

USE OF THE VAN DER WAALS BROADENING OF ATOMIC  
ARGON LINES TO MEASURE THE GAS TEMPERATURE IN AN  
ATMOSPHERIC PRESSURE Ar-He SURFACE WAVE DISCHARGE

J. MUÑOZ<sup>1</sup>, M. S. DIMITRIJEVIĆ<sup>2</sup>, C. YUBERO<sup>1</sup> and M. D. CALZADA<sup>1</sup>

<sup>1</sup>*Grupo de Espectroscopía de Plasmas. Edificio A. Einstein (C-2),  
Campus de Rabanales. Universidad de Córdoba, 14071 Córdoba, Spain  
E-mail: fa1cazal@uco.es*

<sup>2</sup>*Astronomical Observatory, Volgina 7, 11160 Belgrade, Serbia*

**Abstract.** The use of the van der Waals broadening to measure the gas temperature in an atmospheric pressure Ar-He surface-wave discharge is studied comparing the obtained results with those given by the OH radical and extended to He proportions up to 50%. Influence of the electron density through Stark broadening of the calculation of this parameter is found to be negligible. A good agreement is found between both techniques. Spectral line 603.2 nm is found to be the best choice for this purpose. An increase in the temperature from 1200 K to 2000 K is found when He is added to the discharge.

## 1. INTRODUCTION

A common characteristic of most of the technological applications of plasmas is that they are carried out with gas mixtures. When more than one kind of gas is present in the discharge, the complexity of experimental determination of plasma parameters by spectroscopic techniques increases as a consequence of the existence of different types of species in the discharge. Studying such influences is important for the application of diagnosis techniques in plasmas generated with gas mixtures. Usually, the gas temperature ( $T_g$ ) is measured from the analysis of the rotational spectra of molecular species existing in the discharge, such as the OH species,  $N_2^+$ , CN or  $C_2$ . But sometimes, as is the case of the Ar-He microwave plasma studied herein, these species can not be properly detected. In such cases,  $T_g$  can be determined from the Doppler or the van der Waals broadenings of emitted atomic spectral lines, which are related to this parameter.

While theoretically any spectral line could be used for the determination of  $T_g$  from its van der Waals broadening ( $w_W$ ), studies carried out by several authors (see J. Muñoz et al. (to be published) and references therein) have stated that only a few lines can be used for this purpose. On the other hand, the theory does not describe equally well the van der Waals broadening for each spectral line and for each kind of perturbers, and so investigations devoted to find out most convenient lines for this purpose are of interest.

A method to measure the gas temperature  $T_g$  from atomic lines whose Stark broadening is comparable with the van der Waals one was proposed by Yubero *et al.* (2007). Gas temperature was obtained from the origin ordinate corresponding to the Lorentzian width for zero electron density which could be considered approximately equal to van der Waals line width. The best argon atomic lines for the gas temperature  $T_g$  calculation in an argon microwave plasma at atmospheric pressure were found to be 603.2 nm, 549.6 nm and 522.1 nm. On the other hand, in the study of Christova *et al.* (2004) the Stark broadening of the 425.9 nm line was examined. By extrapolating the results of this work to their experimental conditions, Yubero *et al.* obtained that the van der Waals width value of the above mentioned line as about 90% of the total Lorentzian width and the gas temperature from the van der Waals broadening of this line was equal to 1380 K. Consequently, the use of 425.9, 603.2, 549.6 and 522.1 nm lines to measure  $T_g$  in an Ar-He SWD has been considered in the present study.

In this work, the use of the van der Waals broadening of the atomic lines to determine the gas temperature in Ar-He plasmas, taking into account both argon and helium atoms as perturbers has been analyzed in an atmospheric pressure surface wave discharge with a setup similar to that described in the work of J. Muñoz *et al.* (2008). The values of the gas temperature inferred from this broadening have been compared with the ones obtained from the spectra emitted by the OH molecular species in the discharges.

## 2. GAS TEMPERATURE DETERMINATION

The Lorentzian width can be considered as the sum of the Stark and the van der Waals broadenings under our experimental conditions. The Stark broadening of these lines was estimated using the expression given by Griem (1964) for the electron density, calculated for different Ar-He mixtures from the  $H_\beta$  line using the data from Gigosos *et al.*(1996).

Table 1: Van der Waals and Lorentzian broadenings of the 603.2 atomic argon line for the different He concentration in the discharge

[He](%)	$w_S$ ( $\times 10^{-2}$ nm)	$w_L$ ( $\times 10^{-2}$ nm)
0	0.154	2.915
5	0.134	2.632
10	0.110	2.363
15	0.108	2.091
20	0.099	1.999
25	0.096	1.964
30	0.094	1.949

In Table 1, the values of the 603.2 nm Lorentzian width and the Stark broadening for the studied Ar-He mixtures are shown. One observes that  $w_S$  is one order lower than  $w_L$ . So, the assumption that  $w_L$  is mainly due to the van der Waals effect does not induce a significant error in the calculation of  $T_g$ . A similar result was obtained for

the 425.9 nm line. Following from Yubero et al. (2007), the van der Waals broadening of these two lines in the case of an Ar-He mixed gas discharge as can be written as:

$$w_W(425.9 \text{ nm}) = \chi_{Ar} \frac{1.479}{T_g^{0.7}} + \chi_{He} \frac{1.059}{T_g^{0.7}} \quad (1)$$

$$w_W(603.2 \text{ nm}) = \chi_{Ar} \frac{4.217}{T_g^{0.7}} + \chi_{He} \frac{3.019}{T_g^{0.7}} \quad (2)$$

Values of  $T_g$  obtained using the expressions above can be seen in Figure 1. There,  $T_g$  values have been compared with those ones obtained considering  $\chi_{He} = 0$  and with the ones obtained from the OH molecular specie.

From these figures, it can be seen that the  $T_g$  values obtained from OH radical only experience a little variation when He is added in a 5% in the mixture and, from this percentage on, the temperature keeps almost constant at 1500 K. This can be due to a lack of sensitivity of the OH radical for temperatures above 1600 – 1800 K.

A larger dispersion in  $T_g$  values obtained from the 425.9 nm line can be observed compared to those obtained from the 603.2 nm line. This is a consequence of its smaller Lorentzian width, which results in a higher error in the deconvolution process. Consequently, the 603.2 nm line should be considered more appropriate for the purpose of obtaining the gas temperature from its van der Waals broadening.

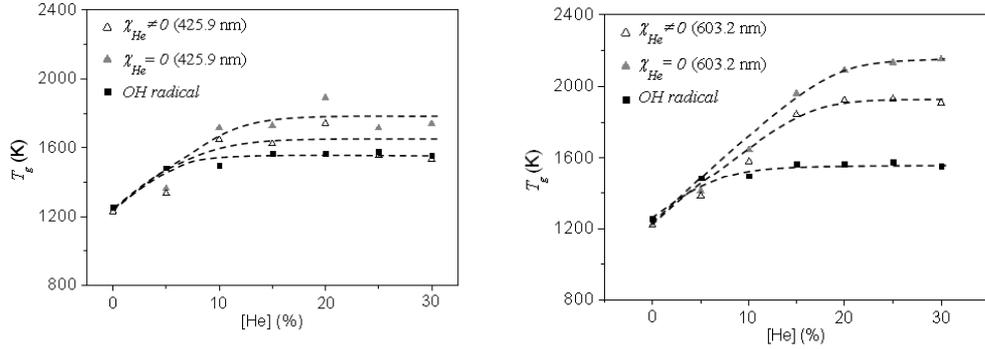


Figure 1: Gas temperature calculated using the (0 – 0) 309 nm rovibrational band of the OH radical and 425.9 nm (left) and 603.2 nm (right) atomic argon lines taking into account (hollow triangle) and neglecting (full triangle) the contribution of He to the van der Waals broadening.

It is important to remark that, even while the larger difference in  $T_g$  temperatures obtained taking into account the influence of Helium in the van der Waals broadening in equations (1) and (2) is only about 300 K, the new term added to the equations in the case of gas mixtures shall not be rejected, specially for higher He proportions.

The measurement of  $T_g$  in a discharge generated with Ar-He mixtures for He percentages over 30% was carried out using the van der Waals broadening of the 603.2 nm atomic line, following the procedure proposed previously.

In order to verify the non-influence of the coolant used, the gas temperature were also calculated for the interval between 0% and 30% of He in the mixture. In Figure

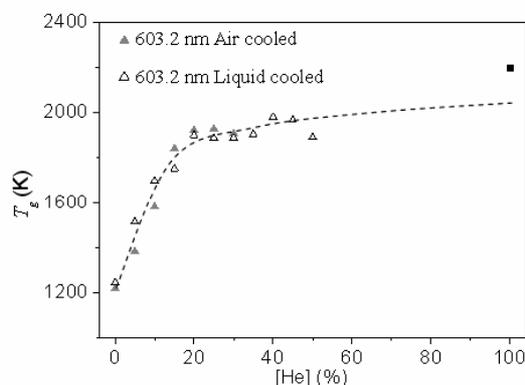


Figure 2: Gas temperature calculated using the van der Waals broadening of the 603.2 nm argon atomic line.

2, the  $T_g$  values obtained in this way are shown. It can be seen that the same values for this parameter are obtained in both cases, using air or dielectric liquid as coolant of the discharge tube. An extrapolation to 100% of He is shown too, the  $T_g$  value for a pure He discharge obtained in this way being approximately equal to 2200 K, which is in a good agreement with that obtained in Kabouzi *et al.* (2002).

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