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Data on Stark Broadening of N VI Spectral Lines

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Abstract: Data on Stark broadening parameters, spectral line widths and shifts, for 15 multiplets of N VI, which spectral lines are broadened by collisions with electrons, protons, alpha particles (He III) and B III, B IV, B V and B VI ions, are presented. They have been calculated, using the semiclassical perturbation theory, for temperatures from 50,000 K to 2,000,000 K, and perturber densities from 10^{16} cm^{-3} up to 10^{24} cm^{-3}. These data are particularly of interest for the analysis and modelling of atmospheres of hot and dense stars, as e.g., white dwarfs, and for investigation of their spectra, but also for analyis ad modelling of laser driven plasma in proton-boron fusion research.

Dataset: Supplementary Files

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1. Introduction

Data for spectral lines, broadened by collisions with surrounding charged particles (Stark broadening) are useful for analyzis, modelling and dignostics of various plasmas in astrophysics , laboratory, fusion experiments and technology, as well as for laser produced plasma. Such data and the corresponding databases are especially needed in astronomy and astrophysics, for stellar spectroscopy, radiative transfer calculation, abundance determination, stellar atmosphere modelling etc.

Spectral lines of N VI are present in cosmic plasma (see e.g., [1–3]), so that the corresponding Stark broadening data are needed for their analyzis and synthezis. Such data are particularly needed for hot and dense stars as for example white dwarfs, since in the conditions in their atmospheres Stark broadening is often the dominant broadening mechanism. Since Stark broadening data enter in the calculation of absorption coefficient, besides for abundance detrmination and atmosphere modelling, they are needed for calculation of a number of quantities and equations where the absorption coefficient enters.

Another interesting topic for the application of Stark broadening data for N VI is the proton-boron fusion [4], producing energy by aneutronic fusion reactions without radioactive species. We note that in some experimental devices [5] two boron nitride (BN) targets are used. On the first BN target is focused a laser beam, which generates protons that collide with the other BN target triggering nuclear reactions. In order to optimize the fusion yield, a plasma diagnostic is needed [6] and Stark broadening data for N VI may be useful for such purposes. Also, the presence of the multiply charged boron ions B IV, B V and B VI is clearly identified [7], so that broadening of N VI by collisions with multiply charged boron ions is also of interest.

By employing the semiclassical perturbation theory (see for example [8] and references therein), we calculated Stark widths and shifts, for 15 multiplets of N VI broadened by collisions with the most important charged constituents of stellar and proton-boron fusion plasma: electrons, protons, alpha

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particles (He III), B III, B IV, B V and B VI ions, for a grid of temperatures and perturber densities. The behavior of N VI Stark widths and shifts within a spectral series has been discussed in [9] and data for a perturber density of 10^{16} cm^{-3}, together with the applications to white dwarf atmospheres, have been presented in [10]. Here, all data for a greed of temperatures and perturber densities are presented as an online data set in computer readable form.

2. The Semiclassical Perturbation Method

For calculations of Stark broaening parameters, the semiclassical perturbation theory [8,11,12] has been used. Withim the frame of this theory, full width at half intensity maximum (FWHM-W) and shift (d) of an isolated spectral line of a non-hydrogenic ion, which is broadened by collisions with charged particles, are given with the following expression:

$$W = N\int vf(v)dv\left(\sum_{i'\neq i}\sigma_{ii'}(v)+\sum_{f'\neq f}\sigma_{ff'}(v)+\sigma_{el}\right)$$

$$d = N\int vf(v)dv\int_{R_3}^{R_D}2\pi\rho d\rho\sin(2\varphi_p). \quad (1)$$

where i and f are the inital and final level of the corresponding transition, i' and f' are their perturbing levels, N is the perturber density, v velocity of the perturber, $f(v)$ the Maxwellian velocity distribution, and ρ is the impact parameter of the perturbing particle.

The inelastic cross sections $\sigma_{kk'}(v)$, $k = i, f$, in the equation above, are included as an integral of the transition probability $P_{kk'}(\rho, v)$, over the impact parameter ρ :

$$\sum_{k'\neq k}\sigma_{kk'}(v) = \frac{1}{2}\pi R_1^2 + \int_{R_1}^{R_D}2\pi\rho d\rho\sum_{k'\neq k}P_{kk'}(\rho, v). \quad (2)$$

The elastic collisions and resonances are taken into account with the formula:

$$\sigma_{el} = 2\pi R_2^2 + \int_{R_2}^{R_D}2\pi\rho d\rho\sin^2\delta + \sigma_r,$$

$$\delta = (\varphi_p^2 + \varphi_q^2)^{\frac{1}{2}}. \quad (3)$$

Here, σ_{el} is the elastic cross section, φ_p (r^{-4}) and φ_q (r^{-3}), are phase shifts due to the polarization and quadrupolar potential (for more details see [11]). The symmetrization procedure and cut-offs R_1, R_2, R_3,and R_D are described in [12]. The term σ_r which gives the contribution of Feshbach resonances, σ_r is described in detail in [13].

For positively charged perturbers, i.e., potons and ions, since the Coulomb force is not attractive but repulsive, trajectories are different. Moreover, there is no contribution of Feshbach resonances.

3. Data Description

Within the frame of the semiclassical perturbation theory [8,11,12], Stark broadening parameters, widths (FWHM) and shifts of spectral lines for 15 N VI multiplets have been calculated. The obtained set of data is for collisions of N VI ions with electrons, protons, He III (alpha particles) and boron ions B III, B IV, B V and B VI, which are charged perturbers of particular importance for white dwarfs and proton-boron fusion. The data for full width at half maximum of intensity (W), and shift (d) are given in Tables within the data set in Supplementary Material for temperature values of 50,000 K 100,000 K, 300,000 K, 500,000 K, 1,000,000 K and 2,000,000 K, and perturber densities from 10^{16} cm^{-3} up to 10^{24} cm^{-3}, in the case of N VI collisions with electons, protons and alpha particles (He III), and up to 10^{21} cm^{-3} for boron ions, because for higher densities the impact approximation is not valid.

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The needed atomic energy levels for NVI, are from [14] and they are also in the NIST database [15]. All details of calculations are described in [10]

In the Tables in Supplementary Material is given and the quantity C [16]. When it is divided by the corresponding FWHM (W) one obtains the maximal perturber density for the validity of isolated line approximation.

4. User Notes

It should be noted that the wavelengths given in the Tables in Supplementry Material are calculated using atomic energy levels which are used for the Stark broadening parameter calculations and may be different from wavelengths present in the NIST database. If we want to change wavelength for the wavelength of a line within the considered muliplet, for the wavelength from NIST or for the experimental one, we can do this for the width using the expression:

$$W_{cor} = \left(\frac{\lambda_{new}}{\lambda}\right)^2 W. \tag{4}$$

and the similar one for the shift. Here, W_{cor} is the corrected width, λ_{new} is the NIST, or experimental, or observed value, or the value for a line within a multiplet, λ is the calculated wavelength, or the value for a multiplet as a whole and W is the corresponding width from Tables in the Supplementary Material.

If we want to obtain the line profile $F(\omega)$, we can use the following relation:

$$F(\omega) = \frac{W/(2\pi)}{(\omega - \omega_{if} - d)^2 + (W/2)^2}. \tag{5}$$

Here

$$\omega_{if} = \frac{E_i - E_f}{\hbar}$$

where E_i, E_f are the energies of initial and final atomic energy level, respectively.

5. Conclusions

The computer readable data set presented here and available online as Supplementary Material, contains Stark broadening parameters, widths and shifts for 15 N VI multiplets, obtained with the help of the semiclassical perturbation theory [8,11,12]. The data for N VI spectral lines broadened by collisions with electrons, protons, He III, B III, B IV, B V and B VI ions are given for a grid of temperatures and perturber densities.

The presented data set is first of all of interest for hot and dense stars like white dwarfs, where they can be used for abundance determination, analyzis and synthezis of stellar spectra, stellar atmosphere modelling and opacity and radiative transfer calculations. This data set is also important for proton-boron fusion experiments, particularly when the boron nitride BN, as a target for laser radiation, is used.

Supplementary Materials: The following supporting information are available online at: https://www.mdpi.com/article/10.3390/0010000/s1, Tables from S1-16 up to S9-24 present Stark widths and shifts of N VI spectral lines broadened by collisions with electrons, protons and alpha particles (He III), from a perturber densitity of 10^{16} cm^{-3} (S1-16) up to 10^{24} cm^{-3} (S9-24). Tables from S10-16 up to S15-21 present Stark widths and shifts of N VI spectral lines broadened by collisions with B III, B IV, B V and B VI ions, from a perturber densitity of 10^{16} cm^{-3} (S10-16) up to 10^{21} cm^{-3} (S15-21).

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