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ION CHARACTERISTICS TO THE 667.82 nm He I SPECTRAL LINE SHAPE

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Abstract. Ion characteristics of the 667.82 nm He I spectral line profiles have been investigated at electron densities between 4.4×10^{22} and 8.2×10^{22} m^{-3} and electron temperatures between 18 000 and 33 000 K in plasmas created in five various discharge conditions using a linear, low-pressure, pulsed arc as an optically thin plasma source operated in a helium-nitrogen-oxygen gas mixture. On the basis of the observed asymmetry of the line profiles we have obtained their ion broadening parameters (A) caused by influence of the ion microfield on the line broadening mechanism and also the influence of the ion dynamic effect (D) on the line shape. Our A and D parameters represent the first data obtained experimentally by the use of the line profile deconvolution procedure. We have found stronger influence of the ion contribution to this He i line profile than the semiclassical theoretical approximation provides.

1. Introduction

Helium atoms and ions are present in many kinds of cosmic light sources and their radiation is very useful for astrophysical plasma diagnostical purposes (Griem 1974, 1997). In plasmas with electron densities (N) higher than 10^{21} m^{-3}, where the Stark effect begins to play an important role for the He I spectral lines broadening, knowledge of the Stark broadening characteristics is necessary. A significant number of theoretical and experimental studies are devoted to the He I Stark FWHM (full-width at half intensity maximum, W) investigations (Lesage & Fuhr 1999, and references therein). The aim of this work is to present measured Stark broadening parameters of the 667.82 nm (2p $^1P^0_1$ - 3d $^1D_2$ transition) neutral helium (He I) spectral line at (18 000 - 33 000) K electron temperatures (T) and at electron densities of $(4.4 - 8.2)\times10^{22}m^{-3}$. Using a deconvolution procedure described by Milosavljević & Poparić (2001) we have obtained, for the first time, on the basis of the observed line profile asymmetry, the ion contribution to the line shape from the quasistatic ion (parameter A) and ion dynamic effect (coefficient D) (Griem 1974, Barnard et al. 1974, Bassalo et al. 1982) and, also, the separate electron (W_e) and ion (W_i) contributions to the total Stark width (W_t). As a plasma source we have used a linear, low-pressure, pulsed arc operated in five various discharge conditions. Our measured W_t, W_e, W_i and A values have been compared to all available theoretical and experimental data.

2. Experiment

The modified version of the linear low pressure pulsed arc (Djeniže et al. 1998, 2002) has been used as a plasma source. The working gas was helium - nitrogen - oxygen mixture (90% He + 8% N_2 + 2% O_2). The tube geometry used and the corresponding discharge conditions are presented in Table 1 in Milosavljević and Djeniže (this proceedings).

Spectroscopic observation of spectral lines was made end-on along the axis of the discharge tube described in details in Djeniže (2002).

The line profiles were recorded by a step-by-step technique using a photomultiplier (EMI 9789 QB and EMI 9659B) and a grating spectrograph (Zeiss PGS-2, reciprocal linear dispersion 0.73 nm/mm in the first order) system. The instrumental FWHM of 8 pm was obtained by using narrow spectral lines emitted by the hollow cathode discharge.

The plasma reproducibility was monitored by He I lines radiation and, also, by the discharge current using the Rogowski coil signal (it was found to be within ±5%). Using the double plasma length method, described in Milosavljević (2001), an absence of self-absorption was found in the case of the investigated line profiles.

The plasma parameters were determined using standard diagnostic methods. Thus, the electron temperature was determined from the ratios of the relative line intensities of four N III spectral lines (409.74 nm, 410.34 nm, 463.42 nm and 464.06 nm) to the 463.05 nm N II spectral line with an estimated error of ±10%, assuming the existence of LTE (Griem 1974). All the necessary atomic data were taken from NIST (2002) and Glenzer et al. (1994). The electron density decay was measured using a well-known single wavelength He-Ne laser interferometer technique (with 1.5 mm laser beam diameter) for the 632.8 nm transition with an estimated error of ±9%. The electron densities and temperatures, obtained at the moment when the line profiles were analyzed, are presented in Table 1 in Milosavljević and Djeniže (this proceedings).

3. Numerical procedure for deconvolution

The proposed function for various line shapes, Eq. (1) is of the integral form and includes several parameters. Some of these parameters can be determined in separate experiments, but not all of them. Furthermore, it is impossible to find an analytical solution for the integrals and methods of numerical integration should be applied. This procedure, combined with the simultaneous fitting of several free parameters, requires a number of computer-supported mathematical techniques.

$$K(\lambda) = K_o + K_{\max}\int_{-\infty}^{\infty} exp(-t^2)\cdot\left[\int_0^{\infty}\frac{H_R(\beta)}{1+\left(2\frac{\lambda-\lambda_o-\frac{W_G}{2\sqrt{\ln 2}}\cdot t}{W_e}-\alpha\cdot\beta^2\right)^2}\cdot d\beta\right]\cdot dt. \quad (1)$$

Here K_o is the baseline (offset) and K_{max} is the maximum of intensity (intensity for $\lambda=\lambda_o$) (Milosavljević and Poparić 2001). $H_R(\beta)$ is an electric microfield strength distribution function of normalized field strength $\beta=F/F_o$, where F_o is the Holtsmark field strength. A ($\alpha=A^{4/3}$) is the static ion broadening parameter as a measure of the relative importance of ion and electron broadenings. R is the ratio of the mean

Table 1: Line Broadening characteristics of the HeI 667.82 nm spectral line. Measured: total Stark FWHM (W_t^{exp} in pm within ±12% accuracy), electron Stark width (W_e^{exp} in pm within ±12% accuracy), ion Stark width (W_i^{exp} in pm within ±12% accuracy), static ion broadening parameter (A^{exp}, dimensionless within ±15% accuracy) and ion dynamic coefficient (D^{exp}, dimensionless within ±20% accuracy) at a given electron temperature (T in 10^3 K) and electron density (N in 10^{22}m^{-3}). Ref presents the values given in this work (Tw) and those used from other authors: K, (Kelleher 1981); P, (Pérez et al. 1991); M, (Mijatović et al. 1995); Ga, (Gauthier et al. 1981); VK, (Vujičić and Kobilarov 1988). The index G, BCW and DSB denote theoretical data taken from Griem (1974), Bassalo et al. (1982) and Dimitrijević and Sahal–Bréchot (1990), respectively at a given T and N.

T	N	W_t^{exp}	W_e^{exp}	W_i^{exp}	A^{exp}	D^{exp}	Ref.	W_e^G	W_e^{BCW}	W_e^{DSB}	W_i^{DSB}	A^G	A^{BCW}
33.0	6.1	481	298	183	0.459	1.18	Tw	397	345	358	170	0.282	0.309
31.5	8.2	628	370	258	0.498	1.12	Tw	533	467	502	226	0.300	0.328
30.0	6.7	512	315	197	0.474	1.17	Tw	439	389	402	181	0.282	0.306
28.0	4.4	337	216	121	0.420	1.27	Tw	290	257	266	117	0.252	0.265
18.0	5.0	361	240	121	0.413	1.26	Tw	358	323	323	124	0.249	0.271
20.9	1.03	98			0.171	1.74	K						
30.1	3.2	231					P						
19.3	0.25	22					M						
20.0	10.0	960					Ga						
26.0	7.1	620					VK						

distance between the ions to the Debye radius, i.e. the Debye shielding parameter and W_e is the width (FWHM) of the $j_{A,R}$ profile (Griem 1974).

For the purpose of the deconvolution iteration process we need to know the value of K function (1) as a function of λ for every group of parameters (K_{max}, λ_o, W_e, W_G; R, A). The function $K(\lambda)$ is in integral form and we have to solve a triple integral in each step of the iteration process of varying the above group of parameters. The first integral in the K function is the microfield strength distribution function, $H_R(\beta)$, the second one is the $j_{A,R}(\lambda)$ function and the third is the convolution integral of a Gaussian with a plasma broadened spectral line profile $j_{A,R}(\lambda)$ (denoted by $K(\lambda)$ in Eq. (1)). None of these integrals has an analytic solution and they must be solved using numerical integration (Milosavljević and Poparić 2001, Milosavljević 2001).

After numerical integration the fitting procedure itself can be started. For Eq. (1), the fitting procedure will give the values for W_G, W_e, λ_o, R, A and K_{max}.

This sophisticated deconvolution method, which allows the direct determining of all six parameters by fitting theoretical K-profile (1), to experimental data, requires a sufficient number of experimental points per line, and small statistical errors.

4. Results and discussion

The plasma-broadening parameters (W_t, W_e, W_i, A, D) of the recorded line profiles at measured N and T values obtained by our deconvolution procedure are presented in Table 1 together with the results of other authors. Various theoretical (G, BCW, DSB) predictions of the W_e, W_i, and A are also given. For the normalization of the A^G and A^{BCW} values to our electron density the $N^{1/4}$ numerical factor (Griem 1974) was used.

In order to make the comparison between measured (W_t^{exp}) and calculated (W_t^{th})

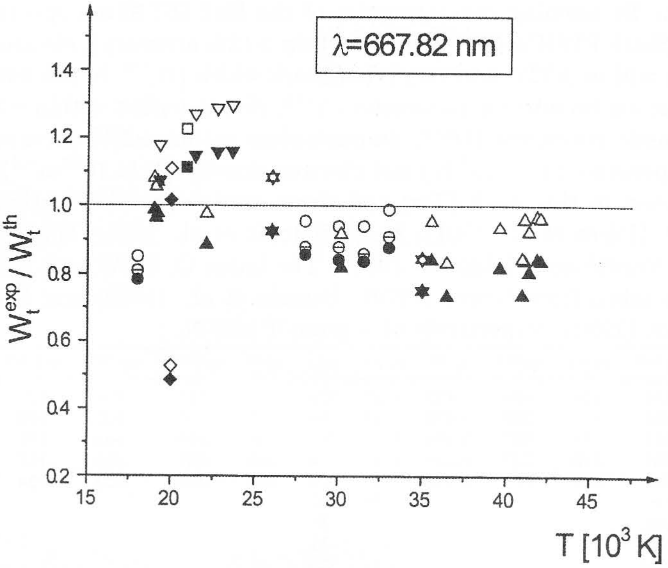

Fig. 1: Ratios of the experimental total Stark FWHM (W_t^{exp}) to the various theoretical (W_t^{th}) predictions vs. electron temperature for λ= 667.82 nm. ○, ◇, ▽, △, □ and ✡ represent our experimental data and those from Gauthier et al. (1981), Mijatović et al. (1995), Pérez et al. (1991), Kelleher (1981), and Vujičić and Kobilarov (1988), respectively. Filled, empty and half divided symbols represent the ratios related to the theories taken from Griem (1974), Bassalo et al. (1982) and Dimitrijević and Sahal–Bréchot (1990), respectively.

total (electron + ion) width values easier, the dependence of the ratio W_t^{exp}/W_t^{th} on the electron temperature is presented graphically in Fig. 1 for the researched line.

The W_t^G (Griem 1974) and W_t^{BCW} (Bassalo et al. 1982) values are calculated using Eq. (226) from Griem (1974) with the W_e and A values predicted by the G (Griem 1974) and BCW (Bassalo et al. 1982) theoretical approaches, respectively. The W_t^{exp}/W_t^{th} ratios related to the Dimitrijević and Sahal–Bréchot (1990) data have been calculated only for our experimental values. Namely, for the W_i^{DSB} calculations it is necessary to know the helium ion concentration connected to the plasma composition. We have performed this for our discharge conditions only.

It turns out that our W_e^{exp} and W_i^{exp} are the first separate experimental electron and ion Stark width results obtained by using our deconvolution procedure (Milosavljević and Poparić 2001). Our W_e^{exp} results are smaller than the G approximation for all the investigated lines. The two approximations (BCW and DSB), in the case of the 667.82 nm line, provide smaller W_e values than the G approximation, but they are also higher than ours. It pointed out that the W_e values calculated by Freudenstein and Cooper (1978) and Dimitrijević and Konjević (1986), for the 667.82 nm line, exceed all other W_e data presented in Table 1.

Inspecting Fig. 1 one can conclude that the Griem (1974) W_t values lie above all experimental and theoretical data except the results from experiments reported by Mijatović et al. (1995) and Kelleher (1981). This is clear at higher electron temperatures (see Fig. 1). Theoretical W_t values presented by Bassalo et al. (1982) lie about 10% - 30% below Griem's values. The W_t values ($W_e + W_i$) presented by Dimitrijević and Sahal–Bréchot (1990) agree with ours (W_t^{exp}) to within 3% - 18%.

We have found a clear contribution of the ion influence to the line broadening due to the quasistatic ion effect expressed with the ion broadening parameter (A). Our A^{exp} values are the first data obtained directly by the use of the line deconvolution procedure. They are higher than what the G and BCW approaches yield by about 40% and 34%, respectively. Furthermore, we have found that the ion dynamic effect, expressed as the D coefficient, multiplies the quasistatic ion contribution by about 1.2 for the 667.82 nm line. It should be pointed out that we have found good agreement between our W_i^{exp}/W_t^{exp} and theoretical W_i^{DSB}/W_t^{DSB} (Dimitrijević and Sahal–Bréchot 1990) ratio values. These are 37.5% (30.5%). As can be seen, this agreement is within the estimated experimental accuracies (± 12%) of the W_i^{exp} and W_t^{exp} values. One can conclude that the ion contribution to the total line width increases with the upper-level energy of the transition and plays a more important role than what the G and BCW approximations provide.

5. Conclusion

Using a line deconvolution procedure (Milosavljević and Poparić 2001, Milosavljević 2001) we obtained, on the basis of precisely recorded He I spectral line profile, their Stark broadening parameters: W_t, W_e, W_i, A and D. We found that the ion contribution to the line profile plays a more important role than the semiclassical approximation provides, which must be taken into account in the use of this He I line for plasma diagnostical purposes according to the estimations made by the semiclassical perturbation formalism (Dimitrijević and Sahal–Bréchot 1990).

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