THE 447 mm HeI COMPLEX LINE AS A TOOL TO DETERMINE ELECTRON CONCENTRATION IN PLASMAS

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ABSTRACT

The helium 447 mm complex line has been studied with the use of a wall stabilized arc fed at atmospheric pressure by pure He, He-H_2, He-Ne-H_2 or He-Ar-H_2 mixtures for electron concentrations between $8\,10^{20}$ to $2\,10^{22}$ m^{-3}. Our data lead us to propose some simple formulae which could be useful for practical determination of the electron concentrations of helium plasmas with an accuracy of ±15 % and without taking into account the chemical composition of the plasma.

1. INTRODUCTION

The helium 447 mm complex line composed of both 2^3P - 4^3D allowed (447,15 mm) and 2^3P - 4^3F forbidden (447 mm) transitions may have an application as a good tool to determine the electron concentration in helium containing plasmas. This is one of the strongest helium lines, well isolated from other ones, and the forbidden peak F appears clearly for electron concentration Ne ∿ $8\,10^{21}$ m^{-3} having about 5 % of the allowed peak A intensity. All the following three parameters, the F/A ratio, the ratio of minimum intensity C between the two lines to the allowed peak intensity C/A, and the forbidden to allowed peak separation S, grow as Ne increases. It gives a good basis for practical application of the observed 447 mm line shape to plasma diagnostics.
In order to propose simple empirical formulae useful for plasma diagnostics, a systematic experimental study on the HeI 447 mm line excited in an arc plasma of different composition is presented.

2. EXPERIMENT

The experimental set up consists of an atmospheric pressure wall stabilized arc as the excitation source and a high resolution spectrometer.
A high stability d.C. power supply provides the arc current (15 to 130 A) ; Arc channel (diameter 8 mm) is stabilized by 8 water cooled copper discs. The cathode is made of tungsten and anode is made of copper.
We have verified that the plasma composition is constant along the arc channel (length : 9,5 cm). The arc device is fed (35 - 180 cm^3/s) by different gases :

Pure Helium
Helium with 0.2 to 1.5 % of Hydrogen
Helium with 0.2 to 0.6 % of Hydrogen

Helium with 0.2 to 0.5 % of Hydrogen and 2.3 to 23 % of Neon
Helium with 1.6 to 10 % of Argon.

The observations of the axial part of the arc are made end-on by means of two 1 mm dia-pine holes separated by 1.2 m one from each other. Using an additionnal microscope lens for aperture adjustment, the micropositioning mounts for the arc, we obtained a high spatial resolution of 1/600 rd which when combined with a good spectral resolution (53000) of an Ebert-Fastie Spectrometer provided good conditions for line shape measurements. For calibration purposes we used a tungsten ribbon lamp calibrated at the NBS Washington. The line profiles were recorded by a strip chart recorder connected to a high quality photomultiplier.

3. MEASUREMENTS

In every experimental run (88 different physical conditions) we recorded the profiles of HeI 447 mm complex line and H_β 486.1 mm, NeI 585.2 mm or ArII 480.6 mm lines.

From such collection of data we were able to determine the electron concentration Ne, the electron temperature T and the concentration of ions. Those plasma parameters linked together with the experimental profiles of the investigated helium line allowed us to search out the best functional dependences of S, F/A and C/A upon Ne and to see if and how the chemical composition of the plasma or its temperature influences such relations.

3.1. Electron concentration

For 75 experimental conditions with 0.1 to 1.5 % of hydrogen, it was possible to determine Ne from H_β line Stark broadening. We chose the theoretical description of H_β line shape of Vidal-Cooper-Smith (1).

For practical purposes, we propose here the formula derived by us from (1).

$$\text{Log Ne} = 22{,}578 + 1{,}478 \log D - 0{,}144 (\log D)^2 - 0{,}1265 \log T \qquad [1]$$

Ne in m^{-3}

D : full width of H_β line at half of its maximum intensity in mm.

T : temperature in K.

This formula, walid for $0.0316 \lesssim \text{Ne}\ (10^{22}\ m^{-3}) \lesssim 3.16$ and $5\ 000 \lesssim T(K) < 20\ 000$, gives the Ne value within an accuracy of ± 5 %. Temperature determination is explained in the following section.

3.2. Temperature

The temperature of the plasma was derived from the following set of equations :

$$Ne = f(D,T) \qquad [1]$$

$$NHe = f(I_{447.1}, T) \qquad [2]$$

$$N_H = f(I_{H\beta}, T) \qquad [3]$$

$$N_{Ne} = f(I_{585.2}, T) \qquad [4]$$

$$N_{Ar} = f(I_{480.6}, Ne, T, \Delta E \text{ ion}) \qquad [5]$$

$$\Delta E \text{ ion} = f(Ne) \qquad [6]$$

$$N_{He} + N_H + N_{Ne} + N_{Ar} + 2\ Ne = p/kT \qquad (7)$$

where N_{He}, N_H, N_{Ne} and N_{Ar} are the concentrations of Helium, Hydrogen, Neon and Argon atomes respectively.
$I_{447.1}$, $I_{H\beta}$, $I_{585.2}$ and $I_{480.6}$ are the absolute emission coefficients of HeI 447.15 nm, H_β 486.3 nm, NeI 585.2 nm and ArII 480.6 nm respectively.
ΔE ion is the ionization energy lowering (we used Unsold formula)
p : pressure (atmospheric for all runs).
The values of the transition probabilities contained in the equations [2-5] were taken from NBS tables (2,3).
The $I_{447.1}$ was obtained by doubling the intensity of the red half-profile of the allowed helium line ; the far wings correction of the line emission coefficients was done according to (4).
The temperature derived from the above equations is an "excitation temperature" probably close to electron temperature ; with our experimental conditions the temperature was in the range 11520 - 14540 K.

3.3. Ion concentrations

In order to check the influence of the ion perturbers on the complex line shape parameters (S, F/A and C/A) we also calculated the ion concentration in plasma for every experimental conditions.
Of course for pure helium plasma we assumed NHe^+ = Ne.
For others cases, ion concentration was calculated using Saha equation.

4. DISCUSSION

Having four sets of data from 88 different plasma conditions, we were able to look for the dependence of S, F/A, C/A parameters of the HeI 447.1 nm line as a function of the electron concentration Ne.
We propose the following formulae :

$$\text{Log Ne} = 23{,}056 + 1{,}586 \text{ Log } (S - 0{,}156) + 0{,}25 [\log (S - 0{,}156)]^2 \quad [8]$$

$$\text{Log Ne} = 22{,}563 + 1{,}658 \text{ Log } F/A + 0{,}257 (\log F/A)^2 \quad [9]$$

$$\text{Log Ne} = 21{,}041 + 3{,}372\ C/A - 1{,}38\ (C/A)^2 \quad [10]$$

when Ne is in m^{-3} and S in nm.

We found out a relatively good agreement for Ne = f(S) calibration as compared to almost all theoretical values (5) (6) ; we are also in good agreement with Diatta et al (7) results obtained in a plasma jet.
Our F/A values agree with the theoretical ones only for Ne $\simeq 10^{21}$ m^{-3} ; for higher electron concentrations, we are close to experimental values of Diatta et al (7), Kelleher (8).
Our C/A values are in accordance with the theory proposed by Barnard et al (9) for Ne = $3 10^{21}$ m^{-3} but slightly higher than the ones predicted in other theoretical works.

5. CONCLUSION

The formulae [8], [9], [10] allow to determine the electron concentration in the range of about $0{,}1 \leq$ Ne (10^{22} m^{-3}) ≤ 2 with an accuracy of ±15 % without any additionnal knowledge of plasma temperature and composition.
After a statistical analyses of the data, a weak ion motion effect appears expressed to be proportional to the $\left(\frac{T}{\mu}\right)^{1/2}$ parameter (μ reduced mass)

but for diagnostic purposes this effect on line shape parameters of the HeI 447 mm complex line can be neglected for plasmas at electron concentrations $1 10^{21}$ to $2 10^{22}$ m^{-3} and temperatures 10 000 to 15 000 K when a 15 % accuracy is sufficient.

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