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Temperature dependence of Stark width of the 463.054 nm N II spectral line

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Abstract. Stark width of the 463.054 nm singly ionized nitrogen spectral line, that belong to 3s – 3p transition, have been measured in a linear pulsed, low pressure, arc discharge. The working gas was helium-nitrogen-oxygen mixture. Electron densities of $0.75\,10^{23}$ m^{-3} to $1.45\,10^{23}$ m^{-3} were determined in the electron temperature range between 30 000 K – 38 000 K. The measured values have been compared with our calculated data, using the modified semiempirical approximation. On the basis of the agreement among experimental and theoretical Stark width data, the isolated 463.054 nm N II spectral line can be recommended as convenient spectral line for plasma diagnostics.

Key words: lines, profiles-atomic data-methods: laboratory

1. Introduction

The abundance of nitrogen atoms in the Earth atmosphere and the great number of singly ionized nitrogen spectral lines (N II) in stars spectra make them important for plasma diagnostic purposes over a wide range of electron temperature. Namely, information on the chemical evolution of the elements in stars and stellar associations (Cuhna & Lambert 1994; Leuenhagen & Hamann 1998) and on the kinetics, dynamics and structure of the galaxies (Bland-Hawthorn et al. 1997), can be supplied on the basis of the N II spectral lines. If the Stark broadening is the principal pressure broadening mechanism in plasmas (with 10^{22} m^{-3} – 10^{27} m^{-3} electron density), on the basis of Stark width values it is possible to obtain other basic plasma parameters e.g. electron temperature (T) and density (N), essential in the modeling of the stellar atmospheres (Lesage 1994). It is of interest to find spectral lines with well-know Stark width values convenient in plasma diagnostics. A number of experimental papers deal with Stark FWHM (full-width at half intensity maximum, w) of singly ionized nitrogen spectral lines from multiplet $^3P^0$ – ^3P (No. 5) belonging to 3s – 3p transition (Day & Griem 1965; Berg et al. 1967; Jalufka & Craig 1970; Konjević et al. 1970; Popović et al. 1975; Purcell & Barnard 1984; Purić et al. 1987; Djeniže et al. 1990; Perez et al. 1997; Milosavljević & Djeniže 1998). The 463.054 nm spectral line, that belong to this multiplet, is the most investigated spectral line in the N II spectrum. Up to this time eight experiments (Berg et al. 1967; Jalufka & Craig 1970; Konjević et al. 1970; Popović et al. 1975; Purcell & Barnard 1984; Purić et al. 1987; Perez et al. 1997; Milosavljević & Djeniže 1998) deal with Stark FWHM investigation of this line. However, no theoretical Stark FWHM predictions exist for this line, to the knowledge of the authors (Fuhr & Lesage 1993). Experimental Stark FWHM data of the 463.054 nm spectral line lies in a wide range of the electron temperature, from 6 500 K up to 54 000 K. Most of the existing experimental w data lies about 22 000 K electron temperature.

The aim of this paper is to provide some new experimental Stark FWHM data on 463.054 nm N II spectral line at electron temperatures between 30 000 K and 38 000 K. Namely, knowledge of the Stark FWHM dependence upon the electron temperature in the plasma is important for testing their theoretical predictions based on various approaches. We have measured the Stark FWHM of 436.054 nm N II spectral line at: 30 000 K, 33 000 K, 35 000 K and 38 000 K electron temperatures and correspondent electron densities: (0.75, 1.15, 1.30, 1.45) 10^{23} m^{-3}, respectively. The theoretical dependence of Stark width w on the electron temperature, on the basis of the modified semiempirical approximation (Dimitrijević & Konjević 1980) has been calculated as well.

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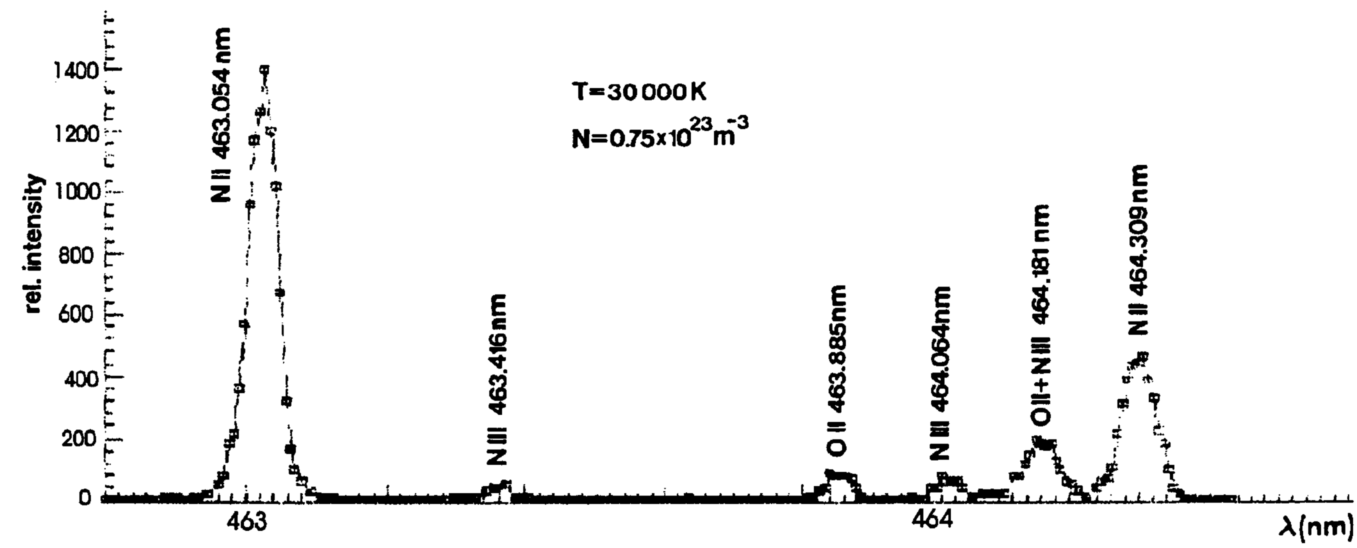

Fig. 1. Recorded spectrum with the investigated 463.054 nm N II spectral line. (Exp. b_3: $T = 30\,000$ K , $N = 0.75\,10^{23}$ m^{-3})

2. Experiment

The modified version of the linear low pressure pulsed arc (Djeniže et al. 1990; Milosavljević & Djeniže 1998) has been used as a plasma source. A pulsed discharge driven in a quartz discharge tube of various inner diameters (Φ): 5 mm and 25 mm with an effective plasma length (H) from 6.2 cm to 14 cm. Varying the dimensions of the discharge tube allows variation of the electron temperature over a wide range. The tube has end–on quartz window. On the opposite side of the electrodes the glass tube was expanded in order to reduce erosion of the glass wall and also sputtering of the electrode material onto the quartz windows. The working gas was helium –nitrogen–oxygen mixture (90% He + 8% N_2 + 2% O_2) at 267 Pa filling pressure in the flowing regime. Spectroscopic observation of isolated spectral line was made end–on along the axis of the discharge tube. A capacitor of 8 μF was charged up to 4.5 kV (exp. a) and a capacitor of 14 μF was charged up to 2.6, 3.4 and 4.2 kV, respectively (exp. b). The line profiles were recorded using a shot-by-shot technique with a photomultiplier (EMI 9789 QB) and a grating spectrograph (Zeiss PGS-2, reciprocal linear dispersion 0.73 nm/mm in first order) system. The instrumental FWHM of 0.008 nm was determined by using the narrow spectral lines emitted by the hollow cathode discharge. The recorded profile of these lines are Gaussian in shape within 8% accuracy in the range of the investigated spectral line wavelengths. The exit slit (10 μm) of the spectrograph with the calibrated photomultiplier was micrometrically traversed along the spectral plane in small wavelength steps (0.0073 nm). The photomultiplier signal was digitized using an oscilloscope, interfaced to a computer. A sample output, as example, is shown in Figs. 1 and 2.

A standard deconvolution procedure (Davies & Vaughan 1963) was used. The measured profiles were of the Voigt type due to the convolution of the Lorentzian Stark and the Gaussian profiles from Doppler and instrumental broadening. For the electron densities and temperatures of our experiments the Lorentzian fraction in the Voigt profile was dominant (over 85%). Van der Waals and resonance broadening were estimated to be smaller by more than an order of magnitude in comparison to Stark, Doppler and instrumental broadening. The deconvolution procedure was computerized using the least square algorithm. The Stark widths were measured with ±12% error. Great care was taken to minimize the influence of selfabsorption on Stark width determinations. The opacity was checked by measuring relative line intensity ratios within multiplet No. 5 (463.054 nm and 464.309 nm, see Fig. 1).

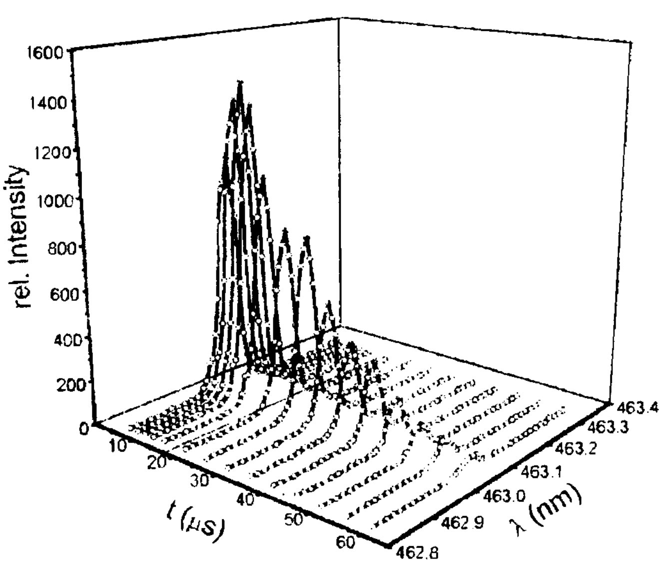

Fig. 2. Temporal evolution of the investigated spectral line profile during the plasma decay (exp. b_3)

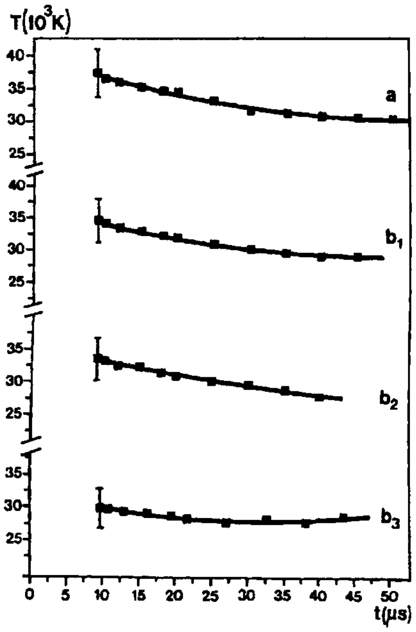

Fig. 3. Temporal evolution of the electron temperature (T) at various discharge conditions: a (8 μF, 4.5 kV, Φ = 5 mm, H = 6.2 cm), b_1 (14 μF, 4.2 kV, Φ = 25 mm, H = 14 cm), b_2 (14 μF, 3.4 kV, Φ = 25 mm, H = 14 cm), b_3 (14 μF, 2.6 kV, Φ = 25 mm, H = 14 cm)

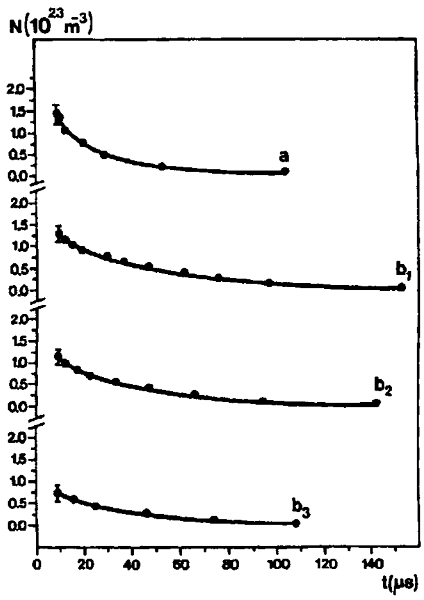

Fig. 4. Electron density (N) decay at various discharge conditions. The symbols are same as in Fig. 3

Table 1. Experimental Stark FWHM ($w_{\rm m}$) values at various electron temperatures (T in 10^3 K) and electron densities (N in $1\,10^{23}$ m^{-3}). Various discharge conditions (see Fig. 3) are denoted by: a, b_1, b_2 and b_3

T (10^3 K)	N (10^{23} m^{-3})	$w_{\rm m}$ (nm)	Exp.
30	0.75	0.020	b_3
33	1.15	0.030	b_2
35	1.30	0.032	b_1
38	1.45	0.036	a

Table 2. Calculated Stark FWHM ($w_{\rm th}$) at $N = 1\,10^{23}$ m^{-3} electron density

T (10^3 K)	$w_{\rm th}$ (nm)	T (10^3 K)	$w_{\rm th}$ (nm)
5	0.0668	40	0.0242
10	0.0472	50	0.0226
20	0.0334	60	0.0216
30	0.0273		

The values obtained were compared with calculated ratios of the products of the spontaneous emission probabilities and the corresponding statistical weights of the upper levels of the lines. The necessary atomic data were taken from Wiese et al. (1966). It turns out that these ratios differed by less than ±9% testifing to the absence of self-absorption, which could be caused by small partial pressure of the N_2 in the discharge tube. The plasma parameters were determined using standard diagnostic methods (Rompe & Steenbeck 1967). The electron temperature was determined from the ratios of the relative intensities of four N III spectral lines (409 74 nm; 410 34 nm; 463 42 nm and 464 06 nm) to the investigated N II spectral line with an estimated error of ±10%, assuming the existence of LTE. All the necessary atomic data were taken from Wiese et al. (1966) and Glenzer et al. (1994). The electron temperature decay is presented in Fig. 3. The electron density decay was measured using a well known single wavelength He-Ne laser interferometer (Ashby et al. 1965) for the 632.8 nm transition with an estimated error of ±7% . The electron density decay is presented in Fig. 4 .

3. Theory

For evaluation of Stark widths and shifts of non − hydrogenic lines of ionized atoms, various theoretical approaches have been used, see e.g. Griem (1974). For example, in the case of the singly ionized atoms semiclassical and quantum-mechanical approaches have been applied. However, both approaches involve considerable labor, especially the quantum-mechanical method. Griem (1968) suggested a simple semiempirical impact approximation based on Baranger's (1958) original formulation together with the use of an effective

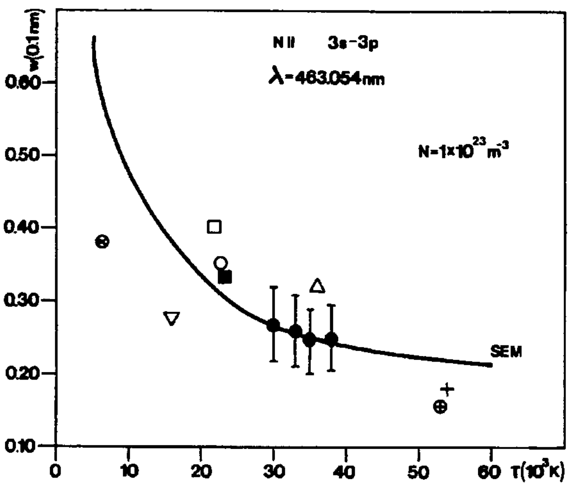

Fig. 5. Theoretical Stark FWHM (w) dependence on the electron temperature scaled to the electron density of a $1\,10^{23}$ m^{-3} for the 463.054 nm N II spectral line. •, our experimental results and those of the other authors: □, Berg et al. (1967); ○, Jalufka & Craig (1970); ∇, Konjević et al. (1970); ■, Popović et al. (1975); △, Purcell & Barnard (1984); ⊕, Purić et al. (1987); ⊗, Perez et al. (1997); +, Milosavljevć & Djeniže (1998). Theory: —, our calculated impact widths on the basis of the modified semiempirical approximation (SEM). The error bars include the uncertainties of the width and electron density measurements

Table 3. Ratio of the measured to the calculated Stark FWHM at $N = 1\,10^{23}$ m^{-3} electron density for various electron temperatures obtained in various experiments. * denote averaged electron temperaure between 5 000 K and 8 000 K from Perez et al. (1997)

T (10^3 K)	$w_{\rm m}$ (nm)	$w_{\rm m}/w_{\rm th}$	Ref.
6.5*	0.0380	0.66	Perez
16.2	0.0279	0.74	Konjević
22.0	0.0400	1.27	Berg
22.8	0.0350	1.13	Jalufka
23.2	0.0333	1.09	Popović
30.0	0.0267	0.98	This
33.0	0.0261	1.00	This
35.0	0.0246	0.97	This
36.0	0.0322	1.29	Purcell
38.0	0.0248	1.00	This
53.0	0.0155	0.70	Purić
54.0	0.0179	0.82	Milosavljević

Gaunt-factor approximation proposed by Seaton (1962) and Van Regemorter (1962). For singly ionized atoms this semiempirical formula agrees with experiment on the average to within ±50% (Griem 1974). In order to apply semiempirical approach (Griem 1968) to the lines of multiply ionized atoms Dimitrijević & Konjević (1980) made certain modifications to this method. Then, this approach was applied to the evaluation of multiply charged ion Stark width, see e.g. Dimitrijević & Konjević (1980). Apart from this application the modified semiempirical formula (SEM) was used for singly charged ions as well, see e.g. Dimitrijević (1996).

In order to test the applicability of SEM for evaluation of plasma widths of singly charged ions we shall calculate the Stark FWHM's of 460.354 nm N II line and compare them with measured values. Electron impact width have been calculated on the basis of the modified semiempirical approximation (Dimitrijević & Konjević 1980). The necessary atomic data were taken from Wiesse et al. (1966).

4. Results

Our experimental results of the measured Stark FWHM ($w_{\rm m}$) values at various electron temperatures (T) and electron densities (N) are given in Table 1. The calculated Stark FWHM values $w_{\rm th}$ at $N = 1\,10^{23}$ m^{-3} are presented in Table 2.

5. Discussion

The theoretical Stark FWHM dependence on the electron temperature together with the values of the other authors and our experimental results at the electron density of $N = 1\,10^{23}$ m^{-3} are presented graphically in Fig. 5, assuming the domination of the electron impact mechanism to the line broadening.

The agreement between the existing experimental Stark FWHM ($w_{\rm m}$), including our new data, and calculated ($w_{\rm th}$) data on the basis of the modified semiempirical approximation is satisfactory, especially in the electron temperature range between 23 000 K and 38 000 K. At lower electron temperatures the existing experimental $w_{\rm m}$ data lies under theoretical $w_{\rm th}$ values. The situation is the same at higher electron temperatures. Ratios $w_{\rm m}/w_{\rm th}$ are presented in Table 3. It should be pointed out that the scatter of the ratio $w_{\rm m}/w_{\rm th}$ around one is acceptable taking into the experimental uncertainties and the reliability of the theoretical approximation.

6. Conclusion

Within the experimental accuracy and reliability of the theoretical approximation, agreement between measured and calculated Stark FWHM values for the 463.054 nm N II spectral line was found over a wide range of electron temperatures. The only exception is at 6 500 K electron temperature where the modified semiempirical formula predicts 1.5 times higher value in comparison to existing experimental result (Perez et al. 1997). Therefore, the isolated 463.054 nm N II spectral line can be recommended as convenient spectral line in a plasma diagnostics.

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