STARK LINE BROADENING WITHIN SPECTRAL SERIES OF POTASSIUM ISOELECTRONIC SEQUENCE

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1. Introduction

In the presented paper Stark widths of transitions within ns-np, np-ns, np-nd, nd-np and nd-nf spectral series of potassium like emitters are investigated using regularity approach.

Stark width data of elements analyzed in the presented paper are of great interest for astrophysics and plasma technologist. In the last decade, potassium has become the element of interest in investigations of the evolutionary phases of globular clusters, for example in NGC 104, NGC 6752, NGC 6809, NGC 2808etc. It has been found that [K/Fe] abundance ratios display correlations with abundance ratios of some other elements and Fe and this can be used in the investigation of the chemical evolution of stars. Data of Stark widths are of interest for calculations of potassium K I abundance in the solar atmosphere and in atmosphere of Metal-Poor stars. Ca II Stark data are of interest for opacity research of young stellar objects. Intensity of Ca ii emission lines can be used for validation of turbulent chromosphere theory or the magnetic accretion theory for classical T Tauri stars. Ca II lines are present in 25 percent of DA white dwarfs not in binary or common proper motion systems. Ti IV ions can be found in quasars and various stellar plasmas. Titanium alloys and Titanium Nitride (TiN) are of interest for investigations related to the problem of the first wall in fusion reactors. Because of the high thermal loads, particularly during the type 1 ELMs (edge-localized mode: a disruptive instability occurring in the edge region of fusion devices), a strong erosion of the plasma-facing components is expected. Ti IV can be detected under these conditions.

The uncertainties in the solar opacity calculations are due to the line broadening, dominated by the Stark effect. The information about the abundance of the chemical elements in the stars is important for understanding their chemical evolution.

2. THEORETICAL BACKGROUND

The electron configuration of the ground state of K I and Ca II is [Ar]4s with term ^{2}S, while [Ar]3d is the electronic configuration of Sc III, Ti IV and V V, with term ^{2}D. Except for this competition of levels in terms of the lowest energy, i.e. the energy of the ground state, they all have similar excited states. Except for this competition of levels in terms of the lowest energy, i.e. the energy of the ground state, they all have similar excited states. Regularities of atomic parameters within spectral series of the investigated isoelectronic sequence are expected.

In the present investigation the Stark width functional dependence on the ionization potential of the upper level of the corresponding transition (χ) and on the rest core charge of the ionized emitter (Ze), within spectral series of the copper isoelectronic sequence, has been investigated. The effects of electron density and temperature on the Stark broadening of spectral lines have been analyzed, too.

The formula from which the Stark broadening regularities can be determined is given by [9]:

$$\omega * = \frac{\omega}{Z_e^{c_1}} = a \cdot log(\chi^{-b}) \qquad (1)$$

ω* [rad/s] is the reduced Stark width, χ [eV] is the electron binding energy on the upper level of analyzed transition, Z_e is the rest core charge of the emitter , Z_e = 1, 2, 3... for neutrals, singly charged ions and so on, respectively; $a = const \cdot N_e \cdot f(T_e)$; b is a fitting coefficient. Parameter c_1 can be found by analyzing the quality of the fit which is determined by factor R^2 (Dojčinović et al. 2019.).

3. RESULTS AND DISCUSSION

Regularity analysis within copper like emitters include 54 spectral lines: Cu I (11), Zn II (11), Ga III (10), Ge IV (17), Kr VIII (5). Stark width data used in the present study are taken from Stark B data base [3]. Data were complemented with available experimental data of Stark widths. χ values are taken from NIST atomic database [2].

Stark widths used in the present investigation are normalized at electron density $N_e = 10^{16}$ cm $^{-3}$, taking into account the constant ratio $\Delta\lambda/N_e$ [1].

Temperature data normalization has been done according to [4]:

$$f(T) = A + B \cdot T^{-C} \qquad (2)$$

The coefficients A, B and C are independent of temperature.

Software, which role is calculation of parameters A, B and C by using of Eq. (2), was made and it enable normalization at wanted temperature.

Two examples of above explained fitting procedure are represented at Fig. 1. and Fig. 2. where transitions 4s-4p and 3d-6p have been analyzed. The values of parameters are A = 6.26 x 10^7, B = 1.89 x 10^5, C = -0.47 for 4s-4p transition and A =-4 x 10^7, B = 8.53 x 10^7, C =-0.22 for 3d-6p transition, respectively. Stark widths data at temperature T = 100,000 K are calculated before the start of regularity investigation for all analyzed transitions.

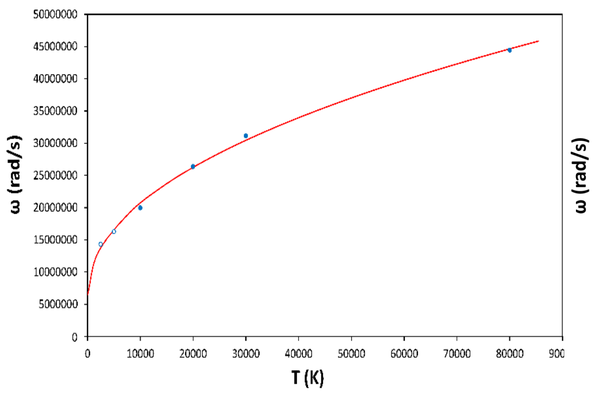

Figure 1. Stark widths functional dependence on temperature for transition 4s-4p (767.62 nm) within emitter K I

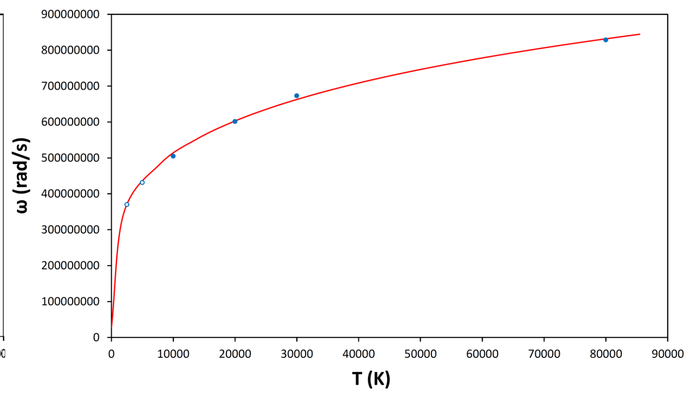

Figure 2. Stark widths functional dependence on temperature for transition 3d-6p (1338.4 nm) within emitter K I

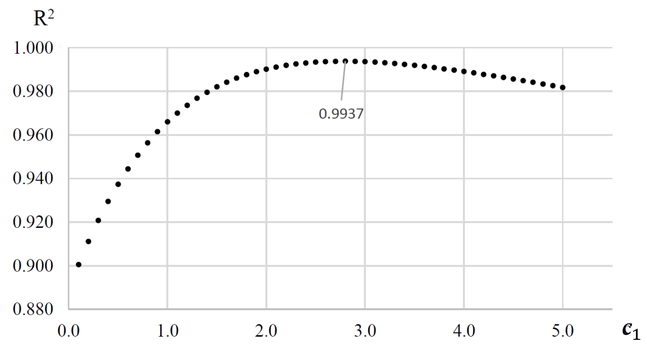

Fig. 3. Determination of the best exponent c for all spectral series of K I isoelectronic sequence at T = 100 000 K and $N_e = 10^{16}$ cm^{-3}. R^2 is correlation factors of fits.

Value of parameter c_1 in Eq. (2) has been determined by the process of monitoring the change in fit quality (determined by factor R^2) when changing the value of the parameter c [5]. Fig. 3 it can be concluded that the fit has the best quality if parameter c is approximately equal to 2.8.

Additionally, another software was made for analysis of Stark broadening dependence on the upper level ionization potential according to the Eq. (2). As an example of fitting procedure, dependence of Stark width on temperature has been presented for ns-np and np-nd transitions within K I (Fig. 4. and Fig. 5). In the present investigation data are given at same electron density $N_e = 10^{16}$ cm $^{-3}$ and at temperature T = 100 000 K.

According to fitting parameters, Stark widths for any transition within ns-np, np-ns, np-nd, nd-np and nd-nf spectral series of potassium isoelectronic sequence can be calculated using formula (4):

$$\Delta\lambda = p \cdot 10^{-20} \cdot \frac{Z_e^{2.8} N_e}{\chi^q} \lambda^2 \qquad (3)$$

Values of parameters p and q are given in Table 1. In Eq. (3) λ and Δλ are expressed in [m], Ne is expressed in [m] and χ is expressed in [eV].

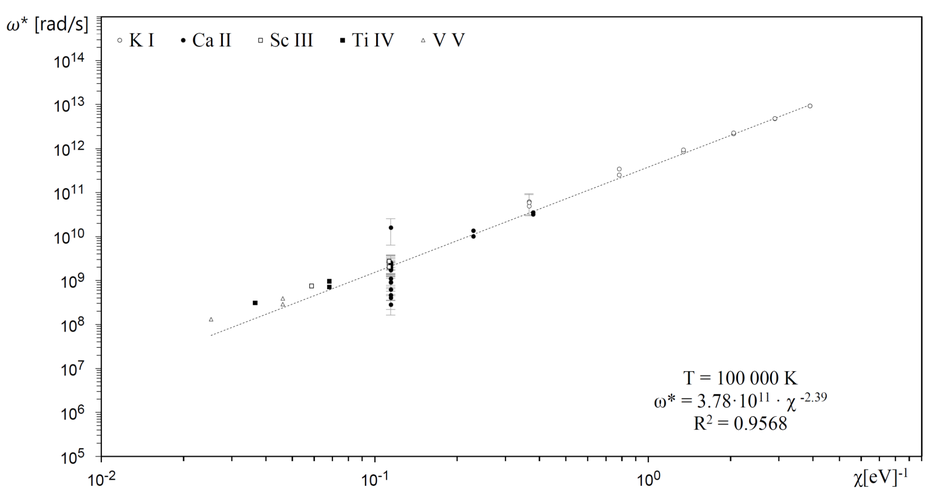

Fig 4. The electron impact contributions to Stark widths (in rad/s) versus inverse upper level ionization potential (in eV) for ns-np spectral series of K I isoelectronic sequence

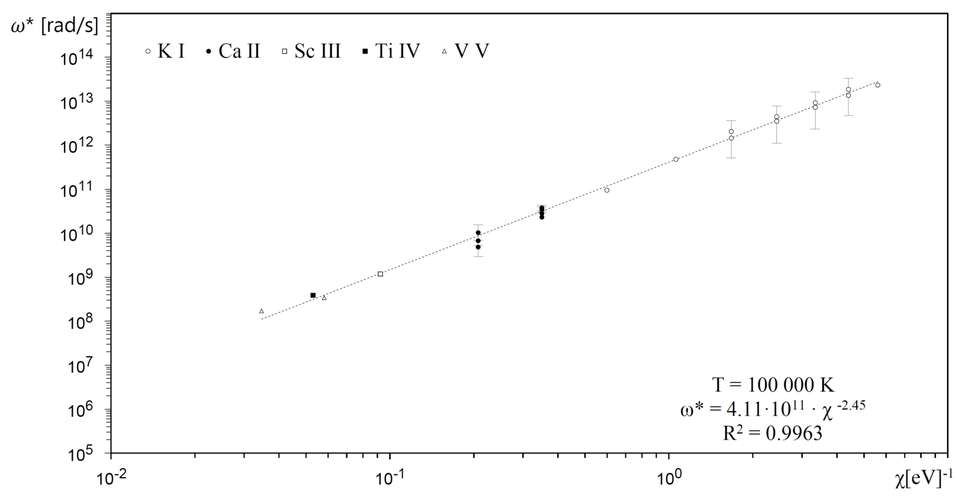

Fig 5. The electron impact contributions to Stark widths (in rad/s) versus inverse upper level ionization potential (in eV) for np-nd spectral series of K I isoelectronic sequence

Spectral Series	p	q
*n*s-*n*p	2.00	2.39
*n*p-*n*s	1.87	2.39
*n*p-*n*d	4.11	2.45
*n*d-*n*p	3.87	2.34
*n*d-*n*f	3.61	2.54

Table 1. Values of parameters p and q in equation (3) for analyzed spectral series

Emitter	Transition	λ [nm]	Δλ [nm]
Ti IV	4d-5f	126.51	1.04×10^{-3}
Ti IV	6p-7d	315.67	3.40×10^{-2}
Cr VI	4d-5p	116.72	2.77×10^{-4}
Cr VI	4d-4f	126.48	1.43×10^{-4}
Cr VI	5p-6s	134.27	3.54×10^{-4}
Cr VI	4s-4p	141.76	4.17×10^{-5}
Cr VI	5p-5d	217.66	1.18×10^{-3}
Fe VIII	3d-7f	14.98	3.23×10^{-7}
Fe VIII	3d-6f	15.76	3.57×10^{-7}
Fe VIII	3d-5f	17.28	4.30×10^{-7}
Fe VIII	3d-4p	19.47	1.38×10^{-6}
Fe VIII	3d-4f	20.98	6.33×10^{-7}

Table 2. The calculated values of Stark widths ($T = 100\,000$ K and $N_e = 10^{16}$ cm^{-3})

Results of presented regularity analysis enable calculation of Stark widths for any transitions within ns-np, np-ns, np-nd, nd-np and nd-nf spectral series of the potassium isoelectronic sequence (in the temperature range $10^{-2} \cdot \chi_0$ and χ_0) whose Stark widths cannot be calculated with other methods. Examples of lines whose Stark widths could not be calculated using other theoretical models because of the lack of required parameters are given in Table 2.

4. CONCLUSIONS

Results of presented regularity analysis enable calculation of Stark widths for any transitions within ns-np, np-ns, np-nd, nd-np and nd-nf spectral series of the potassium isoelectronic sequence. Calculation of Stark widths of potassium-like ions is of interest for astrophysics and plasma physics.

6. References

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