STARK BROADENING OF SPECTRAL LINES WITHIN COPPER LIKE EMITTERS

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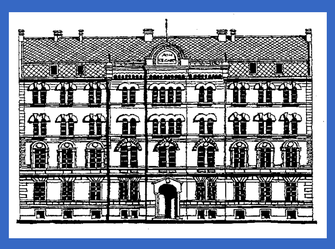

1. Introduction

Stark broadening data are significant for the investigation of astrophysical and laboratory plasmas. Years of investigation of the Stark effect phenomena leads to the conclusion of regularity existence within the spectral series of the same isoelectronic sequence. In the presented paper, Stark width regularities within the copper isoelectronic sequence are investigated, using available data for Cu I, Zn II, Ga III, Ge IV and Kr VIII.
Copper is widely used in electrical industry as an electrode material, so Stark data of copper are important for industrial laboratories. Stark widths of zinc, gallium, germanium and krypton are of interest for astrophysics. Spectral lines of zinc are used for determination of metallicity and content of dust in cosmic objects. Gallium is present in hot white drafts, while germanium is found in stellar and interstellar atmosphere [4]. Krypton is a product of s (neutron capture in slow time scale orderly evolution of stellar interiors) and r (neutron capture in fast time scale in type I supernovae) processes [1].

Modelling and simulations play an important role in astrophysical research - they allow determining the real nature of the analyzed sources if the input parameters are adequate. Extensive atomic data are important in eliminating uncertainties in astrophysical models. Stark widths data are required to be included in the codes used in spectrum analysis in the region where Stark broadening is present.

Recent investigations in the field of opacity calculations are based on modelling and developing of different codes used for precise calculations and on experimental projects where theory can be tested. These codes often use Voigt profiles for bound–bound transitions in opacity calculations. The Lorentz width is due to the natural and Stark broadening. 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 copper isoelectronic sequence members is [Ar]3d104s, with term 2S. The energy level 3d10 is stable, so the properties of these atoms are predominantly determined by a single-electron transition. Regularities within spectral series of the copper 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 [3]:

$$\omega = Z_e^{c_1} \cdot a_1 \cdot N_e \cdot f(T_e) \cdot (\chi^{-b_1}) \qquad (1)$$

where ω [rad/s] is the Stark width, χ [eV] is defined as a positive value of the electron binding energy on the upper level of the transition of interest, Z_e = 1, 2, 3... for neutrals, singly charged ions and so on, respectively, and a_1, b_1 and c_1 are coefficients independent of electron density and ionization potential for a particular transition and the rest core charge of the emitter.

Eq. (1) can be written in a form where regularities inside isoelectronic sequence are obvious and convenient for analysis:

$$\log(\omega^*) = \log(\frac{\omega}{Z_e^{c_1}}) = \log(a) + b \cdot \log(\chi^{-1}) \qquad (2)$$

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 [6]. Data were complemented with available experimental data of Stark widths. χ values are taken from NIST atomic database [2].

In presented investigation the ratio $\Delta\lambda/N_e$ has been assumed as constant. Generally, for non-hydrogen atoms this ratio is constant at low densities, but at high densities the influence of Debye shielding has to be taken into account - in this case, the linear dependence of Stark broadening on electron density is verified for a large number of spectral transitions.

Temperature data normalization has been done according to [3]:

$$f(T) = A + B \cdot T^{-c} \qquad (3)$$

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. (3), was made and it enable normalization at wanted temperature. Table 1. with parameters A, B and C for transition 4s-4p within analyzed emitters (except for Ga III for which there is no data in Stark-B database for 4s-4p transition) is given as an example of results of the fitting procedure.

Emitter	λ [nm]	A	B	C
Cu I	324.8	4.08E+07	1.28E+03	75E-02
Zn II	206.2	1.08E+09	-9.76E+08	83E-04
Ge IV	120.2	6.07E+09	6.07E+09	11E-04
Kr VIII	66.6	5.31E+07	-8.06E+07	20E-03

Table 1. Parameters A, B and C for 4s-4p transition used for temperature normalization

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_1 [5]. From Fig. 1 it can be concluded that the fit has the best quality if parameter c is approximately equal to 4.

Additionally, another software was made for analysis of Stark broadening dependence on the upper level ionization potential according to the Eq. (2). Results are represented at Fig. 2.

In the present investigation data are given at same electron density $N_e = 10^{16}$ cm $^{-3}$ and at temperature T = 100 000 K.

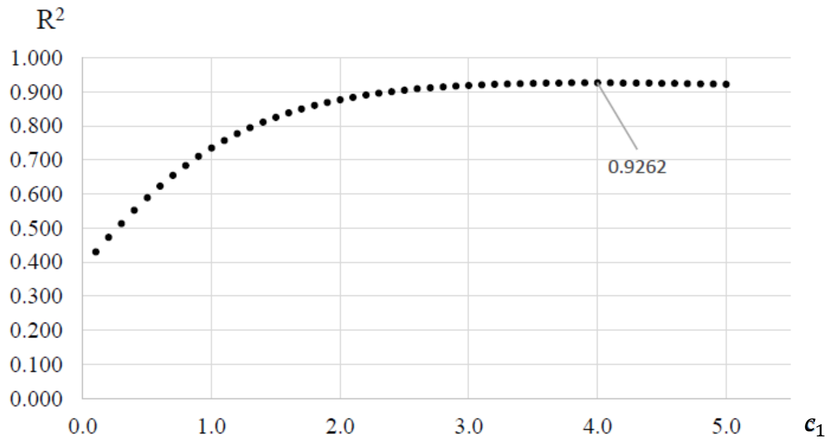

Fig. 1. Determination of the best exponent c_1 for all spectral series of Cu isoelectronic sequence at T = 100 000 K and $N_e = 10^{16}$ cm^{-3}. R^2 is correlation factors of fits.

Unique formula for Stark width determination for all transitions within copper like emitters, with minimum required atomic parameters (upper level ionization potential) is given in Eq. (4).

$$\Delta\lambda = 1.49 \cdot 10^{-20} \cdot \frac{Z_e^4 N_e}{\chi^{2.62}} \lambda^2 \qquad (4)$$

λ and Δλ are expressed in [m] and χ is expressed in [eV].
The simple model presented in this paper enable predictions for spectral lines (in the temperature range $10^{-2} \cdot \chi_0$ and χ_0) whose Stark widths cannot be calculated with other methods.

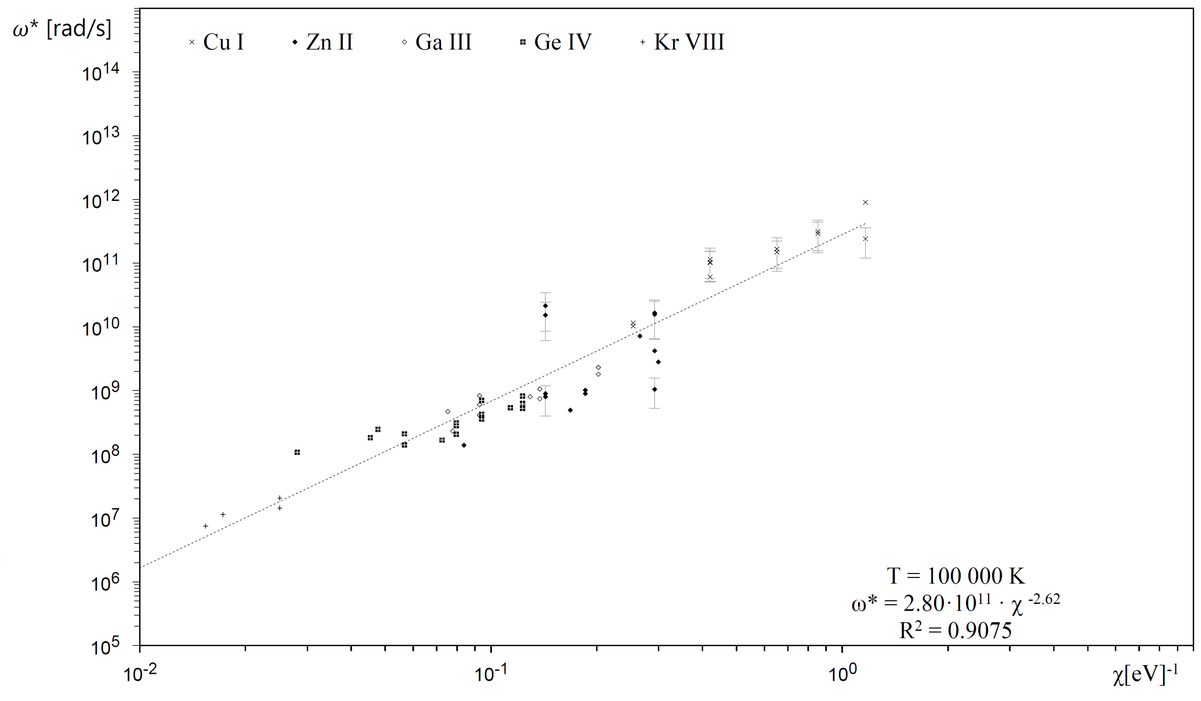

Fig 2. . The electron impact contributions to Stark widths (in rad/s) versus inverse upper level ionization potential (in eV) for all analyzed spectral series of Cu isoelectronic sequence

4. CONCLUSIONS

Simple model proposed in this paper enable calculation of Stark broadening data for any chosen transition within copper like emitters, by using a minimum number of parameters and it has simplest form in comparison with other methods.
Presented results are useful in extending the amount of available Stark width data. Additionally, algorithms which have been made for fast data processing enable quality control and provide verification of theoretically calculated results.

6. References

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