Stark broadening of potassium lines

N. Konjević
Institute of Physics, 11001 Beograd, P.O. Box 57, Yugoslavia
(Received 14 January 1985)

Recently published Stark broadening data of potassium ns-$4p$ and nd-$4p$ lines have been reexamined. Newly derived data are compared with theoretical results obtained from a simple approximative formula. The experiment agrees with theoretical results, in average, within ±20%.

I. INTRODUCTION

Stark broadening of neutral-atom lines in plasmas has been a subject of numerous experimental studies (see, e.g., Refs. 1–3). These experiments were critically evaluated,[1–3] and selected data for helium through calcium and cesium were compared with results of comprehensive semiclassical calculations by Benett and Griem.[1,4] Typical agreement, within ±20%–30%, has been found.[1–3] Recently, semiclassical calculations were extended to the lines of some elements heavier than calcium.[5] This time, disagreements with the experiment were large, but the critical evaluation of experimental data indicates that, in most cases, the experiment must be blamed for these discrepancies.[5,6]

In a recent experiment, Stark broadening parameters of potassium ns-$4p$ and nd-$4p$ lines have been measured in a wall-stabilized arc.[7] The experimentally determined Stark widths were compared with the results of semiclassical theoretical calculations by Benett and Griem.[1,4] An agreement within 30% for the lines in the ns-$4p$ series is found, while the measured Stark widths of the nd-$4p$ series lines were only one-third of the theoretical values. Intrigued by this large discrepancy between theory and experiment, we have performed analysis of both theoretical data and experiment in order to find the causes for this disagreement.

II. THEORY

First, the analysis of theoretical data in Refs. 1 and 4 indicates that the average wavelengths of 582.5 and 535.4 nm for multiplets $4p\ ^2P^o$–$6d\ ^2D$ and $4p\ ^2P^o$–$7d\ ^2D$, respectively, are incorrectly assigned. The author of Ref. 7 used wavelengths only to identify these multiplets and, therefore, incorrect theoretical data were taken for comparison. Here, it is still puzzling whether average wavelength or multiplet designation is wrong for these two sets of theoretical data in Refs. 1 and 4. To clear this up we performed theoretical calculations of electron-impact linewidths and ion-broadening parameters α for both investigated spectral series of neutral potassium. For these calculations we used a simple formula[8] (SF) to estimate Stark widths of neutral lines. This formula was, after certain simplifications, derived from the semiclassical theoretical approach[1,9] employed in Refs. 1 and 4 for evaluation of neutral-atom Stark widths. Calculated theoretical half-half-widths w_{SF} are given, together with data from Refs. 1 and 4, which are introduced in Table I in accordance with multiplet identification. It is clear from the comparison of both sets of data at 5000 K that data for multiplet $4p\ ^2P^o$–$6d\ ^2D$ and $4p\ ^2P^o$–$7d\ ^2D$ from Refs. 1 and 4 should be used in accordance with their multiplet identification. The correct aver-

TABLE I. Comparison of calculated Stark broadening parameters for potassium ns-$4p$ and nd-$4p$ lines. With w_{SC} and α_{SC} are designated data from Refs. 1 and 4 (SC denotes semiclassical), while w_{SF} and α_{SF} are calculated here from simple approximate formula (Ref. 8).

Transition	Wavelength (nm)	Electron-impact half-half-widths (Å) at $N_e = 1\times10^{16}$ cm^{-3}			Ion-broadening parameter at $N_e = 1\times10^{16}$ cm^{-3}		
		w_{SC} at 5000 K	w_{SF} at 5000 K	w_{SF} at 2950 K	α_{SC} at 5000 K	α_{SF} at 5000 K	α_{SF} at 2950 K
$4P^o_{1/2}$-$5S_{1/2}$	1249.2	0.375	0.320	0.265	0.056	0.054	0.062
$4P^o_{1/2}$-$6S_{1/2}$	693.0	0.448	0.421	0.341	0.092	0.071	0.083
$4P^o_{1/2}$-$7S_{1/2}$	579.5	0.881	0.898	0.717	0.129	0.088	0.104
$4P^o_{1/2}$-$8S_{1/2}$	533.4	1.75	1.89	1.50	0.163	0.104	0.123
$4P^o_{1/2}$-$9S_{1/2}$	509.4	· · ·	3.69	2.95	· · ·	0.120	0.141
$4P^o_{1/2}$-$10S_{1/2}$	495.1	· · ·	6.72	5.41	· · ·	0.135	0.159
$4P^o_{3/2}$-$3D_{5/2}$	1174.5	0.136	0.248	0.199	0.029	0.042	0.050
$4P^o_{3/2}$-$4D_{5/2}$	695.5	0.520	0.660	0.541	0.094	0.041	0.047
$4P^o_{3/2}$-$5D_{5/2}$	582.5	· · ·	1.42	1.18	· · ·	0.053	0.061
$4P^o_{3/2}$-$6D_{5/2}$	535.4	2.76	2.90	2.41	0.189	0.066	0.076
$4P^o_{3/2}$-$7D_{5/2}$	510.7	4.96	5.60	4.67	0.243	0.079	0.091
$4P^o_{3/2}$-$8D_{5/2}$	496.0	· · ·	10.15	8.48	· · ·	0.091	0.104

aged wavelengths for these multiplets are given in Table I. Apart from evaluation of data at 5000 K, we performed calculations for 2950 K for two purposes; these results will later be used for comparison with the experiment and to demonstrate electron-impact width dependence upon electron temperature in the low-temperature region. From the comparison of w_{SF} data at 5000 and 2950 K, it is clear that the frequently used statement that "the Stark widths are not strongly dependent on temperature"[7] cannot be used in this particular case. Differences of up to 20% between electron-impact linewidths at 5000 and 2950 K can be detected in Table I.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results[7] and calculated data from the simple formula[8] are given together in Table II. Here it should be pointed out that theoretical results in this table include ion broadening, since its contributions to the total linewidth may be, in the case of neutral lines, considerable. The omission of ion broadening (see Table I in Ref. 7) introduces an additional uncertainty in the comparison of the theory and experiment. All the data necessary for the calculation of total linewidths in Table II are taken from Table I.

Detailed analysis of the experimental procedure in Ref. 7 shows that an error has most probably been made during the derivation of the Stark widths from the experimental profiles. Namely, in Ref. 7, the instrumental width, 0.42 Å, was determined by using the $7S_{1/2}$-$4P_{1/2}$ line from a low-current potassium spectral lamp and "The Stark (electron and ion) linewidth was then simply obtained by subtracting the instrumental width from the measured linewidth."[7] If we assume a Gaussian instrumental profile (a reasonable assumption for a good monochromator), the resulting profile (instrumental + Stark) is the so-called Voigt profile. In the case of a Voigt profile, one has to use a deconvolution procedure to derive the Lorentzian part (Stark profile) from the experimental profile. Knowing the instrumental half-width, 0.42 Å, and the experimental linewidth, we were able to perform the deconvolution using a standard procedure described in Ref. 10. New results for the potassium line's Stark widths are given on Table II, together with uncorrected ones and theoretical data. If we exclude the result, the most narrow line 578.2 nm (instrumental half-width is the same as the Stark width) the average agreement with theoretical calculations is now much better and well within the limits of the estimated experimental error.

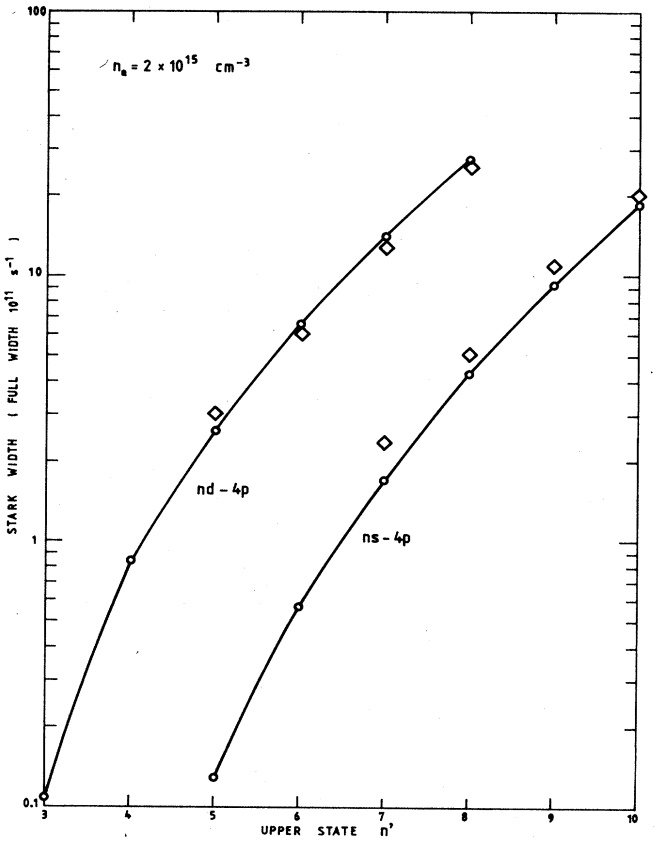

FIG. 1. Stark widths of the ns-$4p$ and nd-$4p$ lines of K I vs the upper-state quantum number n'. ○, theoretical widths; ◇, measured widths.

Finally, the newly derived experimental Stark widths of ns-$4p$ and nd-$4p$ lines of K I are plotted versus the upper-state quantum number n' in Fig. 1 (compare with Fig. 4 in

TABLE II. Comparison of experimental Stark widths of potassium lines from Ref. 7 with newly derived experimental data, and with the results of theoretical calculations w_{SF}.

Transition	Wavelength (nm)	Full Stark (Å) widths at $N_e = 2\times10^{15}$ cm^{-3} and $T_e = 2950$ K w_m from Ref. 7	w_m derived here	w_{SF}
$4P^o_{1/2}$-$7S_{1/2}$	578.2	0.27	0.42	0.31
$4P^o_{1/2}$-$8S_{1/2}$	532.3	0.54	0.76	0.65
$4P^o_{1/2}$-$9S_{1/2}$	508.4	1.21	1.51	1.29
$4P^o_{1/2}$-$10S_{1/2}$	494.2	2.25	2.59	2.39
$4P^o_{3/2}$-$5D_{5/2}$	583.2	0.37	0.55	0.47
$4P^o_{3/2}$-$6D_{5/2}$	536.0	0.72	0.97	1.00
$4P^o_{3/2}$-$7D_{5/2}$	511.2	1.53	1.84	1.96
$4P^o_{3/2}$-$8D_{5/2}$	496.5	3.25	3.58	3.59

Ref. 7), together with theoretically evaluated Stark widths (electron + ion broadening) for the same experimental conditions. Smooth dependence of the Stark widths, both experimental and theoretical, on the upper-state quantum number n' is evident. This was expected from the work of Wiese and Konjević.[11]

IV. CONCLUSION

We have performed simple theoretical calculations of the Stark broadening parameters of the lines belonging to nd-$4p$ and ns-$4p$ series of potassium, and they are found to be in good agreement with the results of semiclassical theoretical approach.[1,4,9] We have also reexamined the experimental procedure in Ref. 7, and new experimental results for the Stark widths of K I lines are obtained. These new experimental data agree well with our simple theoretical calculations and, in an indirect way, with semiclassical calculations by Benett and Griem[1,4] as well. Direct comparison between the experiment and Benett and Griem's calculations[1,4] is not possible, since the experiment has been performed under experimental condition ($T_e = 2950$ K) which is not covered in Refs. 1 and 4.

[1]H. R. Griem, *Spectral Line Broadening by Plasmas* (Academic, New York, 1974).
[2]N. Konjević and J. R. Roberts, J. Phys. Chem. Ref. Data **5**, 209 (1976).
[3]N. Konjević, M. S. Dimitrijević, and W. L. Wiese, J. Phys. Chem. Ref. Data **13**, 619 (1984).
[4]S. M. Benett and H. R. Griem, University of Maryland Report No. 71-097, 1971.
[5]M. S. Dimitrijević and N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **30**, 45 (1983).
[6]M. S. Dimitrijević and N. Konjević, in *Spectral Line Shapes,* edited by K. Burnett (Walter de Gruyter, Berlin, 1983), Vol. 2.
[7]J. P. Hohimer, Phys. Rev. A **30**, 1449 (1984).
[8]S. A. Freudenstein and J. Cooper, Astrophys. J. **224**, 1079 (1978).
[9]H. R. Griem, M. Baranger, A. C. Kolb, and G. Oertel, Phys. Rev. **125**, 177 (1962).
[10]J. T. Davies and J. M. Vaughan, Astrophys. J. **137**, 1302 (1964).
[11]W. L. Wiese and N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **28**, 185 (1982).