Van der Waals broadening in atmospheric pressure surface wave discharges sustained in rare gases

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Introduction

Research on van der Waals broadening has become one of the most important issues in recent spectroscopy studies since the values of this parameter can be easily related by means of the Lindholm–Foley theory to that of the gas temperature, being the knowledge of the later determining on the heavy particles kinetics.

In the present study, the profiles of several rare gas atomic lines arising from an atmospheric pressure microwave (2.45 GHz) surface wave discharge have been studied in order to determine the most suitable lines for measuring gas temperatures.

Line Broadening of Atomic Lines

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

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

being λ the wavelength of the spectral line in nm, α the pertuber polarizability in cm^{-3}, $<\bar{R}^2>$ the difference of the square radius of the emitting atom in the upper and lower levels of the considered transition, μ the reduced emitter-perturber mass in a.m.u. and N the density of pertubing atoms in cm^{-3}. The previous equation can be simplified using the appropriate atomic parameters and the ideal gas law to obtain the following expression,

$$w_W(\mathrm{nm}) = \frac{C_W}{T_{gas}^{0.7}} \qquad (2)$$

being C_W a coefficient that depends on the transition and the nature of the interacting atoms considered.

However, not every spectral line can be used for the calculation of gas temperature. Recent experimental research [1,2] has demonstrated that only a few lines can be used for this purpose as a consequence of the limitations arising from the theory not describing equally well the van der Waals broadening for each spectral line and each kind of perturbers, and the need of a deconvolution process to separate the van der Waals broadening. Moreover, the contribution of the Stark broadening must also be considered since its contribution to the total Lorentz width can become non negligible [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.

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 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).

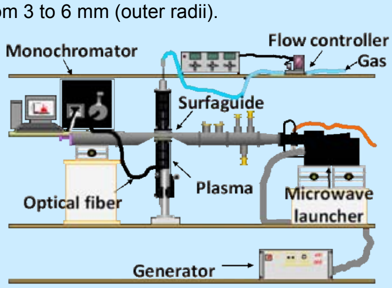

***Figure 1.** Experimental Setup*

Light emited by the discharge was analyzed with a 1m Czerny-Turner monochromator (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 series and the rovibrational spectra from OH (306–312 nm) and N_2^+ (389 –392 nm) molecular species were registered for electron density measurement [3] and gas temperature calculation respectively. A Hamamatsu R928P photomultiplier was used as 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.

Experimental Results

The first step to analyse the profiles is to separate the Gaussian (Doppler and Instrumental) and Loretzian (Stark and van der Waals) contributions using a commercial process of deconvolution based on the Levenberg-Marquardt non-linear algorithm for minimum squares (Table I).

Electron density was measured using Stark broadening of the H_β hydrogen line [3] and this value was used to calculate the Stark broadening of the atomic lines used for T_{gas} calculation and evaluate its influence.

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

System	λ (nm)	w_G ($\cdot10^{-2}$ nm)	w_L ($\cdot10^{-2}$ nm)	n_e ($\cdot10^{14}$ cm^{-3})	w_S ($\cdot10^{-2}$ 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	1.93 ± 0.03	0.98 ± 0.04	1.37 ± 0.09	0.030 ± 0.003
Ar I	603.21	1.33 ± 0.02	3.07 ± 0.20	1.37 ± 0.09	0.22 ± 0.03

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

Table II. Coefficients for Tgas determination from the van der Waals broadening and atomic data employed in its calculation.

System	λ (nm)	α ($\cdot10^{-25}$ cm^{-3})	$<\bar{R}^2>$	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 this coefficients, gas temperature values were calculated considering and neglecting the influence of the Stark effect. Results obtained with rovibrational bands in agreement with previous experimental results [1, 4-5] are provided for comparison.

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

System	λ (nm)	T^{OH}_{gas} (K)	T^{N2+}_{gas} (K)	T^L_{gas} (K)	T^W_{gas} (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

Conclusions

- **Gas temperature results obtained from van der Waals Broadening of rare gas lines is in good agreement with results obtained from the rovibrational spectra of molecular species and those previously reported in the literature for the same kind of discharges.**
- **Even though the Stark broadening is small, its influence must be taken into account for gas temperature calculation purposes, especially in the case of He.**
- **Further theoretical and experimental research on the description of the van der Waals broadening is needed.**

References

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