*36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, O-2.017 (2009)*

Gas temperature Determination in Atmospheric Pressure Surface Wave Discharges from Atomic Line Broadening

J. Muñoz[1], C. Yubero[1], M.S. Dimitrijević[2], M. D. Calzada[1]
[1]*Grupo de Espectroscopía de Plasmas (Universidad de Córdoba), Córdoba, Spain*
[2]*Astronomical Observatory, Belgrade, Serbia*

Introduction

Research on van der Waals broadening is a very important issue in recent spectroscopy studies because the values of this parameter can be easily related to those of gas temperature, the knowledge of the later being a determining factor in heavy particle kinetics.

From the Lindholm–Foley theory (see [1] and references therein), it is possible to obtain the following expression relating the gas temperature (T_{gas}) and the van der Waals broadening (w_W) of a given spectral line,

$$w_W = 8.18\times10^{-26}\lambda^2\left(\alpha < \overline{R}^2 >\right)^{2/5}\left(\frac{T_g}{\mu}\right)^{3/10} N \tag{1}$$

being λ the wavelength of the spectral line in nm, α the pertuber polarizability in cm^{-3}, $< \overline{R}^2 >$ the difference of the square radius of the emitting atom in the upper and lower levels of the transition under consideration, μ the reduced emitter-perturber mass in a.m.u. and N the density of perturbing atoms in cm^{-3}.

Equation (1) can be simplified using the appropriate atomic parameters and substituting the density of perturbing atoms with the ideal gas law. In this way a new expression can be obtained:

$$w_W = \frac{C_W}{T_g^{0.7}} \tag{2}$$

where C_W is a coefficient that depends on the transition and the nature of the interacting atoms under consideration.

From equation (2), it could be thought that the van der Waals broadening of every spectral line can be used for the calculation of gas temperature. However, recent experimental research has demonstrated that only a few lines [1, 2] can be used for this purpose as a consequence of the the fact that the theory does not describe equally well the van der Waals broadening for each spectral line and for each kind of perturbers, and also due to the need for a deconvolution process to separate the van der Waals broadening from the total width of the spectral line.

Moreover, the contribution of Stark broadening must also be considered when studying van der Waals broadening of experimental line profiles since its contribution to the total Lorentz width can no longer be negligible [1] at high enough electron densities. In our case, the Stark broadening (w_S) was calculated using the following expression

$$w_S = 2 w_e n_e 10^{-16} \qquad (3)$$

w_e being the electron-impact half widths in nm taken from [3] and n_e the electron density in cm^{-3}.

Experimental Setup

Figure 1 shows a schematic block diagram of the plasma source and the optical detection and data acquisition systems for emission spectroscopy measurements.

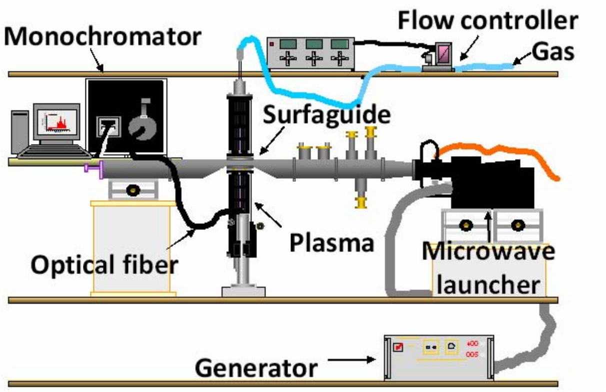

Figure 1. Experimental Setup

Microwave power was provided to the plasma by a SAIREM 12 kT/t microwave (2.45 GHz) generator of 2000 W maximum power in continuous mode. The power was coupled to the plasma by a surfaguide device, and two impedance matching means made the power reflected to the generator lower than 5% of the incident power.

High purity (99.999%) He, Ne and Ar were used as plasma gases with different flows ranging from 0.5 to 2 slm (standard litre per minute). The flows were controlled by HI-TEC flow controllers (IB 31) with differing maximum flow limits (0.25 and 5 slm).

The discharge was contained in quartz tubes of several radii ranging from 2 to 5 mm (inner radii) and from 3 to 6 mm (outer radii). Since the tubes containing the discharge suffer a great deal of damage for powers over 300 W, the discharge tube was coaxially surrounded by another quartz tube of 8.5 mm internal radius in order to avoid this problem. This external tube made up a jacket through which a dielectric liquid (1-Tetradece) or air circulated when necessary.

An optical fiber was used to pick up the light emitted from the discharge and drive it to the entrance slit of a Czerny–Turner monochromator of 1 m focal length (Jobin-Ybon Horiba 1000 M) previously calibrated and equipped with a 2400 grooves/mm holographic grating. Together with He, Ne and Ar atomic lines, the H_β (486.13 nm) line from the Balmer and the rovibrational spectra from OH (306–312 nm) and N_2^+ (389 – 392 nm) molecular species were registered for electron density measurement and gas temperature calculation respectively. A Hamamatsu R928P photomultiplier (spectral interval of 200–750 nm) was used as a detector for the atomic (He, Ne, Ar and H) lines and a Symphony CCD was the detector used for OH and N_2^+ radical spectra.

Results and Discussion

In high pressure discharges, line profiles can be approximated to a Voigt function stemming from the convolution of Gaussian (Doppler and Instrumental) and Lorentzian (Stark and van der Waals) profiles. Then the first step to analyse the profiles is to separate the Gaussian and Loretzian contributions. This was carried out using a commercial process of deconvolution based on the Levenberg-Marquardt non-linear algorithm for minimum squares (Table I).

Table I. Experimental broadenings of the lines measured in this work. Stark broadening was calculated from the electron density.

System	λ (nm)	w_G (10^{-2} nm)	w_L (10^{-2} nm)	n_e (10^{14} cm^{-3})	w_S (10^{-2} nm)
He I	396.47	1.91 ± 0.06	0.72 ± 0.06	0.50 ± 0.05	0.088 ± 0.009
He I	492.19	2.01 ± 0.05	1.06 ± 0.05	0.50 ± 0.05	0.163 ± 0.017
Ne I	724.51	1.34 ± 0.02	0.65 ±0.02	1.04 ± 0.07	0.045 ± 0.005
Ar I	425.93	1.933 ± 0.03	0.98 ± 0.04	1.37 ± 0.09	0.030 ± 0.003
Ar I	603.21	1.33 ± 0.02	3.07 ± 0.2	1.37 ± 0.09	0.22 ± 0.03

Since the Lorentzian width is a result of the addition of the effects of the Stark and van der Waals broadenings, electron density was measured using the relationship between the Stark broadening of the H_β hydrogen line and electron density [3]; then this value was used to calculate the Stark broadening of the atomic lines used for T_{gas} calculation and determine its influence in the calculations.

On the other hand, substituting the atomic data available in expression (1), the C_W coefficients appearing in (2) were calculated for the lines used in this work. The results and data used in this calculation are shown in Table II.

Table II. Coefficients for T_{gas} determination from the van der Waals broadening and atomic data employed in its calculation.

System	**λ (nm)**	**α (·10^{-25} cm^{-3})**	$\langle \overline{R}^2 \rangle$	**μ**	**C_W (nm)**
He I	396.47	2.049	575.73	2	1.298
He I	492.19	2.049	471.82	2	1.847
Ne I	724.51	3.956	14.25	10	0.792
Ar I	425.93	16.411	378.12	20	1.479
Ar I	603.21	16.411	932.83	20	4.217

Using these coefficients, gas temperature values were calculated considering and ignoring the influence of the Stark effect. Results obtained with rovibrational bands agree with previous experimental results [1, 4-5] and are provided for comparison (Table III).

Table III. Gas temperature calculated from the different rovibrational bands and the van der Waals broadening neglecting (T_{gas}^{L}) and considering (T_{gas}^{W}) the Stark broadening.

System	**λ (nm)**	T_{gas}^{OH} (K)	$T_{gas}^{N_2^+}$ (K)	T_{gas}^{L} (K)	T_{gas}^{W} (K)
He I	396.47	---	2000 ± 200	1700 ± 200	2000 ± 350
He I	492.19	---	2000 ± 200	1600 ± 100	2000 ± 300
Ne I	724.51	1200 ± 120	---	1000 ± 50	1100 ± 150
Ar I	425.93	1400 ± 140	---	1300 ± 100	1400 ± 150
Ar I	603.21	1400 ± 140	---	1100 ± 100	1300 ± 150

As can be seen, even though the Stark broadening is small, its influence must be taken into account for T_{gas} calculation purposes, especially in the case of He. Further research on this subject, both theoretical and experimental, is necessary.

Acknowledgements

This work was subsidised by the Ministry of Science and Technology (Spain) within the framework of project num. ENE2005-00314, and by the Serbian Ministry of Science through project 146001.

REFERENCES

[1] Yubero *et al.* Spectrochimica Acta B, 62 (2007) 169 – 176.

[2] Muñoz *et al.* Spectrochimica Acta B, 64 (2009) 167 – 172.

[3] Griem, *Plasma spectroscopy* (1964) McGraw-Hill (New York).

[4] Kabouzi *et al.* Journal of Applied Physics, 91, (2002) 1008 – 1019.

[5] Sainz *et al.* Spectrochimica Acta B, 63 (2008) 948 – 956