Stark widths and shifts of Kr II uv spectral lines

S. Djurović,[1] R. J. Peláez,[2] M. Ćirišan,[1] J. A. Aparicio,[2] and S. Mar[2]
[1]*Faculty of Science, Department of Physics, Trg Dositeja Obradovića 4, 21000 Novi Sad, Serbia*
[2]*Departamento de Física Teórica Atómica y Óptica, Facultad de Ciencias, Universidad de Valladolid, 47071 Valladolid, Spain*
(Received 17 July 2008; published 23 October 2008)

This work reports measured Stark parameters of singly ionized krypton lines. A low-pressure pulsed arc with 92% of He and 8% of Kr was used as a plasma source. Measured electron densities and electron temperatures were in the range $(0.7-2.0)\times10^{23}$ m^{-3} and 16 000–20 000 K, respectively. All investigated spectral lines belong to the uv spectral region.

DOI: 10.1103/PhysRevA.78.042507 PACS number(s): 32.70.Jz, 32.30.Jc, 32.60.+i

I. INTRODUCTION

Generally speaking, Stark broadening data of nonhydrogenic spectral lines are of interest for both astrophysical and laboratory plasmas. They are usually used in plasma diagnostics. In addition, Stark broadening data of Kr II lines can be useful for verification of theoretical calculations and investigation of regularities and systematic trends in the case of singly ionized noble gases. There are both experimental [1–4] and theoretical studies [5–8] on Kr II Stark parameters in the literature. A more comprehensive set of data can be found in Refs. [9–12].

Kr II spectral lines data are also very important for industry, where krypton is used in the production of lasers and light sources.

Although the interest exists, very few experimental Stark parameters data for Kr II spectral lines in the region below 400 nm can be found in the literature. Stark halfwidths of five lines in Pitman and Konjević [1], one in del Val *et al.* [4], 17 in Bertuccelli and Di Rocco [7,8], and two halfwidths and one shift in Milosavljević *et al.* [13] have been reported until now.

In this paper, we present measurements of 52 Stark halfwidths and 32 Stark shifts of Kr II spectral lines from 42 multiplets. Out of this, 48 halfwidths and 32 shifts are reported here for the first time. Stark halfwidths (full width at half maximum—FWHM) of spectral lines from 4*d*-4*f*, 4*d*-5*f*, 5*s*-5*p*, 5*p*-5*d*, and 5*p*-6*s* transition arrays were measured. Most of the lines belong to the 4*d*-4*f* transition array. All analyzed spectral lines are within the uv region, 208–400 nm. So, with these results, we practically expand the current database of Kr II Stark parameters to the uv region. Only four halfwidth results presented in this paper correspond to the lines analyzed in Pitman and Konjević [1] and Bertuccelli and Di Rocco [7]. Some of the measured halfwidth and shift data were compared with theoretical calculations [14–16].

A study of the Stark broadening of spectral lines requires an accurate determination of electron density. In this experiment, a two-wavelength interferometric method was used for electron density determination, in order to avoid the influence of heavy particles on the variation of plasma refractive index. Apart from taking care of experimental conditions and plasma diagnostics, attention was also paid to the proper fitting and deconvolution procedure.

The Stark parameters data presented in this paper can be useful for comparison with future experimental data, as well as with actual and future theoretical calculations.

II. EXPERIMENT

Experimental apparatus and procedure was described in detail in previous works [17–19], but some details will be given here, for completion. Plasma was produced in a cylindrical tube of Pyrex glass, 175 mm in length, having an internal diameter of 19 mm. The mixture 92% of He and 8% of Kr at a pressure of 2.6 kPa continuously flowed through the discharge tube. The gas in the tube was preionized by a continuous current of several mA, in order to ensure plasma reproducibility. Plasma was created by discharging a capacitor bank of 20 μF, charged up to 8200 V, through the tube.

Spectroscopic measurements were performed along the tube, 2 mm off the tube axis, symmetrically to the laser beam direction, where interferometric electron density measurements were performed. The light emitted from the plasma was limited by two diaphragms and focused by a concave mirror of 150 mm focal length onto the entrance slit of a monochromator equipped with a 2400 lines mm^{-1} grating. The slit width of 35 μm was selected in order to obtain the best compromise between intensity and resolution. The spectrometer was calibrated in wavelength, as well as in spectral intensity, with uncertainties lower than 1% and 5%, respectively. Inverse linear dispersion at 300 nm was 3.5 pm/channel. The spectra were recorded using an ICCD (intensified charge coupled device) camera at 12 different instants, from 30 to 150 μs since the beginning of the discharge. The exposure time was usually 5 μs. In this experiment, Kr II spectra were recorded in the wavelength interval 208–400 nm.

In order to minimize the effect of sputtering in the optical transmittance of the system, windows of the tube were replaced after approximately every 900 discharges, and the electrodes were polished several times during the experiment.

III. PLASMA DIAGNOSTICS

For electron density determination two-laser wavelength (543.0 and 632.8 nm) interferometry was used. This method is based on the fact that a variation of plasma refractive

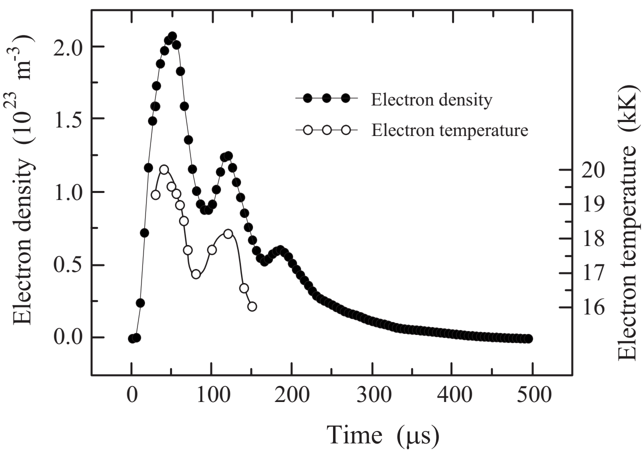

FIG. 1. Temporal evolution of electron density and temperature.

index depends on the densities of plasma species. By using two-wavelength interferometry, the influence of heavy particles on the variation of plasma refractive index is eliminated. Interferometric end-on measurements were performed during plasma life, simultaneously with the spectroscopic ones. The discharge tube was placed in one of the arms of a Twyman-Green interferometer. Both laser beams were passing through the tube in the axial direction, 2 mm off the tube axis. For every instant, interferograms of 500 μs were recorded for each of the wavelengths operating in the interferometer. An example of temporal evolution of the measured electron density is shown in Fig. 1. Since the discharge current was not critically damped, there are three maxima appearing in the electron density time dependence graph.

Measured electron densities, used for analyses in this work were in the range $(0.7-2.0)\times 10^{23}$ m^{-3}. The error in electron density measurements was estimated to be lower than 10%. Intensities of 12 Kr II lines in the spectral interval 450–520 nm and their transition probabilities [20,21] have been used to obtain excitation temperature by the Boltzmann-plot technique. In a time interval of interest in this experiment, the temperature was varying from 16 000 to 20 000 K. Statistical uncertainty for this plasma parameter was estimated to be lower than 15%. Temporal evolution of the temperature in the time interval of interest is also shown in Fig. 1. The variation of electron density and temperature are in agreement.

IV. EXPERIMENTAL DATA TREATMENT

Apart from taking care of experimental conditions and plasma diagnostics, attention was also paid to the proper experimental data treatment. For each observed instant of the plasma life, ten spectra of the analyzed spectral interval were recorded, five with and five without a mirror placed behind the plasma tube. The results of both recordings were averaged. A comparison of these two averaged spectra was used for self-absorption check. This paper comprises halfwidth results only of the spectral lines that showed no self-absorption effect. An incandescent calibrated lamp, emitting like a blackbody at 3041 K, and a deuterium lamp were used in order to obtain the spectrometer transmittance for all wavelengths of interest and for all ICCD channels. All spectra were corrected by this transmittance curve, whose uncertainty was estimated to be lower than 4%.

After this correction the spectra were fitted to sums of asymmetrical Lorentzian functions, which represent the spectral profiles, and a linear function, which represents the continuum. In the case of Kr II lines, asymmetry was negligible. This procedure allows us to measure line intensity, center position, and halfwidth, even in the case of overlapping lines. The uncertainty of the line wavelength determination was taken into account in the total experimental error.

The next step was deconvolution procedure. The dominant broadening mechanism for the present plasma conditions is Stark effect. Two other pressure-broadening mechanisms, i.e., resonance and van der Waals broadening, were found to be negligible. Therefore, only Gaussian (instrumental+Doppler) and Stark broadening mechanisms were taken into account in this procedure. For more details see Refs. [19,22].

V. RESULTS AND DISCUSSION

Within the spectral region 200–400 nm, Stark halfwidths w_m of 53 Kr II lines from 42 multiplets and Stark shifts d_m of 32 lines from 28 multiplets have been measured. All measured w_m and d_m values are presented in Table I. In the first four columns multiplet numbers, configurations, terms, and wavelengths of the analyzed spectral lines are given. The next two columns contain measured halfwidths and shifts and their corresponding statistical errors. All presented data correspond to an electron density of 10^{23} m^{-3} and a temperature of 18 000 K. For 38 multiplets, line wavelengths and corresponding transitions were taken from the NIST atomic spectra database [23]. In some cases, the information on the multiplet was incomplete (multiplets: 12–18). Data for the last four lines in Table I do not exist in the database [23]. These data were taken from Striganov and Sventitskii tables [24], but transition and multiplet data are still missing.

A. Halfwidth results

For each analyzed spectral line, a dependence of its Stark halfwidth on electron density was plotted. This dependence is clearly linear for all the lines. Examples of linear fit with minimally scattered points, in the case of line 261.671 nm, and highly scattered points, in the case of line 230.173 nm, are shown in Fig. 2. Clear linear trends were observed even in case of highly scattered points. A similar situation was found in case of Stark shift measurements, as well. The values of w_m and d_m obtained from these fits at $N_e = 10^{23}$ m^{-3} are given in Table I.

In Fig. 2, the linear fit data are given. Small systematic error always appears [y intercept, +1.09, case (a) and −2.23 case (b)]. These systematic errors and standard deviation were taken into account when calculating the errors given in Table I.

In some cases, there was a problem with the spectral line classification, as well as the problem of identifying the line

TABLE I. Experimental Stark halfwidths w_m and shifts d_m of Kr II uv lines. All data are normalized to $N_e = 10^{23}$ m^{-3} and correspond to an electron temperature of 18 000 K. The wavelength denoted by * is taken from [24].

Multiplet no	Transition array	Multiplet	Wavelength (nm)	w_m (pm)	d_m (pm)
1	$4s4p^6$-$4s^2 4p^4(^1D)5p$	^2S-$^2P^o$	242.636	28.77±4.03	−7.2±0.6
			231.202	27.15±3.53	−6.5±1.3
2	$(^3P)5s$-$(^3P)5p$	^4P-$^4S^o$	346.010	20.32±1.42	−4.4±0.5
3		^4P-$^4D^o$	398.778	21.81±1.09	−4.4±0.8
			391.258	23.83±4.77	−4.1±0.4
4		^4P-$^2D^o$	399.484	23.08±2.77	−4.3±0.2
			366.345	18.63±3.17	−4.6±0.6
5	$(^3P)5p$-$(^3P)5d$	$^4S^o$-^4P	387.544	142.27±21.34	28.2±3.1
6		$^4P^0$-^4D	365.393	71.56±6.44	30.7±0.6
7		$^4D^o$-^4D	392.008	98.43±2.95	35.3±1.1
8		$^2P^o$-^2P	347.005	93.17±23.29	44.8±3.1
9		$^2D^o$-^2F	399.795	89.70±22.43	37.8±1.9
10	$(^3P)5p$-$(^1D)5d$	$^2P^o$-^2D	270.134	35.51±4.97	$\|d\|<1$
11	$(^1D)5p$-$(^1D)5d$	$^2F^o$-^2F	350.325	117.15±11.72	45.3±4.1
12	$4d$-$(^3P_o)4f$	-$^2[3]^0$	273.326	38.44±2.31	3.8±0.4
13	$4d$-$(^3P_1)4f$	-$^2[2]^o$	231.424	24.20±4.60	
14		-$^2[2]^o$	262.044	36.19±2.53	3.4±0.3
15		-$^2[4]^o$	279.581	38.75±4.65	2.4±0.4
16	$4d$-$(^3P_2)4f$	-$^2[1]^o$	280.320	41.11±4.11	$\|d\|<2$
17		-$^2[2]^o$	257.203	32.74±1.31	
18		-$^2[3]^o$	297.887	41.29±2.06	
19	$(^3P)4d$-$(^3P_o)4f$	^4F-$^2[3]^o$	231.553	26.25±3.68	
20		^2P-$^2[3]^o$	236.275	25.60±3.58	
21	$(^3P)4d$-$(^3P_1)4f$	^4F-$^2[3]^o$	234.438	32.50±2.28	1.7±0.5
			230.174	29.42±4.41	
22		^4F-$^2[4]^o$	231.632	24.86±2.73	2.1±0.6
			222.793	23.67±2.13	
23		^2F-$^2[2]^o$	261.671	38.12±1.14	
24		^2F-$^2[3]^o$	259.248	32.62±3.59	2.9±0.4
25		^2F-$^2[4]^o$	242.833	28.12±2.53	2.6±0.4
26	$(^3P)4d$-$(^3P_2)4f$	^4P-$^2[1]^o$	264.927	45.22±1.81	
			264.306	44.76±1.34	
27		^4P-$^2[3]^o$	283.300	38.00±4.56	3.0±0.6
28		^4D-$^2[2]^o$	210.979	21.53±2.15	
29		^4D-$^2[3]^o$	209.337	27.46±1.92	
30		^4D-$^2[4]^o$	209.623	22.87±3.66	
			208.815	25.18±3.02	
			208.673	25.80±5.68	
31		^4F-$^2[4]^o$	237.553	23.64±4.26	
32		^4F-$^2[5]^o$	235.370	30.40±3.95	
33		^2P-$^2[2]^o$	269.570	37.46±4.12	$\|d\|<1$
34		^2P-$^2[3]^o$	271.616	35.78±6.08	$\|d\|<1$
35		^2F-$^2[3]^o$	297.404	40.49±3.64	
			296.725	42.31±5.08	2.8±0.7
			272.946	35.08±5.61	4.1±1.1
36		^2F-$^2[4]^o$	274.256	42.62±3.84	1.9±0.5

TABLE I. (*Continued.*)

Multiplet no	Transition array	Multiplet	Wavelength (nm)	w_m (pm)	d_m (pm)
37		^2F-$^2[5]^o$	271.240	36.23 ± 2.54	2.3 ± 0.2
38	$(^3P)4d$-$(^3P_2)5f$	^2F-$^2[4]^o$	228.268	28.15 ± 1.13	1.9 ± 0.4
			228.307*		
39	$5s'$-	^2D-6^o	228.779	27.35 ± 1.09	1.6 ± 0.3
40	$4d'$-	^2D-11^o	299.984	58.47 ± 5.26	
41			258.908	36.19 ± 3.26	4.1 ± 0.4
42			225.032	30.86 ± 4.63	

that really appears in the spectrum when a difference between the positions of two lines (Kr II and Kr III line) is less than the resolution of the experimental system. In Table I, there is a halfwidth result for spectral line Kr II 228.268 nm (mult. 38), classified as belonging to the transition $(^3P)4d\ ^2F$-$(^3P_2)5f^2[4]^o$, as given in the NIST database [23].

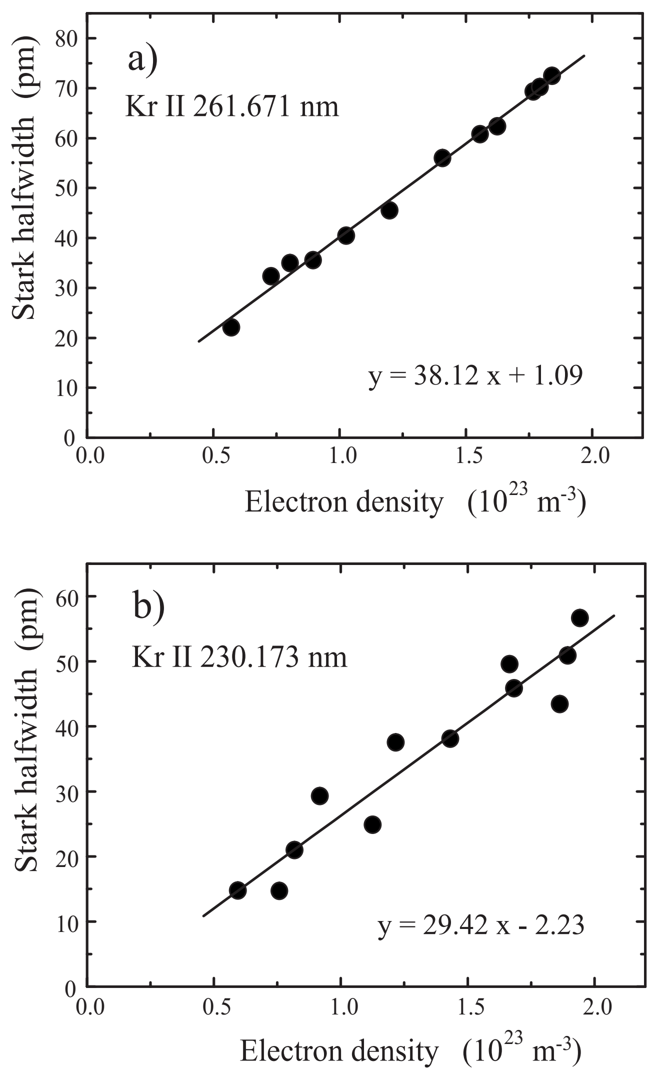

FIG. 2. Example of the Kr II 261.671 nm line (a) and the Kr II 230.173 nm line (b) halfwidth versus electron density and its linear fit.

In this database this line is notated with 0 intensity, on the scale of maximal 3000. On the other hand, there is a line in Striganov and Sventitskii [24] having the closest wavelength value, 228.307 nm (denoted by an asterisk in Table I), to the measured wavelength of the analyzed line, but having no data on multiplet or transition array. In tables [24], this line is notated with intensity 30 on the scale of maximal 1000. A recording of this line is shown in Fig. 3(a). A measurement of the line position gives a wavelength value closer to the value from the tables [24]. What complicates the situation even more is that there is a Kr III line at 228.280 nm. In addition, there are no data on this Kr III line in tables [24]. If we consider that the wavelength of the Kr II line is 228.307 nm, the position of the Kr III 228.280 nm line would probably be as shown in Fig. 3(b). One should take into account that the Kr III line is a low intensity line. Furthermore, spectral line intensity measurements show that Kr III lines practically disappear at electron densities below 10^{23} m^{-3}. The linear trend of the 228.307 nm line halfwidth dependence on electron density does not vary over the electron density range of this experiment. This allowed us to consider the Kr II 228.307 nm line as an isolated one and include its halfwidth result in Table I.

There are a few more similar cases concerning the existence of nearby low intensity lines. So, in the same manner, we considered Kr II 391.258 nm, 262.044 nm, 279.581 nm, 222.793 nm, 235.370 nm, and 258.908 nm lines, from multiplets 3, 14, 15, 22, 32, and 41, respectively, as isolated lines in the case of our plasma conditions.

In six multiplets there are Stark halfwidth results for two lines per multiplet and in two multiplets there are halfwidth results for three lines per multiplet. These data can be used for comparing the Stark halfwidth results within a multiplet. For this comparison it would be better to convert the results in angular frequency units, in order to avoid the influence of the wavelength. Multiplet 35 is a good example. The halfwidths expressed in angular frequency units are $(8.6, 9.1, \text{and } 8.9) \times 10^{11}$ s^{-1}. All these values are within $\pm 3\%$ of the average value. There is a similar situation in the case of all the other multiplets containing two or three Stark halfwidth results.

A comparison of present Stark halfwidth results with other available experimental [1,7] and theoretical [14,16] results is presented in Table II.

We have presented our halfwidth results, and there are only four results to be compared to the halfwidth values

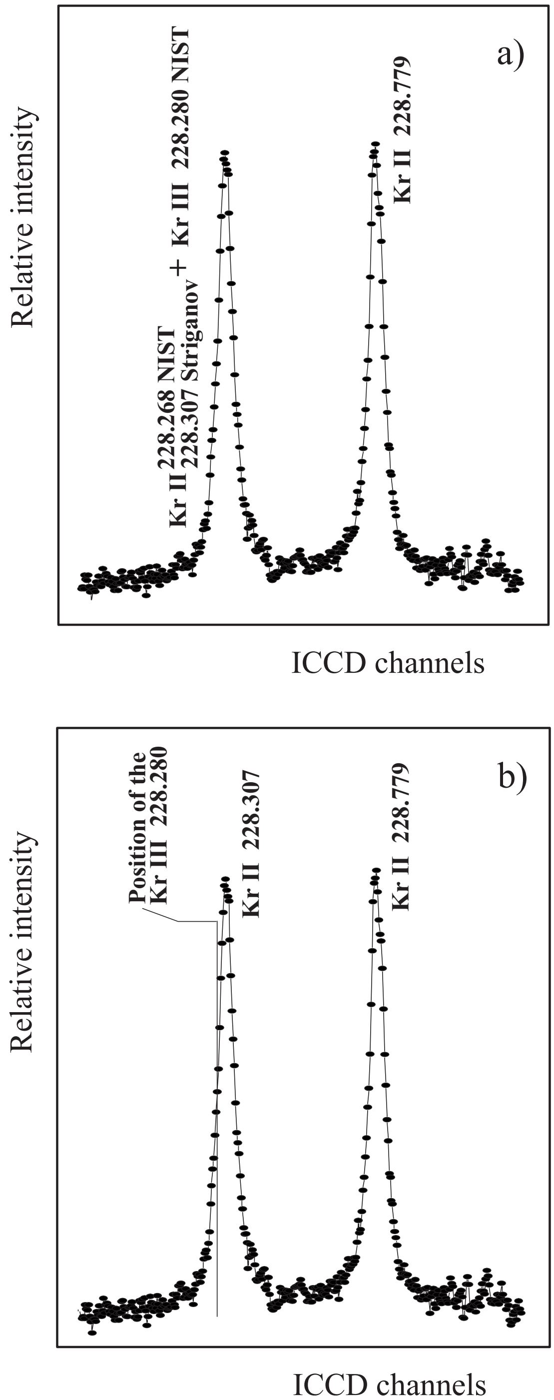

FIG. 3. Kr II 228.268 (228.307) nm line mult. 38 (a) and probable position of Kr III 228.280 nm (b).

previously measured by other authors. The halfwidths of the lines 399.484 (mult. 4), 387.544 nm (mult. 5), and 392.008 nm (mult. 7) are compared to the results from Bertuccelli and Di Rocco [7]. The experimental errors are also taken from [7]. There is a reasonable agreement between the present result and the result from Ref. [7] in the case of the line in mult. 4. A discrepancy between the results for the other two lines is obvious. The ratio $w_m/w_{m\,[7]}$ is 3.03 and 3.28, respectively. The halfwidth data in Ref. [7] are given in wavelength number units (cm^{-1}) for the same electron density as in present work, but for a different electron temperature (10 000 K). In order to make a comparison, the results from [7] were recalculated into pm units and adjusted to the temperature of 18 000 K, using the halfwidth temperature dependence $w \sim T^{1/2}$. There is no reasonable explanation for these discrepancies. The profile of Kr II 392.008 nm line is shown in Fig. 4. There are a few overlapping Kr II and Kr III lines nearby, but they were taken into account during the fitting procedure. The nearby Kr II 391.258 nm line, also shown in Fig. 4, has a halfwidth value close to the halfwidth result given in Ref. [7]. It is obvious that the 392.008 nm line (mult. 7) is much broader and its halfwidth is a few times larger than the halfwidth of the 391.258 nm line, i.e., larger than the halfwidth result from Ref. [7]. This comparison confirms the validity of the halfwidth result presented in this paper. A similar situation was found in case of the 387.544 nm line, as well.

A comparison of the present halfwidth result for the line 347.005 nm (mult. 8) with the result from Pitman and Konjević [1] shows a reasonable agreement. In order to make a comparison, the halfwidth result from [1] was recalculated to fit plasma conditions in this work. The halfwidth values are in agreement, within the experimental errors. Here, it should be pointed out that this line had a low intensity and a bit noisy shape in the present experiment. However, this was taken into account for experimental error estimation.

There are only five halfwidth results, presented in this paper, that can be compared to the available theoretical data [14,16]. The comparison is given in Table II. The halfwidth values from Popović and Dimitrijević [16] were recalculated to fit present experimental plasma conditions, while the other theoretical values were obtained by calculations based on the modified semiempirical formula (MSE) (for details, see Dimitrijević and Konjević [14]). MSE calculations were performed only in cases for which all necessary perturbing levels data were available. Our experimental halfwidth values are in very good agreement with calculations based on modified semiempirical formula [14]. The ratio $w_m/w_{[14]}$ is between 0.8 and 1. The ratio $w_m/w_{[16]}$ is a little bit higher, between 1 and 1.3, but it is still reasonably good for an experimental or theoretical data ratio.

B. Shift results

Stark shifts d_m in this work were obtained using a method described in Aparicio *et al.* [25]. First of all, it is assumed that there is no Stark shift ($d_m=0$) when electron density is $N_e=0$. Since the exact position of an observed spectral line on the detector at $N_e=0$ is unknown, this value is obtained by plotting the measured line center position of each observed spectral line as a function of N_e and, by means of linear fit, extrapolating to zero electron density. Once this value is substracted from the measured values of the line center position, these differences multiplied by the linear inverse dispersion of the spectroscopic system allow one to obtain the desired Stark shift d_m values (in pm).

Examples of Stark shift dependence on electron density for two close spectral lines are shown in Fig. 5. Stark shift for the Kr II 271.240 nm line shows clear linear dependence

TABLE II. The comparison of present experimental halfwidth results with other experimental [1,7] and theoretical [14,16] data. All data are normalized to $N_e=10^{23}$ m^{-3} and correspond to an electron temperature of 18 000 K.

Multiplet no.	Transition array	Multiplet	Wavelength (nm)	w_m (pm)	w [Ref.] (pm)	$\frac{w_m}{w_{[14]}}$	$\frac{w_m}{w_{[16]}}$
2	$(^3P)5s$-$(^3P)5p$	^4P-$^4S^o$	346.010	20.32±1.42		1.04	1.33
3		^4P-$^4D^o$	398.778	21.81±1.09		0.79	1.12
			391.258	23.83±4.77		0.95	1.34
4		^4P-$^2D^o$	399.484	23.08±2.77	28.90±1.45 [7]	0.93	
			366.345	18.63±3.17		0.93	
5	$(^3P)5p$-$(^3P)5d$	$^4S^o$-^4P	387.544	142.27±21.34	43.32±2.17 [7]		
7		$^4D^o$-^4D	392.008	98.43±2.95	32.53±1.63 [7]		
8		$^2P^o$-^2P	347.005	93.17±23.29	79.55±15.91 [1]		

on electron density with small standard deviation. The Kr II 271.616 nm line is a low intensity line, practically having no shift. Here, as it can be seen from Fig. 5(b), experimental points are scattered within ±1.5 pm. This value is actually the precision of shift measurements in this work. Experimental shift errors were estimated in the same manner as halfwidth errors.

There are relatively large positive (red) Stark shifts of the lines from multiplets 5–9 and 11, all belonging to the $5p$-$5d$ transition array. The expression "relatively large" means large in comparison with most of the measured line shifts and the corresponding halfwidths. The ratio halfwidth or shift for these lines is between 2.1 and 2.8. In other cases, this ratio is between 4 and 20. The nearest perturbing levels and their positions in relation to the upper and lower transition level are responsible for these large shifts. An example of transition levels and their nearest perturbing levels for the 365.393 nm line from multiplet 6 is shown in Fig. 6.

Positions of the perturbing levels cause the red and relatively large shift of this spectral line. A similar situation was found for the 392.008 nm line from multiplet 7. In the case of line 347.005 nm from multiplet 8, no data on nearby per-

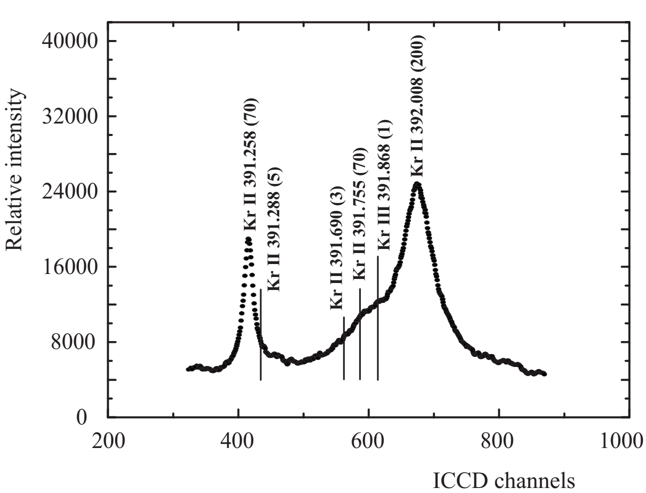

FIG. 4. Part of the spectrum around the Kr II 392.008 nm line.

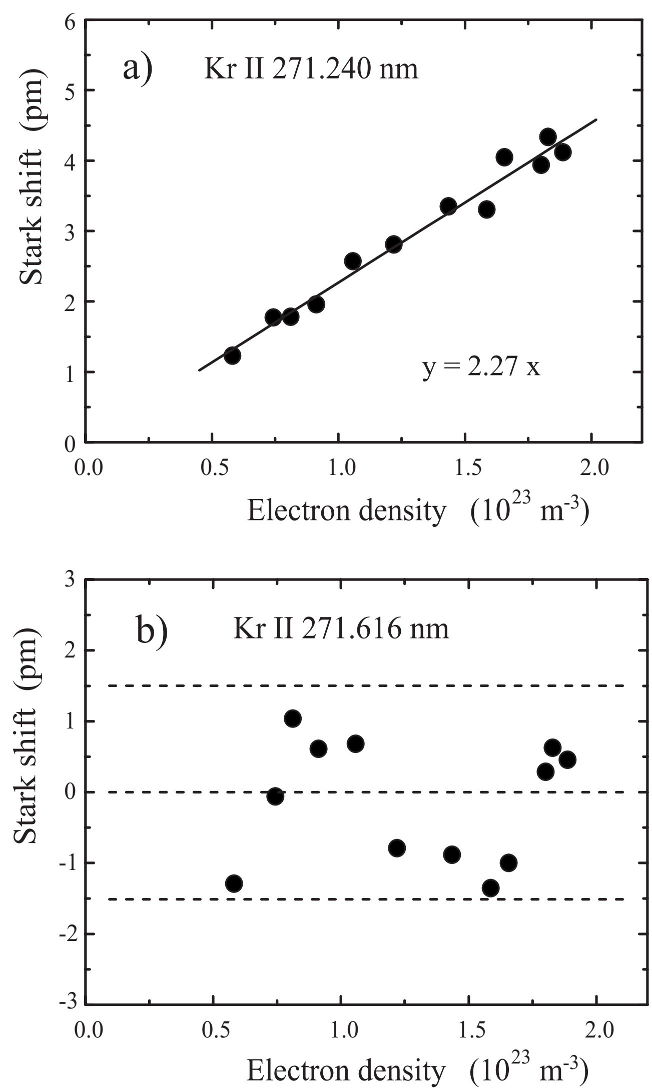

FIG. 5. (a) Example of Stark shift dependence on electron density for the Kr II 271.240 nm line and (b) the Kr II 271.616 nm line.

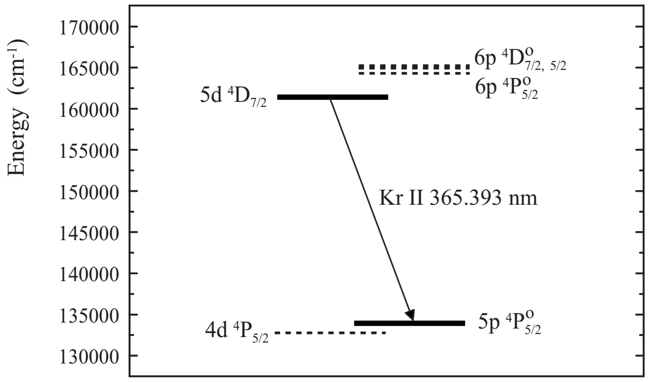

FIG. 6. Transition levels and nearest perturbing levels which cause the large shift of the Kr II 365.393 nm line, mult. 6.

turbing levels with the same parent term (^3P) were found in the energy levels NIST database [23]. However, there are nearby levels $^2[1]^0$ and $^2[2]^0$ with parent term ($^3P_2$). This might be the explanation of the large red shift. The same explanation can be applied to line 399.795 nm from multiplet 9. On the other hand, in case of lines 387.544 and 350.325 nm from multiplets 5 and 11, respectively, the explanation could not be found using the energy levels data [23].

For a comparison of the shift results within the multiplets, there are only four cases: multiplets 1, 3, 4, and 35. Differences between the shifts of the lines belonging to the same multiplet vary between 0.3 and 1.3 pm. These values are lower than the limit of our measurement precision, so we can say that the agreement of the shift results within the multiplet is very good.

There are no other experimental data for comparison with present shift results. Actually, there is one paper [26] which contains shift data for the three lines presented in this work, but in Ref. [26] the plasma diagnostics data are missing, so a comparison is not possible. A comparison of measured Stark shifts with theoretical data [15,16] is possible for the same lines as in the case of halfwidths comparison. For comparison with modified semiempirical data, calculations based on Dimitrijević and Kršljanin [15] were performed. The reason for such a small number of comparisons is the same as in the case of halfwidths. The calculations were performed only in cases for which complete sets of perturbing levels data, necessary for modified semiempirical calculations, were available in database [23]. The other theoretical data were taken directly from Popović and Dimitrijević [16]. Theoretical data [16] were recalculated to fit present experimental plasma conditions. The results of the comparison are given in Table III.

All measured and calculated data are in agreement concerning shift direction. The ratios between experimental and both theoretical results are between 0.67 and 0.96, except for the Kr II 399.484 nm line where this ratio is 0.52. Stark shift theoretical data from Ref. [16] show a little better agreement with the data presented in this work.

VI. CONCLUSIONS

Radiation from low pressure pulsed arc plasma was studied in order to determine Stark parameters of 52 Kr II spectral lines from 42 multiplets in the wavelength region from 208 to 400 nm. 48 halfwidth and 32 shift experimental results are reported in this paper. With these results the Kr II Stark parameters database is extended to the uv region. The temperature interval (16–20) kK in this experiment was too narrow to analyze Stark parameters temperature dependence.

Special attention was paid to experimental conditions, plasma diagnostics, as well as experimental data treatment. Electron densities were determined by two-wavelength interferometry and electron temperatures by the Boltzmann-plot technique using 12 Kr II lines. Furthermore, a self-absorption check was performed and an appropriate deconvolution procedure was applied.

Since Stark parameters of Kr II lines from the uv region are mostly missing in the literature, a few comparisons are not sufficient in order to give a general opinion on the agreement of our data with the experimental data from other authors.

All measured Stark halfwidths show clear linear dependence on electron density. The halfwidth results belonging to the same multiplet show regular behavior in all cases, i.e., the difference between the results is within a few percent, as predicted in Wiese and Konjević [27,28]. A similar situation has been found in the case of shift results. Here, it should be mentioned that in some cases (for $5p$-$5d$ transition) relatively large shift data were obtained. A possible explanation is given in the text above.

A comparison with the theoretical calculations [14–16] was made only in several cases. For modified semiempirical calculations (Dimitrijević and Konjević [14], Dimitrijević and Kršljanin [15]), in most cases, necessary perturbing lev-

TABLE III. The comparison of some experimental shift data with theoretical data [15,16]. All data are normalized to $N_e = 10^{23}$ m^{-3} and correspond to an electron temperature of 18 000 K.

Multiplet no.	Transition array	Multiplet	Wavelength (nm)	d_m (pm)	$\frac{d_m}{d_{[15]}}$	$\frac{d_m}{d_{[16]}}$
2	$(^3P)5s$-$(^3P)5p$	^4P-$^4S^o$	346.010	-4.4 ± 0.5	0.91	0.96
3		^4P-$^4D^o$	398.778	-4.4 ± 0.8	0.67	0.80
			391.258	-4.1 ± 0.4	0.67	0.73
4		^4P-$^2D^o$	399.484	-4.3 ± 0.2	0.52	
			366.345	-4.6 ± 0.6	0.71	

els data were missing. On the other hand, only a few lines from Popović and Dimitrijević [16] matched the spectral lines presented in this paper. In the case of Stark halfwidths, there is a quite good agreement with the data from Ref. [14]; ratios $w_m/w_{[14]}$ are between 0.8 and 1. In the case of Stark shifts, theoretical data from Ref. [16] show a relatively good agreement with present data; the ratios $d_m/d_{[16]}$ are between 0.7 and 1. This is a very satisfying result, if one takes into account that very low value line shifts have been considered in this work. Once more, the number of comparisons is not enough to obtain more general conclusions about agreement or disagreement between theoretical and experimental results for both widths and shifts.

The Stark halfwidth and shift data, presented in this paper, can be used for plasma diagnostic purposes, as well as for theoretical calculations testing.

ACKNOWLEDGMENTS

We thank S. González for his work on the experimental device, and the Spanish Ministerio de Ciencia y Tecnología and the Consejería de Educación y Cultura de la Junta de Castilla y León for their financial support under Contracts No. FIS2005-03155 and No. VA015A05, respectively. J.A.A. would like to express his personal acknowledgment to the ONCE for help. S.D. thanks the Ministry of Science, Republic of Serbia for support in Project No. 141024.

[1] T. L. Pitman and N. Konjević, J. Quant. Spectrosc. Radiat. Transf. **35**, 247 (1986).
[2] Y. Vitel and M. Skowronek, J. Phys. B **20**, 6493 (1987).
[3] A. Lesage, D. Abadie, and M. H. Miller, Phys. Rev. A **40**, 1367 (1989).
[4] J. A. del Val, R. J. Peláez, S. Mar, F. Rodríguez, V. R. González, A. B. Gonzalo, A. de Castro, and J. A. Aparicio, Phys. Rev. A **77**, 012501 (2008).
[5] M. S. Dimitrijević and M. M. Popović, Astron. Astrophys. **217**, 201 (1989).
[6] H. O. Di Rocco, J. Appl. Phys. **68**, 3732 (1990).
[7] G. Bertuccelli and H. O. Di Rocco, Phys. Scr. **44**, 138 (1991).
[8] G. Bertuccelli and H. O. Di Rocco, Phys. Scr. **47**, 747 (1993).
[9] N. Konjević, M. S. Dimitrijević, and W. L. Wiese, J. Phys. Chem. Ref. Data **13**, 649 (1984).
[10] N. Konjević and W. L. Wiese, J. Phys. Chem. Ref. Data **19**, 1307 (1990).
[11] N. Konjević, A. Lesage, J. R. Fuhr, and W. L. Wiese, J. Phys. Chem. Ref. Data **31**, 819 (2002).
[12] N. Konjević, Phys. Rep. **316**, 339 (1999).
[13] V. Milosavljević, S. Djeniže, M. S. Dimitrijević, and L. Č. Popović, Phys. Rev. E **62**, 4137 (2000).
[14] M. S. Dimitrijević and N. Konjević, J. Quant. Spectrosc. Radiat. Transf. **24**, 451 (1980).
[15] M. S. Dimitrijević and V. Kršljanin, Astron. Astrophys. **165**, 269 (1986).
[16] L. Č. Popović and M. S. Dimitrijević, Serb. Astron. J. **161**, 89 (2000).
[17] M. A. Gigosos, S. Mar, C. Pérez, and I. de la Rosa, Phys. Rev. E **49**, 1575 (1994).
[18] J. A. del Val, S. Mar, M. A. Gigosos, M. I. de la Rosa, C. Pérez, and V. R. González, Jpn. J. Appl. Phys., Part 1 **37**, 4177 (1998).
[19] S. Djurović, R. J. Peláez, M. Ćirišan, J. A. Aparicio, and S. Mar, J. Phys. B **39**, 2901 (2006).
[20] A. de Castro, J. A. Aparicio, J. A. del Val, V. R. González, and S. Mar, J. Phys. B **34**, 3275 (2001).
[21] S. Mar, J. A. del Val, F. Rodríguez, R. J. Peláez, V. R. González, A. B. Gonzalo, A. de Castro, and J. A. Aparicio, J. Phys. B **39**, 3709 (2006).
[22] R. J. Peláez, M. Ćirišan, S. Djurović, J. A. Aparicio, and S. Mar, J. Phys. B **39**, 5013 (2006).
[23] NIST Atomic Spectra Database, http://physics.nist.gov/asd3
[24] A. R. Striganov and N. S. Sventitskii, *Tables of Spectral Lines of Neutral and Ionized Atoms* (Plenum, New York, 1968).
[25] J. A. Aparicio, C. Pérez, J. A. del Val, M. A. Gigosos, M. I. de la Rosa, and S. Mar, J. Phys. B **31**, 4909 (1998).
[26] H. O. Di Rocco and G. Bertuccelli, J. Quant. Spectrosc. Radiat. Transf. **41**, 161 (1989).
[27] W. L. Wiese and N. Konjević, J. Quant. Spectrosc. Radiat. Transf. **28**, 185 (1982).
[28] W. L. Wiese and N. Konjević, J. Quant. Spectrosc. Radiat. Transf. **47**, 185 (1992).