YU ISSN 0015—3206
FZKAAA 16 (2) 201 (1984)

EXPERIMENTAL INVESTIGATIONS OF BROADENING PARAMETERS OF He I 2^3P-4^3D, 4^3F, λ = 447.15 nm LINE IN A LASER PRODUCED PLASMA

BOŽIDAR T. VUJIČIĆ

Institute of Physics, Faculty of Sciences, 21000 *Novi Sad, Dr Ilije Đuričića* 4, *Yugoslavia*

and

LJUBOMIR M. ĆIRKOVIĆ

Department of Physics and Meteorology, Faculty of Sciences, 11001 *Belgrade, P. O. Box* 550, *Yugoslavia*

Received 4 October 1983

UDC 533.91

Original scientific paper

Line profiles of the He I 2^3P-4^3D line and its forbidden component 2^3P-4^3F were examined and the dependence of the parameters of this combination on the electron density in plasma are determined. Following parameters were determined: half-width, peak separation, ratio of peak intensities of forbidden and alllowed line, and ratio of the intensity in the dip to allowed line intensity. The values obtained for different electron densities are compared to the experimental and theoretical results of other investigators.

1. Introduction

Experimental and theoretical investigations of the Stark profile of lines due to allowed and forbidden transitions at elevated electron density have received much attention in the last few years[1–4,8,9,11]. The reason lies in the fact that parameters of this combination strongly depend on the concentration of charged particles in plasma, which can be used as a suitable method for the determination of electron density. On the other hand, the detailed study of profile shapes and all parameters of this transition combination represents extremely sensitive check for the testing of the correctness of current line broadening theories.

There are only few papers dealing with the electron density range above $N_e = 5 \times 10^{22}\,\mathrm{m}^{-3}$ and only one[2] with density $N_e > 10^{23}\,\mathrm{m}^{-3}$, so it was important to study the dependence of line parameters on electron density for higher values of N_e. These reasons stimulated us to perform detailed investigations of the parameters of the combination of the He I 2^3P-4^3D, 4^3F in the wide range of electron density $3 \times 10^{22}\,\mathrm{m}^{-3} < N_e < 1.3 \times 10^{23}\,\mathrm{m}^{-3}$ at the electron temperature $T_e \approx 5 \times 10^4$ K. We have determined line half-width, peak separation, ratio of peak intensities of forbidden and allowed line, and ratio of the intensity in the dip to allowed line intensity, all as a function of electron density in the above mentioned electron density range.

The values obtained are compared to the theoretical predictions and experimental results of other authors.

2. *Apparatus*

The detailed experimental set-up for plasma production and the techniques of measurements of plasma parameters are described elsewhere[7]. The plasma was obtained by focussing the radiation of a TEA-CO_2 laser (Lumonics, Mod. 203—2) delivering the energy of 12—15 J/pulse. The laser pulse shape has a sharp maximum taking one-third of the energy with 150 ns FWHM, followed by a long tail with duration of 2 μs.

The focussing of laser beam was achieved by an axicon mirror with the apex half-angle of 18 degrees. The breakdown occurs along the focal line and a cylindrical plasma is formed about 25 mm in length.

The light from plasma column (side-on) was focused into the entrance slit of one-meter monochromator (Spex 1802) having inverse linear dispersion of 0.7 nm/mm, equipped with an EMI 9659 B photomultiplier an the exit slit. The entrance slit was 20 μm wide and 1 mm high. Signals were taken in a shot-by-shot technique and recorded by oscilloscope. A small part of the laser beam was directed towards a photon drag detector and recorded with the line signals on double beam oscilloscope, for monitoring laser power. The reproducibility of the laser output during the measurement was well within $\pm 10\%$ of the set value.

3. *Determination of plasma parameters*

The time evaluation of the electron density in the plasma, starting from the breakdown till 20 μs, was determined from the Stark widths of the He II 468.6 nm line, the He I 388.9 nm and 471.3 nm lines. Within the time interval from 4 μs to 19 μs after breakdown, where the investigated He I 447.15 nm line was well defined, neutral helium lines were used to evaluate N_e values. Due to the good reproducibility of the plasma and reliability of Stark parameters for He I lines used, the error in determination of N_e in the above mentioned interval is smaller than 10%.

The electron temperatures in this interval were determined from the intensity ratios of He I lines and the continuum. For this purpose He I 587.6 nm and 447.1 nm lines were used. The electron temperature values for the earlier time intervals after breakdown were determined from the ratio of He II 468.6 nm line and He I 587.6 nm line. The electron temperatures in the investigated interval from 4 μs to 19μs after breakdown vary from 5.5×10^4 K to 4.2×10^4 K. The error in the determination of T_e is probably larger due to the appreciable self-absorption of the He I 587.6 nm line, particularly at the early time intervals after breakdown. However according to our estimates the error does not exceed 15% in the worst case.

The electron density and electron temperature as a function of time after breakdown are given in Fig. 1.

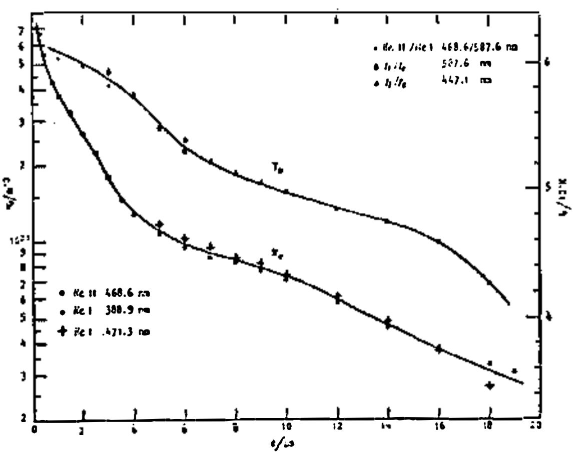

Fig. 1. Electron density and electron temperature vs. time after breakdown.

4. *Experimental results and discussion*

Parameters of investigated line $2^3P—4^3D$, 4^3F were analysed from the registered line profiles at different moments after breakdown, i. e. under different N_e and T_e conditions. Typical overall experimental profile of the investigated line is shown in Fig. 2 with parameters assigned: half-withd $\Delta\lambda_{1/2}$, peak separation $\Delta\lambda_{AF}$, intensity of the allowed (I_A) and forbidden (I_F) component, and intensity of the central minimum I_W.

Dependence of the half-width on the electron density is given in Fig. 3, together with theoretical and experimental results of other authors. Error bars for N_e represents $\pm 10\%$, while the errors of measured $\Delta\lambda_{1/2}$ were estimated from the experimental results. The agreement with theoretical results[8,9] is quite satisfactory in the range $3 \times 10^{22}\ m^{-3} < N_e < 1 \times 10^{23}\ m^{-3}$. Experimental values of Ref. 1 are slightly lower, while there is a large discrepancy with the results of Ref. 2 from our results for $N_e < 7 \times 10^{22}\ m^{-3}$. There is only one paper[2] giving results for $N_e > 10^{23}\ m^{-3}$ and there is quite a good agreement with our results in the range $8 \times 10^{22}\ m^{-3} < N_e < 1.3 \times 10^{23}\ m^{-3}$.

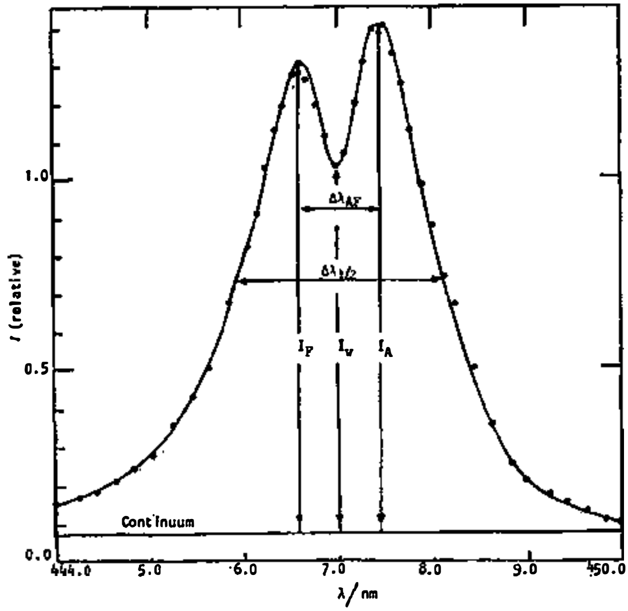

Fig. 2. Experimental profile of the He I 447.15 nm line for $N_e = 5.9 \times 10^{22}\ \mathrm{m}^{-3}$ and $T_e = 4.8 \times 10^4$ K illustrating the investigated parameters.

Fig. 4 represents the separation between the peaks of the allowed and forbidden lines vs. electron density. Our measurements show sistematically lower values of $\Delta\lambda_{AF}$ for about 20%compared to the corresponding theoretical values obtained by the interpolation of the theoretical results of Ref. 9 for $T_e = 2 \times 10^4$ K. Taking into account the temperature dependence of $\Delta\lambda_{AF}$ predicted in Ref. 9 indicating an increase of about 5% when T_e changes from 2×10^4 K to 4×10^4 K, the difference between our results and the theoretical predictions of Ref. 9 becomes even larger. The introduction of ion dynamic shielding effect decreases this disagreement only slightly, because, according to Ref. 9, $\Delta\lambda_{AF}$ decreases for about 6.5% for $N_e = 3 \times 10^{22}\ \mathrm{m}^{-3}$ and $T_e = 4 \times 10^4$ K. Comparison with the theoretical results of Ref. 8 shows similar disagreement. The situation is similar with other experimental results[1,4], and it is interesting to notice that the results of Ref.1 are 5—10% lower than ours in the whole range of N_e.

The ratio of the intensities of the forbidden and allowed line as the function of the electron density is given in Fig. 5. The values of the ratio I_F/I_A are always higher than those obtained in Ref. 1 in the whole N_e range. The deviation is negligible for $N_e < 5 \times 10^{22}\ \mathrm{m}^{-3}$, and it rises with the increase of N_e. Our experiment shows $I_F/I_A > 1$ for $N_e > 8 \times 10^{22}\ \mathrm{m}^{-3}$, which has already been established also in Refs. 2,11. There is an important difference: Ref. 2 indicates that I_F/I_A highly exceeds unity ($I_F/I_A = 1.075$ for $N_e = 1.2 \times 10^{23}\ \mathrm{m}^{-3}$), while our values are only slightly higher from unity for $N_e > 8 \times 10^{22}\ \mathrm{m}^{-3}$. It is known that the selfabsorption of one of the components can essentially influence the value of this and other parameters, so we have investigated the selfabsorption of both components and concluded that this effect can not essentially influence the dependence

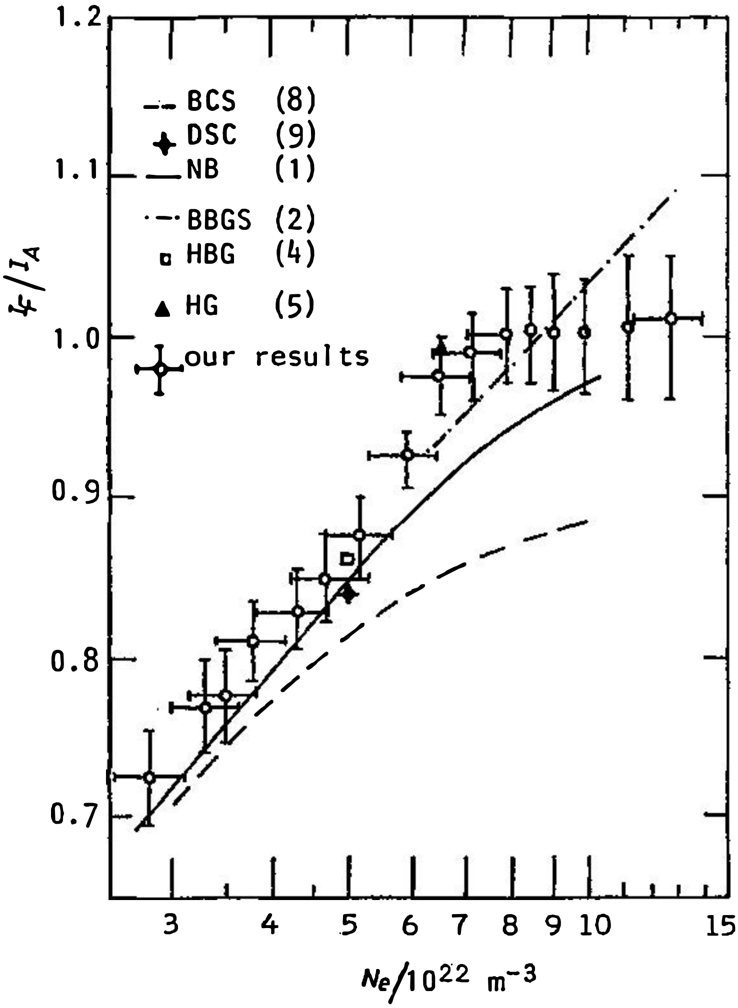

Fig. 3. Total width at half intensity vs. electron density.

presented in Fig. 5, because the correction of the intensity lies deeply within the limits of the experimental error. Fig. 5 shows that our values lies higher than theoretical results[8] with the deviation of order 4% for $N_e < 5 \times 10^{22}$ m^{-3}, while for the $N_e > 5 \times 10^{22}$ m^{-3} the deviation increases with N_e and achieves 13% for $N_e = 1 \times 10^{23}$ m^{-3}.

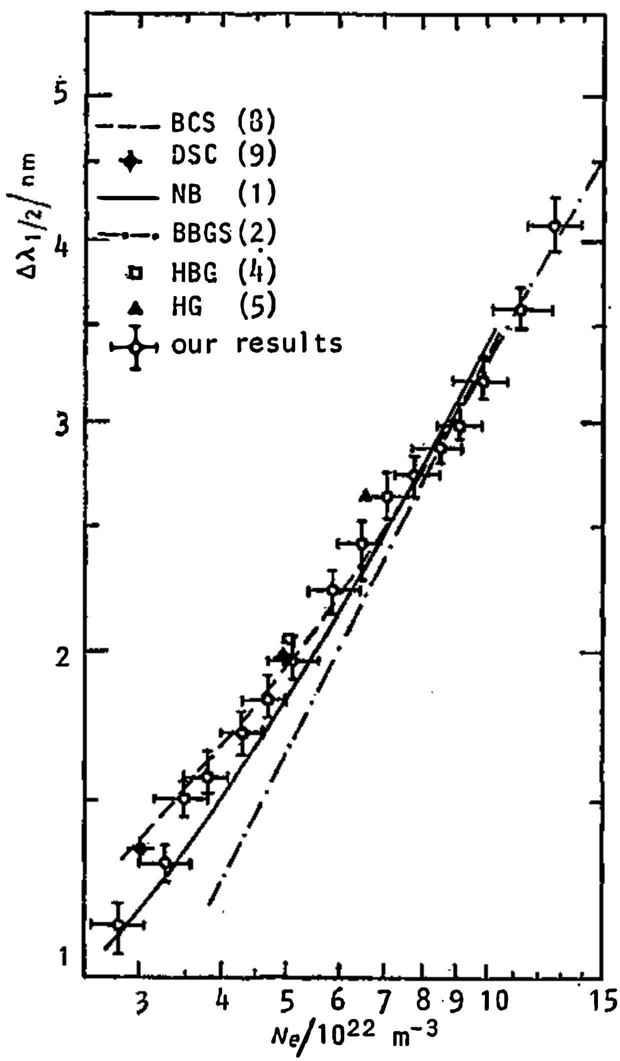

Fig. 4. Peak separation vs. electron density.

The last investigated parameter, the ratio of the intensity of the minimum and the intensity of the allowed line vs. electron density is given at Fig 6. Our results are in reasonable agreement with the experimental results[1] although they are systematically lower about 10%. The results of other authors[2] show larger deviations, and lie below our results for $N_e < 5 \times 10^{22}$ m^{-3} and above for $N_e >$

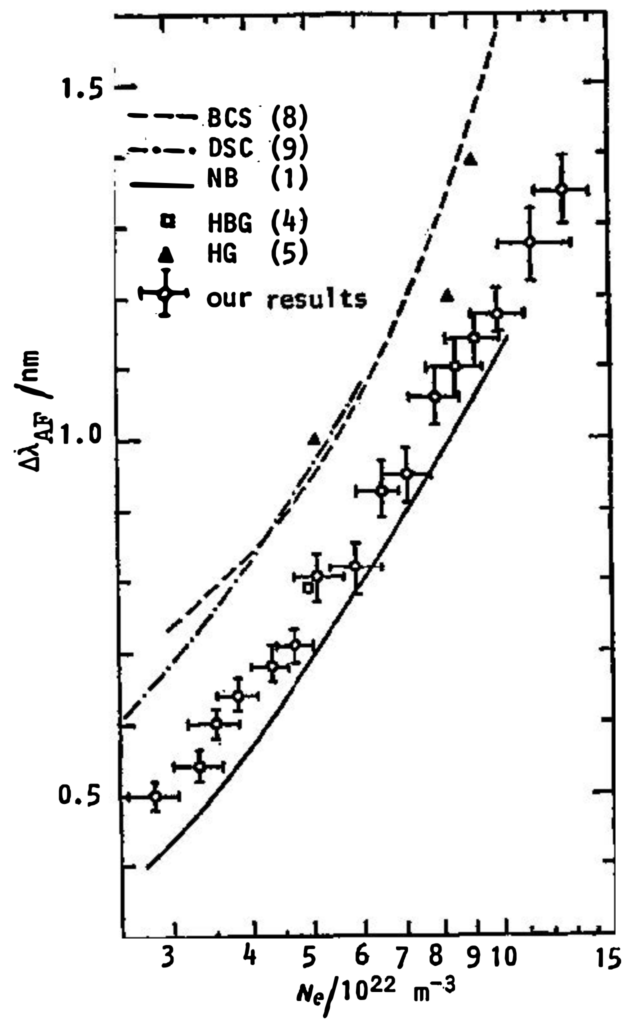

Fig. 5. Ratio of the peak intensity of the forbidden line to the allowed one vs. electron density.

$> 5 \times 10^{22}$ m^{-3}. The comparison with theoretical values[8,9] shows large deviations. These differences become even larger when one takes into account strong temperature dependence of I_w/I_A. The results of Ref. 9 indicate that this ratio decreases for about 20% for T_e change from 2×10^4 K to 4×10^4 K. This could give the values which are 1.8—2.0 times smaller then the values measured in our experiment.

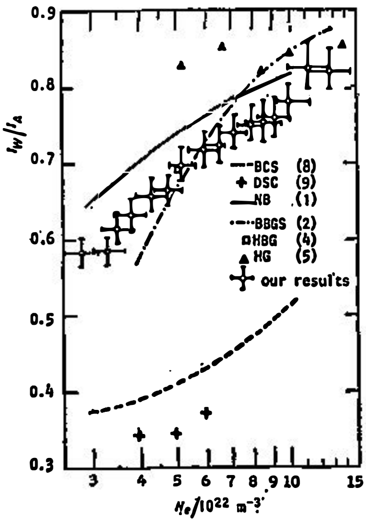

Fig. 6. Ratio of the intensity of the minimum to the maximum intensity of the allowed line vs. electron density.

5. *Summary*

The comparison of our experimental results with the theoretical values for the parameters investigated here allows us to conclude the following:

1. Half-widths of the He I 2^3P—4^3D, 4^3F line is in good agrement with the theoretical results in the whole examined range of N_e.

2. The values of peak separation $\Delta\lambda_{AF}$ is systematicaly 20% lower than the theoretical values in the whole examined range of N_e.

3. The ratio of intensities of allowed and forbidden line significantly deviates from the theoretical results.

4. The ratio of intensity at the minimum and intensity of allowed line is 1.8—2.0 times higher than the theoretically predicted values.

Similar conclusions can be drawn from the other cited experimental results, but due to strong temperature dependence of the parameters $\Delta\lambda_{AF}$ and I_w/I_a it is necessary to be extremly critical during the comparison.

All described disagreements between the theory and experimental results justify further theoretical and experimental study of these line profiles with more precise determination of all plasma parameters, especially the plasma electron temperature.

References

1) R. H. Nelson and A. J. Barnard, JQSRT **11** (1971) 161;
2) G. Baravian, J. Bretagne, J. Godart and G. Sultan, Z. Physik **B 20** (1975) 255;
3) C. S. Diatta, A. Czernishowski and J. Chapelle, Z. Naturforsch. **30** *a* (1979) 900;
4) R. J. Hawryluk, G. Bekefi and E. V. George, Phys. Rev. **A 10** (1974) 265;
5) J. D. Hey and H. R. Griem, Phys. Rev. **A 12** (1975) 169;
6) D. Einfeld and G. Sauerbrey, Z. Naturforsch. **31** *a* (1976) 310;
7) Lj. M. Ćirković, B. T. Vujičić and S. M. Glišić, J. Phys. **D 15** (1982) 229;
8) A. J. Barnard, J. Cooper and L. J. Shamey, Astron. Astrophys. **1** (1969) 28;
9) C. Deutsch, M. Sassi and G. Coulaud, Ann. Phys. **83** (1974) 1;
10) M. Sassi, C. Deutsch and G. Coulaud, Ann. Phys. **89** (1975) 274;
11) J. R. Grieg, L. A. Jones and R. W. Lee, Phys. Rev. **A 9** (1974) 44.

EKSPERIMENTALNO ISPITIVANJE PARAMETARA ŠIRENJA LINIJE HeI $2^3P—4^3D$, 4^3F, $\lambda = 447{,}15$ nm U LASERSKI PROIZVEDENOJ PLAZMI

BOŽIDAR T. VUJIČIĆ

Institut za fiziku Prirodno-matematičkog fakulteta, 21000 *Novi Sad*, *Dr. Ilije Đuričića* 4

i

LJUBOMIR M. ĆIRKOVIĆ

Odsek za fizičke i meteorološke nauke PMF i Institut za fiziku, 11000 *Beograd*

UDK 533.91

Originalni naučni rad

Ispitivani su profili linije $2^3P—4^3D$ i njene zabranjene komponente $2^3P—4^3F$ i određena je zavisnost parametara ove kombinacije od elektronske koncentracije u plazmi. Određene su vrednosti poluširine linije, rastojanje između maksmuma dozvoljene i zabranjene linije, odnos intenziteta u maksimumima, kao i odnos intenziteta u minimumu i intenziteta dozvoljene linije. Dobijene vrednosti ovih parametara za različite elektronske koncentracije poređene su sa rezultatima teorijskih i eksperimentalnih studija drugih autora.