The M-effect, a synergetic result of three body collisions and metastable/resonance radiation trapping

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In a number of previously published papers we presented experimental results on the monochromatization of noble gas emission spectra on the addition of hydrogen (or other electronegative gases) to noble gas discharges. More recently, the selective emission of *two* monochromatic spectral lines emitted in neon-argon mixture a.c. plasmas was reported. In this later case, the addition of hydrogen to the noble gas mixture resulted in the emission of two intense and monochrome lines, the 585.3 nm and the 750.4 nm line. The present paper presents new considerations for the explanation of these results. A three body collision was found to be the elementary process that generates the monochrome radiation. Radiation capture effects or the presence of metastable states are also discussed.

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1. Introduction

The M-effect (monochromatization–effect) is a physical phenomenon characterized by the emission of specific monochromatic line spectra in certain gas mixture plasmas [1], [2]. Recent experiments revealed that this effect can be extended to two or more lines simultaneously just by adding more electropositive gases in the same reaction chamber [3]. This finding opened new aspects of fundamental physics and has also enlarged greatly the potential for applications. For this reason, understanding the mechanisms that result in the appearance of the M-effect is the new challenge.

In this paper, we present new mechanisms that are thought to be responsible for this effect. Three body collisions and also resonance radiation capture (or collisional trapping) of metastable states were found to be the elementary processes generating the monochrome radiation. It is explained here that, in order to obtain single- or multiple-line spectra, a high density of atoms excited on the $2p_1$ energy level must be obtained.

2. Experimental arrangement

The experimental setup for the study of the M-effect in single gases and also in two-gas combinations is presented in [3] and [4], respectively. While the voltage used for the M-effect experiments involving only one electropositive gas at a time was a few keV for either ac or dc discharge, the value of the applied voltage needed to observe the double M-effect was much higher: 25 kV. The frequency of the pulsed discharge in the single-gas case was in the range 10 – 20 kHz. In the case of the double-gas discharge, a frequency of 25 kHz was used. This is an important finding and gives a good start to further research on spectral emission of multiple electropositive gas combinations for the exploration of discharges at higher applied voltage.

A steady gas flow of different gas compositions was controlled using flow-meters. The spectra were acquired using a computer-controlled Optical Multichannel Analyzer (OMA).

3. Discussion of the results

The main requirement for obtaining the M effect is the presence of an electropositive and an electronegative gas mixture in the discharge tube, e.g. Hydrogen and Neon or Hydrogen and Argon. For these cases, the emission was monochromatic and the lines found were 585.3 nm and 750.4 nm, respectively. The emission spectra of other gas mixture discharges like $Ne+Cl_2$ or $Ne+O_2$ have also shown the M-effect.

Moreover, a double M-effect appeared in discharges of two electropositive and one electronegative gas mixtures. Research on a similar double M-effect has never been reported before. Extensive investigation of the single and double M-effect has lead us to some important conclusions concerning the appearance and phenomena related to this effect.

The correlation of our experimental results on the M-effect with published experimental data and also with collision theory on various types of gas mixture discharges, the main collision reaction responsible for the appearance of this effect was put in evidence. A three body collision was found to be the elementary process that generates the monochrome radiation. Radiation trapping and metastable atoms trapping are also believed to take part in this process.

The main reaction in the case of neon-hydrogen mixture discharge is presented in the following equation (1).

$$Ne^{+}+H^{*}(10.20\ eV) + H^{-} = Ne^{*} + H^{*}\ (12.09\ eV) + H \qquad (1)$$

where Ne^{+} is the neon pozitive ion, H^{*} is the excited Hydrogen atom on the 10.20 eV energy level, H^{-} is the Hydrogen negative ion, $Ne^{*}(2p_1)$ is the excited neon atom on the $2p_1$ neon energy level, H^{*} is the Hydrogen atom excited on the 12.09 eV energy level and finally H is the hydrogen atom in the ground state [5]. Dezexcitation of Ne^{*} results in the emission of the single spectral line observed experimentally. Fig. 1 gives the energy level diagram of the particles before and after collision.

The above relation also shows that positive and negative atoms need to be formed in the discharge in order to observe the effect. These charged particles are the result of collision processes.

Due to the strong Coulombian electrostatic forces between opposite sign charged particles (the electronegative and electropositive particles) the particles are attracted and gain energy. The cross section is high [6], therefore the above reaction has a high probability.

The density of negative ions in pulsed discharges is much higher than in d.c discharges. Also, it was proved that excess electrons increase the generation of negative ions. A higher density of negative ions and also electrons than the density of neutrals was observed in the negative glow of d.c. discharges and an even higher in pulsed discharges.

Calculation of the energy balance of the energetic levels involved in equation (1) has shown that the total energy on the left side is equal 31.01 eV and to 31.05 eV on the right side. Their difference gives the energy defect, which is only 0.04 eV, practically zero. This equation is energetically resonant. The corresponding energy for each particle is given in equation (2).

$$Ne^{+}(21.56\ eV) + H^{*}(10.20\ eV) + H^{-}(-0.75\ eV) =$$
$$= Ne^{*}(18.96\ eV) + H^{+}(12.09\ eV) + H\ (0\ eV) \qquad (2)$$

These results have demonstrated that the collision equation (1) is at the origins of the M-effect. Other reactions can be found by simple calculations on the energy balance of similar reactions involving other gas atoms. This finding opened a tremendous research area both for fundamental physics as well as for applications. Based on the M-effect, new monochromatic light sources can be designed.

Further experiments on the dependence of the double M-effect on other experimental parameters are envisaged. Also, the controlled emission of multiple lines is the next obvious step in the research on the M-effect.

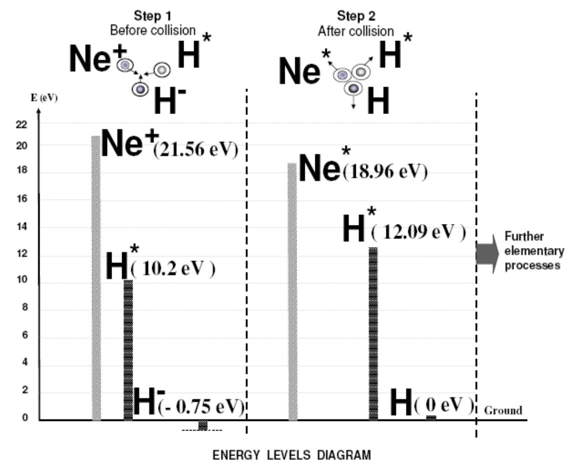

Fig. 1. Energy levels diagram for the species involved in neon-hydrogen mixture discharge (step 1-before collision and step 2-after collision).

4. Conclusions

The mechanism responsible for the generation of the monochrome radiation is based on elementary process of three body collision. This finding was confirmed by the energy level diagram of the collision reaction, considering also the resonant radiation trapping processes.

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