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The Stark broadening of the He I 667.8 nm line

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The half-width and asymmetry parameter of the He I $2\,^1P-3\,^1D$ $\lambda=667.8$ nm line have been measured in a laser produced He plasma for electron densities N_e between 7×10^{22} m^{-3} and 1.7×10^{23} m^{-3}. Results, obtained for the half-width, agree very well with the theoretical results for $N_e \lesssim 10^{23}$ m^{-3} and the agreement becomes somewhat worse for $N_e > 10^{23}$ m^{-3}. We have measured the red asymmetry which is considerable lower than the theoretical one. We have also established good agreement with theoretical $j_{A,R}(x)$ profile for this line.

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1. Introduction

The broadening of the isolated neutral helium lines is described by GBKO theory [1, 2, 3]. In this theory the broadening due to the electron collisions, which is dominant, is treated by an impact approximation and ion influence in quasistatic approximation which is corrected for ion-ion correlations and Debye shielding.

Electron impact broadening yields symmetric and shifted profile of Lorentzian shape, while the ion contribution introduces additional shift and an asymmetry. Line profiles obtained by averaging electron-impact profiles over the static shift due to the instantaneous ion fields, using a suitable distribution function for the microfield strength, have final form in a reduced frequency scale given by

$$j_{A,R}(x)=\frac{1}{\pi}\int\limits_0^\infty \frac{W_R(\beta)\,d\beta}{1+(x-A^{4/3}\beta^2)^2} \tag{1}$$

where the reduced frequency is $x=(\omega-\omega_0-d)/w_e$. The $W_R(\beta)$ is the ion microfield probability distribution, A is the ion broadening parameter which is a measure of the relative importance of ion and electron broadening, d is the shift due to the electron impact, w_e is the electron – impact width (FWHM) and R is Debye shielding parameter.

Electron impact broadening is dominant for all He I spectral lines and ion broadening contributes typically 10–20% for well isolated He I lines. Ion contribution is somewhat higher for the He I 667.8 nm and 501.6 nm lines and both of them are extremely asymmetric.

For $A\leqq0.5$ and $R\leqq0.8$ the total half-width (FWHM) for isolated lines of neutral emitters can be derived from $j_{A,R}(x)$ profiles and expressed [1, 3] in the wellknown form.

$$w=2[1+1.75A(1-0.75R)]\,w_e. \tag{2}$$

The w_e, d and A values have been calculated by Griem [1] and recently by Bassalo et al. (BCW) [5] and Dimitrijević and Sahal-Bréchot (DSB) [6].

The agreement between theoretical widths calculated from w_e and A values given by Griem and measured values obtained with different plasma sources, for well isolated He I lines, is generally good for electron densities below a few times 10^{23} m^{-3} [1, 4]. The agreement is especially good for the He I 388.9 nm and 501.6 nm lines which are used for N_e determination with the accuracy approaching the one obtained from H_β line.

There are only a few papers [4] containing the experimental data for the He I 667.8 nm line-width, and agreement with the theory is much worse, especially for densities $N_e \gtrsim 10^{23}$ m^{-3}. For this reason, we have performed a set of measurements, whose details and results are presented here.

2. Experimental

The experimental set-up for plasma production and the methods and techniques for measurement of plasma parameters were described in details elsewhere [8, 9, 10], so it suffices to provide here only main experimental facts.

The plasma was obtained by focusing TEA-CO_2 laser beam by an axicon mirror inside the chamber filled with helium gas at the pressure about 75 kPa. The breakdown occured along a focal line and the plasma was formed in cylindrical shape about 25 mm long and the diameter of 8 mm. The light from the plasma column (side on) was focused into the entrance slit of 1 m monochromator equipped with photomultiplier at the exit slit. Signal were taken in a shot-by-shot technique and recorded by an oscilloscope with 35 mm camera attached.

Plasma parameters and their time evolution after the breakdown were determined from the Stark parameters of several He I spectral lines. The electron densities were determined from half-widths of the He I 388.9 nm and 501.6 nm lines while the electron temperatures were determined from the line to continuum ratio of the He I 587.6 nm and 447 .1 nm lines. The Abel inversion procedure gave about fifteen sets of line profiles along the radius of plasma cylinder for each moment between 4 μs and 20 μs after the breakdown. That gave sufficient number of the line profiles for various values of plasma densities and temperatures. The differences between the N_e values obtained from one and the other above mentioned lines do not exceed 8% in the whole electron density range $(6–17) \times 10^{22}$ m^{-3}. The electron temperature obtained from line to continuum ratio for 587.6 nm line exceed for about 17% corresponding values of 447.1 nm line probably due to errors in procedure for self-absorption correction. N_e and T_e values used here are average values obtained for the above mentioned lines determined with the errors which do not exceed $\pm 8\%$ and $\pm 15\%$ for N_e and T_e respectively.

The Abel inversion procedure and correction for self-absorption (when it was necessary) were used for all mentioned lines and, of course, for ivnestigated He I 667.8 nm line.

3. Results and discussion

The criterion for validity of the quasistatic approximation $[\sigma = (w_e \rho_m / 2 v_r) > 1$, where ρ_m is the mean ion distance and v_r is relative radiator-ion velocity] is fully satisfied under the conditions of our plasma for all line of interest [10]. The experimental data thus may be compared with the theoretical line profiles and half-widths calculated for quasistatic ion regime.

The He I spectral lines with forbidden components can be treated as isolated for relatively low electron density [6]. This is especially the case for the here investigated He I 667.8 nm line, whose forbidden component $2\,^1P - 3\,^1P$ is located about 5 FWHM far from the allowed one (towards blue) and whose peak intensity is less than 1% of the allowed one [10].

The experimental half-widths obtained from measured line profiles are presented in Fig. 1 together with the theoretical results of Griem, BCW and DSB calculated by using (2). Because of weak temperature dependence, all theoretical half-widths were calculated for electron temperature $T_e = 30$ kK which is the mean value of measured temperatures for our plasmas (26 kK–35 kK).

The measured half-widths are systematically lower than the Griem's values, while the agreement with BCW and DSB calculations is much better and lies inside $\pm 15\%$ for the whole N_e range. Also, as it can be seen in Fig. 1 and Table 1 the agreement is generally worse for higher N_e.

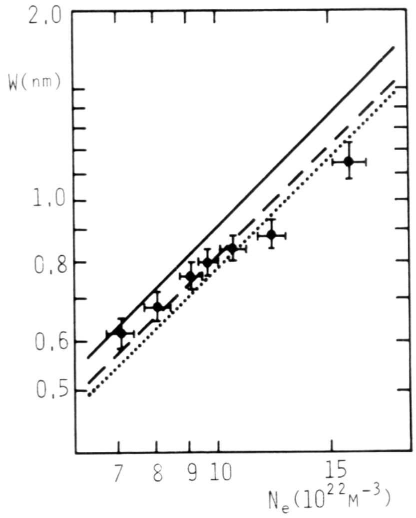

Fig. 1. Half-width of the He I 667.8 nm line as a function of electron density. Comparisons are made with Griem's theory (solid curve). BCW theory (dashed curve) and DSB theory (dotted curve) all for $T_e = 30$ kK. Dots: this work

Table 1. Comparison of measured and theoretical half-widths of the He I 667.8 nm line

$N_e \times 10^{22}$ (m^{-3})	W_m (nm)	W_m/W_{th}		
		GRIEM	BCW	DSB
16.2	1.15	0.76	0.85	0.87
12.3	0.88	0.77	0.86	0.89
10.6	0.84	0.86	0.95	1.00
9.7	0.80	0.90	1.00	1.04
9.15	0.76	0.91	1.00	1.06
8.1	0.68	0.92	1.01	1.08
7.1	0.62	0.97	1.05	1.14

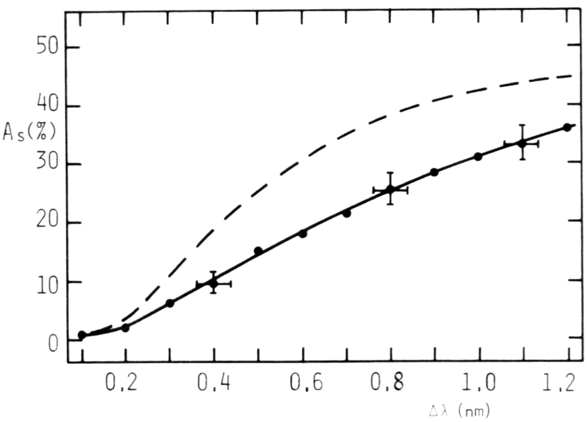

Fig. 2. Asymmetry parameter (3) of the He I 667.8 nm line as a function of wavelength separation from line center. Dots: present experiment; solid curve: best fit of experimental data for $N_e = 1.06 \times 10^{23}$ m^{-3} and $T_e = 31$ kK. Dashed curve: theory of Ya'akobi et al. for $N_e = 1 \times 10^{23}$ m^{-3} and $T_e = 30$ kK taken from tabulated data in [7]

The asymmetry of a line can be defined by quantity

$$A_s(\Delta\lambda) = \frac{I_R - I_B}{I_R + I_B} \quad (3)$$

where I_R and I_B are the line intensities at wavelength separation $\Delta\lambda$ and $-\Delta\lambda$ from the measured line center, respectively. The line has red asymmetry if $A_s(\Delta\lambda) > 0$.

We have measured the red asymmetry for $\Delta\lambda$ up to 2 FWHM. The measured asymmetry is lower than the theoretical one obtained from tabulated profiles of Ya'akobi et al. [7], as it is presented in Fig. 2. The discrepancies, for example, are about 70%, 40% and 20% at 0.5, 1.0 and 1.5 FWHM, respectively.

In order to check the fact that we can neglect the influence of the forbidden component $2\,^1P - 3\,^1P$ and consider the He I $2\,^1P - 3\,^1D$ as isolated, we made the computer program for $j_{A,B}(x)$ profiles calculation by integrating (2) numerically using Hooper's field strength distribution function. Our results for $j_{A,R}(x)$ completely agree with those of Woltz [11] in the whole x-value range used here.

Using appropriate normalization, we have compared the experimental and theoretical profiles of the He I 667.8 nm line. The general agreement over the x-range ± 5 is very good for Griems w_e, d and A values (Fig. 3), and a little bit worse for BCW and DSB calculation.

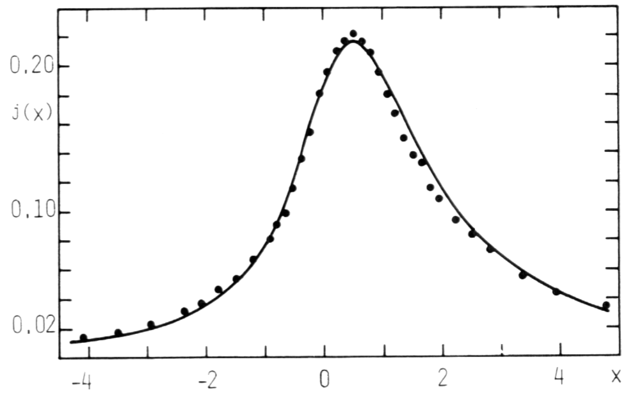

Fig. 3. Comparison of the measured end theoretical profiles of the He I 667.8 nm line in reduced wavelength scale for $N_e = 1.06 \times 10^{23}$ m^{-3} and $T_e = 31$ kK. Dots: our measurement; solid curve: theory of Griem

4. Conclusion

In this paper we report results of measurements of Stark widths and asymmetry of the He I 667.8 nm line. Line shapes were measured in a laser-produced plasma at electron densities between 6 and 17 $\times 10^{22}$ m^{-3} and temperatures between 26 kK and 35 kK.

The results of the comparison with theoretical calculations [1, 5, 6] show the following: The half-widths are systematically lower than [1] within 3% and 24% for lower and upper limit of our N_e range, respectively, while they agree with [5, 6] within 15%. The asymmetry is between 70% and 20% lower than [7].

Finally, we have established very good agreement with $j_{A,B}(x)$ theoretical profiles of this line.

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