Spectroscopic determination of the electrical parameters of a micro-wave discharge in helium plasma

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This paper is based on the study of the emitted radiation by electrical discharge plasma, caused in the helium a pressure of 4.8 Torr, a power MW of 108W. The study numerical model allows the identification of several spectral lines. With the Boltzmann method the study have calculated the electronic temperature (Te=3.23eV), it corresponds to the classification scale of plasmas. The application of the Saha law gives the electronic density of the electrical discharge plasma (Ne=3.67x10¹³ cm⁻³). The calculated theoretical spectra are in good agreement with the experimental ones.

Key words: Discharge plasma, broadening, shape of spectral line, thermodynamic equilibrium.

INTRODUCTION

The spectroscopy optical emission is a technique frequently used in the electrical discharge plasmas characterization (Wujec and Musielok 1999; Grycuk et al., 2002). The study of the emitted light by discharge, allow us to collect a lot of information on the discharge parameters, such as the electronic density and the electronic temperature. The interest in this study is to investigate the experimental spectres emitted by the electrical discharge plasma (discharge MW). The study presented the diagnostic model for the determination of the temperature and the electronic density of the medium. The Boltzmann and Saha laws have been applied at local thermodynamic equilibrium conditions. To achieve this aim, the study developed a numerical program.

Experimental device

The studied experimental spectres are registered from an experimental setup witch carried out by Shakhatov and Yu (2012). The registration system of spectra (Spectrometer AVASPEC) is based on optical fibers. The emitted spectra are registered through a window of quartz (transparent matter with a wave length entre 200-800 nm), this window is placed in the central part of the gas discharge chamber (at the cathode). The radiation spectres intensity is the mean value on the observation line coincide with the discharge chamber axis. According to Shakhatov and Yu (2012), the measure error of the radiation intensity is about 12 to 14%. The experimental spectrum registered is presented in the Figure 1.

Theoretical spectra

A numerical program is elaborated to calculate the spectra

Figure 1. Experimental spectrum resulting from a discharge chamber MW (2.45GHz) caused in Helium at pressure 4.8 Torr and power of 108W [4].

Theoretically. It is based on the atomic physics data of each element, on the collisions’ parameters of Van Der Waals and on the different types of broadening of the lines profile (Natural, Doppler, Stark, and experimental).

Computing program of the line profile

This program allows the theoretical modelling of spectra lines. It is based on the atomic physics data of each component and the following equations:

- The Maxwell-Boltzmann Distribution, the Boltzmann law, the Saha law, the Dalton law, the electric neutrality law and the law of conservation of matter. The program considers the broadening lines: natural, Doppler, Stark, Van der Waals, instrumental broadening of Gaussian shape, instrumental broadening of Lorentz’s shape and Voigt Profile. The spectroscopic methods are used in this program. The electrical discharge can contain pure gas or gas impurities.

The recommended data are as follow:

- The minimal wave length.
- The maximal wave length.
- Number representing the spectre
- Gas pressure (P).
- Van Der Waals Constant
- Experimental width: Gaussian shape.
- Experimental width: Lorentzian shape.
- Atomic masse.
- Input files of the atomic data bases of each component.

To study the experimental spectra, the data bases from atomic physics for all the elements have been set up that may exist in the medium (He, He+) and the possible impurities (O, Fe, H, Al) (NIST). The data base gives the concerned energy levels, the statistical weights associated to each energy level, the transitions’ wave lengths of the radiative transitions probabilities. The calculated spectra are presented in the Figure 2.

Spectroscopic diagnostic method

There is two categories of spectroscopic methods which are used for the determination the temperature and electronic density as: methods based on the study of the line shape (broadening and shift), methods based on the study of the continuous spectrum using the ratio of the intensities of spectral lines (Charlotte, 1967; Griem, 1994). The second method is used as a diagnostic first, the study assumed that the different particles are independent, and that thermodynamic equilibrium has been locally established at each point of the plasma, then the medium is considered to be at local thermodynamic equilibrium (L.T.E.). The distribution functions of Maxwell-Boltzmann and the Saha law remain valid. In this case, the spectroscopic diagnostic could be applied to deduce the temperature and density.

Method of two raises intensities ratio

The chemical composition of a medium which is frequently difficult to know precisely, especially when the studied spectra come from impurities of the electrodes (with the target and the substrate) or the cavity walls. To determine the temperature, the study preferred to use the ratio of the intensity of two lines of the Helium in two different ionization stages (He and He+). The comparison between the theoretical spectrum (Figure 2) and the experimental spectre (Figure 1), allows identification of the spectral lines are represented in Tables 1 and 2.

RESULTS AND DISCUSSION

Determination the electronic density

Saha’s law has been applied to estimate the electron density of the study plasmas.

To a helium plasma, Saha’s law is given by the following
Figure 2. Theoretical spectra for each element.

Table 1. Atomic physics data for some obtained spectra and experimental intensities concerning of He.

<table>
<thead>
<tr>
<th>N° peak</th>
<th>λ (nm)</th>
<th>A_ji (S^-1)</th>
<th>E_i (ev)</th>
<th>E_j (ev)</th>
<th>g_i</th>
<th>g_j</th>
<th>I_exp (a.u)</th>
<th>Conf_i</th>
<th>Conf_j</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>492.330</td>
<td>1.99 E +07</td>
<td>21.218044</td>
<td>23.736357</td>
<td>3</td>
<td>3</td>
<td>0.7</td>
<td>1s2p (1P0)</td>
<td>1s4d (1D)</td>
</tr>
<tr>
<td>2</td>
<td>501.707</td>
<td>1.4 E +07</td>
<td>20.615796</td>
<td>23.087040</td>
<td>1</td>
<td>1</td>
<td>1.6</td>
<td>1s2s (1S)</td>
<td>1s3p (1P0)</td>
</tr>
<tr>
<td>3</td>
<td>587.759</td>
<td>3.94 E +07</td>
<td>20.964248</td>
<td>23.073678</td>
<td>1</td>
<td>1</td>
<td>5.9</td>
<td>1s2p (3p0)</td>
<td>1s3d (3D)</td>
</tr>
<tr>
<td>4</td>
<td>667.999</td>
<td>6.38 E +07</td>
<td>21.218044</td>
<td>23.074097</td>
<td>3</td>
<td>3</td>
<td>3.5</td>
<td>1s2p (1P0)</td>
<td>1s3d (1D)</td>
</tr>
<tr>
<td>5</td>
<td>706.715</td>
<td>1.54 E +07</td>
<td>20.964117</td>
<td>22.718488</td>
<td>3</td>
<td>3</td>
<td>3.3</td>
<td>1s2p (3P0)</td>
<td>1s3s (3S)</td>
</tr>
</tbody>
</table>

The following steps are taken to simplify Equation 1:

1. Calculate the primary density of the Helium gas.
2. Application of the conservation of matter law.
3. Neglect the ionic density (He++).
4. Application of law electric neutrality of the plasma.

Then the simplified formula of the Saha law is:

\[
\frac{N_{e} \times N_{He^{+}}}{N_{He}} = \frac{2 \times B_{He^{+}}(T)}{B_{He}(T)} \frac{(2 \pi m_{e} k_{b} T)^{3/2}}{h^{3}} \times \exp \left( -\frac{E_{i}}{k_{b} T} \right)
\]

Where

- \( m_{e} \): is the electron mass
- \( N_{e} \): is the electronic density.
- \( N_{He^{+}} \): is the ionic density \( He^{+} \).
- \( N_{He} \): is the density of the Helium (neutral) \( He \).
- \( B_{He^{+}} (T) \): is the partition function of \( He^{+} \).
- \( B_{He} (T) \): is the partition function of \( He \).

The initial density of Helium gas:

\[
N_{0} = \frac{P}{k_{b} T}
\]
Table 2. Atomic physics data for some obtained spectra and experimental intensities concerning He⁺.

<table>
<thead>
<tr>
<th>N° peak</th>
<th>λ (nm)</th>
<th>Aii (S⁻¹)</th>
<th>Ei (ev)</th>
<th>Ej (ev)</th>
<th>gi</th>
<th>gj</th>
<th>I&lt;sub&gt;exp&lt;/sub&gt; (a.u)</th>
<th>Conf&lt;sub&gt;i&lt;/sub&gt;</th>
<th>Conf&lt;sub&gt;j&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>468.58</td>
<td>2.2 E +08</td>
<td>48.3158</td>
<td>51.01679437</td>
<td>6</td>
<td>8</td>
<td>2.1</td>
<td>3d (2D)5/2</td>
<td>4f (2F0)7/2</td>
</tr>
<tr>
<td>2</td>
<td>656.199</td>
<td>2.2 E +07</td>
<td>51.016816</td>
<td>52.906245</td>
<td>8</td>
<td>10</td>
<td>2.6</td>
<td>4f (2F0)7/2</td>
<td>6g (2G)9/2</td>
</tr>
</tbody>
</table>

And the partition function for He and He⁺ is equal to weight statistical at ground state, and the ionization energy for helium is equal to 24.6 eV. The numerical application of the last equation gives the following electronic density:

\[ Ne = 3.67 \times 10^{13} \text{cm} \]

From the obtained results, the study notice that:

1. The medium is weakly ionized and that the neutral species are predominate.
2. The ionization rate of the medium is equal to \(2.3 \times 10^4\), it is within the standards of cold plasma (\(10^{-4}\) to \(10^{-1}\)).
3. On the other hand, the study observe that the electronic density of the plasma is near to \(10^6\), near \(10^{12}\) particles per \(\text{cm}^3\); it is the case of the micro discharge plasmas (Raimbault, 2010).

The electronic temperature

The intensities ratio method of two lines is used to compute the temperature but for two lines in two different stages.

The study take the peak n=°4 in the Table 1 and the peak n=°2 in the Table 2.

\[ T_e = \frac{(E_m - E_R)}{R} \times \frac{\ln(\lambda_A / \lambda_E)}{\ln(N_{He}^+/N_{He}) - \ln(N_{He}^+/N_{He})} \]

(3)

Where \( R = \frac{I_1(\text{exp})}{I_2(\text{exp})} \)

After numerical application in the Equation 3, the temperature in Kelvin is \( T_e = 37449.27 \text{K} \) (in electron volt is \( T_e = 3.23 \text{ eV} \)). The obtained electronic temperature is very good. In particular, the electrons’ temperature is typically included between 3 and 5eV Chabert, 2014 and Toader, 1996.

Conclusions

Proposed numerical model allowed us to identify several spectral. This shows that the calculated theoretical specters are in good agreement with the experimental specters by using the Boltzmann method, the study have calculated the electronic temperature, \( T_e = 3.23 \text{eV} \). This also coincides well with the classification scale of plasmas. The application of the Saha law, gives us the correct value of the electronic density of electrical discharge plasma (\(Ne=3.67 \times 10^{13}\text{cm}^3\)).

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES


