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PLASMA PHYSICS

MONOCHROMATISATION EFFECT – AC/DC DISCHARGES COMPARATIVE BEHAVIOR

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Abstract. The monochromatisation effect consists in the decrease of the emission spectra of an electronegative-electropositive gas mixture discharge to only few intense spectral lines or even one line, as in the case of Ne-H_2 gas mixture (the so called M-effect). The paper presents the general aspect of this behavior wich is outlined for Ar+H_2 and He+O_2 gas mixtures discharges. The differences consist in the number of the dominant spectral lines appeared. Thus, at least two different dominant spectral lines were found to increase and give rise to the M-effect in an AC discharge. In a DC discharge, similar to the Ne-H_2 gas mixture discharge, the appearance of one single intense spectral line is reported.

Key words: M-effect, dominant spectral lines, energy defect.

1. INTRODUCTION

In a number of previously published papers we reported that, with hydrogen addition to neon, a reduction of the neon emission spectra to practically one line was observed. The wavelength of this line, λ_1=585.3 nm, corresponds to the 2p$_1$-1s$_2$ transition [1,2]. Due to the fact that the remaining spectra had practically one line, this phenomenon was called the "Monochromatisation effect" (**M-effect**). In order to characterize the "amplitude" of this effect, we introduced the M parameter defined as the relative intensity ratio of the increased single line to an arbitrary reference line. For neon, the two lines are λ_1=585.3 nm and λ_2= 614.3nm and the *M* parameter:

$$M=\frac{I_{\lambda_1=585.3\text{nm}}}{I_{\lambda_2=614.3\text{nm}}}. \quad (1)$$

In the case of pure neon discharges, the value of the *M* parameter (defined as the ratio of the two same spectral lines λ_1=585.3 nm and λ_2= 614.3 nm) is of the order of a few units, whereas at 40% hydrogen content in the neon-hydrogen gas mixture, a value as high as 40 was found. These results were obtained for a dielectric barrier discharge (PDP-type) in ($Ne+H_2$) mixture at pressures around 10^{+2} Torr. The emission spectrum of a discharge in pure neon is presented in Fig. 1. The spectrum of (Ne+1%Ar) + 40%H_2 mixture discharge under identical experimental conditions is shown in Fig. 2.

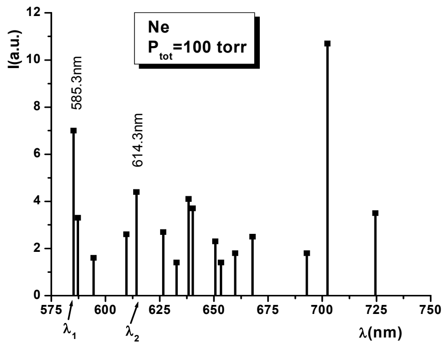


Fig. 1 – Emission spectrum of a PDP discharge in *pure neon* (λ_1=585.3nm, λ_2=614.3nm).

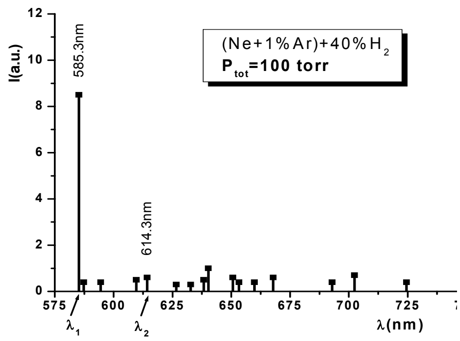


Fig. 2 – Emission spectrum of (Ne+1%Ar) + 40%H_2 gas mixture PDP discharge. (λ_1=585.3nm, λ_2=614.3nm).

2. EXPERIMENTAL SET-UP

The AC dielectric barrier discharge in argon-hydrogen and helium-oxygen gas mixtures was produced between two thin, parallel and linear aluminum electrodes of 5 mm width and 200 mm length [5]. Both electrodes were covered with 20µm glass dielectric layer. The distance between the electrodes (i.e. discharge space) was $d \leq 1$ mm. The thin film conductors were obtained by deposition in vacuum on two glass plates through a mask. The electrical supply was an AC 1k$V_{pk\text{-}pk}$ square wave voltage with an optimum of frequency in the range of 10–50 kHz. The measurements performed for different types of discharges have established that for values which are not in the frequencies range of (10–50) kHz the M-effect is much weaker [3]. The PDP discharge device can be pumped down and filled with various gas mixtures. The optical emission spectra of the discharge were registered using a Varian-Techtron spectrometer and a RCA photomultiplier.

The experimental set-up used for measurements in DC discharges consists in a discharge tube from 30 mm diameter Pyrex glass, having a central part of quartz, in order to allow the passage of the UV radiation [5]. The length of this part was of 80 mm and the total length of the tube 160 mm. The two electrodes are made of Φ 1.5 mm tungsten rod. The top of the electrodes (1-2 mm) is sharp while, the rest is covered with glass in order to limit the discharges out of the inter-electrodes space. The distance between the two electrodes was 8 mm. The discharge tube was connected to the vacuum pumping unit and can be filled with various gas mixtures at the established pressures. An OMA (Optical Multichannel Analyzer), with the spectral range 200–900 nm and 1.5 nm resolution was used in order to record the spectra of the emitted light.

3. RESULTS AND DISCUSSION

We present the registered spectra for the AC (PDP type) and DC discharges in ($Ar+H_2$) and ($He+O_2$) gas mixtures in Figs. 3–12. The total pressure of the gas mixtures, as well as the percentages of electronegative gas (hydrogen, respectively oxygen) were specified directly on the graphs.

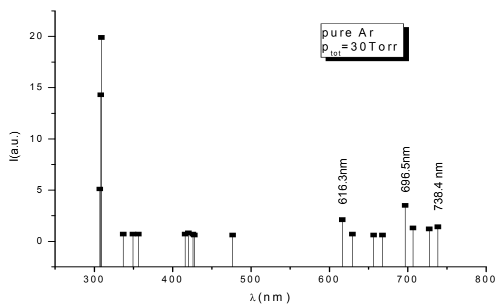


Fig. 3 – Emission spectrum of a PDP-type discharge in *pure argon*.

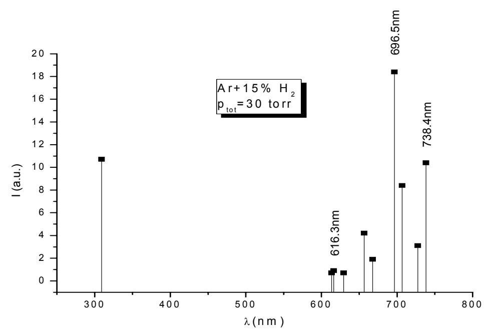


Fig. 4 – Emission spectrum of a PDP-type discharge in ($Ar+15\ \%\ H_2$).

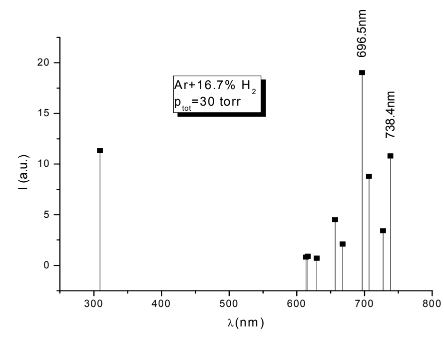


Fig. 5 – Emission spectrum of a PDP-type discharge in ($Ar+16.7\ \%\ H_2$).

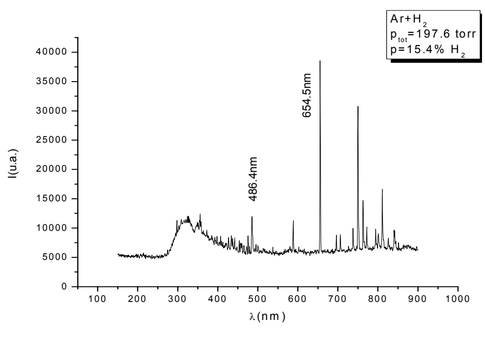


Figure 6 Emission spectrum of a DC discharge in ($Ar+15.4\ \%H_2$) at p_{tot}=197 Torr.

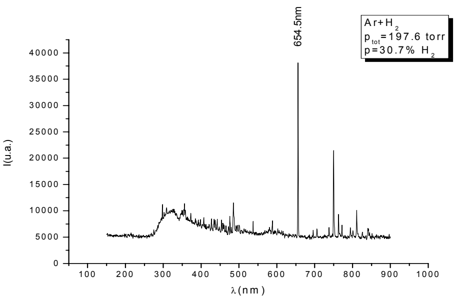


Fig. 7 – Emission spectrum of a DC discharge in (Ar+30.4 %H_2) at p_{tot}=197 Torr.

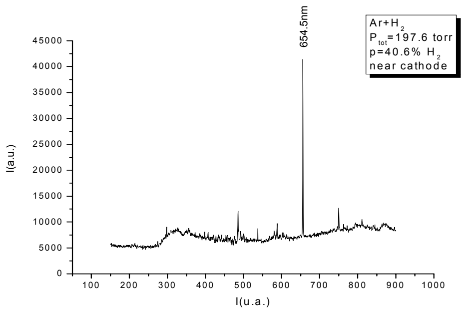


Fig. 8 – Emission spectrum of a DC discharge *in* (Ar+40.6 %H_2) at p_{tot}=197 Torr (near cathode).

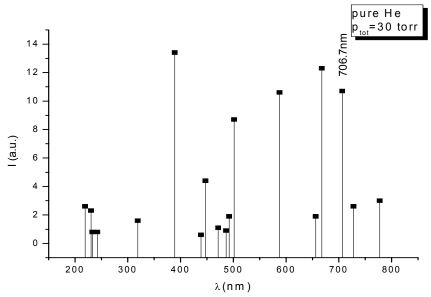


Fig. 9 – Emission spectrum of a PDP-type discharge in *pure helium*.

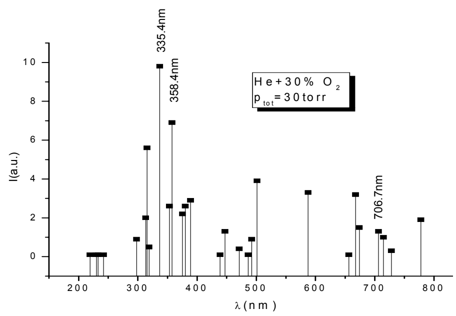


Fig. 10 – Emission spectrum of a PDP-type discharge in (He+30%O_2).

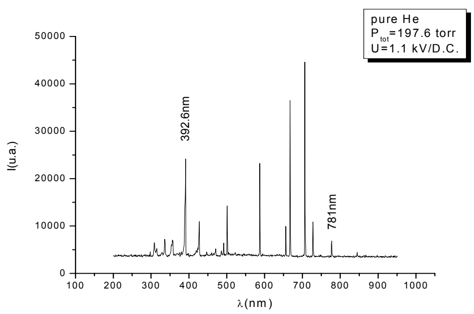


Fig. 11 – Emission spectrum of a DC discharge in pure *helium*.

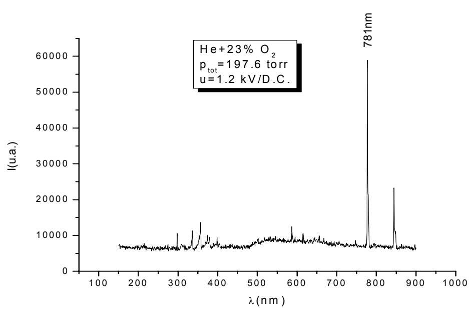


Fig. 12 – Emission spectrum of a DC discharge in (He+23%O_2) gas mixture.

In Figs. 3–5, the M-effect for the argon-hydrogen gas mixture appears in a PDP type discharge for more than one single intensive line, the dominant lines chosen being λ_1=738.4 nm and λ_1=696.5 nm (the reference spectral line λ_2=616.3 nm). The maximum values of the M parameter suitable to these two spectral lines are reached for $p(H_2)$ = 15.0% – $M(\lambda_1$=738.4nm) = 12.3 and respectively $p(H_2)$ 16.7% – $M(\lambda_1$=696.5nm) = 21.9. The total pressure of the gas mixture was about 30 Torr. The entire aspect of the spectrum is shifted to IR wavelengths.

In the case of an argon-hydrogen gas mixture DC discharge, the M-effect consists in a single, intense dominant spectral line with λ_1=654.5 nm (spectral reference line λ_2=486.4nm), as it can be observed in Figs. 6–8. The maximum value of the M parameter is reached at $p(H_2)$ =40.6% – M(λ_1=654.5nm)=3.3. The total pressure of the gas mixture was 197 Torr.

In Figs. 9–10, the M-effect for the helium-oxygen gas mixture appears in a PDP type discharge for more than one single intensive line, the dominant lines chosen being λ_1=335.4nm and λ_1=358.4nm (spectral reference line λ_2=706.7nm). The maximum values of the *M* parameter suitable to these two spectral lines are reached for $p(O_2)$=25–30%, namely $M(\lambda_1$=335.4nm) = 7.5 and $M(\lambda_1$=358.4nm) = 5.5. The total pressure of the gas mixture was about 30 Torr. The entire aspect of the spectrum is shifted to UV wavelengths.

In the case of helium-oxygen gas mixture DC discharge, the M-effect consists in a single, intense dominant spectral line with λ=781nm (spectral reference line λ_2=392.6nm), as it can be observed in Figs. 11–12. The maximum value of the *M* parameter is reached for $p(O_2)$=23% – $M(\lambda_1$=781nm) = 7.8. The total pressure of the gas mixture was 197.6 Torr.

As shown in our previous papers [4, 5], the M-effect is the result of the resonant three-body collision reaction of ionized and excited atoms. The general form of the reaction, in case of the M-effect, is:

$$P^{+} + N^{-} + N^{met} \rightarrow P^{*} + N^{\text{ground state}} + (N^{met})^{*} + \Delta E, \tag{2}$$

where the used notations are the following: P and N are symbols of the atoms of electropositive and respectively electronegative gases in the mixture, P^+ is the symbol for the positive ion, N^- is the symbol of the negative ion, N^{met} is the symbol for the metastable negative atom, $(N^{met})^*$ is the symbol of the excited electronegative atom standing in a upper state energy that the metastable level, P^* is the electropositive atom in an excited state and ΔE is the reaction energy defect.

In the particular cases of argon-hydrogen and helium-oxygen gas mixtures, the general equation (2) can be written as following:

$$\begin{aligned} &\text{Ar+ (15.76eV) + H- (0.75eV)} + H_{met} \text{ (10.2eV)} \rightarrow \\ &\rightarrow \text{Ar*} + H_{met}\text{*(12.09eV) + H (0 eV)}, \end{aligned} \tag{3}$$

$$\begin{aligned} &\text{He+(24.5eV) + O-(1.46eV)} + O_{met} \text{ (9.146eV/9.521eV)} \rightarrow \\ &\rightarrow \text{He*} + O_{met}\text{*(10.74eV) + O (0 eV)}. \end{aligned} \tag{4}$$

For excited argon and helium atoms are suiting the energies values of the spectral dominant lines presented hereinbefore. The electronegative atoms in the energetic level with n=2 are acting like metastable atoms due to the phenomenon of resonant radiation trapping at pressures bigger than 10 Torr.

As established in our previous papers [11], more than one dominant spectral lines appear when the defect of energy reaction is $\Delta E \leq \pm 10^{-1}$ eV. For instance, in the case of (Ar+H_2) gas mixture ΔE= -0.21 eV for λ=696.5 nm and ΔE= +0.18 eV for λ=738, 4 nm [12]. The possibility that the three-body reaction could occur, even when the reaction energy defect is different from zero [6–10], was experimentally established in the case of M-effect, but the increase of the dominant spectral lines number is due to the structure of the Ar spectrum. Thus, the Ar spectrum of the excited energetic levels in Paschen notation is formed by the 4-s lines ($1s_2$-$1s_5$) and the 10 p-lines ($2p_1$-$2p_{10}$).

The He spectrum is even more complicated due to his specific structure of energetic levels (orto and para helium). From these reasons, the number of combinations of the permitted transitions between these levels is greater than in the case of Ne spectrum consisting in a single s-line ($1s_2$) and 10 p- lines which finally leads to the appearance of more dominant spectral lines (with respect of the transitions rules for dielectric dipole).

The difference between the two types of discharges concerning the dominant spectral lines and the aspect of spectra consists in the fact that, in the PDP discharge, the M effect could appear at moderate pressure (30 Torr), while in the DC discharge, even in the same gas mixture, the total pressure is much higher (around 200 Torr).

The explanation of this different behavior is due to the specific proprieties of these two types of discharges.

Thus, the PDP-discharge is characterized, in the after–glow phase, by low electronic temperature (about 2–3 eV), high density of the negative ions (about 5×10^{11}cm^{-3}), high density of electrons (about 10^{12} cm^{-3}) and low electric field (near to zero) [13], so that the collisional couplings between the excited energetic levels of Ar /He could take place gradually (like in the neon spectrum case).

In the DC discharge, the M-effect appears only in the negative-light region [14], which is characterized by a high density of electrons and negative ions. In the same time the electric field, due to the sharp form of the electrodes, is far more intense than in the case of the PDP discharge. For this reason, the permitted transitions between the excited energetic levels are realized directly, without intermediary stages, which finally lead to the appearance of one dominant spectral line.

The electrical parameters of the PDP discharges were defined as following:

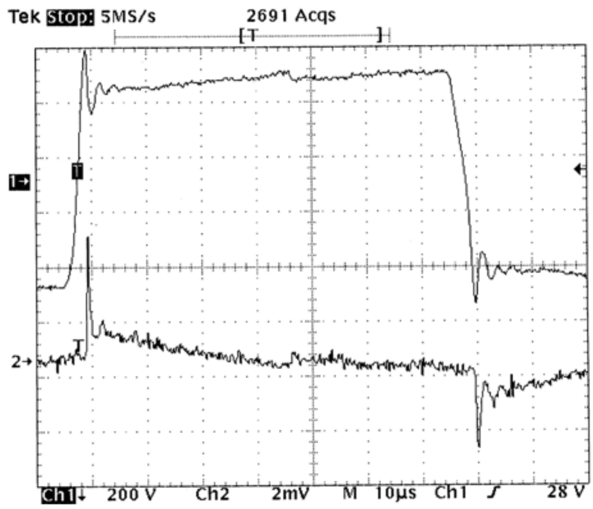
– τ_u – the electric voltage pulse time, in the range (60–75) μs

– τ_i – the electric intensity pulse time, in the range (1–2) μs

– V_{pp} –peak-to-peak electric voltage applied on discharge, in the range (700–1200)V

– ν – the frequency of the supply source ~7 kHz

– i – the discharge electric current, in the range (9–15) mA (Fig. 13).



V_{pp}= 944 V
I= 9.2mA
ν= 7.098 kHz
τ_i =1.25μs

Fig. 13 – The temporal dependence of the electric voltage/intensity pulse in a PDP discharge.

When the Paschen condition is fulfilled, which was the case in our experiments, the PDP is a luminescent, evenly and homogenous discharge, in his glow-phase.

For the DC discharge the electrical parameters values were:

– *U*, the ignition voltage, in the range (400-1200)V;

– *I*, the discharge electric current, in the range (6–23)mA, τ_u =74 μs.

5. CONCLUSIONS

As it can be observed, from the data presented, in a DC discharge only a single, intense spectral line appears both in Ar+H_2 and He+O_2 gas mixtures. Contrary to this situation, in a PDP discharge there are more dominant spectral lines that appear.

These different behaviors are due, on a side, of the specific experimental parameters of the DC/AC discharges and on the other side to the specific structure of the Argon and Helium spectra.

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