Spectroscopic determination of the electron temperature in non-LTE argon and neon plasmas

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Abstract

This work presents an experimental study of neon and argon surface wave plasmas at atmospheric pressure. Emission spectroscopy has been used to determine the electron temperature by using the line-to-continuum intensity ratio method. The interpretation of the excitation temperature T_{exc} as the electron temperature T_e leads an error even in situations close the equilibrium in using this method. In plasmas very far from the equilibrium the excitation temperature that characterizes the excitation spectrum is not unique. Thus, we show that T_{exc} should be addressed correctly in order to obtain reliable results of T_e. It is found that the excitation temperature of high-lying levels ArI (closest to the ionization threshold) agrees with the electron temperature which contrasts with the NeI results.

Keywords: Plasma diagnosis; Electron temperature; Microwave plasmas; Emission spectroscopy

1. Introduction

The electron temperature (T_e) is a central parameter for plasmas, the knowledge of which is fundamental with a view to developing their applications in spectrochemical analysis and technology [1]. In this context, it is crucial to set up appropriate diagnostic means, from which the main plasma parameters can be measured. The use of probes to measure T_e can alter the electromagnetic fields into the discharge which provoke changes in its proprieties. On the other hand, Thomson scattering is difficult to implement in plasmas where the density is of the order 10^{14}cm^{-3} because of the weak cross section for scattering [1]. Thus, one of the most common diagnostic tools is to determine the excitation temperature (T_{exc}) from the spectral emission of the plasma due to this optical technique being easy to implement and non-intrusive [2].

2. Experimental arrangement and diagnostic methods

The surface-wave sustained plasma columns studied were generated by using a *surfaguide* device [3], which allows microwave energy (2.45 GHz) to be coupled to the discharge. We have varied the absorbed microwave powers from 50 to 250 W. Argon and neon discharges were produced within quartz capillary tubes of 1 and 2.5-mm inner diameter respectively. The discharge gases are 99.99% pure argon and neon, flowing at 0.5 l/min and coming out into the room through the open end of the discharge tube.

The gas temperature was considered equal to the rotational temperature T_{rot} obtained of the rotational spectrum for the Q_1 branches of the (0-0) of the OH radical, which resulted from the dissociation of water traces present in the plasma gas.

The absolute populations of the different (argon and neon) atomic levels n_p were determined from measurements of the intensity I_p of the spectral lines corresponding to atomic transitions starting at each specific level using the following expression:

$$I_p = \frac{hc}{4\pi}\frac{A_{pq} n_p}{\lambda} \tag{1}$$

where A_{pq} is the coefficient for spontaneous emission from level p to level q, and λ the wavelength of the corresponding transition.

The total population density of atoms in the plasma n_T is determined from the equation for the ideal gas:

$$P = n_T k T_g \tag{2}$$

where the pressure P is 1 atm and T_g is the previously calculated gas temperature.

The population n_p of a level p is related with n_T through:

$$\frac{n_p}{n_T} = \frac{g_p}{Z}\exp\left(-\frac{E_p}{kT_{exc}}\right) \tag{3}$$

where Z is the partition function of the element considered, defined as

$$Z = \sum_p g_p \exp\left(-E_p / kT_{exc}\right) \tag{4}$$

Expression (3) can be simplified considering that the number of atoms in the ground state is much higher than those excited

$$n_T \approx n_1 \tag{5}$$

Sola *et al.* [4] have studied experimentally the line to continuum ratio of the ArI 430nm line in a microwave argon plasma at atmospheric pressure. They used the following equation to derive the electron temperature:

$$\frac{I_p}{\varepsilon_c} = \left(\frac{3\sqrt{3}h^4}{4e^6}\right)\left(\frac{c^3\varepsilon_0^3}{k}\right)\frac{A_{pq}g_p}{Z^+}\frac{\lambda}{T_e\xi}\exp\left(\frac{E_{ion}}{kT_e} - \frac{E_p}{kT_{exc}}\right) \qquad (6)$$

However, these authors obtained the excitation temperature with a Boltzmann-Plot of the upper levels instead of expression (3), assuming that all excitation temperatures are equal in the plasma. This assumption can lead an error when studying plasmas far from the Boltzmann equilibrium.

3. Results and Discussion

Figure 1 shows the axial distribution of T_g obtained for the neon and argon discharges. It is observed that T_g remains constant (approx 1300K) along the plasma columns according (within the error bar) to previous experimental works in similar experimental conditions for an argon plasma [2]. Therefore, n_I is supposed to be constant along the plasma column.

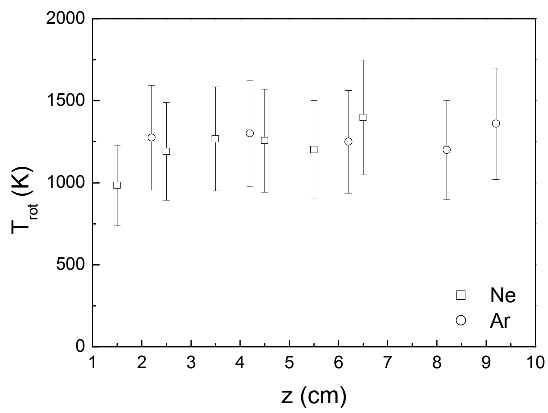

Figure 1: Measured gas temperature as function of axial position for the different plasma column studied.

In Table 1, it is shown the experimental results of both line to continuum ratio and excitation temperature of different spectral lines. The electron temperature obtained with each line is also included. As can be seen, the argon plasma is close to a partial Local Thermodynamic Equilibrium because a few lines present an excitation temperature close to the electron temperature. Thus, it is possible to identify the excitation temperature obtained with the high lying levels with the electron temperature. In contrast, all of NeI lines are far from the equilibrium. Hence, the interpretation of the excitation temperature as the electron temperature leads an error. On the other hand, the electron temperature is quite different to the gas temperature in both argon and neon discharges. Therefore, we can ensure that both plasmas are two temperatures plasma (2T plasmas).

λ (nm)	I/ε_c (nm)	T_{exc}(K)	T_e(K)
Argon (z = 9.2cm)			
912.3	7.67	7352	9207
866.79	7.37	7299	8193
852.14	31.30	7284	8174
842.6	66.88	7246	8313
826.45	39.45	7354	7440
811.53	8.96	7275	9497
794.81	38.94	7299	8181
430.01	0.62	7152	7456
Neon (z = 6.5cm)			
585.25	0.47	9313	12565
650.65	0.40	9492	13873
653.29	0.07	9463	13881
692.95	0.32	9485	13621
717.39	0.01	9502	14912
724.52	0.05	9830	15062

Table 1: Experimental results of both line to continuum ratio and excitation temperature of different spectral lines. The electron temperature obtained with each line is also included.

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