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Stark broadening of neutral helium lines and spectroscopic diagnostics of pulsed helium plasma

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Abstract. Stark broadening parameters (widths and shifts) of two He I isolated spectral lines are measured in a plasma of a low-pressure pulsed arc. Plasma electron densities, determined by spectroscopic method based on previously calibrated He I lines, ranges from 1×10^{16} cm^{-3} to 6×10^{16} cm^{-3}. The plasma electron temperature acquired by a Boltzmann plot of several He I lines, lies in the interval 8 000–30 000 K. Results of this work are compared with theoretical predictions and with other experimental data.

PACS. 52.70.-m Plasma diagnostic techniques and instrumentation – 52.70.Kz Optical (ultraviolet, visible, infrared) measurements – 32.70.Jz Line shapes, widths, and shifts

1 Introduction

Stark broadening parameters of helium spectral lines are of interest for plasma diagnostic purposes, and they can be used also for the testing of theoretical calculations. In previous papers we have already calibrated several isolated He I lines [1,2]. These calibrations have interest as a quick (almost real time) and accurate way of plasma diagnostics, with possibilities of being applied to laboratory and stellar plasmas. This paper shows, in the first part, how these calibrations can be applied with good results. In the second part new Stark broadening and shift data for two isolates neutral helium lines are reported. The results are compared with other experimental and theoretical data.

2 Experiment, measurements, and plasma diagnostics

The plasma source is a pulsed discharge. The whole experimental arrangement appears in Figure 1. A more exhaustive description can be found elsewhere [3], but few additional details, concerning present experiment, will be given here. The discharge lamp is filled with pure helium at a constant flow of 10 cm^3/min and a pressure of 1.6 kPa. The gas in the lamp is pre-ionized with a continuous current to ensure plasma reproducibility. The plasma is created by the discharge of a capacitor bank of 20 μF charged up to 7 300 V. Under these experimental conditions, the measured lines have good intensity. Possible self-absorption in the measured lines, is checked with the help of the M mirror, see Figure 1, placed behind the discharge lamp. This fact allows comparing the spectra taken with and without this mirror.

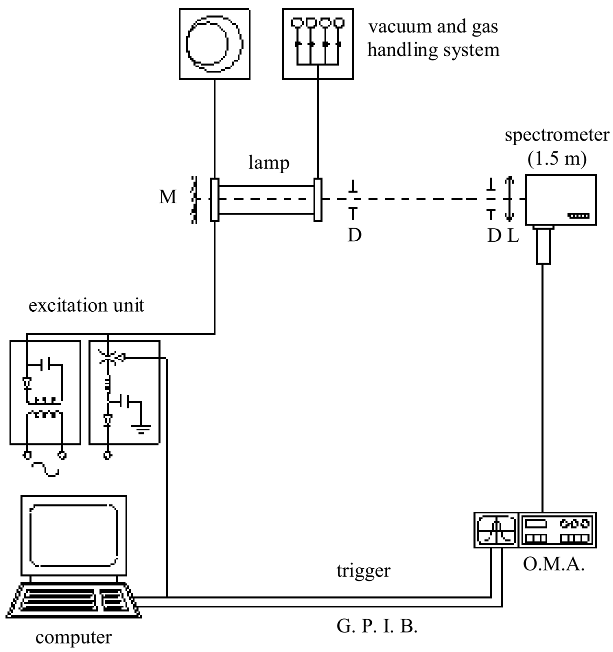

Fig. 1. Experimental arrangement.

The light from the discharge lamp is axially observed, all the spectra are taken with a Jobin-Yvon spectrometer of 1.5 m focal length, and a 1 200 lines/mm holographic grating, with a dispersion of 0.126 Å/channel at 5 890 Å in the first order. In Table 1 the spectral lines measured in this experiment are shown.

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Table 1. Spectral lines studied in this experiment.

Element	λ(Å)	Transition
	7 065.190	$2p\ ^3P^0–3s\ ^3S$
	6 678.151	$2p\ ^1P^0–3d\ ^1D$
He I	5 015.678	$2s\ ^1S–3p\ ^1P^0$
	4 713.145	$2p\ ^3P^0–4s\ ^3S$
	3 888.648	$2s\ ^3S–3p\ ^3P^0$

Under the experimental conditions of this work, contributions of instrumental and Doppler broadening to the measured line profiles are found to be negligible. Self-absorption was carefully checked by measuring the optical depths of the plasma for each line, in cases of small self-absorption it was corrected. All spectra are taken at different instants of the plasma life. Plasma lasts in our experiment more than 250 μs, and the measurement time of a spectrum varies between 3 and 5 μs, so that they, compared with plasma duration, can be regarded as instantaneous, because during this short period of time, plasma conditions remain essentially constant.

Electron density along the plasma lifetime was obtained by a prior calibration with the lines 4 713, 6 678 and 5 016 Å [1]; Figure 2a shows the results. The first remark is good agreement of all data; this fact reveals the reliability of calibration. In the cases of big variation of electron density, discrepancies between extreme values do not exceed 10%. The mean value in Figure 2a is taken as a final value for plasma electron density.

Plasma temperature has been obtained by using Boltzmann plot of all studied He I lines. In order to reduce low accuracy of electron temperatures derived from the Boltzmann plot of He I lines with close upper levels, we have used a large number of spectra recordings, Figure 2b shows the results. The error in the temperature evaluation is estimated to be about 20%. Nevertheless it should be noticed that the dependence of plasma parameters with temperature is very weak.

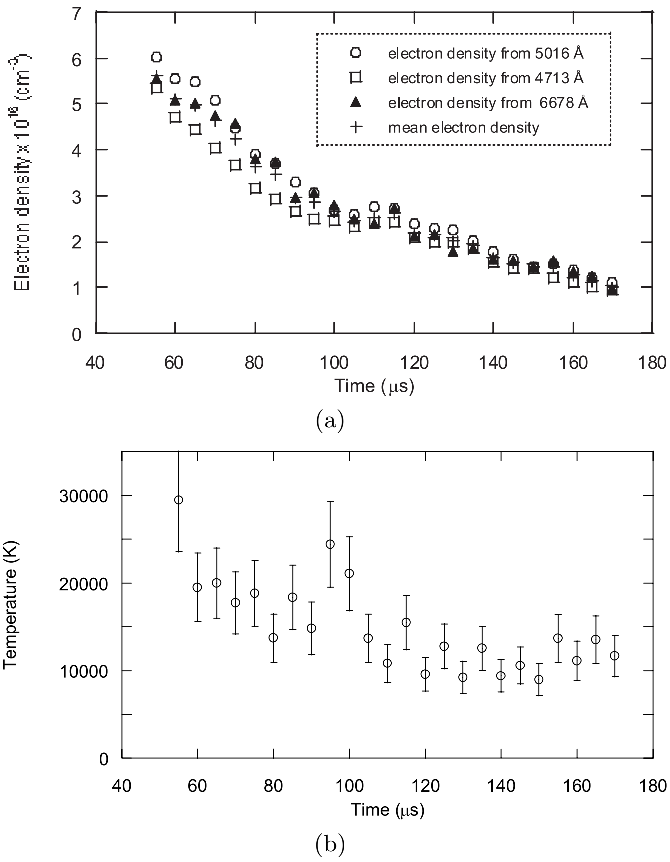

Fig. 2. (a) Plasma electron density *versus* time from different calibrations lines. (b) Plasma electron temperature *versus* time. Error bars are shown.

3 Results for helium lines and discussion

The obtained results for the two He I lines are summarized in Figures 3, 4, 5, and 6. In the two first ones, we have included FWHM and shift for the 7 065 Å line, and the same for the 3 889 Å line in Figures 5 and 6. In order to make comparisons all figures include other available experimental and theoretical data. Contrary to other experiments of the same kind, all our results presented in Figures 3–6 are reported in a large density range.

Figure 3 shows a good linear dependence in a quite wide electron density interval for the results of this experiment. Although the experimental data [5,6] are outside of the range of our measurements good agreement is found. Data from [7] agree well with our results at low electron densities, but at higher densities the discrepancies between both sets of data are significant. Unfortunately there are no more experimental results to compare, but this fact opens the possibilities for new experimental measurements to solve this problem. The comparison with theoretical data by Griem [4] shows good agreement at lower electron density, but slight discrepancy appears as soon as electron density increases see Figure 3. The average ratio of measured ($w_{\rm exp}$), over theoretical widths ($w_{\rm th}$): $w_{\rm exp}/w_{\rm th}$ is 1.05 for the whole interval of electron densities.

Similar comment one can make for shift data in Figure 4. Again good linear fit may be drawn through our data in a large electron density range. The agreement with Mijatovic *et al.* [6] is quite good. The agreement with theoretical by Griem [4] is good at low electron densities. However, with an increase of electron density, gradual increase of discrepancy between theory and experiment can be noticed, see Figure 4. The mean ratio between our experimental, $s_{\rm exp}$, and theoretical shifts, $s_{\rm th}$, [4] is 1.18 in the electron density range of our measurements.

Figure 5 shows FWHM for the 3 889 Å *versus* electron density and in this case more other experimental results [8–11] available. With exception of results from [9] our data are slightly higher than other, but they may be fitted well with a straight line. Large line widths in our experiment may be consequence of the presence of small uncorrected self-absorption. Namely, this strong helium line is prone to self-absorption, which is due to problems

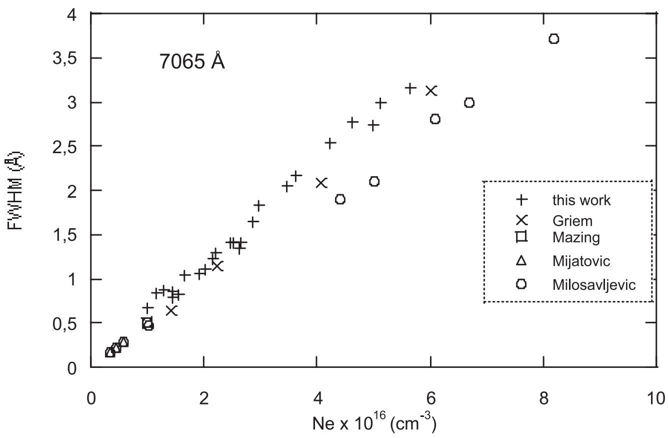

Fig. 3. Stark full width at half-maximum, FWHM, for the 7 065 Å He I line as a function of the electron density. Preceding experimental and theoretical results are included.

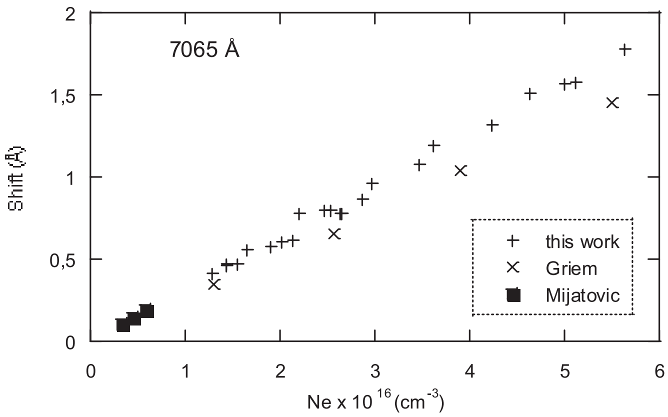

Fig. 4. Stark shift for the 7 065 Å He I line as a function of the electron density; experimental and theoretical results from previous works are included in the plot.

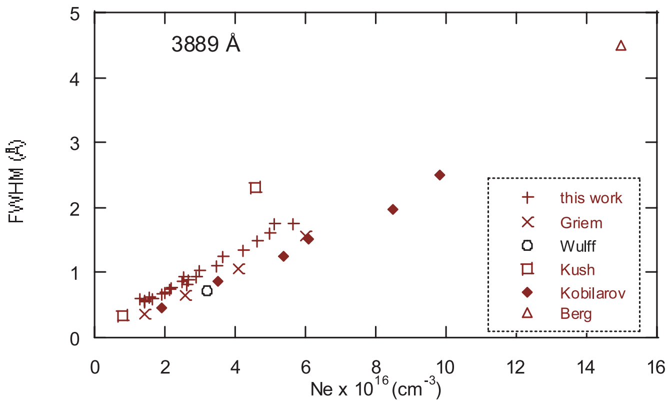

Fig. 5. Stark full width at half maximum for the 3 889 Å He I line as a function of the electron density; experimental and theoretical results from previous work are included in the plot.

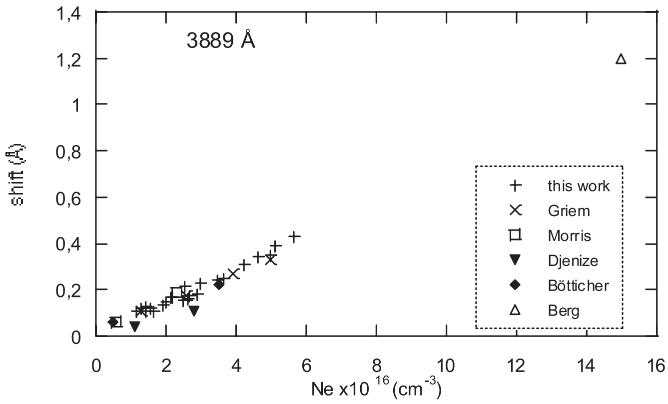

Fig. 6. Stark shift for the 3 889 Å He I line as a function of the electron density; experimental and theoretical results from previous work are included in the plot.

related pulse to pulse plasma reproducibility difficult to correct. The average ratio of measured w_{exp}, over theoretical widths w_{th}: $w_{\mathrm{exp}}/w_{\mathrm{th}} = 1.15$ for the whole interval of electron densities.

In the last figure, Figure 6, measured shifts of the 3 889 Å are presented together with other experimental results [9,11–14]. All experimental and theoretical data in this figure are in a very good mutual agreement. We have also compared our results with the ones from Kobilarov [11] (not included in Fig. 6), and in the range of electron densities $(1.9–3.5) \times 10^{16}$ cm^{-3}, where a shift increment of 0.11 Å is reported. The shift increment of 0.115 Å is determined in our experiment for the same electron density range.

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