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WIDTH MEASUREMENTS OF THE PLASMA BROADENED HeII BALMER-BETA LINE

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We report measured Stark widths of the HeII 121.5 nm line. A pulsed low pressure arc was used as a light source. The plasma conditions corresponded to electron temperature of 4.5 eV and electron densities in the range (3.9—6.2) × 10^{22} m^{-3}. Electron densities derived from the comparison of the measured widths of 121.5 nm line and Kepple's theoretical results agree within ±5% with those obtained from the width of HeII Pashen-alpha (468.6 nm) line.

1. *Introduction*

In this paper we describe an experimental study of the plasma broadened VUV transition of ionized helium at 121.5 nm. Such measurements of HeII line profile remain of significance for two reasons. Firstly, experimental studies of line shapes for ionized emitters are of general interest in connection with diagnostics of different types of plasmas like e. g. laser-generated and laser compressed plasmas. Secondly, even for HeII there are relatively few high precision experimental results which can be used for both testing of theoretical calculations and plasma diagnostics purposes.

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Earlier theoretical and experimental studies dealing with broadening and shift of HeII 121.5 nm line are reviewed in Ref. 1. Since then several papers$^{2-4)}$ have been published. With exception of Ref. 4, all measurements of the shape of HeII 121.5 nm line were performed at electron densities $N_e > 1 \times 10^{23}\,\mathrm{m}^{-3}$. Piel and Slupek$^{4)}$ in a high precision experiment measured shape of HeII 121.5 nm line at $N_e = 5.5 \times 10^{22}\,\mathrm{cm}^{-3}$ and compared with calculations by Kepple$^{5)}$ and Lee$^{6)}$. The comparison shows that the theoretical profile according to Kepple$^{5)}$ fits quite well, except for the too pronounced central structure$^{4)}$.

2. *Experiment*

A. Plasma source and experimental procedure

A low pressure pulsed arc is used as a plasma source (see Fig. 1). It consists of low inductance discharge capacitor having a peak voltage rating 25 kV and capacitance 3.5 μF. The pulsed arc is fired at 12 kV by a spark gap and the ringing frequency of the whole circuit including discharge vessel, is 12.6 μs. The discharge tube is made of quartz glass with 11 mm internal diameter. For the measurements of the optical depth of spectral line, an additional aluminium electrode with a thin iron surrounding sleeve is located inside the discharge. The iron sleeve is on the electrode so one can move it from the outside by means of a magnet. In this way it is possible to vary the plasma length and, accordingly, the absorption condition of plasma layer under investigation without changing electrical impedance of the circuit. This technique has been used recently by Radtke and Günter$^{7)}$ to study Balmer spectrum of hydrogen in a plasma of a flashlamp.

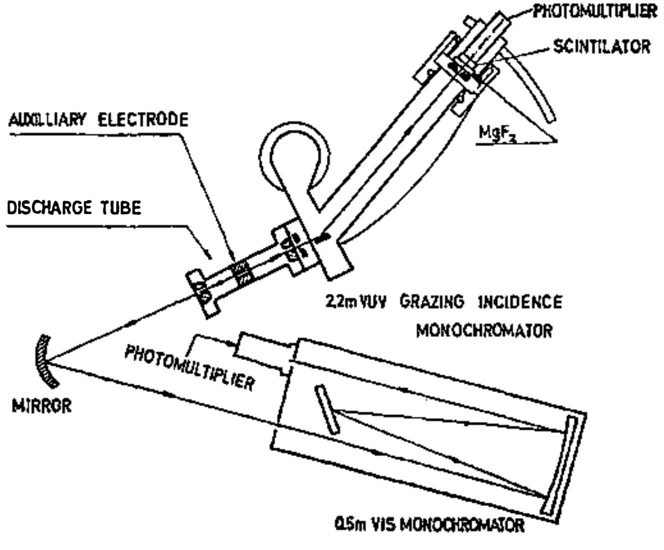

Fig. 1. Schematic diagram of the experimental set-up.

Holes 2 mm dia., are located at the center of the end electrodes for end-on plasma observations. During the experiment a continuous flow through the discharge tube of helium at a pressure of 50 Pa is maintained.

The light from a pulsed arc is observed end-on on a shot-to-shot basis with a 2.2 m grazing VUV monochromator from one side, and 0.5 m monochromator from the other side (see Fig. 1) for plasma observations in visible region of the spectrum. VUV monochromator with 50 μm slits has a measured instrumental half-width of 0.042 nm, while visible monochromator with 20 μm slits has instrumental half-width of 0.035 nm. In both cases instrumental profile has a Gaussian shape. The instrumental function and wavelength calibration were checked using a low pressure Penning discharge. For the work with VUV monochromator a 2 mm thick MgF_2 filter was used to remove light from second order, since it transmits 50% of the light at 121.5 nm but essentially none below 110 nm.

Our main concern with HeII line shape measurements was the possible distortion arising from self-absorption. In order to determine optical thickness of the investigated lines, we recorded line profiles from two plasma lengths by positioning the movable electrode. From these recordings we determined $k_\lambda l$ where k_λ is the spectral line absorption coefficient and l is the plasma length along the direction of observation. Within the limits of experimental scatter we measured $k_\lambda l \approx 0$ indicating that both observed HeII lines in our conditions were not distorted by the self-absorption. Fitting of experimental data of the line profile with the theoretical ones was performed in an iterative manner. Starting values of the electron density N_0 and line position λ_0 were chosen. According to these values theoretical line profile was computed, using appropriate tables[5)] and in this way a discrete number of points has been obtained. In the next step theoretical line profile was convolved with the instrument profile.

Traditionally, convolution is computed via fast Fourier transformation, but in our case we could simplify the computations using a fact that instrument profile is Gaussian. This simplification was done first, by interpolation of the theoretical line profile with parabolic splines, and subsequently, by convolving each of the parabolic sections with Gaussian. This step is easily performed analytically: in other words, convolution of the Gaussian $f(x) = \exp(bx^2)$ and parabola $g(x) = a_2x^2 + a_1x + a_0 \quad x \in [C, D]$ can be computed as:

$$\int_{\infty}^{\infty} f(u-x)\, g(x)\, \mathrm{d}x = 2\,(\pi/b)^{1/2}\,[a_2/(2b) + a_2u^2 + a_1u + a_0]\,[\mathrm{erf}((u - C)\, b^{1/2}) + \mathrm{erf}(u - D)\, b^{1/2})] - 1/(2b)\exp(-b\,(u - C)^2)\,[-ua_2 - a_1 - a_2C] + 1/(2b)\exp(-b\,(u - D)^2)\,[-ua_2 - a_1 - a_2D]$$

where erf is error function.

After the convolution has been performed, least square method was used to fit the experimental values to the convolved theoretical curve, i. e. the sum $\sigma^2 = \sum |Y_n - (It_n + B)|$ was minimized (Y_n are theoretical values, t_n are experimental values, B is background parameter, and I is the line intensity). This is the end of one iteration. In the next iteration new values of N_e and λ_0 are chosen and the whole procedure is repeated. The process is terminated when σ^2 can not be further improved.

B. Plasma diagnostics

For electron-density measurements we use the width of HeII 468.6 nm line. The full width at half maximum $\Delta\lambda_{\mathrm{FWHM}}$ of this line is related to the electron density N_e using the following relationship[8,9]:

$$N_e = 3.31\,(\Delta\lambda_{\mathrm{FWHM}})^{1.21} \times 10^{23}\ \mathrm{m}^{-3} \qquad (1)$$

where $\Delta\lambda$ is in nm units. This equation is based on the fitting of the experimental data and in fact closely agrees with calculations by Griem and Shen[10].

The axial electron temperature is determined from the ratio of HeII 468.6 nm and HeI 587.6 nm lines[11].

3. Results and discussion

Results of experimental measurements of Pashen-alpha HeII (468.6 nm) and Balmer-beta HeII (121.5 nm) Stark width are given in Table 1. In the same table electron densities derived from a) the width of 468.6 nm line using theoretical profiles by Kepple[5] and from Eq. (1), and b) from the width of 121.5 nm line and theoretical profiles of Kepple[5] are given also. Measured electron temperature 4.5 eV is found, within the limit of experimental error, to be constant for all experimental conditions in Table 1. Example of photoelectric measurements of the emission profiles of the ionized helium lines at 468.6 and 121.5 nm are shown in Figs. 2A and B. The solid lines are the best fit theoretical curves of Kepple[5] convolved with the instrumental profile (taken to be Gaussian).

TABLE 1.

468.4 nm			121.5 nm	
Width [nm]	Electron density × 10^{-22} [m^{-3}]		Width [nm]	Electron density × 10^{-22} [m^{-3}]
	Kepple[5]	Eq. (1)		Kepple[5]
0.265	5.4	6.2	0.102	6.3
0.310	6.4	8.0	0.117	7.6
0.180	3.4	4.1	0.074	4.0
0.170	3.2	3.8	0.073	3.9

Experimental results: widths of HeII 468.6 and 121.5 nm lines and corresponding electron densities at electron temperature 4.5 eV.

The overall 468.6 nm line profile was found in good agreement with the theory[5]. However, derived electron density from theoretical profiles by Kepple[5] is systematically lower than those obtained from Eq. (1) for about 15—20% (see Table 1). This is in agreement with Refs. 8 and 9.

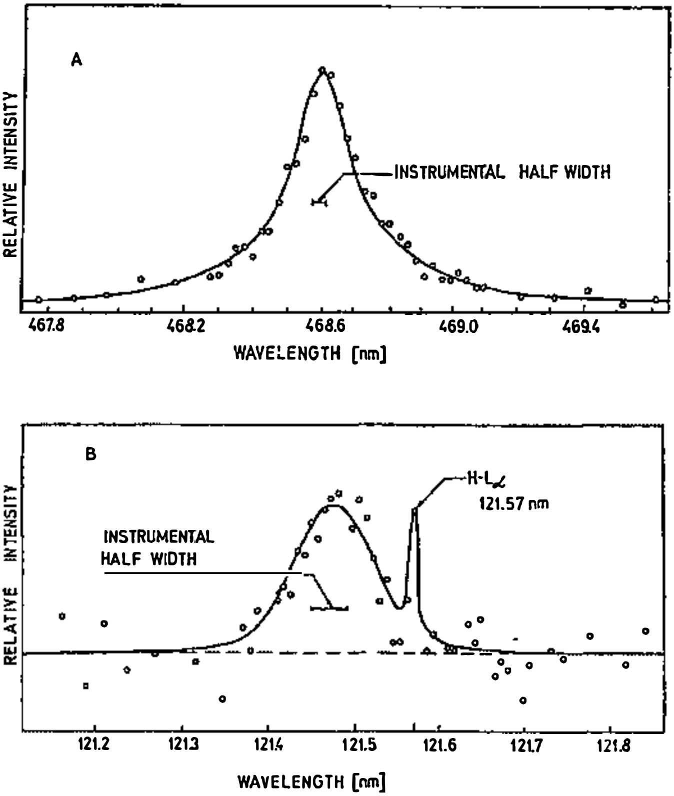

Fig. 2. Measured and best-fit theoretical profiles[5] of HeII 468.6 nm (A) and HeII 121.5 nm line (B). Dashed line is best-fit value for continuum.

Although shot-to-shot reproducibility of the discharge in VUV spectral region is much worse than for 468.6 nm (see Fig. 2 A and B) obtained results for electron density (see Table 1) are consistent within ±5% with those obtained from the width of 468.6 nm and Eq. (1). Here one should notice that on the red wing of 121.5 nm Lyman-alpha line of neutral hydrogen appears, which is present in the plasma as an impurity. This line was also detected in preceding experiments[2,4].

Estimated experimental error in electron density measurements are as follows: electron density from the width of HeII 468.6 nm and Eq. (1), ±10% (see Refs. 8 and 9) and electron temperature ±15%. The accuracy of electron density measurements from the profile of HeII 121.5 nm and theoretical calculations of Kepple[5] is very difficult to estimate from the scatter of experimental points (see Fig. 2B). However, consistency of electron density data derived from this line and from the widths of extensively studied HeII 468.6 nm line (see Table 1) suggests an accuracy of the order of ±15%.

4. *Conclusions*

In this paper we report results of experimental study of HeII 121.5 nm line in a plasma of low pressure pulsed arc. Electron density is determined from the width of HeII 468.6 nm line while electron temperature is determined from the intensity ratio of HeII 468.6 nm to HeI 587.6 nm lines. Electron densities derived from the HeII 121.5 nm and theoretical profiles of this line by Kepple[5] agree within ±5% with those derived from the width of 468.6 nm line and Eq. (1).

References

1) H. R. Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974);
2) J. R. Van Zandt, J. C. Adcock, Jr. and H. R. Griem, Phys. Rev. A **14** (1976) 2126;
3) C. C. Smith and D. D. Burgess, J. Phys. B **11** (1978) 2087;
4) A. Piel and J. Slupek, Z. Naturforsch. A **39** (1984) 1041;
5) P. C. Kepple, Phys. Rev. A **6** (1972) 1; Report No. 72-018, Univ. of Maryland, College Park, Md., (1971);
6) R. W. Lee, J. Phys. B **12** (1979) 1145;
7) R. Radtke and K. Günter, Contrib. Plasma Phys. **26** (1986) 143;
8) T. L. Pittman and C. Fleurier, in Proceedings of the Sixth International Conference on Spectral Line Shapes, Boulder, Walter de Gruyter, Berlin (1983);
9) T. L. Pittman and C. Fleurier, Phys. Rev. A **33** (1986) 1291;
10) H. R. Griem and K. Y. Shen, Phys. Rev. **122** (1961) 1940;
11) R. Mewe, Brit. J. Appl. Phys. **18** (1967) 107.

MERENJA ŠIRINE HeII BALMER-BETA LINIJE U PLAZMI

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U radu su dati rezultati merenja širine HeII 121,5 nm linije u plazmi impulsnog lučnog pražnjenja. Elektronske gustine dobijene poređenjem merene širine HeII Balmer-beta linije i teorijskih proračuna Kepple-a slažu se u granicama ±5% sa elektronskim gustinama dobijenim iz poluširine HeII Pashen-alfa linije.