot \left[A_q(z_{i',f'}) + iB_q(z_{i',f'}) \right] + \frac{4}{15}\left(\frac{\hbar a_0}{m v \rho^2}\right)^2 \left(\left\langle l_i \left| \frac{r}{a_0} \right| l_i \right\rangle \right)^2 \left(\left\langle l_f \left| \frac{r}{a_0} \right| l_f \right\rangle \right)^2 \cdot (2l_i+1) \cdot \\ \cdot (2l_f+1) \begin{pmatrix} l_i & 2 & l_i \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} l_f & 2 & l_f \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} l_i & 2 & l_i \\ l_f & 1 & l_f \end{pmatrix} \Bigg]\end{aligned} \tag{7}$$

for atoms, and

$$\omega + id = \frac{4\pi}{3v}\left(\frac{\hbar}{m}\right)^2 N \sum_r \left(\left\langle l_r \left| \frac{r}{a_0} \right| l_i \right\rangle \right)^2 \frac{\max(l_{i'}, l_i)}{2l_i+1} (a_c + ib_c) \tag{8}$$

for singly charged ions, with

$$\begin{aligned} a_c + ib_c = \frac{3}{2}(0.60 \pm i \cdot 0.44) \left[2\pi \sum_{l_{i'}} \left(\left\langle l_{i'} \left| \frac{r_i}{a_0} \right| l_i \right\rangle \right)^2 \frac{\max(l_{i'}, l_i)}{2l_i+1} \right]^{2/5} \cdot \\ \cdot \left[\sum_{l_{i'}} \left(\left\langle l_{i'} \left| \frac{r_i}{a_0} \right| l_i \right\rangle \right)^2 \frac{\max(l_{i'}, l_i)}{2l_i+1} \right]^{=1} \end{aligned} \tag{9}$$

These, in turn, can be related to quantum numbers as through Eq. (7) from Griem (1974):

$$\sum \left| \left\langle J' \left| r_i \right| J' \right\rangle \right|^2 = \frac{a_0^2}{2J+1} S \tag{10}$$

where a_0 is the Bohr radius, J is the total orbital quantum number and S is the line strength.

When LS coupling is assumed, S can be factored:

$$S = \sigma(M)\sigma(L)\sigma^2 \tag{11}$$

where $\sigma(M)$ and $\sigma(L)$ are tabulated (Allen, 1963) multiuplet and intra multiplet relative line strengths, and σ is the integral of the radial wave function for the transition. Often it is

acceptable to model the jumping electron as being under the influence of a screened central charge. In the Coulomb approximation (Bates and Damgaard, 1949):

$$\sigma(n_{l-1}^*, l-1, n_l^*, l) = \frac{1}{Z_c}\left[\frac{3n_l^*}{2}\left(\frac{\left|n_l^{*2} - l^2\right|}{4l^2 - 1}\right)\right]^{1/2} \varphi(n_{l-1}^*, n_l^*, l) \tag{12}$$

where l is the larger of azimuthal quantum numbers, l_i , l_f, $\varphi(n_{l-1}^*, n_l^*, l)$ is a tabulated correction factor (Oertel and Shomo, 1968), and n^* is the effective principle quantum number:

$$n^* = Z_c\left(\frac{E_H}{E_\infty - E}\right)^{1/2} = Z_c\left(\frac{E_H}{\chi}\right)^{1/2} \tag{13}$$

where E_H, and E_∞ are the ionization potentials of hydrogen and the emitter and E is the state energy. In Moore (1949) extensive energy tabulations are given. Two cases can be considered:

$$n_l^{*2} = \frac{Z_c^2 E_H}{E_\infty - E_l} = \begin{cases} \dfrac{Z_c^2 E_H}{\chi_i}; l = l_i \\ Z_c^2 E_H \displaystyle\sum_{v=0}^{\infty} (-1)^v \frac{(E_i - E_f)^v}{\chi_i^{v+1}}; l = l_f \end{cases} \tag{14}$$

where the second version of Eq. (14) is Taylor expansion of 1 / $(E_\infty - E_l)$ for $\chi_i > E_i - E_f$; knowing that $E_\infty = \chi_i + E_i$ and $E_l = E_f$.

Eqs. (12) and (14) can be combined to give the explicit dependence of the transition integral on the potential χ and rest core charge Z_c of the emitter. Stark broadening functions *A(z), b(z),* and *B(z), b(z)* (Griem, 1974) can be expressed as serial Bessel functions. Substitutions in Eqs. (7) and (9) and their rearranging then yield explicit functional dependence on χ and Z_c:

$$\omega, d = \left(\frac{Z_c E_H}{\chi}\right)^2 \sum_{v=0}^{\infty} A_v \left(\frac{Z_c}{\chi}\right)^v \tag{15}$$

For highly stripped ions, $\chi >> Z_c E_H$, and Eq. (15) reduces to

$$\omega, d \approx \left(\frac{Z_c}{\chi}\right)^2 \tag{16}$$

Occasionally a single term will dominate the series in Eq. (15). This occurs for: (a) particular spectral series, multiplet, supermultiplet and transition arrays; (b) analogous transitions of homologous atoms and ions; (c) a fixed transition of ions within an isoelectronic sequence, and (d) the same transition within a particular isonuclear group of ions as it will be demonstrated in the next section of this review.

A new approach to the problem of the Stark broadening regularities was proposed (Salakhov *et al.,* 1991). Instead of looking for regularities within Stark broadening parameters of the spectral lines, the regularities were found for Stark parameters of the corresponding energy levels connected with the dipole transitions. It was found that Stark width (ΔE_q) and shift (Δd_q) of a given energy level can be expressed as:

$$\Delta E_q = A(n_q^*)^b \tag{17}$$

$$\Delta d_q = B(n_q^*)^b \tag{18}$$

where coefficients *A, B, a,* and *b* are independent of the effective quantum number. Stark width and shift of a line from transition between initial (i) and final (f) energy level, neglecting interference term, are given as

$$\omega = \Delta E_i + \Delta E_f \tag{19}$$

$$d = \Delta q_i + \Delta q_f \tag{20}$$

where Δq_i and Δq_f have to be taken with their appropriate signs. Stark parameters E_q and Δd_q can be determined using the existing data bases for particular type of transition.

In addition, it was found that one particular term in the series given by Eq. (5) is predominant, so the general form of the above mentioned dependencies is

$$\omega = A_k \chi^{-k} \tag{21}$$

where the coefficient A_k is independent of the upper level ionization potential χ, and simultaneously it is a function of rest core charge, electron density and temperature. In order to investigate Stark parameter regularities, an accurate set of theoretical and experimental data is needed for multiplet, supermultiplet, transition array, homologous, isoelectronic, and isonuclear sequences; or the same type of transition (for instance resonance) along the periodical system of elements for different stages of ionization, under the same plasma conditions characterized by particular electron density and temperature. Therefore, the Stark parameter dependencies on the electron density and temperature have to be well determined to make possible the normalization of the data given for different temperatures and densities to particular ones at which the types of regularities have to be investigated. Of special interest are dependencies on the rest core charge of the emitter within isoelectronic or isonuclear sequences or on the nuclear charge number within particular transitions of homologous group of atoms or ions, and on the upper level ionization potential in all the above mentioned cases. The Stark parameter dependence on the electron density is well established, and in the case of nonhydrogenic emitters it is linear. However, Stark width dependence on the electron temperature is different from line to line for all spectra. Therefore, the correction to the temperature dependence has to be done with great care for all data used, in particular case of the verification of certain type of mentioned dependencies and regularities. For instance, instead of the commonly adopted temperature dependence of $T^{-1/2}$ for ion lines, one has to use, from line to line (Purić and Šćepanović, 1999), the whole spectrum of functions of the form:

$$f(T) = A + BT^{-C} \tag{22}$$

Different kinds of regularities within Stark parameters of given spectra can be explained on the bases of their dependencies on the upper level ionization potential. A general form of that dependence in the case of the particular transition array is

$$\omega, d = N_e f(T) / z^c = a\chi^{-b} \tag{23}$$

where ω/d is the line width/shift in angular frequency units; χ is the corresponding upper level ionization potential expressed in *eV*; *z* is the rest core charge of the emitter as seen by the electron undergoing the transition. The coefficients *a, b* and *c* are independent of the ionization potential (for particular electron temperature and density) for a given transition.

Moreover, it has been found that the coefficient c is a universal constant approximately equal to 5.20. The procedure for Stark broadening data predictions was

described elsewhere. A comprehensive set of Stark broadening data of the investigated ions has been used here to demonstrate the existence of Stark width data regularities within this group of spectral lines.

3. RESULTS AND DISCUSSION

It has been verified that Eq. (23) is appropriate for all investigated transitions in all groups of the ions above mentioned, at different temperatures and electron densities. Namely, for Stark width, it was found that the best fit can be obtained if $f(T)$ is taken as given by Eq. (22) instead of $T^{1/2}$ (for some of 450 calculations of lines see Fig. 1).

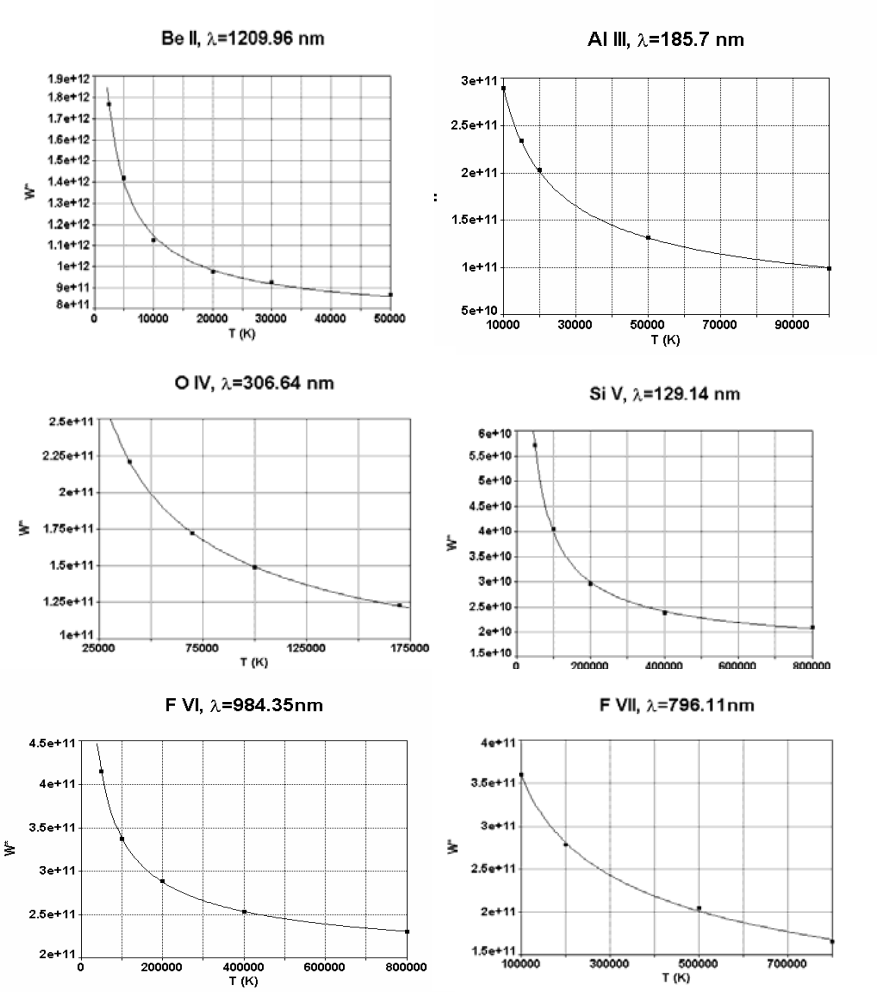

Fig. 1: Reduced Stark width dependencies on the rest core charge, within spectral lines originating from 2*p*-*nd* (n = 3, 4, 5), 2*s*-*np* (n = 2, 3), 2*p*-3*s*, 3*d*-*np* (n = 4, 5), 3d-4*f*, 3*p*-*nd* (n = 3, 4, 5), 3*p*-*ns* (n = 4, 5), 3*s*-*np* (n = 3, 4, 5), 4*s*-*np* (n = 4, 5), 4*p*-*nd* (n = 4, 5), 4*p*-5*s*, 5*p*-5*d* and 5*s*-5*p* were found (Purić and Šćepanović, 1999 and references therein) and shown in Fig. 2. It was found that the appropriate coefficients are $a = 1.95 \times 10^{12}$ and $b = 3.1$.

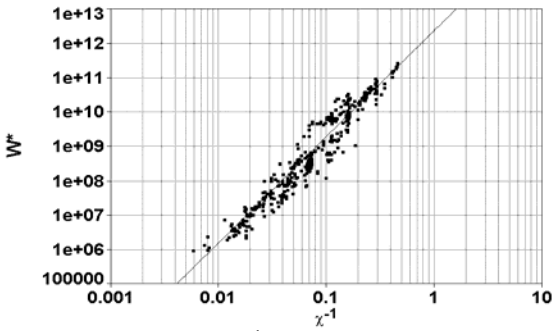

Fig. 2: Reduced Stark width W* (rad s^{-1}) vs. inverse value of upper level ionization potential χ (eV) of the multiply charged ion of different elements along the periodic system.

Experimental reduced Stark width dependencies on the upper level ionisation potential and the rest core charge within spectral lines originating from 3*s*-3*p* and 3*p*-3*d* similar transition under the different plasma condition we used and calculated (Šćepanović and Purić, 2003 and references therein). After being well established and checked using existing theoretical data these dependencies can be used to predict additional Stark broadening data for the lines for which neither theoretical nor experimental data are yet available. The function of the inverse of the upper level ionisation potential χ of the corresponding transition is given in Fig.3 (Šćepanović and Purić, 2003) for 3*s*-3*p* and in Fig. 4 (Šćepanović and Purić, 2003) for 3*p*-3*d*.

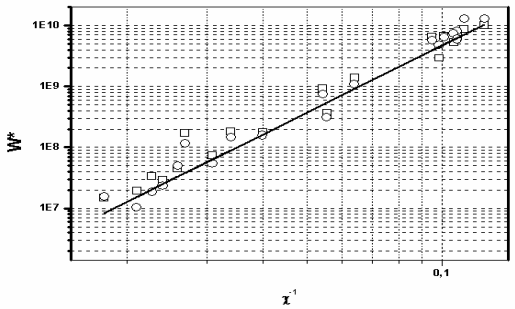

Fig. 3: Reduced Stark width W* (rad s^{-1}) vs. inverse value of upper level ionization potential χ (eV) of the multiply charged ion of different elements for 3s-3p transition array, squares for experimental width, circles for calculated width and line for the trend.

Making use of the theoretical results to find the systematic trends (Šćepanović and Purić, 2003 and references therein), it was found that the coefficients are as follows: a = 2.21 x 10^{13} and b = 3.67 for 3*s*-3*p* transitions, a = 4.22 x 10^{12} and b = 3.4 for 3*p*-3*d* transitions. In Fig. 5 (Šćepanović and Purić, 2003) we used the established coefficients from Fig. 2.

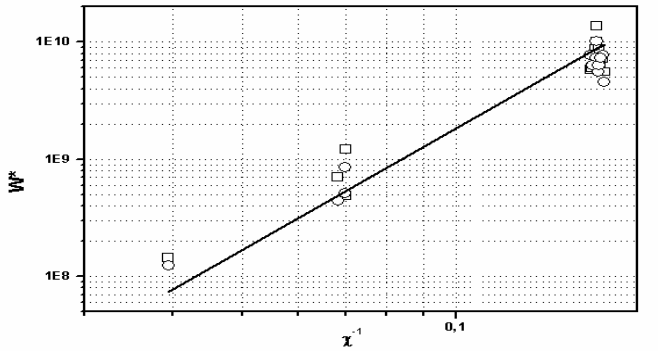

Fig. 4: Reduced Stark width W* (rad s^{-1}) vs. inverse value of upper level ionization potential χ (eV) of the multiply charged ion of different elements for 3p-3d transition array, squares for experimental width, circles for calculated width and line for the trend.

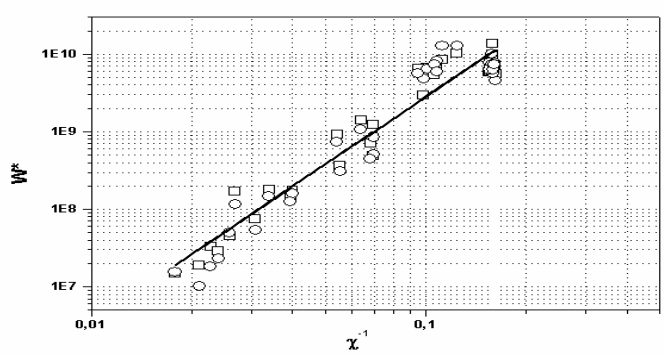

Fig. 5: Reduced Stark width W* (rad s^{-1}) vs. inverse value of upper level ionization potential χ (eV) of the multiply charged ion of different elements for 3p-3d and 3p-3d transition array, squares for experimental width, circles for calculated width and line for the trend.

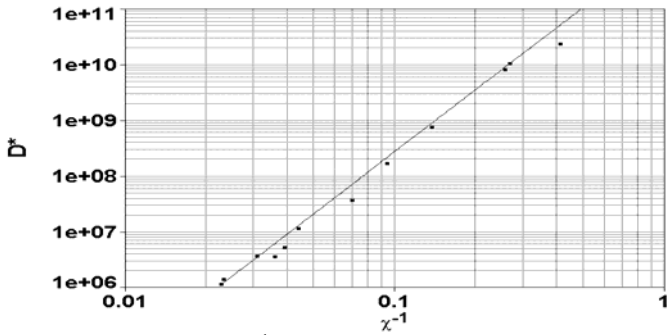

Fig. 6: Reduced Stark shift D* (rad s^{-1}) vs. inverse value of upper level ionization potential χ (eV) of the multiply charged ion of different elements from *3p-ns* (*n*=2,3) transition arrays.

Reduced Stark width dependencies on the rest core charge, within spectral lines originating from *3p-ns* (*n*=2,3) transition arrays were found (Šćepanović and Purić, 2002 and references therein) and shown in Fig. 6. It was found that the appropriate coefficients are $a = 1.57 \times 10^{12}$ and $b = 3.7$. The corresponding correlation factor for all the figures was almost equal to unity.

All data correspond to an electron density $N_e = 10^{23}$ m^{-3} and for different temperatures being normalized using Eq. (22) at $T = 10^5$ K.

5. CONCLUSION

Searching for different types of regularities and systematic trends, which can simplify complicate theoretical calculations especially used in astrophysics, is of great interest. Therefore the aim of this paper was to establish as precisely as possible the Stark parameters dependence on the rest core charge ot the emitters. The dependence was verified through introduction of the Stark widths and shifts reduced values $\omega^* = \omega \cdot z^{-5.20}$, and $d^* = d \cdot z^{-5.20}$, where z is the rest core charge of the emitter seeing by the electron undergoing transition (z = 1, 2, 3, ….for neutral atom, singly, doubly charged ion…respectively) and demonstrating their dependence on the upper level ionization potential. This work successfully proves the existence of the regularities. They are graphically presented for different transition arrays for various ion stages of many elements. Temperature dependence is very important for studying Stark parameters regularities and therefore we have used theoretical values obtained by different authors for 450 spectral lines originating from different stages of ionisations of investigated elements in order to determine Stark parameters temperature dependence through introduced coefficients *A, B* and *C* for these lines used in systematic trends analysis for temperature data normalization. Normalization at an electron density was used as being linear function for non-hydrogenic emitters.

In studying regularities of Stark widths we have treated 23 transition arrays. First, we have successfully found *a* and *b* coefficients values for the introduced reduced Stark broadening parameters $\omega^* = \omega \cdot z^{-5.20}$ for the investigated transition arrays separately to determine their dependences on the upper level ionisation potential. Second, we have treated Stark widths reduced values all together (for all investigated spectral lines originating from different transition arrays and ionisation stages) and have found that they satisfy a universal dependence on the upper level ionization potential similar to those obtained treating transition arrays separately. The obtained theoretical dependence has been compared with experimentally determined Stark widths for 46 spectral lines published so far and an agreement within ± 17 % was found.

Similar procedure was used to obtain Stark shift reduced values dependence on the upper level ionization potential. In this case we had for analysis a smaller sample of published data especially for temperature correction. Therefore, temperature normalization has been done using Stark shift dependence as inverse value of square root of electron temperature. We have studied 9 transition arrays and for each of them we found values of *a* and *b* coefficients. .Finally, Stark parameters reduction using their dependence on the rest core charge of the emitter and the found dependences on the upper level ionization potential can be regarded as being well established using the published theoretical and experimental data so far. Therefore they can be used to estimate the needed Stark widths and shift data for the lines not investigated so far.

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