Temperature dependence of Stark broadening for several Si II lines

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(Received 19 May 1992)

The Stark broadening parameters of several Si II lines have been measured in a pulsed discharge. Experimental results are compared with theoretical predictions and with other experiments.

PACS number(s): 52.70.Kz

There is a great interest in the study of silicon spectral lines, for ionized silicon is nearly always present in many laboratory and stellar plasmas. For this reason, it will be very useful to have calibrated silicon lines, in order to solve the problem of plasma diagnostics for near and remote sources. Unfortunately, the present situation is far from that.

Stark broadening parameters of four silicon singly ionized multiplets, (2) $4s\,^2S-4p\,^2P^\circ$, (3) $3d\,^2D-4f\,^2F^\circ$, (5) $4p\,^2P^\circ-4d\,^2D$, and (7.05) $4d\,^2D-7f\,^2F^\circ$, have been measured in a pulsed discharge. The results from this work are compared with other data. For one of the four measured multiplets (7.05), there are no previous experimental results in the available literature; for the rest of them, a good number of experiments [1–9] exists, from the earliest by Miller [1] and Konjevic *et al.* [2] to the present work. These results have already been collected by Konjevic and Wiese in their last critical review [10]. In this review, the authors point out the large scatter of the experimental data, and the need for more accurate measurements in order to clarify the situation and to probe theoretical predictions. In fact, semiclassical theory [11] predicts for these lines an appreciable variation of the width with the temperature: approximately 20% increase in the width when the temperature decreases from 20 000 to 10 000 K. This temperature dependence cannot be observed with the available experimental data. In this work, we have done our measurements in a wide electron-temperature interval, roughly from 14 000 to 32 000 K, which is much bigger than anyone else has done, in order to get an idea about the relationship between linewidths and temperature.

In earlier experimental studies [2,4], silicon lines were obtained from the silicon coming from the glass of the discharge tube, and it was argued [6] that this might have produced a nonhomogeneous distribution of silicon in the tube. To avoid this problem, we have worked with a pulsed discharge operating in a SiH_4-He mixture. The lamp was filled with a continuous gas flow with different ratios of the two compounds. The time between two consecutive shots was long enough to let the gas flow sweep away all the impurities from the lamp. The plasma source has been described elsewhere [12,13] and no more details will be added here. Only from the experimental point of view, it will be of interest to indicate the difficulties of working with silane, because this gas requires a very well-isolated gas system. Otherwise, silica appears elsewhere in the installation. Care was taken in establishing experimental conditions under which it was possible to observe unabsorbed silicon lines, especially since some of them are strong candidates for self-absorption.

All plasmas were created by discharging a capacitor bank of 20 μF charged up to 8000–8500 V. The plasma source was always observed end-on. The light from the lamp entered a 1.5-m spectrograph, with a grating of 1200 lines/mm, and the profiles were recorded by an optical multichannel analyzer [12]. Two sets of measurements were done. In the first set we measured only at one time (at the peak of maximum plasma intensity), while in the second one, the measurements were taken at two times (during the decay). In this way, it was possible to reach different conditions of electron density and temperature.

In computer processing of the experimental spectra, all the profiles have been corrected for Doppler and instrumental broadening, even though these broadening mechanisms give values which are almost negligible compared with Stark broadening.

Determination of the electron density was done with the help of the 6678-Å and 5016-Å He I lines, which have been calibrated in previous experiments [12,13] by interferometric methods. Both lines give values of electron density which are very close, within the limits of our experimental errors (which are estimated to be about 15% [12]). The electron temperatures were obtained, assuming local thermodynamic equilibrium (LTE), by a Boltzmann plot of several Si II lines (6371, 6347, 5056, 5041, and 4130 Å), and by the intensity-ratio method with the same lines. Results from both methods are in good agreement within the estimated errors (about 10%).

The measured full widths at half maximum intensity (FWHM) are given in Tables I–IV. Data from previous experiments [1–10] and theoretical calculations [11,14] are also included, all with their corresponding values of electron density and temperature.

Discussion and comparison of results can be better seen from Figs. 1–3. In these figures, we show the results only for one of the lines of each multiplet, because they are very similar within every multiplet. Figure 1 shows, for the 6371-Å line [multiplet No. (2)], the FWHM's as a function of the temperature. These FWHM's have been normalized to 10^{17} electrons cm^{-3}, on the assumption that the widths scale directly with the electron density. This figure includes the results from this work as well as from previous experiments and theoretical calculations. Our results agree well with the measurements of Lesage, Sahal-Bréchot, and Miller [6] and those by Chiang and Griem [7], and they show, in a very large temperature interval, the tendency with the temperature predicted by the theory. We have to point out that this is the most interesting feature of our present results. But when we try to compare our results with the rest of the experimental data, we face serious problems because they show a large scatter. The reasons for this are difficult to find out. First, we can mention that the lines of this multiplet are strong candidates for self-absorption, and self-absorption will be present in different degrees in the experiments.

TABLE I. Stark FWHM's for the lines of multiplet (2).

λ(Å)	N_e (10^{16} cm^{-3})	T (K)	w(Å)	w/N_e (10^{-17}Å cm^3)	Reference
6371	9.19	31 500	1.29	1.40	This work
	6.62	16 400	1.23	1.86	This work
	5.65	13 900	1.22	2.16	This work
	18.20	8 500	2.34	1.29	2
		10 000		1.15	3
		8 700		1.00	4
		10 600		1.04	4
		12 800		0.92	4
		16 400		0.82	4
		10 000		1.93	6
		18 000		2.22	7
		16 000		1.24	9
		20 000		1.1	9
		22 000		1.28	9
		5 000		2.92	11
		10 000		2.34	11
		20 000		1.96	11
		40 000		1.74	11
		5 000		2.90	14
		10 000		2.09	14
		20 000		1.60	14
		40 000		1.35	14
6347	9.19	31 500	1.22	1.33	This work
	6.62	16 400	1.25	1.89	This work
	5.65	13 900	1.20	2.12	This work
	18.20	8500	2.44	1.34	2
		10 000		1.1	3
		10 000		1.96	6
		18 000		2.14	7
		16 000		1.24	9
		20 000		1.24	9
		22 000		1.28	9
		5 000		2.92	11
		10 000		2.34	11
		20 000		1.96	11
		40 000		1.74	11
		5 000		2.90	14
		10 000		2.09	14
		20 000		1.60	14
		40 000		1.35	14

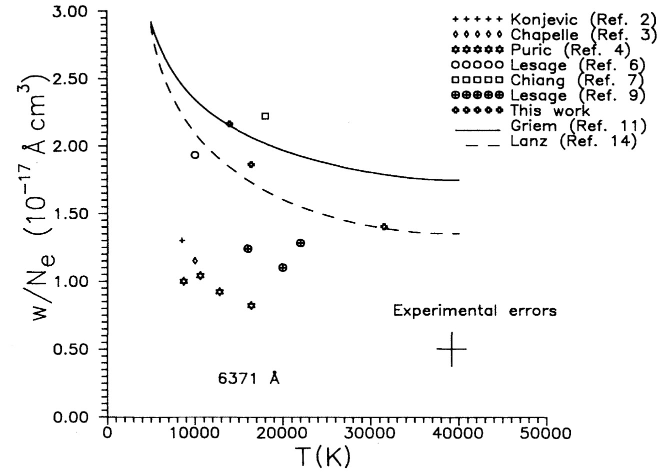

FIG. 1. Stark FWHM's (referred to an electron density of 10^{17} cm^{-3}) for the Si II 6371-Å (2) line vs electron temperature: Comparison of results.

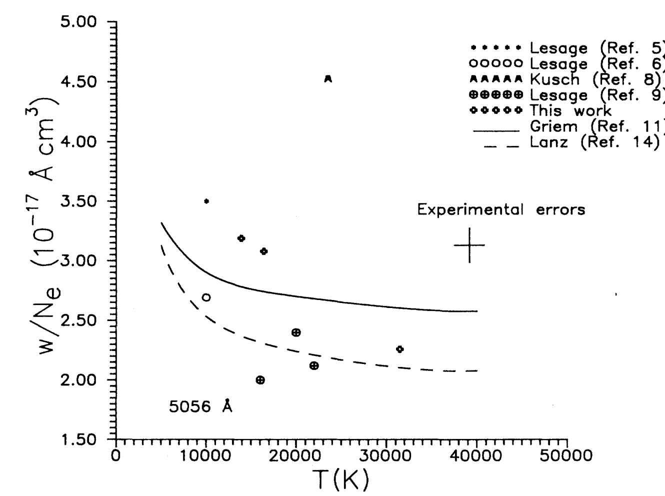

FIG. 2. Stark FWHM's for the Si II 4130-Å (3) line.

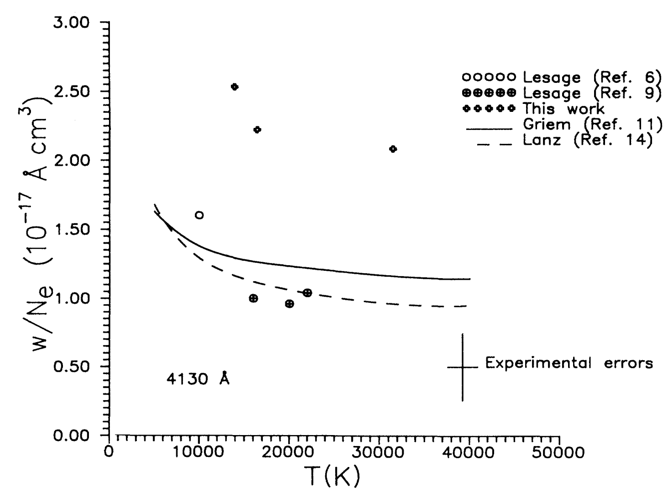

FIG. 3. Stark FWHM's for the Si II 5056-Å (5) line.

Also, inhomogeneities will appear in some of the earlier measurements. But self-absorption and inhomogeneity are not enough to explain the discrepancies found within the experimental data, which in some cases exhibit differences of a factor of 2 or even larger.

For the 5056-Å line [multiplet No. (5)], Fig. 2 shows the comparison of results. Again our measurements show the theoretically predicted trend, but the rest of the experimental data show a large scatter. For the 4130-Å line [multiplet No. (3), Fig. 3] the same remarks can be made. In this case, our measurements are much bigger than those of anyone else. The reason for these big values might come from the overlap of this line with the 4128-Å line. In computer processing of the spectra we have eliminated the parasite line with the help of a method based on the symmetry of the line, so that a possible lack of symmetry can be an important source of errors. The contribution of this effect to the linewidth can be estimated as 20%, and it has been included in the errors bars which appear in Fig. 3. Unfortunately, we cannot quantify this uncertainty in previous experiments. This overlap must be present in all of them, but we do not have any idea about the way in which the spectra from other experiments have been processed. Again, the important fact is that present results show the predicted tendency with the temperature.

Finally, for the line at 4621 Å [multiplet (7.05)], there are no previous experiments with which to compare. The discrepancies with theoretical calculations (Table IV) are rather large, bigger than one order of magnitude. The measured values seem to be quite reasonable, but we are not able to explain why the calculated values are so large for this multiplet. However, the tendency with the tem-

TABLE II. Stark FWHM's for the lines of multiplet (3).

λ(Å)	N_e (10^{16} cm^{-3})	T (K)	w(Å)	w/N_e (10^{-17}Å cm^3)	Reference
4130	9.19	31 500	1.91	2.08	This work
	6.62	16 400	1.47	2.22	This work
	5.65	13 900	1.43	2.53	This work
		10 000		1.60	6
		16 000		1.0	9
		20 000		0.96	9
		22 000		1.04	9
		5 000		1.63	11
		10 000		1.38	11
		20 000		1.23	11
		40 000		1.14	11
		5 000		1.68	14
		10 000		1.29	14
		20 000		1.06	14
		40 000		0.95	14
4128	6.62	16 400	1.31	1.98	This work
	5.65	13 900	1.29	2.28	This work
		10 000		1.58	6
		16 000		1.0	9
		20 000		0.96	9
		22 000		1.04	9
		5 000		1.63	11
		10 000		1.38	11
		20 000		1.23	11
		40 000		1.14	11
		5 000		1.68	14
		10 000		1.29	14
		20 000		1.06	14
		40 000		0.95	14

TABLE III. Stark FWHM's for the lines of multiplet (5).

λ(Å)	N_e (10^{16} cm^{-3})	T (K)	w(Å)	w/N_e (10^{-17}Å cm^3)	Reference
5056	9.19	31 500	2.08	2.26	This work
	6.62	16 400	2.04	3.08	This work
	5.65	13 900	1.80	3.19	This work
		10 000		3.5	5
		10 000		2.69	6
		23 500		4.53	8
		16 000		2.0	9
		20 000		2.40	9
		22 000		2.12	9
		5 000		3.32	11
		10 000		2.90	11
		20 000		2.70	11
		40 000		2.58	11
		5 000		3.13	14
		10 000		2.53	14
		20 000		2.24	14
		40 000		2.08	14
5041	9.19	31 500	2.05	2.23	This work
	6.62	16 400	1.64	2.48	This work
	5.65	13 900	1.40	2.48	This work
		10 000		3.5	5
		10 000		2.53	6
		23 500		3.90	8
		16 000		2.16	9
		20 000		2.42	9
		22 000		2.08	9
		5 000		3.32	11
		10 000		2.90	11
		20 000		2.70	11
		40 000		2.58	11
		5 000		3.13	14
		10 000		2.53	14
		20 000		2.24	14
		40 000		2.08	14

TABLE IV. Stark FWHM's for the lines of multiplet (7.05).

λ(Å)	N_e (10^{16} cm^{-3})	T (K)	w(Å)	w/N_e (10^{-17}Å cm^3)	Reference
4621	9.19	31 500	1.04	1.13	This work
	6.62	16 400	1.13	1.71	This work
	5.65	13 900	1.30	2.30	This work
		5 000		38.2	11
		10 000		35.4	11
		20 000		33.6	11
		40 000		31.4	11
		5 000		22.8	14
		10 000		23.3	14
		20 000		24.0	14
		40 000		24.0	14

perature of our own data is the same as was found for the other lines.

To sum up, we can say that the variation with the temperature of the Stark width of some Si II multiplets has been observed in a very wide temperature interval. Reasonable agreement has been found between present results and theoretical predictions. Still, serious disagreements between different experimental data suggest the necessity of further investigations.

The authors thank the Spanish Dirección General de Investigación Científica y Técnica (Ministerio de Educación y Ciencia) for its financial support under Contract No. PB-90-0353.

[1] M. H. Miller (unpublished).
[2] N. Konjevic, J. Puric, L. J. Cirkovic, and J. Labat, J. Phys. B **3**, 999 (1970).
[3] J. Chapelle and A. Czernichoswski, Acta Phys. Pol. A **41**, 753 (1972).
[4] J. Puric, S. Djenize, J. Labat, and L. J. Cirkovic, Z. Phys. **267**, 71 (1974).
[5] A. Lesage and M. H. Miller, C. R. Acad. Sci. **280B**, 645 (1975).
[6] A. Lesage, S. Sahal-Bréchot, and M. H. Miller, Phys. Rev. A **16**, 4, 1617 (1977).
[7] W. T. Chiang and H. R. Griem, Phys. Rev. A **18**, 1169 (1978).
[8] H. J. Kusch and K. Schröder, Astron. Astrophys. **116**, 255 (1982).
[9] A. Lesage, B. A. Rathore, I. S. Lakicevic, and J. Puric, Phys. Rev. A **28**, 4, 2264 (1983).
[10] N. Konjevic and W. L. Wiese, J. Phys. Chem. Ref. Data **19**, 6 (1990).
[11] H. R. Griem, *Spectral Line Broadening by Plasmas* (Academic, New York, 1974).
[12] C. Pérez, I. de la Rosa, A. M. de Frutos, and S. Mar, Phys. Rev. A **44**, 6785 (1991).
[13] I. de la Rosa, C. Pérez, A. M. de Frutos, and S. Mar, Phys. Rev. A **42**, 7389 (1990).
[14] T. Lanz, M. S. Dimitrijevic, and M. C. Artru, Astron. Astrophys. **192**, 249 (1988).