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Calibration of the Stark-broadening parameters of the 728.1-nm He I line

C. Pérez, J. A. Aparicio, I. de la Rosa, S. Mar, and M. A. Gigosos
Departamento de Optica, Universidad de Valladolid, 47071 Valladolid, Spain
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Stark-broadening parameters (width and shift) of the 728.1-nm helium neutral line ($2p^1P^0$-$3s^1S$) have been measured in a pulsed arc plasma. The measured line is well isolated and with enough intensity to be considered a very convenient calibration line. Electron density, which was obtained by the interferometry of two wavelengths, ranges from 1.50×10^{22} m^{-3} to 1.45×10^{23} m^{-3}. The temperature, acquired by a Boltzmann plot of several He I lines, lies in the interval 16 000 − 25 000 K. The results of this work are compared with the experimental and theoretical available data. Afterwards, all of them are used to calibrate the line broadening parameters.

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I. INTRODUCTION

Stark-broadening parameters of helium spectral lines present interest in plasma diagnostics. In a previous paper [1], we have already calibrated three isolated He I lines. Here we will reinforce that list, giving calibration data about another He I line. In the present case, we will include not only width but also shift data. These calibrations have interest, as a quick and accurate way of diagnostics, with possibilities of being applied to laboratory and to stellar plasmas.

For this subject, there are not many papers in the available literature. We have found only two results for the width and only one for the shift; they all appear in Refs. [2,3]. These previous experimental data lay in a very short electron density interval. In this work, measurements of width and shift are given in a very wide electron density range, almost one order of magnitude. With all these data we have been able to achieve a precise calibration of the Stark parameters of the line under study.

II. EXPERIMENTAL SETUP AND PLASMA DIAGNOSTICS

All the measurements have been carried out in a pulsed plasma. The whole experimental arrangement appears in Fig. 1. A more exhaustive description can be found elsewhere [4]; here we give few additional details concerning the present experiment. The discharge lamp filled with pure helium at a constant flow of 28 cm^3/min and a pressure of 30 mbar. The plasma was created by discharging a capacitor bank of 20 μF charged to 7500 − 8000 V. Under these experimental conditions, the measured spectral lines have good intensities and, at the same time, a negligible self-absorption. Possible self-absorption is checked, in the experiment, with the help of the mirror $M4$ placed behind the lamp; this allows us to compare the spectra taken with and without this mirror.

Electron density and temperature were obtained by two independent methods; this fact gives the required accuracy to the calibration measurements. According to Fig. 1, the interferometric and spectroscopic data have been taken 2 mm off the lamp axis, and from symmetrical positions referred to the axis. This can be done based on the high cylindrical symmetry of the electron density and temperature in our lamp. This fact has been experimentally proved in a previous work [5]. Electron density was obtained by two-wavelength interferometry [6], the discharge lamp placed in one of the arms of a Twyman-Green interferometer, illuminated simultaneously with two lasers, one helium-neon (632.8 nm) and an argon (488.0 nm). Each laser is individually uncoupled from the interferometer, with the help of the corresponding polarization beam splitter (PBS1 and PBS2, respectively) and a quarter-wave plate ($\lambda/4$).

There are also, as can be seen in Fig. 1, two spectroscopic channels giving complementary information. One of them, with the highest spectral resolution, consisting of a Jobin-Yvon spectrometer of 1.5 m focal length, a 1200 lines/mm holographic grating, and a dispersion of 0.0126 nm/channel at 589.0 nm in the first order, was used to measured the interesting spectral lines. The second channel with a lower resolution, a Jarrell-Ash spec-

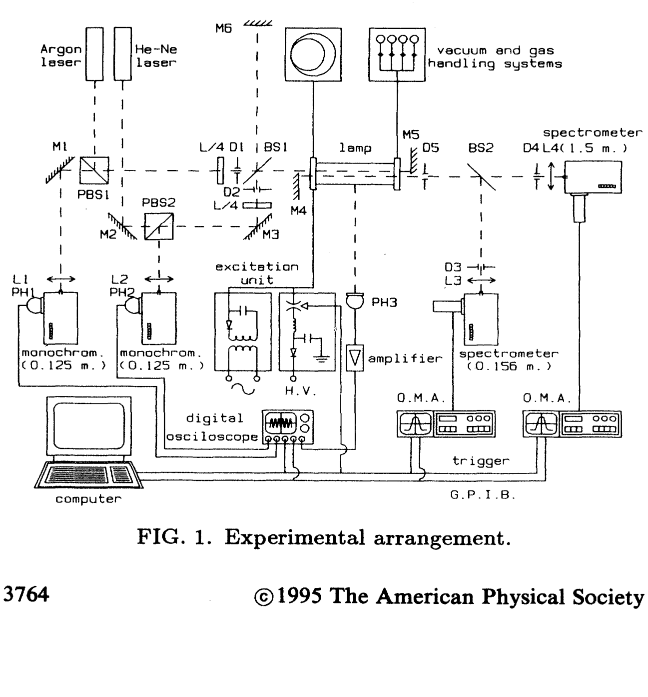

FIG. 1. Experimental arrangement.

trometer of 0.156 m focal length, was used to check, during the whole experiment, the 501.6 nm He I line, in order to have a continuous control of the plasma repetitiveness.

All the experimental data have been taken following the plasma temporal evolution. Plasma life, in this experiment, is about 350 μs. We have done three runs of measurements, all of them under the same experimental conditions. The agreement between results confirms the high repeatability of the measurements.

Assuming that the population of the He I upper levels obeys the Boltzmann law, we have calculated the temperature by a Boltzmann plot, with the intensity of several He I lines (388.8, 471.3, 501.6, 667.8, 706.5, and 728.1 nm). The results of this method give an occupation temperature of He I lying in the interval 16 000 – 25 000 K. To avoid inaccuracy derived from the use of lines with close upper levels, we have used a high number of spectra. We have also verified that the Saha equation gives similar values of temperature.

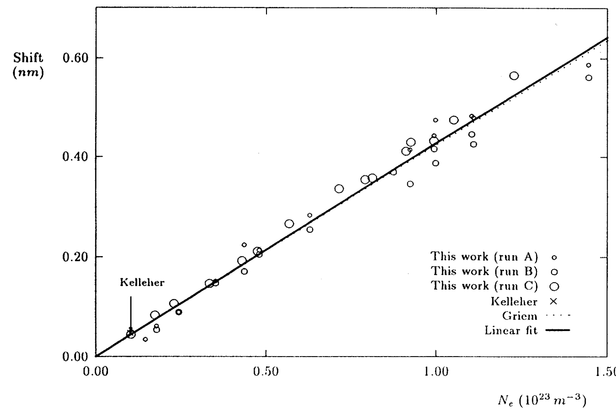

FIG. 3. Stark shift for the 728.1 nm line as a function of the electron density; experimental and theoretical results from previous works are included in this plot. Data of Kelleher and Griem are from Refs. [3] and [8], respectively.

III. RESULTS AND DISCUSSION

The spectra and interferometric records have been processed according to different methods elaborated in our laboratory. Details about them can be found in Refs. [4,7]. During the computation of the spectra other broadening mechanisms different from Stark, such as instrumental, Doppler, self-absorption, or plasma inhomogeneity, have been evaluated and taken into account, eventhough all these broadenings are almost negligible. The results of the whole process are summarized in Figs. 2 and 3. In them we have plotted the full widths at half maximum (FWHM) and the shifts of the line, respectively, as a function of the electron density. In both figures we have included the results from this work in the three runs, the theoretical data by Griem [8], and the few prior experimental results available. The straight lines in the figures are the least-squares fit of all data.

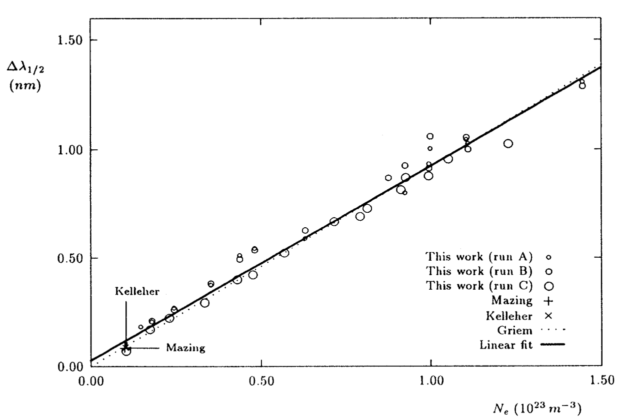

FIG. 2. Stark FWHM for the 728.1 nm line as a function of the electron density; experimental and theoretical results from previous works are included in this plot. The data marked by Mazing, Kelleher and Griem are taken from Refs. [2,3], and [8], respectively.

In these figures, there are some important facts worth mentioning here. The first one is that with only one experiment, we have achieved a very wide electron density interval, $1.50 \times 10^{22} - 1.45 \times 10^{23}$ m^{-3}. It is also important to stress the repeatability of our measurements. Finally, if we compare our results with others, we find a very good agreement with the theoretical results by Griem, and we do not find significant discrepancies with previous experimental results. This good agreement with Griem's predictions should be emphasised as a significant result. As we have worked with a high number of data, it has been possible to reduce the experimental errors to a minimum. All data show, in both cases (widths and shifts), a good linear fit. We have not included the temperature in these calibrations, because it is practically constant (around 20 000 K) along the interval in which we have worked.

We can sum up this work by giving the equation of the linear fit, which appears in Fig. 2, and that we propose as the calibration line for the width of the 728.1 nm line versus electron density:

$$w\ (\mathrm{nm}) = 8.96(\pm 0.14) \times 10^{-24} N_e\ (\mathrm{m}^{-3}) + 0.0282(\pm 0.0108)\ . \quad (1)$$

We suggest that this calibration expression is suitable to be used in the electron densities interval, in which it has been experimentally obtained, that is, $1.50 \times 10^{22} - 1.45 \times 10^{23}$ m^{-3}. Extrapolation to higher electron densities can be done without any problem, because the relative errors are very small. However, one has to be very careful when going to lower electron densities, because relative errors can be significant due to the non-null value of the origin ordinate.

For the shifts we have worked in a different way. We have not measured the absolute shifts, because the unperturbed wavelength could not have been determined with the necessary accuracy. Nevertheless, we have been able to measure the relative shifts with a very high precision.

According to that, we give as another interesting result of the present work the ratio shift to electron density for the 728.1 nm line. The value of this ratio is

$$s\ (\text{nm})/N_e\ (\text{m}^{-3}) = 4.28(\pm 0.09) \times 10^{-24}\ . \qquad (2)$$

We will give for this ratio the same advice given for the width, in order to be preferably used in the same electron density interval in which it has been obtained, or in higher densities, only in this case we can assure the reader that the relative errors are irrelevant.

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