

Considerations on the Penning reactions role for the monochromatisation – effect in noble gases-hydrogen mixtures

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The paper deals with the Penning reactions role in the decreasing process of the dominant spectral lines number which appear in multiple noble gases-hydrogen mixtures in comparison with single noble gas-hydrogen mixture. These reactions could be considered as a redistribution energy agent between the heavy particles (excited, ionized, neutral), involved in the monochromatisation –effect appearance.

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1. Introduction

The monochromatisation effect (M-effect), which consists in the reduction of an electronegative-electropositive gas mixtures discharge emission spectrum to only a few (or even one) lines, was largely explained in our previous published papers [1-8], as well as its generation mechanisms, namely the polar ion-ion recombination and the energy resonance condition. In fact, the so called "monochromatisation-effect" consists in the reduction of the discharge emission spectrum practice at one single line, namely $\lambda = 585.3$ nm, in (Ne + 1%Ar + H₂) or (Ne + 1%Xe + H₂) gas mixtures. In the present experiments it was used a Dielectric Barrier Discharge (DBD). The effect was observed also in DC/RF discharges, but it was weaker than in AC discharge.

Figs. 1a and b show the emission spectrum of a Plasma Discharge Panel (PDP) in pure Ne, respectively the emission spectrum in a (Ne + 1%Ar + 40% H₂) gas mixture.

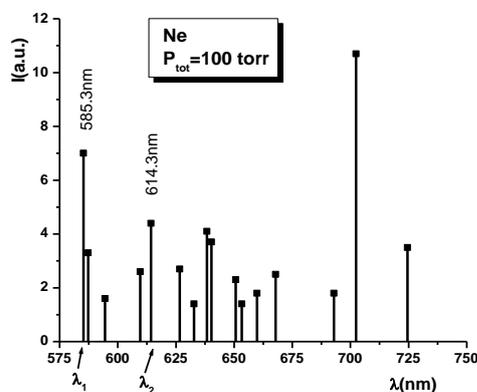


Fig. 1a. Emission spectrum of PDP discharge in pure Neon gas.

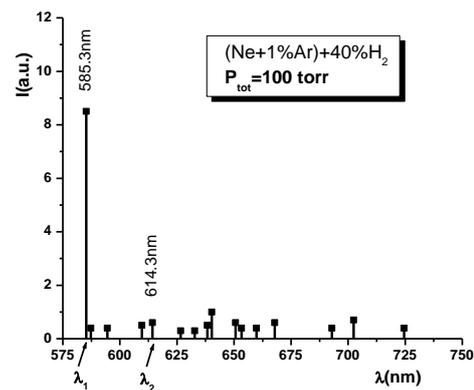


Fig. 1b. Emission spectrum of PDP discharge in (Ne + 1%Ar) + 40%H₂ gas mixture.

In order to characterize the "quality" of this effect, it was introduced the M parameter defined as the relative intensity ratio of the increased single line, called *dominant spectral line*, and an *arbitrary reference spectral line*. For neon, these two spectral lines were chosen as $\lambda_1 = 585.3$ nm, respectively $\lambda_2 = 614.3$ nm.

The M parameter so defined is:

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

In case of the pure neon discharges, the value of the M parameter was of order of a few units, whereas at 40% hydrogen content in the neon-hydrogen gas mixture, a value as high as 40 units was found. These results were obtained for a dielectric barrier discharge in (Ne + H₂) mixture at a total pressure values around 100 Torr. It is important to notice that the argon percentage in the gas mixture is very low (around 1%).

The last studies performed on the monochromatisation-effect in multiple noble gases (Ne+Ar/Xe or Ne+Ar+Xe) with hydrogen mixtures reveals

the existence of the dominant spectral lines, namely 585.3 nm(Ne), 750.4 nm(Ar), 882.3/823.5/823 nm (Xe), for a total pressure up to 80 Torr [9, 10]. The percentage of hydrogen was around 35% but in these experiments the noble gases percentages were equal, i.e 32%, a value much more high than 1% in the initial experiment. The M parameter value for the 585.3 nm Neon spectral line was maximum for a total pressure of 40 Torr, after that the M parameter for the dominant spectral lines of the other noble gases (Ar or Xe) involved in the mixture became more important. This behavior of the 585.3 nm spectral line was the same in both experiments, i.e. the intensity of the spectral line was maximum for a total pressure value around 40 Torr, after this value it has decreased.

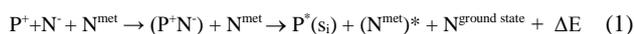
2. Experimental set-up

The experimental set-up device for the first experiment was largely presented in our previous papers [1-8]. It consisted in a plasma discharge panel (PDP), with the electrodes distance up to 1 mm value and the total pressure gas mixtures value up to 100 Torr. The set-up device for the experiments in double or triple noble-gases and hydrogen mixtures consisted in an electrical discharge with the interelectrodes distance up to 10 mm at the same total pressure of the gases mixture [9, 10].

3. Results and discussion

As it was noticed in our previous papers [11, 12], the main mechanism involved in the generation of monochromatisation-effect is based on the *resonant polar three-body reaction*, which represents an extension of the Landau- Zener theory [14,15].

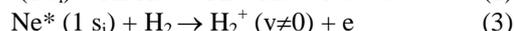
The general form of this reaction can be written as:



where s_i is the notation for the selective populated level.

The used notations are the following: P and N are symbols of the atoms of electropositive and respectively the 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, $(N^{\text{met}})^*$ 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 notation for energy defect of reaction.

This generation mechanism for the monochromatisation effect is common for all types of electropositive-electronegative gases mixtures either a simple mixture, namely (*Ne/Xe/Ar+H₂*) or a multiple noble gases with hydrogen mixture, namely (*Ne+Ar+Xe+H₂*). The quenching mechanisms are the Penning reactions, respectively, the radiative/non-radiative collisional processes:



$i = 2, 3, 4, 5, \dots$ (The Penning reactions)

In the multiple noble gases-hydrogen mixtures in which the xenon and neon (or neon and argon) were in equal partial pressures, the role of the Penning reaction became preponderant so that it appears a sort of "thermalization" of the noble gases atoms energy. This fact could induce the appearance of a smaller quantity of noble gases metastable/excited atoms, which play a very important role in the generation of M-effect [1]. By the appearance of a finer structure of the noble gases atoms energy levels, the collisional process could produce more non-radiative des excitations so that only the noble gases atoms that fulfill more closely the energetic resonant condition remain ($\Delta E = \pm 0.1$ eV) [11, 12]. This is the explanation of the fact that in the multiple noble gases with hydrogen mixtures the number of dominant spectral lines is obviously reduced comparative with the case of the simple mixture, namely one single noble-gas and hydrogen (Figs. 3 and 4 comparative with Fig. 5)- [9, 10].

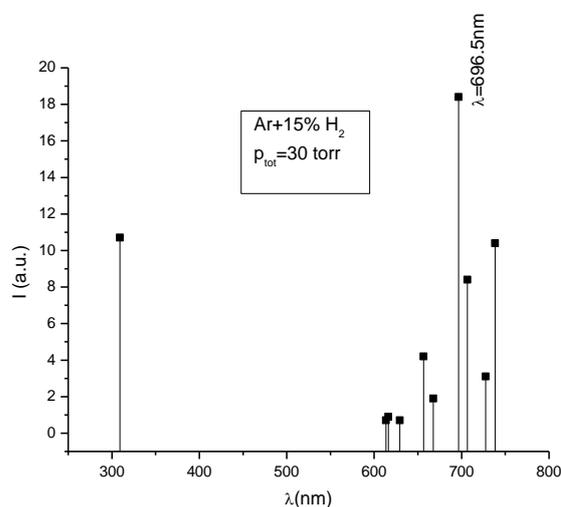


Fig. 3. Emission spectrum of a PDP-type discharge in (*Ar+15% H₂*).

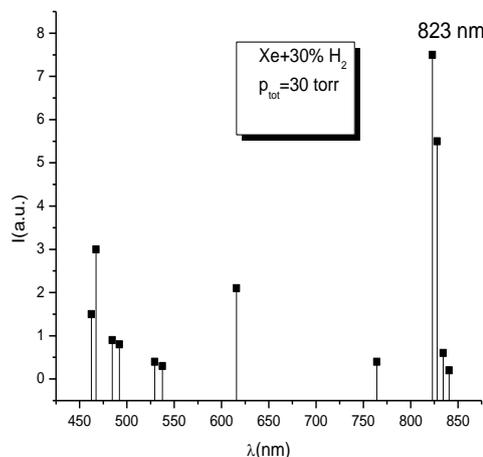


Fig. 4. Emission spectrum of a PDP-type discharge in (*Xe+30% H₂*).

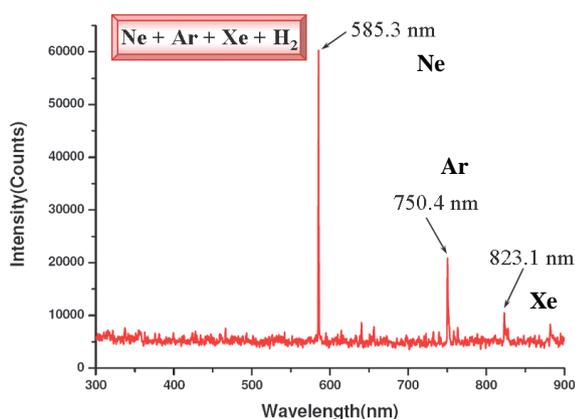


Fig. 5. Emission spectrum in (Ne-Ar-Xe+50% H_2) mixture discharge at $P_{Tot} = 80$ Torr.

It is interesting to notice that in a simple mixture xenon-hydrogen the monochromatisation -effect does not even appear, [11, 13]. Once again the explanation consists in the fact that the energetic structure of the xenon spectrum does not permit the achievement of the resonant energetic condition whose fulfillment becomes more possible in multiple noble gases–hydrogen mixtures because of the energy levels variety existence.

Another argument for the consideration of the Penning reactions as an important mechanism reaction in the appearance of the monochromatisation-effect in multiple noble gases and hydrogen mixtures is the experimental fact which was underlined by the authors [9, 10] that this effect is independent of the total gas pressure as long as the partial pressures of the involved gases remain unchanged.

4. Conclusions

The main reaction mechanisms involved in monochromatisation – effect existence are: the resonant polar three-body reaction, the Penning reactions and the radiative/non-radiative collisional processes. In mixtures containing an equal proportion of noble gases, comparable with the hydrogen concentration, the Penning reactions play an important role in the M-effect intensification.

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