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STARK SHIFT OF SEVERAL Kr II SPECTRAL LINES

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Abstract. Stark shifts of thirteen singly charged krypton (Kr II) ion spectral lines have been measured in the linear, low pressure, pulsed arc at 17 000 K electron temperature and 1.65x10^{23} m^{-3} electron density. The measured shift values have been compared to the theoretical data calculated by us by using the modified semiempirical method.

1. INTRODUCTION

For the first time by means of the Goddard high resolution spectrograph on the Hubble space telescope, krypton has been detected in the spectra of the interstellar medium (Cardelli et al. 1991, Cardelli and Mayer 1997) which represents the material from which the young early type stars (as e. g. Ap and Bp type stars where Stark broadening data are of interest) are formed (Leckrone at al. 1993). Moreover, krypton is present in many light sources and lasers as the working gas. If the Stark broadening is the principal pressure broadening mechanism in plasmas (with 10^{22} - 10^{27} m^{-3} electron density), it is possible to obtain from Stark width and shift values other basic plasma parameters as e.g. electron temperature (T) and density (N), essential for the stellar atmospheres modeling. Consequently, the knowledge of the Stark broadening parameters (the width and the shift) of ionized krypton (Kr II) spectral lines is of interest for plasma diagnostic purpose.

In the case of the Kr II Stark shift investigations the available literature is poor. Namely, since the first Kr II lines Stark shift investigation (Mandel'shtam 1962), only one experiment (Vitel and Skowronek 1987) provided reliable Stark line shifts of three Kr II spectral lines. In Di Rocco et al. (1989) Kr II line shifts have been investigated but without a reliable plasma parameter determination so that the comparison with our results is not possible. In this work we will present measured and calculated Stark shift (d) values of fourteen Kr II spectral lines. Stark shift values of eleven Kr II lines were not known before.

Measurements have been performed at 17 000 K electron temperature and 1.65x10^{23} m^{-3} electron density in krypton plasma created in the linear, low pressure, pulsed arc discharge. The d values have been calculated within the frame of the modified semiempirical method.

2. EXPERIMENT

The modified version of the linear low pressure pulsed arc (Djeniže et al. 1991 - Milosavljević and Djeniže 1998) has been used as a plasma source. The working gas was pure krypton at 130 Pa filling pressure in flowing regime. Spectroscopic observation of isolated spectral lines was made end-on along the axis of the discharge tube. A capacitor of 14 μF was charged up to 1.5 kV. 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 spectrograph exit slit (10 μm) with the calibrated photomultiplier was micrometrically traversed along the spectral plane in small wavelength steps (0.0073 nm). The averaged photomultiplier signal (five shots at the same spectral range) was digitalized using an oscilloscope, interfaced to a computer.

The Stark shifts were measured relative to the unshifted spectral lines emitted by the same plasma and have been corrected for the electron temperature decay. Stark shift data are determined with ±0.0008 nm error at given N and T. The electron temperature was determined from the ratios of the relative intensities of nine Kr II spectral lines with an estimated error of ±9%, assuming the existence of LTE, according to the criterion from Griem (1974). The electron density decay was measured using the well known single laser interferometry technique (Ashby et al. 1965) for the 632.8 nm He-Ne laser wavelength with an estimated error of ±7% . The electron density and temperature decay are presented in Milosavljević et al. (2000) (Fig. 5).

At 20μs and 300μs after the beginning of the discharge, when the Kr II spectral line center positions were obtained, the found electron densities were 1.65x10^{23} m^{-3} ±7% and 0.03x10^{23} m^{-3} ±80% , respectively.

3. METHOD OF CALCULATION

According to the MSE approach (Dimitrijević and Kršljanin 1986) the electron Stark shift is given as

$$d = N\frac{4\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}\cdot\{\varepsilon_{\ell_i,\ell_i+1}\mathbf{R}^2[n_i\ell_i, n_i(\ell_i+1)]\widetilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_i,\ell_i+1}}\right)-$$

$$-\varepsilon_{\ell_i,\ell_i-1}\mathbf{R}^2[n_i\ell_i, n_i(\ell_i-1)]\widetilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_i,\ell_i-1}}\right)-$$

$$-\varepsilon_{\ell_f,\ell_f+1}\mathbf{R}^2[n_f\ell_f, n_f(\ell_f+1)]\widetilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_f,\ell_f+1}}\right)+$$

$$+\varepsilon_{\ell_f,\ell_f-1}\mathbf{R}^2[n_f\ell_f, n_f(\ell_f-1)]\widetilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_f,\ell_f-1}}\right)+\left(\sum_{i'}\mathbf{R}^2_{ii'}\right)_{\Delta n\neq 0}g_{sh}(x_{n_i}, x_{n_i+1})-$$

$$-2\sum_{i'(\Delta E_{ii'}<0)}\mathbf{R}^2_{ii',\Delta n\neq 0}g_{sh}\left(\frac{E}{\Delta E_{n_i,\ell_i,n_{i'},\ell_{i'}}}\right)-\left(\sum_{f'}\mathbf{R}^2_{ff'}\right)_{\Delta n\neq 0}g_{sh}(x_{n_f}, x_{n_f+1})+$$

$$+2\sum_{f'(\Delta E_{ff'}<0)} \mathbf{R}^2_{ii',\Delta n\neq 0} g_{sh}\left(\frac{E}{\Delta E_{n_f,\ell_f,n_{f'}\ell_{f'}}}\right) + \sum_k \delta_k\} \qquad (1)$$

where the initial level is denoted by i and the final one by f the square of the matrix element $\{\mathbf{R}^2[n_k\ell_k, n_k(\ell_k \pm 1)],\quad k = i, f\}$ being

$$\mathbf{R}^2[n_k\ell_k, n_k(\ell_k \pm 1)] = \left(\frac{3n_k^*}{2Z}\right)^2 \frac{\ell_>}{2\ell_k + 1}(n_k^{*2} - \ell_k^2)\Phi^2(n^{*2}_{\ell_k-1}, n^{*2}_{\ell_k}, \ell_k) \qquad (2)$$

and

$$\left(\sum_{k'} \mathbf{R}^2_{kk'}\right)_{\Delta n\neq 0} = \left(\frac{3n_k^*}{2Z}\right)^2 \frac{1}{9}(n_k^{*2} + 3\ell_k^2 + 3\ell_k + 11) \qquad (3)$$

where $\ell_> = \max(\ell_k, \ell_{k'})$, ℓ denoting the angular momentum quantum number.

In Eqs. (1 – 3) N and T are electron density and temperature, respectively, and Φ^2 is the Bates-Damgaard factor tabulated *e.g.* in Oertel and Shomo (1968). Here, $g(x), g_{sh}(x)_{sh}$ and $\tilde{g}(x), \tilde{g}_{sh}(x)$ are the semiempirical (Griem 1968) and the modified semiempirical (Dimitrijević and Konjević 1980, Dimitrijević and Kršljanin 1986) Gaunt factors for Stark width and shift, respectively. The factor $\varepsilon_{kk'} = (E_{k'} - E_k)/|E_{k'} - E_k|$, where E_k and $E_{k'}$ are respective energies of the considered and its perturbing level. The sum $\sum_k \delta_k$ is different from zero only if perturbing levels strongly violating the assumed approximations exist and may be evaluated as

$$\delta_i = \pm\mathbf{R}^2_{ii'}\left[g_{sh}\left(\frac{E}{\Delta E_{i,i'}}\right) \mp g_{sh}(x_{n_i,n_i+1})\right], \qquad (4)$$

for upper level, and

$$\delta_f = \mp\mathbf{R}^2_{ff'}\left[g_{sh}\left(\frac{E}{\Delta E_{f,f'}}\right) \mp g_{sh}(x_{n_f,n_f+1})\right], \qquad (5)$$

for lower level. In Eqs. (4) and (5) subscripts correspond to $\Delta E_{jj'} < 0$; $x_{n_k,n_k+1} \approx 3kTn_k^{*3}/(2Z^2E_H)$, where $\Delta E_{kk'} = |E_k - E_{k'}|$, n_k is the principal, n_k^* the effective principal quantum number, $E = 3kT/2$ and $(Z - 1)$ is the ionic charge.

4. RESULTS AND DISCUSSION

The needed atomic energy levels for Kr III have been taken from Sugar and Musgrove (1991). The results of the measured Stark shift (d_m) values at T=17 000 K electron temperature and 1.65x10^{23} m^{-3} electron density are shown in Table 1. Our theoretical d_{th} values are presented in Table 2.

Table 1. Measured Stark shift (d_m) values for the Kr II lines at the observed electron temperature (T) of 17 000 K and electron density (N) of 1.65 × 10^{23} m^{-3}. Positive shift is toward the red.

Transition	*Multiplet*	λ (nm)	d_m .(nm)
5s-5p	$^4P_{5/2}$-$^4P^0{}_{3/2}$	465.89	-0.0010
	$^4P_{3/2}$-$^4P^0{}_{1/2}$	483.21	-0.0014
	$^4P_{5/2}$-$^4D^0{}_{7/2}$	435.55	-0.00
	$^4P_{5/2}$-$^4D^0{}_{5/2}$	473.90	-0.0014
	$^4P_{3/2}$-$^4D^0{}_{5/2}$	476.57	-0.00
	$^2P_{3/2}$-$^2P^0{}_{1/2}$	484.66	-0.00
	$^2P_{3/2}$-$^2P^0{}_{3/2}$	461.53	-0.00
	$^2P_{3/2}$-$^2D^0{}_{5/2}$	461.91	-0.00
5s′-5p′	$^2D_{3/2}$-$^2F^0{}_{5/2}$	463.39	-0.0018
	$^2D_{5/2}$-$^2F^0{}_{5/2}$	457.72	-0.00
	$^2D_{5/2}$-$^2P^0{}_{3/2}$	447.50	-0.0017
	$^2D_{5/2}$-$^2D^0{}_{5/2}$	408.83	-0.0017
5p-5d	$^4D^0{}_{5/2}$-$^4F_{7/2}$	377.81	0.0090

Table 2. Stark shift values (d in nm) calculated by using the modified semiempirical method (Eqs. 1-5) for the Kr II spectral lines, at 10^{23} m^{-3} electron density.

	T (10^4 K)				
λ (nm)	1	2	3	4	5
473.90	-0.0101	-0.0074	-0.0063	-0.0058	-0.0056
465.89	-0.0111	-0.0082	-0.0070	-0.0064	-0.0062
483.21	-0.0111	-0.0082	-0.0070	-0.0064	-0.0062
435.55	-0.0083	-0.0061	-0.0051	-0.0047	-0.0044
476.57	-0.0089	-0.0066	-0.0056	-0.0051	-0.0049
484.66	-0.0125	-0.0092	-0.0078	-0.0071	-0.0069
461.53	-0.0104	-0.0076	-0.0064	-0.0058	-0.0055
461.91	-0.0099	-0.0073	-0.0061	-0.0055	-0.0052
463.39	-0.0056	-0.0036	-0.0029	-0.0028	-0.0028
457.72	-0.0091	-0.0066	-0.0056	-0.0051	-0.0049
447.50	-0.0103	-0.0071	-0.0057	-0.0051	-0.0049
408.83	-0.0065	-0.0047	-0.0039	-0.0035	-0.0033
378.31	0.0057	0.0107	0.0134	0.0149	0.0154
377.81	0.0076	0.0128	0.0155	0.0168	0.0172

One can conclude on the basis of the Table 1. and Table 2., that the d_m values are very small. Within the accuracy of measurements (0.0008 nm) many of them were equal to zero. Our calculations give higher absolute d values than the measured ones. Our calculated and measured Stark shift values, in the case of the Kr II lines (Table 1. and Table 2.), have the same sign. For the lines that belong to the 5s-5p and 5s′-5p′ transitions d is negative and for lines from the 5p-5d transition d is positive. Our measured d_m values confirm the observed negative sign by Vitel and Skowronek (1987) for three Kr II lines (473.90 nm, 465.89 nm and 435.55 nm). Evident Stark shift, in our measurements, was observed only for the 377.81 nm Kr II line which belongs to the higher lying 5p-5d transition. In all cases the shift values are considerably smaller than width values. This indicates that particular important contributions have different sign and that their mutual cancellation results in shifts much smaller than widths. Since the assumed accuracy of the method is ±50 % of the width value, the reliability of these small shifts is much lower. Therefore, d_m/d_{th} ratios are not presented in this paper.

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