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STARK BROADENING OF NEUTRAL ARGON LINES BY PLASMAS

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1. INTRODUCTION

Plasma broadened spectral lines of neutral argon, in the visible region of electromagnetic spectra, have been extensively investigated in order to obtain Stark broadening parameters (see Konjević et al. (1976, 1982, 1990) and references therein). Although these investigations covered a number of lines, there is a lot of space for further experimental investigations. Todays experimental techniques improve the accuracy of obtained data in some cases almost for the order of magnitude. Also, in the most of previous investigations, in order to obtain Stark widths of the lines, deconvolution of symmetric Voigt profile has been applied although plasma broadened profiles are asymmetrical. Some of the close argon lines have not been investigated due to complicated procedure of line profile separation. Reported data contained Stark widths and shifts only, with the exception of Jones et al. (1986) where the experimental results for ion broadening parameter A were also reported.

In order to obtain Stark broadening parameters (widths, shifts and A) with high accuracy it is necessary to fulfil several conditions:

a) plasma source must be highly reproducible, in the case of pulsed plasma source or very stable, in the case on continous source,
b) an experimental technique for spectral intensity measurements should provide high accuracy of measurements,
c) attention should be paid to plasma diagnostics techniques (electron density and temperature measurements),
d) proper numerical procedures for experimental profiles treatment should be applied (for example Abel inversion procedure, line separation procedure, deconvolution procedure etc.). For example, in the cases of strongly asymmetric lines, the error of up to 25 % could be introduced if one applies deconvolution procedure for Voigt profile instead for asymmetric profile,
e) the influence of other broadening mechanisms must be taken into account.

In this work all of above mentioned conditions tried to be fulfilled in order to obtain high accurate data of Stark broadening parameters. Also, applied deconvolution procedure, made possible to determine the ion broadening parameter of investigated lines. Stark broadening parameters are determined for twelve neutral argon lines in the visible spectrum. Close spectral lines were also investigated, some of them for the first time. Obtained results are listed in a table and also compared with the theoretical and experimental results of other authors when available.

2. EXPERIMENTAL

In this chapter the experimental procedures and plasma diagnostics will be described.

2. 1. PLASMA SOURCE

Wall stabilized arc was used as a plasma source. It consists of a stack of 7.1 mm thick water-cooled copper plates separated by 0.5 mm thick insulating Teflon gaskets. The diameter of arc channel is 5 mm and its length is 70 mm The arc was operating under atmospheric pressure with the gas mixture containing 99 % Ar and 1 % H_2. The mixture with the flow rate of 3 l/min is introduced into the arc from both ends. Stabilized power supply with the current stabilization of 0.3 % was used to supply the arc with the current of 30 A.

2. 2. LINE SHAPE AND SHIFT RECORDINGS

In order to avoid radiative transfer problems when radiation is recorded end-on, plasma was observed side-on at twelve position along plasma column radius. Plasma radiation was focused 1:1 onto the entrance slit of 1-m monochromator by means of the concave mirror M_2, see Fig. 1. The height of the entrance slit was 0.3 mm while the width of entrance and exit slit was 20 μm introducing the instrumental width of 0.018 nm. Monochromator is equipped with 1200 g/mm grating, high resolution stepping motor (36000 steps/rev), used for grating movements, and photomultiplier.

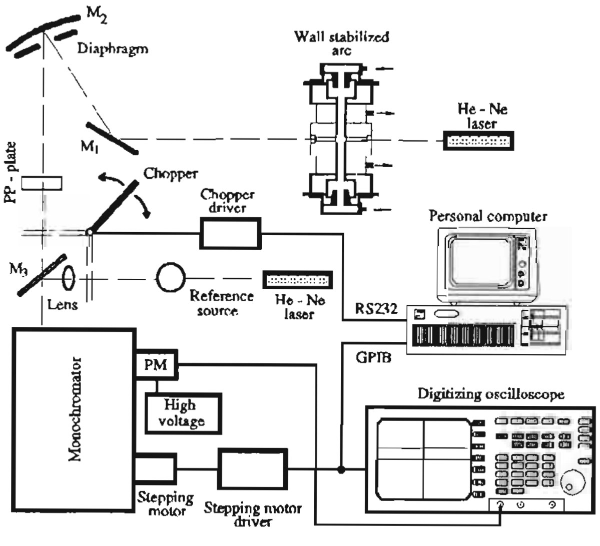

Fig. 1. Experimental setup.

A low-pressure Geissler tube was used as a source of unshifted argon spectral lines. The same mixture used for the arc is introduced under the low pressure in Geissler tube. The lines emitted from this source are also used for the instrumental width measurements. For the shift measurements, the light form Geissler tube was also focused onto the slit of the monchromator, see Fig. 1. The mirror M_3 is partially reflecting so the light from both, arc plasma and reference source have the same optical path from the mirror M_3 to the exit slit of the monochromator. Using the chopper C light is recorded from the arc or from a reference source alternatively.

Signals from the photomultiplier were led to the digitizing oscilloscope working in the averaging mode (32 samples over 200 ms). Using this technique for spectral intensity measurements the error less than 1 % was attained, while the accuracy of wavelength settings was 0.0025 nm. The stepping motor (HP-IB interface), chopper C (RS-232 interface) and oscilloscope (HP-IB interface) were controlled by the PC. The same computer was used for data aquisition.

2. 3. PROCESSING OF RECORDED LINE PROFILES

The line profiles recorded at twelve positions along the plasma column radius were Abel inverted (Djurović 1998). After this an advanced deconvolution procedure (Nikolić et al. 1998) for asymmetric line profiles was applied in order to separate Gaussian part (instrumental + Doppler) from the plasma broadened part. The influence of resonance and Van der Waals broadening mechanisms (Griem 1964) were taken into account also. The same deconvolution procedure was applied to close lines also. Since the one of the fitted parameters in this procedure is ion broadening parameter A, this procedure was used for determination of this parameter. The center of the lines were always determined at the maximum of peak intensity.

In order to determine the position of unshifted lines, profiles recorded from the reference source were fitted by least square method to the Gaussian.

Examples of recorded profiles together with the fitted profiles and profiles recorded from reference source are presented in Figs. 2 and 3.

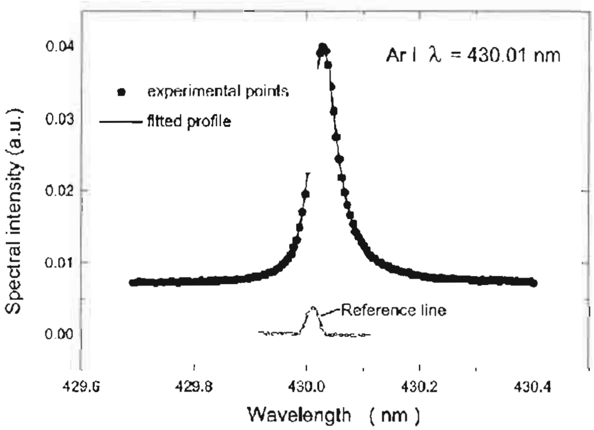

Fig. 2. An example of isolated Ar I line.

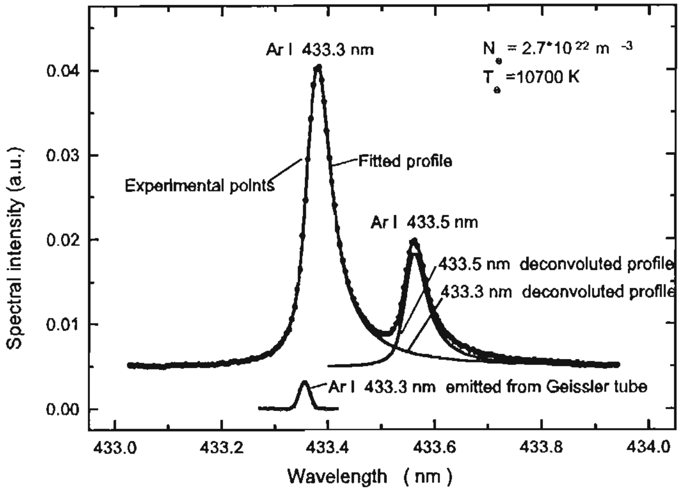

Fig. 3. An example of two close Ar I lines.

2. 4. PLASMA DIAGNOSTICS

An electron density in the range (0.74 – 2.90) × 10^{22} m^{-3} along the plasma radius was determined from the widths of the Balmer H_β line in conjunction with theoretical calculations by Vidal et al.(1973). The arc temperature ranging (9280 - 10750) K was deduced from plasma composition data using procedure described by White et al. (1958). Estimated uncertainty of reported electron densities and temperatures do not exceed ±9 % and ±3 %, respectively.

3. RESULTS AND DISCUSSION

Obtained values for widths and shifts for various electron densities and temperatures were compared with the theoretical values (Griem 1974). Theoretical values were calculated for corresponding electron densities and temperatures accordingly with the formulas for static ion approximation (Eqs. (226) and (227) in Griem 1974). In these formulas electron impact width, electron impact shift and ion broadening parameter enter as the theoretical values. For two of investigated lines these values are not existing. For five of them these values can be estimated from the existing values for the lines from the same multiplet (Griem 1974). Theoretical data for widths and shifts are corrected for the Debye shielding effect. Results of such comparisons are given in Table 1. together with the results of other authors and estimated errors. Results of this work are presented through an average values. Since error of measurements are given before, in Table 1. only standard deviation of obtained results are given. Results of other authors are, in some cases, given as the range of obtained results of the comparisons (they are marked with symbol §). These values are taken from critical reviews (Konjević et al. 1974,1990) together with estimated uncertainties: A – less 15 %; B – between 15 % and 30 %. Results with estimated uncertainties C – more

30 % are not taken for comparisons in this work. There are also four results (Djurović et al. 1997; Musielok 1994); Djeniže et al. 1995 and de Izarra et al. 1993), included in Table 1., which have not been critically reviewed since they are quite recent.

Table 1. Values of measured over theoretical widths and shifts for investigated Ar I spectral lines. References: 0 – this work; 1 – Bues et al. (1966-67); 2 – Griem (1962); 3 – Chapelle et al. (1967); 4 – Queffelec and Girault (1971); 5 – Sculz and Wende (1968); 6 –Jones et al. (1986); 7 – Jones et al. (1987); 8 – Chernichowski and Chapelle (1983); 9 – Abbas (1988); 10 – Djurović et al. (1997); 11 – Musielok (1994); 12–Djeniže et al. (1995); 13 – de Izarra et al. (1993). Results of this work are given as an averaged values with standard deviation for widths (s_w) and shifts (s_d). For the lines marked with (*) theoretical values were estimated from the values for the lines from the same multiplet for which theory exists. Letters in parenthesis in the last column denote accuracy estimated by critical reviews (Konjević et al. 1976, 1984, 1990). Symbol # denotes that only range of obtained comparison is given. Error reported by the authors of Refs. 12 and 13 is between 10 and 20 %.

λ (nm)	N_e (10^{22} m^{-3})	T (K)	$\overline{w_m/w_{th}}$	s_w	$\overline{d_m/d_{th}}$	s_d	Ref.
*415.86	0.74 - 2.90	9280 - 10750	0.724	0.032	1.088	0.024	0
4s[3/2]^0 - 5p[3/2]	1.42 - 11.4	9960 - 13100	0.67	0.028	0.87	0.074	1(B)
	1.7 - 18	9270 - 14830	0.83-1.07	–	1.01	–	2(B)#
	6.23	11900	0.91	–	–	–	6(A)
	6.2	11900	0.92	–	–	–	7(A)
	3.1 - 9.9	10800 - 12600	0.989	0.096	–	–	11
*418.19	0.74 - 2.90	9280 - 10750	0.616	0.038	0.633	0.025	0
4s'[1/2]^0 - 5p'[1/2]	1.42 - 11.40	9960 - 13100	0.57	0.015	0.657	0.065	1(B)
	1.1 - 8.6	9650 - 12500	0.78-0.91	–	–	–	3(B)#
	3.1 - 9.9	10800 - 12600	0.80-0.83	–	–	–	11
*419.07	0.74 - 2.90	9280 - 10750	0.565	0.047	0.887	0.060	0
4s[3/2]^0 - 5p[5/2]							
419.10	0.74 - 2.90	9280 - 10750		No	theory		0
4s'[1/2]^0 - 5p'[3/2]							
419.83	0.74 - 2.90	9280 - 10750	0.536	0.041	0.691	0.041	0
4s[3/2]^0 - 5p[1/2]	1.42 - 11.4	9960 - 13100	0.428	0.038	0.79	0.062	1(B)
420.07	0.74 - 2.90	9280 - 10750	0.628	0.064	0.756	0.032	0
4s[3/2]^0 - 5p[5/2]	1.42 - 11.4	9960 - 13100	0.584	0.022	1.00	0.056	1(B)
	1.7 - 9.2	9720 - 12610	0.82-0.90	–	0.78-0.84	–	2(B)#
	4.5	13400	0.87	–	–	–	11
425.94	0.74 - 2.90	9280 - 10750	0.726	0.048	0.691	0.035	0
4s'[3/2]^0 - 5p'[1/2]	1.42 - 11.4	9960 - 13100	0.561	0.015	0.777	0.055	1(B)
	0.47 - 3.5	8900 - 11070	0.729	0.039	0.764	0.033	10
	1.4 - 9.9	9800 - 12600	0.77	–	–	–	11(A)
	2.6	14000	–	–	0.62	–	12

Table 1. Continued

λ (nm)	N_e (10^{22} m^{-3})	T (K)	w_m/w_{th}	s_w	d_m/d_{th}	s_d	Ref.
*426.63	0.74 - 2.90	9280 - 10750	0.540	0.078	0.866	0.055	0
4s[3/2]^0 - 5p[3/2]	1.42 - 11.4	9960 - 13100	0.691	0.020	1.28	0.073	1(B)
	1.4 - 9.9	9800 - 12600	1.00	0.113	–	–	11
427.22	0.74 - 2.90	9280 - 10750	0.700	0.043	0.942	0.030	0
4s[3/2]^0 - 5p[3/2]	1.42 - 11.4	9960 - 13100	0.651	0.028	1.136	0.100	1(B)
	6.2	11900	0.85	–	–	–	6(A)
	1.4 - 9.9	9800 - 12600	0.85	0.09	–	–	11
	2.2	16000	–	–	0.55	–	12
*430.01	0.74 - 2.90	9280 - 10750	0.740	0.053	0.611	0.030	0
4s[3/2]^0 - 5p[5/2]	1.2 - 9.4	9750 - 12200	0.590	0.019	0.944	0.06	1(B)
	1.7 - 13.2	9720 - 13500	0.75-0.84		0.81-1.2		2(B)#
	1.1 - 5.9	9600 - 11800	0.52-1.02	–	0.96-1.51	–	4(B)#
	6.2	11900	0.77	–	–	–	6(A)
	1.1 - 11	9000 - 15500	0.76-0.83	–	–	–	8(A)#
	2.2 - 14.4	10200 - 14200	0.75-0.96	–	–	–	9(B)#
	3.1 - 9.9	10800 - 12600	0.81	0.059	–	–	11
	18.2	13000	0.85	–	–	–	13
433.36	0.74 - 2.90	9280 - 10750		No	theory		0
4s'[1/2]^0 - 5p'[3/2]							
*433.53	0.74 - 2.90	9280 - 10750	0.501	0.026	0.730	0.034	0
4s'[1/2]^0 - 5p'[1/2]	1.42 - 11.4	9960 - 13100	0.647	0.040	0.771	0.069	1(B)
	1.0 - 7.0	9550 - 12100	0.69-0.73	–	–	–	5(B)#

In order to make experimental results in Table 1 comparable, electron densities determined from H_β line, in works published before 1973. had to be corrected to VCS theory (Vidal et al. 1973).

One can see from the Table 1 that values obtained from various experiments differ considerably, in some cases almost for 100 % (see 426.63 nm line). There is no rule about agreement between any of the experiments. However, disagreement between experiment and theory is obvious (disagreement could be defined as [$1 - |experimental\ value/theoretical\ value|$]). Depending on the considered line and Stark broadening parameters this is in the range of almost 60 % and 0 %. An average value of the disagreement between experiment and theory (including both parameters is about 20 %)

An general conclusion could not be drawn, except that the measurements of this kind should be continued in order to give more precise answer about the Stark broadening parameters of argon lines.

4. CONCLUSION

This paper is an attempt to give reliable experimental data of Stark broadening parameters of neutral argon lines. Twelve spectral lines were investigated. Attention was paid on precise spectral intensity recordings, wavelength measurements and procession of obtain data. An averaging technique was applied for spectral intensity recordings, while high resolution stepping motor was used for the rotation of monchromator's grating and wavelength settings. An advanced deconvolution procedure was applied in order to obtain Stark broadening parameters free of systematical error introduced by applying the method for deconvolution of symmetrical lines.

Obtained results for widths and shifts of investigated spectral lines are compared with the theoretical values (if exist) and with the experimental results of other authors. This comparison showed strong disagreement between the experimental results, but in most cases considerable disagreement between experimental and theoretical values also exists. Final conclusion about the values of Stark broadening parameters of neutral argon lines demands more high precision experimental work.

References

Abbas A., Basha T. S. and Abdel-Aal Z. A.:1988, *Jap. J. Appl. Phys.* **27**, 801.
Bues I., Haag T. and Richter J.: 1966-67, *Laboratoriumsbericht aus dem Institut für Experimentalphysik der Universität Kiel.*
Chapelle J., Cabonne Sy. A., Cabannes F. and Blandin J.: 1967, *JQSRT* **8**, 1201.
Chernichowski A. and Chapelle J.: 1983, *Acta Phys. Pol A* **63**, 67.
Djeniže S., Skuljan Lj. and Konjević R.: 1995, *JQSRT* **54**, 581.
Djurović S. : *to be published*
Djurović S., Mijatović Z., Kobilarov R. and Konjević N.: (1997), *JQSRT* **57**, 695.
Griem H. R.: 1962, *Phys. Rev* **128**, 515.
Griem H. R.: 1964, *Plasma Spectroscopy*, McGraw-Hill, New York.
Griem H.R.: 1974, *Spectral Line Broadening by Plasmas*, Academic, New York.
de Izarra C., Chapelle J., Chernichowski A. and Vallee O.: 1993, *JQSRT* **49**, 433.
Jones D. W., Pichler G. and Wiese W. L.: 1987, *Phys. Rev. A* **35**, 2585.
Jones D. W., Wiese W. L. and Woltz L. A.: (1986), *Phys. Rev A* **34**, 450.
Konjević N., Dimitrijević M. S. and Wiese W. L.: 1984, *J. Phys. Chem. Ref. Data* **13**, 619.
Konjević N. and Roberts J. R.: 1976, *J. Phys. Chem. Ref. Data* **5**, 209.
Konjević N. and Wiese W. L.: 1990, *J. Phys. Chem. Ref. Data* **19**, 1307.
Musielok J.: 1994, *Acta. Phys. Pol. A* **86**, 315.
Nikolić D. et al.: *to be published*
Queffelec J. L. and Girault M.: 1971, *Rev. Phys. Appl.* **6**, 401.
Schulz P. and Wende B.: 1968, *Zeitschrift für Phusik* **208**, 116.
Vidal C.R., Cooper J. and Smith E.W.: 1973, *astrophys J. Suppl. Ser. No. 214* **25**, 37.
White W.B., Jonson S.M. and Dantzig G.B.: 1958, *J. Chem. Phys.* 28, 751.