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Measured Stark widths and shifts of several N III spectral lines: Temperature dependence

S. Djeniže and V. Milosavljević

Faculty of Physics, University of Belgrade, P.O. Box 368 Belgrade, Serbia, Yugoslavia

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Abstract. Stark parameters (width and shift) of four doubly ionized nitrogen spectral lines, that belong to 3s−3p and 3p−3d transitions (lower multiplets), have been measured in a linear pulsed, low pressure, arc discharge in the nitrogen-oxygen and helium-nitrogen-oxygen plasmas in a (30 000 − 54 000) K electron temperature and a (0.75 10^{23} − 2.8 10^{23}) m^{-3} electron density ranges. The measured values have been compared to the existing experimental and calculated data.

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

1. Introduction

Existence of the doubly ionized nitrogen (N III) spectral lines in a great number of various hot stars spectra make them interesting for diagnostic purposes (Wesemael et al. 1985; Underhill 1995). They are transmitters of information about the physical conditions in the place of their birth. Knowledge of the Stark broadening parameters (the width and the shift) of the spectral lines enables modelling various physical processes in the hot star plasmas where the Stark broadening is the principal pressure broadening mechanism. The intensive spectral lines from the lower multiplets are very convenient for experimental investigations (Underhill 1995). In the case of the N III spectra these lines belong to the 3s−3p (multiplet No. 1) and to the 3p−3d (No. 2) transitions. A number of papers (Popović et al. 1975; Källne et al. 1979; Purcell & Barnard 1984; Purić et al. 1987; Glenzer et al. 1994a; Blagojević et al. 1996) deals with the Stark FWHM (full-width at half intensity maximum, w) of these lines. It is evident that existing experimental results of the w show mutually scatter, up to the factor 4, especially in the case of the 3s−3p transition (Glenzer et al. 1994a; Blagojević et al. 1996). On the other hand, only two papers deal with the N III lines Stark shift (d) measurements (Purić et al. 1988; Blagojeviè et al. 1996), to the knowledge of the authors (Fuhr & Lesage 1993, and references therein). The aim of this paper is to provide some new data on several Stark widths and shifts of doubly ionized nitrogen spectral lines belonging to 3s−3p and 3p−3d transitions in the range of a: 30 000 K−54 000 K electron temperature (T). Namely, knowledge of the Stark width and shift dependence upon the electron temperature in the plasma is, also, of a great importance for testing their theoretical predictions based on various approaches. Our measured values of Stark widths and shifts have been compared to the existing experimental results and theoretical predictions based on the semiclassical and modified semiempirical approaches initiated by Dimitrijević & Konjević (1980, 1981a,b) presented by Blagojević et al. (1996).

Send offprint requests to: S. Djeniže

2. Experiment

The modified version of the linear low pressure pulsed arc has been used as a plasma source (Djeniže et al. 1991; Djeniže et al. 1998; Milosavljević & Djeniže 1998). A pulsed discharge driven in a quartz discharge tube of various inner diameter: 5 mm and 25 mm has an effective plasma length from 6.2 cm to 14 cm.Various dimensions of the discharge tube enable possibility of the electron temperature variation in wide range. The tube has end-on quartz windows. On the opposite side of the electrodes (Fig. 1 in Djeniže et al. 1998) 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 nitrogen and oxygen mixture (83% N_2 + 17% O_2) at 70 Pa filling pressure (experiment A) and helium, nitrogen and oxygen mixture (90% He + 8% N_2 + 2% O_2) at 267 Pa filling pressure in flowing regime (experiment B). These gas mixtures are present in many star plasmas. Spectroscopic observation of isolated spectral lines were made end-on along the axis of the discharge

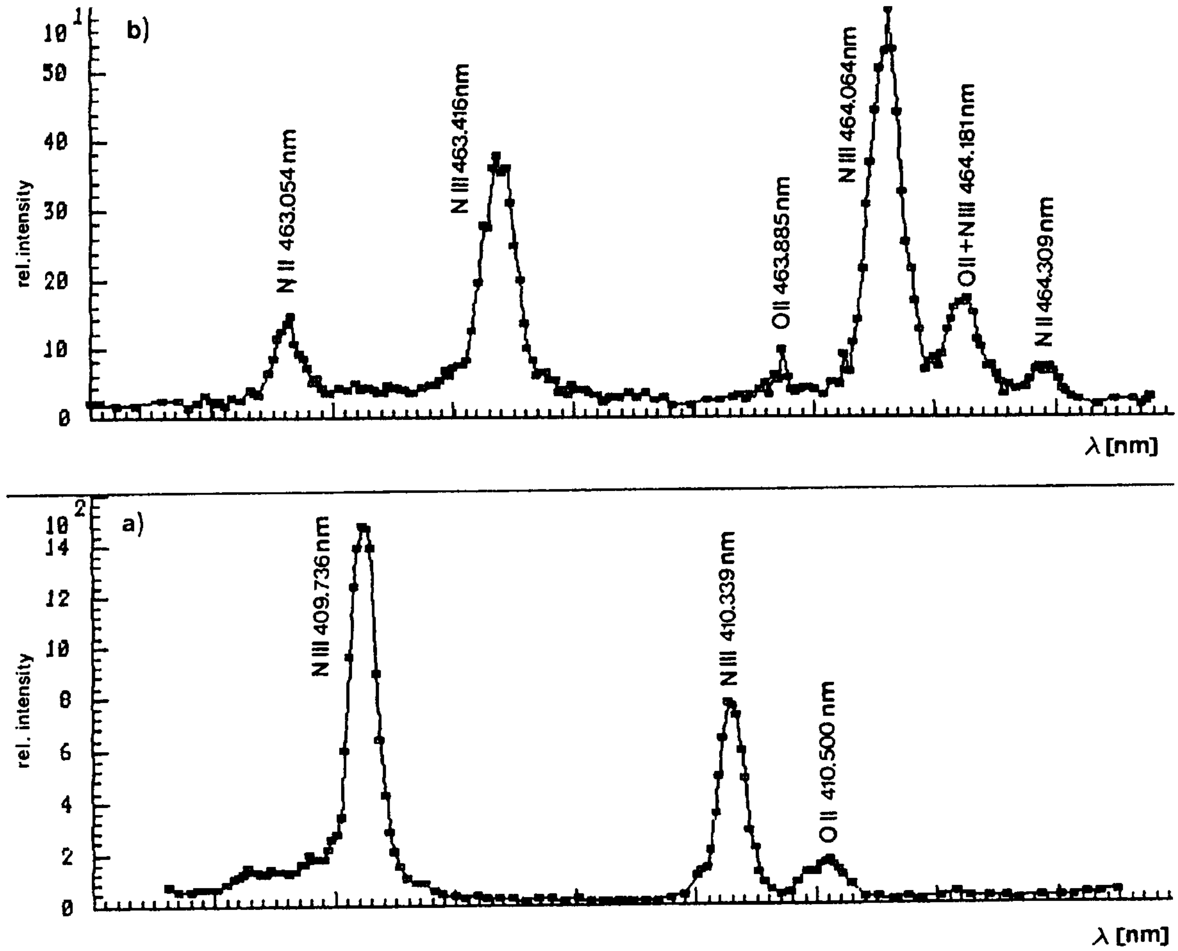

Fig. 1. a,b) Recorded spectrum with the investigated spectral lines of 3s–3p **a)** Exp. B2 (T = 35 000 K , $N = 1.310^{23}$ m^{-3}) and 3p–3d **b)** Exp. A (T = 54 000 K, $N = 2.810^{23}$ m^{-3}) transitions

tube. A capacitors of 14 and 8 μF was charged up to 4.2 kV and 4.5 kV, respectively. The line profiles were recorded by a shot- by-shot technique using a photomultiplier (EMI 9789QB) and a grating spectrograph (Zeiss PGS-2; reciprocal linear dispersion 0.73 nm/mm in the first order and 0.008 nm instrumental FWHM) system following the procedure described by Milosavljević & Djeniže (1998). The photomultiplier signal was digitized using oscilloscope, interfaced to a computer. A sample output, as example, is shown in Figs. 1.

Plasma reproducibility was monitored by the N III line radiation and, also, by the discharge current (it was found to be within 6%). The measured profiles were of the Voigt type due to the convolution of the Lorentzian Stark and Gaussian profiles caused by Doppler and instrumental broadening. For electron density and temperature obtained in our experiment the Lorentzian fraction in the Voigt profile was dominant. 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. A standard deconvolution procedure (Davies & Vaughan 1963) was used. 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 self-absorption on Stark width determinations. The opacity was checked by measuring relative line intensity ratios within multiplet No. 1 and No. 2. 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 Glenzer et al. (1994b). It turns out that these ratios differed by less than ±8% which testifies the absence of self-absorption. The Stark shifts were measured relative to the unshifted spectral lines emitted by the same plasma using the method described by Purić & Konjević (1972). Stark shift data are determined with ±0.0015 nm errors at a given N and T. The plasma parameters were determined using standard diagnostics methods (Rompe & Steenbeck 1967). The electron temperature was determined from the ratios of the relative intensities of the 348.49 nm N IV to 393.85 nm N III and the previous N III to 399.50 nm N II spectral lines, assuming the existence of LTE, with an estimated error of ±10% (experiment A) and from the ratios of the relative intensities of the investigated four N III spectral lines to 463.05 nm and 464.31 nm N II spectral lines with an estimated error of ±9% (experiment B). In the experiment B the electron temperature was, also, determined from the ratio of the relative intensities of the He II Pα (468.6 nm) to 587.6 nm He I spectral lines. All the necessary atomic parameters were taken from Glenzer et al. (1994b) and Wiese et al. (1966). The electron density (N) decay was measured using a well known single wavelength He−Ne laser interferometer for the 632.8 nm transition with an estimated error of ±7%.

3. Results

Our experimental results of the measured Stark FWHM ($w_{\rm m}$) and shift ($d_{\rm m}$) values at various electron temperature (T in 10^4 K) and electron density (N in 10^{23} $\rm m^{-3}$) are given in the Table 1 together with transition arrays and multiplet numbers.

4. Discussion

The theoretical Stark FWHM (w) dependence on the electron temperature together with the values of the other authors and our experimental results at the electron density of 1 10^{23} $\rm m^{-3}$ are presented graphically in Figs. 2 and 3 for the transitions 3s−3p and 3p−3d, respectively. Theoretical values calculated by Blagojević et al. (1996), using the semiclassical-perturbation formalism (Sahal-Brechot 1969a,b), are presented with symbols $DSB_{\rm e}$ and $DSB_{\rm i}$ on the Figs. 2 and 3. $DSB_{\rm e}$ denote electron impact width only, while $DSB_{\rm i}$ denote the sum of electron + ion impact width calculated for our plasma compositions at relevant plasma parameters. Calculated values on the basis of the semiclassical (G) (after Griem 1974), simplified-semiclassical approximation (GM) (Eq. (526) in Griem 1974) and modified-semiempirical formula (DK) (after Dimitrijević & Konjević 1980) are presented by Dimitrijević & Konjević (1980, 1980a,b). Theoretical predictions by Hey (1976) (x), calculated with the semiempirical method, at plasma parameters obtained in Popović et al. (1975) are also presented.

The theoretical Stark shift dependence on the electron temperature together with the values of the other authors and our experimental results at the electron density of 1 10^{23} $\rm m^{-3}$ are presented graphically in Fig. 4 for the transitions 3s−3p and 3p−3d. Theoretical values are calculated by Blagojević et al. (1996) using the semiclassical-perturbation formalism and are presented with symbols $DSB_{\rm e}$ and $DSB_{\rm i}$. $DSB_{\rm e}$ denote electron impact shift only. The ion contribution to the shift is calculated only for our plasma conditions (parameters and compositions in experiments A and B). $DSB_{\rm i}$ denote the sum of electron + ion impact shifts.

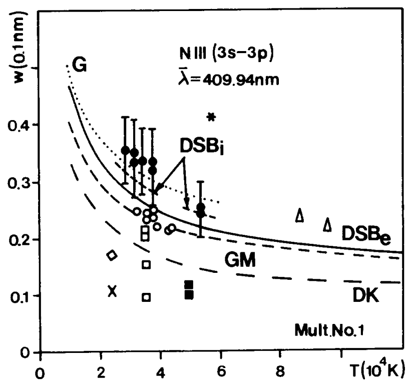

Fig. 2. Theoretical Stark FWHM (w) dependence on the electron temperature scaled to the electron density of a 1 10^{23} m−3 for the 3s−3p transition. •, our experimental results and those of the other authors: ◇, Popović et al. (1975); *, Källne et al. (1979); □, Purcell & Barnard (1984); ■, Purić et al. (1987); △, Glenzer et al. (1994a); ○, Blagojević et al. (1996). Theory: —, semiclassical electron impact widths ($DSB_{\rm e}$) and - - -, semiclassical electron + ion impact widths ($DSB_{\rm i}$) (evaluated only for the plasma parameters in our experiment A and B) using values calculated by Blagojević et al. (1996) on the basis of the semiclassical-perturbation formalism; ...., semiclassical electron impact widths after Griem (G); − − −, simplified semiclassical approximation (Eq. (526) in Griem 1974) (GM); — — —, modified semiempirical formula (after Dimitrijević & Konjević 1980) (DK). The results of: (G), (GM) and (DK) calculations are presented by Dimitrijević & Konjević (1980, 1981a,b). x describe theoretical predictions by Hey (1976) calculated at plasma parameters obtained in Popović et al. (1975). $\overline{\lambda}$ is the mean wavelength for the multiplet. The error bars include the uncertainties of the width and electron density measurements

On the basis of our measured Stark parameters and existing experimental and theoretical values one can conclude:

1. For the lines of 3s−3p transition our experimental Stark FWHM data agree well with theoretical predictions calculated on the basis of the semiclassical theory (G) after Griem (1974). Same trend shows measured values from Glenzer et al. (1994a) at about 90 000 K electron temperature. In the range of the electron temperature: 30 000 K − 54 000 K, within the experimentally accuracy, our data agree, also, with predicted Stark FWHM values based on the semiclassical-perturbation formalism including the ion contribution ($DSB_{\rm i}$). Other experimental data lies under predicted (G), ($DSB_{\rm i}$) and our experimental values.

2. For the lines of 3p−3d transitions our experimental Stark FWHM data, about 35 000 K electron temperature, shows agreement with predictions based on the semiclassical-perturbation formalism including the ion impact contribution ($DSB_{\rm i}$) and, also, within the experimentally accuracy, with prediction based on the simplified semiclassical approximation (GM). Experimental values from Blagojević et al. (1996) agree with our

Table 1. Experimental Stark FWHM (w_m) and shift (d_m) values at various electron temperatures (T in 10^4 K) and electron densities (N in 10^{23} m^{-3}). Transitions, wavelengths and multiplets are, also, presented. Various discharge tube dimensions (inner diameter (Φ) and axially plasma length (H)) are denoted by: A ($\Phi = 5$ mm, $H = 6.2$ cm), B_1 ($\Phi = 5$ mm, $H = 6.2$ cm) and B_2 ($\Phi = 25$ mm, $H = 14$ cm)

Transition	Multiplet	λ(nm)	T	N	w_m (nm)	Exp.	d_m (nm)	Exp.
3s−3p	$^2S-^2P^0$	409.736	5.4	2.80	0.069	A	0.000	A
	(1)		3.9	1.45	0.048	B_1	0.000	B_1
			3.5	1.30	0.042	B_2	0.000	B_2
			3.3	1.15	0.040	B_2	0.000	B_2
			3.0	0.75	0.026	B_2	0.000	B_2
		410.339	5.4	2.80	0.072	A	0.000	A
			3.9	1.45	0.046	B_1	0.000	B_1
			3.5	1.30	0.042	B_2	0.000	B_2
			3.3	1.15	0.038	B_2	0.000	B_2
			3.0	0.75	0.026	B_2	0.000	B_2
3p−3d	$^2P^0-\,^2D$	463.413	5.4	2.80	0.058	A	0.000	A
	(2)		3.9	1.45	0.052	B_1	0.000	B_1
			3.5	1.30	0.046	B_2	0.000	B_2
			3.3	1.15	0.042	B_2	0.000	B_2
		464.064	5.4	2.80	0.054	A	0.000	A
			3.9	1.45	0.054	B_1	0.000	B_1
			3.5	1.30	0.042	B_2	0.000	B_2
			3.3	1.15	0.038	B_2	0.000	B_2

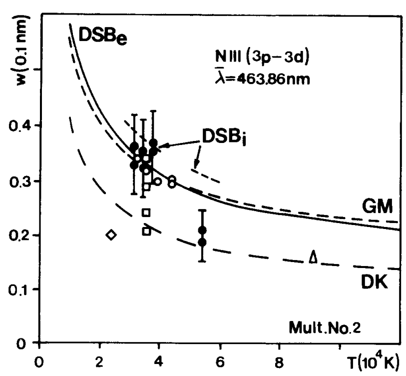

Fig. 3. Same as in Fig. 2 but for the 3p−3d transition

experimental data. The situation is, however, different at elelectron temperatures over 50 000 K. Namely, our Stark FWHM data at 54 000 K and those from Glenzer et al. (1994a), at about 90 000 K, agree with theoretical predictions calculated on the basis of the modified semiempirical approximation (DK).

3. In the case of the Stark shift one can conclude that our measured d_m data, which are equal to zero, within experimental uncertainties (± 0.0015 nm) are not in contradiction with theoretical predictions (see Fig. 4). Namely, the only existing theoretical results of the Stark shifts, calculated on the basis of the semiclassical-perturbation formalism (DSB_e) are very small and have negative sign.

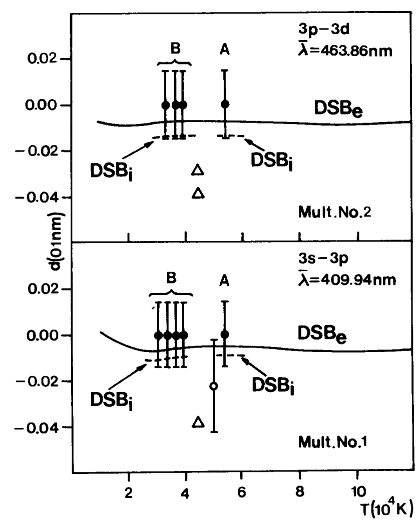

Fig. 4. Theoretical Stark shift (d) dependence on the electron temperature scaled to the electron density of a 1 10^{23} m−3 for the 3s−3p and 3p−3d transitions. •, our experimental results and those of the other authors: ∘, Purić et al. (1988); △, Blagojević et al. (1996). Theory: —, semiclassical electron impact shift (DSB_e) calculated by Blagojević et al. (1996) and − − −, semiclassical electron + ion impact shift (DSB_i) evaluated only for the plasma conditions (parameters and compositions) in our experiment (A and B). $\overline{\lambda}$ is the mean wavelength for the multiplet. The error bars describe the uncertainties of the shift measurements

Inclusion of the ion contribution to the shift ($DSB_{\rm i}$), lead to their increase. Measured Stark shifts by Purić et al. (1988) and Blagojević et al. (1996) have, also, definite negative value. It should be pointed out that the theoretical prediction of the Stark shift values is very sensitive to the number of the perturbing levels included in the calculation. Namely, the number of the perturbing levels has appreciable influence on the shift, including its sign. Omitting some of them, may lead to erroneous results. On the other hand, the use of available oscillator strengths, or those calculated from Coulomb approximation, can lead to results of opposite sign in Stark shift calculation (Djeniže et al. 1993).

5. Conclusion

In general, our new experimental Stark FWHM data agree, within the experimentally uncertainties and reliability of the theory, with the theoretical predictions based on the semiclassical-perturbation formalism that include the influence of the ion contribution to the Stark broadening. The only exception is the w value at a 54 000 K electron temperature in the case of the 3p−3d transition. It should be pointed out that same behaviour is shown for the experimental data from Glenzer et al. (1994a) at about 90 000 K electron temperature. In the case of Stark shifts, we have measured values which were equal to zero. Within experimental uncertainties they agree with calculated data obtained on the basis of the semiclassical-perturbation formalism.

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