The electron density measured using the Stark Broadening of both Hα and Hβ lines in a plasma column sustained by a surface-wave: the ionic dynamic effect

J.M. LUQUE, M.D. CALZADA AND M. SAEZ
DPTO. FISICA, EDIFICIO C-2, CAMPUS DE RABANALES, UNIVERSIDAD DE CÓRDOBA
14071 CÓRDOBA, SPAIN

Abstract

This work presents an experimental study of the influence of the ionic dynamic effect on the electron density measured by using the stark broadening of the hα and hβ lines. We have compared the results obtained by the keple-griem expression and the gigosos model (which introduces this effect). We have found that the applying of this model gives us the same magnitude order for electron density using the two hydrogen lines. In this experimental study, we have used a plasma column sustained by a surface-wave in argon at atmospheric pressure.

1. Introduction

Surface-wave induced plasma is comparatively new plasma source which attracts increasing attention regarding to their fundamental and application aspects [1-3]. The electron density (nₑ) is a characteristic parameter of plasma. The value knowledge of this parameter is very important because the electrons control the discharge kinetics by collisions with the plasma particles (energy transmission).

The broadening of spectral lines has been used as an important non-interfering plasma diagnostic technique. Most of works were made to improve and check experimentally existing theories of spectral line broadening by plasma. Due to large, linear stark effect in hydrogen, the balmer series lines are very useful for measurement of the electron density [4]. Generally, the hβ line has been the one more used for nₑ determination in laboratory plasmas [5]. However, under certain experimental conditions the hβ line is not intensive enough and it is necessary to introduce small amounts of hydrogen into the plasma, which can produce a change in the discharge internal characteristics (kinetics) [6]. Other possibility is to use the hα line, which is more intense, but the classic theory of keple-griem (kg) [4] gives a magnitude order greater than the one obtained by the hβ line. Gigosos et al. [7] have developed acomputational model based on the microfield model method (mmm) theory introducing the ionic dynamic effect in this. Using this model, the theoretic results predict the same value of electron density for both the hα and hβ lines.

This work presents an experimental study of the influence of the dynamic effect on the electron density measured by stark broadening using the hα and hβ lines. We compare the density
value obtained by both the kg theory and the gigosos model, in range \(10^{14}-10^{15} \text{ cm}^3\).
And 1500-2000 k gas temperature. The experiences have been made on an ar plasma column
sustained by a surface-wave at atmospheric pressure.

2. Theory

The line profile depends on the electron density, temperature and composition of the plasma.
This profile has a full width, which is influenced by several broadening mechanisms. The
fundamental kinds of broadening that occur in the plasma are:

A) Doppler broadening, due to the random thermal motion of the emitters.
B) Pressure broadening, due to perturbation of the emitters by charge particles (stark
broadening) and by neutral particles with induced electric fields (van der waals
broadening).

Doppler broadening imparts a gaussian line shape. Pressure broadening produces a lorentzian
line shape. The line image in the focal plane results from convolution of the line and the
instrumental broadening profiles. The result is a voigt shape.

The stark broadening origin is the quantum stark effect: the interactions of emitted atom with
the plasma charge particles (ions and electrons). The theory about the stark broadening was
developed under two different points of view: impact approach and quasi-static approach. In the
experimental conditions of electron density less than \(10^{16} \text{ cm}^3\), the line emission profile can be
explained by the quasi-static approach. In this approach, the emitted particle is fundamentally
under the influence of ions and the field created by ions can be considered quasi static.

due to the large stark effect in hydrogen, its lines are very useful for measurements of
electron density. In agreement with the quasi-static theory \(n_e\) can be calculated by the stark full
width at half-maximum (\(\Delta \lambda_{1/2}^s\)) of the balmer series hydrogen lines through the expression [4]
\[
\Delta \lambda_{1/2}^s = 2.5 \times 10^{-9} \alpha_{1/2} n_e^{2/3}
\]

Where \(\alpha_{1/2}\) is the fractional width at half-height of the stark profile and tabulated by griem [4].
Using the \(h_\alpha\) line to calculate \(n_e\) this expression gives a magnitude order higher than the result by
\(h_\beta\) line.

gigosos et al. [7] have developed a computational model which introduces the ionic
dynamic effect for the hydrogen lines. This effect is due to the field created by the ions which is
not quasi-static and the mobility of the ions produces changes in the line profiles. The theoretic
results predicted by the gigosos computational model are presented in table form. These tables
show the values of lorentzian broadening (\(\Delta \lambda_{1/2}^l = \Delta \lambda_{1/2}^s\)) for each electron temperature and
density fixed. The model gives the same value of electron density calculated by both the \(h_\alpha\) and
\(h_\beta\) lines.

3. Experimental conditions

The experimental device is presented in fig. 1. we have used a plasma column created inside a
fused quartz tube with an inner diameter of 1 mm and atmosphere opened. The microwave power
was supplied by a sairem hf generator of 2.45 ghz frequency and coupled to the plasma using a
surfatron [8] as the surface-wave excitation device. The incident power was 100 w and with a maximum of 5% reflected power. We used argon gas with a flow of 0.25 slpm and it was not necessary to introduce hydrogen in the discharge due to the presence of this element as gas impurity.

The optical system was a jobin-yvon thr-1000s (type czerny-turner) monochromator with a 1m focal length and with a holographic diffractory grating (1200 lines/mm. The linear dispersion was 0.78 and 0.81 nm/mm for hα and hβ, respectively. We used slits (entrance and exit) of 100, 80 and 60 μm to evaluate the influence of instrumental broadening in the density measured. The light emission was picked up radially by an optical fiber that could be moved axially for the measured recording over two positions (z=2 and z=4 cm) along the plasma column.

![Diagram of experimental setup](image)

**Figure 1.** Experimental device showing the plasma source, the axially movable optical fiber that collects light from the plasma, and the spectrophotometer system [5].

4. Results and discussion

The shape of the spectral line profile is formed by different mechanisms of interactions, which cause divers broadening as well as by the contribution of the apparatus function. At atmospheric pressure, the full width at half maximum (fwhm) $Δλ$ of the emitted spectral line is a result of the convolution of a lorentz profile (van der waals and stark broadening) and the gauss profile (doppler effect and instrumental broadening). Thus, the profile of hydrogen lines is assumed to be a voigt one. We have separated the gaussian and lorentzian part of the voigt fit using commercial software (microcal origin from microsoft). Figures 2 and 3 are an example of both line profiles (hα and hβ) used to calculate the electron density.
Figure 2. The $h_a$ profile in $z = 2$ cm from the end of the plasma column ($z = 0$)

Figure 3. The $h_b$ profile in $z = 4$ cm from the end of the plasma column ($z = 0$)
We have obtained the electron density from lorentzian part of profile. We have considered
\[ \Delta \lambda_{1/2}^1 = \Delta \lambda_{1/2}^4, \] neglecting pressure broadening \((10^{-3} \text{ nm contribution})\). We have used the kepple-
griem expression and gigosos model getting results for two positions along the plasma column \((z = 2 \text{ and } z = 4 \text{ cm})\). The results are shown in the table 1.

If we compare these results we can conclude:

A) By using the kepple-griem \((k-g)\) expression the electron density measured by \(h_\alpha\) line is 12% smaller than by using the gigosos model. If we utilise the same formula \((k-g)\) to measure \(n_e\) by \(h_\alpha\) line, the results are 80% higher than using the \(h_\beta\) line. The gigosos model reduces this difference over 60%.

B) The gigosos model predicts theoretic results with the same value of electron density calculated by using the two hydrogen lines. The applying of this model to experimental measurements does not have the same value but it gives the equal order of magnitude. It is for that, the results obtained by using the gigosos model, that introduces the ionic dynamic effect in the stark broadening of hydrogen lines, seem to allow us to use the \(h_\alpha\) in the electron density measurement in experimental conditions in which the \(h_\beta\) is not intense enough. The values obtained by \(h_\alpha\) are not absolute but they could be used to know the magnitude order of \(n_e\).

We will continue this study in a more exhaustive way, using argon plasma column in an experimental condition set of hf power, gas flow, tube inner radius and positions along the column plasma.

<table>
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<th>(Z (\text{cm}))</th>
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<th>Gigosos model</th>
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<td>9.04</td>
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<td></td>
<td>(h_\beta)</td>
<td>5.17</td>
<td>4.62</td>
</tr>
</tbody>
</table>

**Table 1.** Values of the electron density obtained by the hydrogen \(h_\alpha\) and \(h_\beta\) lines in two positions \((z)\) by using the kepple-griem expression and gigosos model

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References


