The First Measured Stark Width and Shift of the 402.6186 nm He I Line

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Stark width (W) and shift (d) of the neutral helium (He I) 402.6186 nm spectral line in the high lying 2p–5d transition have been measured in the optically thin helium plasma created in a linear, low-pressure, pulsed arc discharge at a 52,000 K electron temperature and $1.3 \cdot 10^{23}$ m^{-3} electron density. Obtained data are the first experimental values of the Stark width and shift related to the mentioned He I spectral line. Direct comparison with theoretical results is not possible due to the fact that available data are calculated for considerably lower electron densities. We found that at 10^{23} m^{-3} electron density the lowering of the effective ionization energy has influence on the number and contribution of the perturbing energy levels, especially in the case of the high lying parent energy level of the particular transition. This effect generates lower Stark widths in the high lying He I transitions than the existing theoretical approximations provide. We have found negative Stark shift.

Key words: Plasma Spectroscopy; Line Profiles; Atomic Data.

1. Introduction

The neutral helium (He I) 402.618 nm spectral line in the high lying 2p ^{3}P^0–5d ^{3}D transition represents a sum of three, mutually very close, spectral lines [1] with the dominant intensity of the 402.61860 nm line. It has been registered in many spectra of astrophysical light sources [2 – 7] and used for diagnostic purposes of cosmic plasmas.

There are no experimental investigations dedicated to the shape and shift of this line ([8] and references therein). Only two studies [9, 10] deal with its Stark FWHM (Full-Width at Half of the Maximal intensity W) and shift (d) calculations based on the semiclassical approximations at a 10^{22} m^{-3} electron density (N).

The aim of this work is to present the first measured W and d values of the 402.6186 nm He I spectral line in the optically thin laboratory helium plasma created in a linear, low-pressure, pulsed arc discharge at a 52,000 K electron temperature (T) and $1.3 \cdot 10^{23}$ m^{-3} electron density.

2. The Experiment

A linear, low-pressure arc has been used as a plasma source [11 – 14]. A pulsed discharge was created in a pyrex discharge tube of 5 mm inner diameter and plasma length of 14 cm with magnesium electrodes. The tube has an end-on quartz window. The working

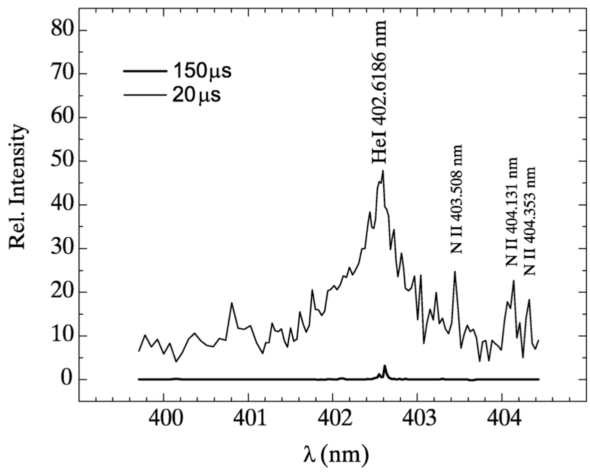

Fig. 1. The recorded profile of the 402.618 nm He I line at two different plasma conditions at 20 μs and 150 μs after the beginning of the discharge.

gas was helium (95% He + 4% N + 1% O) at 532 Pa pressure in the flowing regime. A capacitor of 14 μF was charged up to 55 J bank energy. The discharge conditions have been chosen to maximize the population of the high lying 5d parent energy level of the He I 402.6186 nm transition. Spectroscopic observation of the spectral line was made end-on along the axis of the discharge tube. The line profile was recorded using a step-by-step technique described in our previous publications [15 – 17]. The averaged photomultiplier sig-

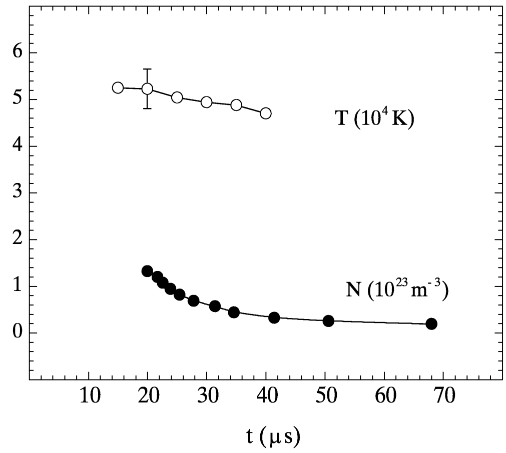

Fig. 2. Temporal evolutions of the electron temperature (T) and electron density (N) during the plasma decay. Error bar represents experimental accuracy.

nal was digitized using an oscilloscope interfaced to a computer. The recorded He I spectral line profile is shown in Fig. 1 for two different plasma conditions during the plasma decay. The presence of N II spectral lines has no influence on the investigated He I line W and d values.

The plasma parameters were determined using standard diagnostics methods [18]. The electron temperature was obtained using the relative line intensity ratio method between the He II P_α 468.6 nm and the He I 587.6 nm lines with ±8% accuracy. The electron density decay was measured using a well-known single wavelength He-Ne laser interferometer technique for the 632.8 nm transition with an estimated error of ±7% in a peak of the N. The temporal evolution of the N and T values is presented in Figure 2.

3. Line Width and Shift Measurements

Due to the fact that the 402.6186 nm He I line originates from a high lying parent energy level with 24.04 eV excitation energy, near to the ionization energy (24.59 eV) of the helium atoms, one can expect that corresponding Stark FWHM will be considerable, especially at the electron densities higher than 10^{22} m^{-3} [9, 10]. Accordingly, the shape of the line can be approximated, with sufficient accuracy, by the symmetrical Lorentz profile [9]. The procedure of the base line estimation is presented in [19, 20]. The Stark width was obtained within ±12% accuracy.

The Stark shift was measured relative to the unshifted spectral line emitted by the same plasma, using a method described in [14, 21]. The Stark shift was obtained with ±16% accuracy.

Table 1. Measured Stark FWHM (W_m) and shift (d_m) of the 402.6186 He I line in the $2p\,^3P^0$–$5d\,^3D$ transition at a given T and N with their estimated accuracies. Negative shift is toward blue.

N [10^{23} m^{-3}]	T [10^4 K]	W_m [nm]	d_m [nm]
1.3	5.2	0.64 ± 0.08	-0.124 ± 0.02

4. Results and Discussion

The experimentally obtained Stark width and shift of the 402.6186 nm line are given in Table 1.

Only two works [9, 10] are dedicated to He I 402.6186 nm Stark width and shift calculations. On the basis of the semiclassical approaches the W and d values are calculated at 10^{22} m^{-3} electron density in both of the mentioned articles. Griem's W_G values [9] are by about 55% higher than those in [10]. Moreover, in [9] positive d_G values are given, while Dimitrijević and Sahal-Bréchot [10] present negative d_{DSB} shifts.

Because our measurements are done at $1.3 \cdot 10^{23}$ m^{-3} electron density, direct comparison with calculated W and d (given at 10^{22} m^{-3} electron density) is not possible. Namely, the 402.6186 nm He I line originates from the high lying (24.04 eV) energy level near to the He I ionization energy (24.59 eV). Corresponding high lying perturbing energy levels 7p, 8p and 7f with energies of 24.30, 24.37 and 24.31 eV, respectively, at $1.3 \cdot 10^{23}$ m^{-3} electron density are practically merged by the continuum due to the lowering He I ionization energy. Following Unsöld's [22] theory, the lowering of the ionization energy at a mentioned N is about 0.35 eV [23]. Therefore, at the mentioned N the He I levels with energies higher than 24.24 eV lie in continuum and do not contribute to the Stark width and shift. This means that a simple linear extrapolation of the theoretical W_G and d_G values in [9] and W_{DSB} and d_{DSB} values in [10] from 10^{22} m^{-3} up to 10^{23} m^{-3} electron density is not possible. It turns out, as an illustration only, that the calculated W values in [9] and [10], generated by electrons at 10^{22} m^{-3} electron density at 40,000 K electron temperature, are 0.494 nm and 0.319 nm, respectively. Our W_m value is by only 50% higher than the mentioned ones, although our N is thirteen times higher.

5. Conclusion

Generally, for high lying He I transitions theoretical calculations of the Stark broadening parameters must take into account the lowering of the ionization energy which results in losing of some high lying perturbing levels. This could result in lower Stark width values than the theories in [9] and [10] at a 10^{22} m^{-3} electron density provide, taking into account the dominant role of the upper perturbing levels in the Stark width. We expect that the Stark shift of the high lying He I transitions is not so sensitive to the ionization energy lowering, because they are created by all perturbing levels of the parent and final levels in the particular transition. We have observed negative Stark shift of the 402.6186 nm He I line which agrees (in sign) with the predictions in [10].

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