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STARK BROADENING DATA FOR N VI SPECTRAL LINES

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Abstract. The results of semiclassical perturbation calculations of Stark widths and shifts, for N VI spectral lines broadened by collisions with electrons, protons, alpha particles (He III) and B III, B IV, B V and B VI ions, are presented and discussed.

1. INTRODUCTION

Data for Stark broadening of spectral lines are useful for a number of topics in astronomy as e.g. for stellar spectroscopy, radiative transfer calculations, abundance determination, stellar atmosphere modelling etc.

Spectral lines of N VI are observed in stellar plasma (see e.g. Fleig et al. (2008), Newman et al. (2021), Ness et al. (2023)), so that the corresponding Stark broadening data are useful for their investigation and interpretation, particularly in the case of hot and dense stars such as e.g. white dwarfs.

Another topic where N VI Stark broadening data are of interest is the proton-boron fusion (Batani, 2023), which is aneutronic and without radioactive species. In some of such experiments, boron nitride target is used (Schollmeier, 2022). Since plasma diagnostic is needed here to optimize the fusion yield (Hegelich et al., 2023), Stark broadening data for N VI are needed for such purpose. Also, data on broadening by collisions with B IV, B V and B VI ions are useful since their presence has been confirmed (Kong et al., 2022).

Recently, we have calculated Stark 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. They have been calculated by employing the semiclassical perturbation method (Sahal–Bréchot, 1969ab, Sahal–Bréchot et al., 2014), 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}. Here we present a short review of obtained results.

Table 1: Stark full widths and shifts at half intensity maximum for N VI multiplets due to interactions with electrons, and protons. The perturber density is 10^{19} cm^{-3}.

TRANSITION	T(K)	ELECTRONS WIDTH(Å)	SHIFT(Å)	PROTONS WIDTH(Å)	SHIFT(Å)
SINGLETS					
N VI $1s^2$-2p	50000.	0.142E-03	-0.300E-04	0.183E-06	-0.382E-06
28.8 Å	100000.	0.933E-04	-0.304E-05	0.546E-06	-0.907E-06
C=0.29E+19	300000.	0.543E-04	-0.640E-06	0.243E-05	-0.262E-05
	500000.	0.431E-04	-0.448E-06	0.401E-05	-0.370E-05
	1000000.	0.322E-04	-0.337E-06	0.650E-05	-0.514E-05
	2000000.	0.247E-04	-0.116E-06	0.914E-05	-0.631E-05
N VI $1s^2$-3p	50000.	0.487E-03	-0.315E-04	0.177E-04	-0.297E-04
24.9 Å	100000.	0.361E-03	-0.154E-04	0.413E-04	-0.513E-04
C=0.16E+18	300000.	0.238E-03	-0.179E-04	0.967E-04	-0.869E-04
	500000.	0.199E-03	-0.175E-04	0.122E-03	-0.101E-03
	1000000.	0.158E-03	-0.137E-04	0.170E-03	-0.120E-03
	2000000.	0.126E-03	-0.105E-04	0.223E-03	-0.139E-03
N VI 2s-2p	50000.	1.89E+00	-0.823E-01	0.261E-02	-0.172E-01
2897.2 Å	100000.	1.36E+00	-0.436E-01	0.113E-01	-0.396E-01
C=0.29E+23	300000.	0.838E+00	-0.488E-01	0.635E-01	-0.948E-01
	500000.	0.681E+00	-0.480E-01	0.954E-01	-0.122E+00
	1000000.	0.525E+00	-0.452E-01	0.156E+00	-0.152E+00
	2000000.	0.414E+00	-0.382E-01	0.215E+00	-0.183E+00
N VI 2s-3p	50000.	0.253E-01	-0.759E-03	0.880E-03	-0.147E-02
173.3 Å	100000.	0.190E-01	-0.792E-03	0.204E-02	-0.254E-02
C=0.79E+19	300000.	0.126E-01	-0.102E-02	0.477E-02	-0.427E-02
	500000.	0.105E-01	-0.100E-02	0.600E-02	-0.497E-02
	1000000.	0.836E-02	-0.814E-03	0.840E-02	-0.589E-02
	2000000.	0.671E-02	-0.640E-03	0.110E-01	-0.678E-02
N VI 3s-3p	50000.	1.12E+02	-3.84E+00	*4.15E+00	*-6.29E+00
9624.6 Å	100000.	8.48E+01	-5.63E+00	*8.93E+00	*-1.06E+01
C=0.24E+23	300000.	5.72E+01	-6.45E+00	*1.89E+01	*-1.73E+01
	500000.	4.83E+01	-6.48E+00	2.37E+01	-2.00E+01
	1000000.	3.87E+01	-5.36E+00	3.33E+01	-2.40E+01
	2000000.	3.10E+01	-4.24E+00	4.19E+01	-2.59E+01
N VI 2p-3s	50000.	0.208E-01	0.917E-03	0.385E-03	0.984E-03
187.9 Å	100000.	0.157E-01	0.140E-02	0.118E-02	0.181E-02
C=0.37E+20	300000.	0.105E-01	0.146E-02	0.292E-02	0.312E-02
	500000.	0.890E-02	0.149E-02	0.365E-02	0.366E-02
	1000000.	0.712E-02	0.128E-02	0.495E-02	0.438E-02
	2000000.	0.569E-02	0.102E-02	0.652E-02	0.499E-02

Table 1: Cont.

TRANSITION	T(K)	ELECTRONS WIDTH(Å)	SHIFT(Å)	PROTONS WIDTH(Å)	SHIFT(Å)
TRIPLETS					
N VI 2s-2p	50000.	0.742E+00	0.979E-02	0.787E-03	-0.444E-02
1901.5 Å	100000.	0.530E+00	-0.137E-01	0.297E-02	-0.104E-01
C=0.19E+23	300000.	0.321E+00	-0.172E-01	0.171E-01	-0.270E-01
	500000.	0.259E+00	-0.164E-01	0.268E-01	-0.349E-01
	1000000.	0.198E+00	-0.155E-01	0.461E-01	-0.455E-01
	2000000.	0.155E+00	-0.140E-01	0.634E-01	-0.544E-01
N VI 2s-3p	50000.	0.199E-01	-0.569E-04	0.204E-03	0.270E-03
161.2 Å	100000.	0.147E-01	0.115E-03	0.499E-03	0.549E-03
C=0.19E+20	300000.	0.959E-02	0.132E-03	0.124E-02	0.107E-02
	500000.	0.800E-02	0.153E-03	0.160E-02	0.126E-02
	1000000.	0.634E-02	0.108E-03	0.218E-02	0.151E-02
	2000000.	0.511E-02	0.892E-04	0.303E-02	0.179E-02
N VI 2s-4p	50000.	0.335E-01	0.143E-03	*0.135E-02	*0.126E-02
122.4 Å	100000.	0.257E-01	0.397E-03	*0.233E-02	*0.209E-02
C=0.48E+19	300000.	0.176E-01	0.657E-03	*0.414E-02	*0.339E-02
	500000.	0.149E-01	0.657E-03	*0.505E-02	*0.394E-02
	1000000.	0.120E-01	0.524E-03	*0.661E-02	*0.463E-02
	2000000.	0.977E-02	0.443E-03	*0.822E-02	*0.531E-02
N VI 3s-3p	50000.	5.32E+01	0.829E+00	0.373E+00	-0.466E+00
6993.0 Å	100000.	3.99E+01	-1.20E+00	0.906E+00	-0.956E+00
C=0.36E+23	300000.	2.65E+01	-1.29E+00	2.27E+00	-1.89E+00
	500000.	2.23E+01	-1.26E+00	3.00E+00	-2.22E+00
	1000000.	1.79E+01	-1.18E+00	4.29E+00	-2.67E+00
	2000000.	1.44E+01	-0.937E+00	6.14E+00	-3.15E+00
N VI 3s-4p	50000.	0.576E+00	-0.121E-02	*0.182E-01	*0.164E-01
474.5 Å	100000.	0.441E+00	-0.555E-03	*0.316E-01	*0.275E-01
C=0.72E+20	300000.	0.303E+00	0.280E-02	*0.569E-01	*0.448E-01
	500000.	0.257E+00	0.273E-02	*0.698E-01	*0.529E-01
	1000000.	0.208E+00	0.149E-02	*0.956E-01	*0.602E-01
	2000000.	0.169E+00	0.157E-02	*0.120E+00	*0.692E-01
N VI 2p-3s	50000.	0.175E-01	0.412E-03	0.203E-03	0.654E-03
180.7 Å	100000.	0.130E-01	0.107E-02	0.703E-03	0.126E-02
C=0.47E+20	300000.	0.857E-02	0.118E-02	0.199E-02	0.224E-02
	500000.	0.721E-02	0.118E-02	0.254E-02	0.261E-02
	1000000.	0.576E-02	0.107E-02	0.333E-02	0.310E-02
	2000000.	0.462E-02	0.865E-03	0.434E-02	0.360E-02
N VI 2p-4s	50000.	0.269E-01	0.150E-02	*0.161E-02	*0.192E-02
131.9 Å	100000.	0.207E-01	0.216E-02	*0.297E-02	*0.322E-02
C=0.10E+20	300000.	0.144E-01	0.259E-02	*0.542E-02	*0.515E-02
	500000.	0.122E-01	0.255E-02	*0.658E-02	*0.606E-02
	1000000.	0.985E-02	0.206E-02	*0.842E-02	*0.692E-02
	2000000.	0.785E-02	0.169E-02	*0.110E-01	*0.780E-02

Table 1: Cont.

TRANSITION	T(K)	ELECTRONS WIDTH(Å)	SHIFT(Å)	PROTONS WIDTH(Å)	SHIFT(Å)
TRIPLETS					
N VI 3p-4s	50000.	0.575E+00	0.246E-01	*0.242E-01	*0.290E-01
524.5 Å	100000.	0.441E+00	0.319E-01	*0.446E-01	*0.487E-01
C=0.16E+21	300000.	0.303E+00	0.382E-01	*0.802E-01	*0.778E-01
	500000.	0.258E+00	0.375E-01	*0.101E+00	*0.918E-01
	1000000.	0.208E+00	0.303E-01	*0.131E+00	*0.104E+00
	2000000.	0.166E+00	0.247E-01	*0.170E+00	*0.122E+00

2. RESULTS AND DISCUSSION

For the calculation of Stark broadening parameters, full widths at half intensty maximum (FWHM - W) and shifts - d for 15 N VI multiplets, the semiclassical perturbtion approach (Sahal–Bréchot, 1969ab, Sahal–Bréchot et al., 2014) has been used. The theoretical method and all detais of calculations are described in Dimitrijević et al. (2023a). Also, the obtained results for N VI Stark widths and shifts due to collisions with electrons, protons, alpha particles (He III) and B III, B IV, B V and B VI ions, for temperatures from 50,000 K to 2,000,000 K, and a perturber density of 10^{16} cm^{-3}, have been presented and discussed. The obtained results have been used to investigate and demonstrate the influence and significance of Stark broadening of N VI spectral lines in atmospheres of white dwarfs. In Dimitrijević et al. (2023b), the behavior of N VI Stark widths and shifts within a spectral series has been investigated and the influence of collisions with different charged particles (e, p, He III, B III, B IV, B V and B VI) on N VI linewidths and shifts due to different perturbers have been compared and discussed in detail. In Dimitrijević et al. (2023b), all above mentioned data for perturber densities from 10^{16} cm^{-3} up to 10^{24} cm^{-3} have been presented as an online data set in computer readable form.

As an example of obtained results, in Table 1 are presented Stark full widths at half intensity maximum and shifts for 15 N VI multiplets due to interactions with electrons, and protons, for a perturber density of 10^{19} cm^{-3} and temperatures from 50,000 K to 2,000,000 K. In the Table is given and the quantity C (Dimitrijević and Sahal-Bréchot, 1984). When it is divided by the corresponding FWHM, one obtains the maximal perturber density for the validity of the isolated line approximation. We checked for all values presented in the Table the validity of impact approximation calculating the value of NV, where V is the collision volume and N the perturber density. If $NV < 0.1$, the impact approximation is valid. We excluded the cases when $NV > 0.5$ from the tables, while for $0.1 < NV \leq 0.5$, we put an asterisk before the corresponding Stark broadening parameter in order to draw attention that this value is on the limit of validity of impact approximation. In Table 2, the same data as in Table 1, but for B V and B VI ions as perturbers are presented,

The obtained results for N VI Stark broadening parameters, obtained in this investigation, will also enter in STARK-B database (http://stark-b.obspm.fr/ - Sahal-Bréchot et al., 2015ab), a part of european Virtual Atomic and Molecular Data Center VAMDC (http://www.vamdc.org/ - Dubernet et al., 2010, 2016, Albert et al.,2020).

Table 2: Stark full widths at half intensity maximum and shifts of N VI multiplets due to interactions with B V and B VI ions. The perturber density is 10^{19} cm^{-3}.

		B V		B VI	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
SINGLETS					
N VI $1s^2$-2p	50000.	0.332E-06	-0.644E-06	0.254E-06	-0.547E-06
28.8 Å	100000.	0.135E-05	-0.270E-05	0.131E-05	-0.302E-05
C=0.29E+19	300000.	0.765E-05	-0.103E-04	0.827E-05	-0.128E-04
	500000.	0.137E-04	-0.155E-04	0.155E-04	-0.197E-04
	1000000.	0.230E-04	-0.224E-04	0.278E-04	-0.293E-04
	2000000.	0.324E-04	-0.284E-04	0.419E-04	-0.382E-04
N VI 2s-2p	50000.	0.524E-02	-0.290E-01	0.434E-02	-0.247E-01
2897.2 Å	100000.	0.313E-01	-0.119E+00	0.320E-01	-0.134E+00
C=0.29E+23	300000.	0.230E+00	-0.381E+00	0.266E+00	-0.483E+00
	500000.	0.371E+00	-0.512E+00	0.464E+00	-0.658E+00
	1000000.	0.640E+00	-0.683E+00	0.828E+00	-0.912E+00
	2000000.	0.842E+00	-0.833E+00	1.10E+00	-1.11E+00
TRIPLETS					
N VI 2s-2p	50000.	0.150E-02	-0.748E-02	0.119E-02	-0.636E-02
1901.5 Å	100000.	0.777E-02	-0.311E-01	0.774E-02	-0.348E-01
C=0.19E+23	300000.	0.574E-01	-0.106E+00	0.672E-01	-0.133E+00
	500000.	0.107E+00	-0.146E+00	0.134E+00	-0.191E+00
	1000000.	0.185E+00	-0.206E+00	0.232E+00	-0.273E+00
	2000000.	0.251E+00	-0.250E+00	0.328E+00	-0.333E+00
N VI 2s-3p	50000.	*0.423E-03	*0.449E-03		
161.2 Å	100000.	*0.156E-02	*0.165E-02		
C=0.19E+20	300000.	*0.450E-02	*0.422E-02		
	500000	*0.619E-02	*0.535E-02		
	1000000.	*0.781E-02	*0.672E-02	*0.101E-01	*0.893E-02
	2000000.	*0.923E-02	*0.816E-02	*0.127E-01	*0.110E-01
N VI 3s-3p	50000.	*0.763E+00	*-0.778E+00	*0.628E+00	*-0.659E+00
6993.0 Å	100000.	*2.81E+00	*-2.88E+00	*3.05E+00	*-3.28E+00
C=0.36E+23	300000.	*8.01E+00	*-7.39E+00	*9.85E+00	*-9.45E+00
	500000	*1.11E+01	*-9.50E+00	*1.41E+01	*-1.26E+01
	1000000.	*1.40E+01	*-1.20E+01	*1.80E+01	*-1.58E+01
	2000000.	*1.71E+01	*-1.43E+01	*2.23E+01	*-1.95E+01

The obtained result are of interest for astrophysical applications as for example for abundance determination, analysis and synthesis of stellar spectra, stellar atmosphere modelling, radiative transfer calculations..., particularly for white dwarfs. They are also useful for proton-boron fusion research, since the boron nitride BN, as a target for laser radiation, is important in such experiments, and N VI spectral lines may be used for diagnostic and modelling of created plasma.

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