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Dedicated to Prof. Ioan-Iovitz Popescu's 75th Anniversary

REPORTS ON THE M-EFFECT – GENERAL CHARACTER AND EXPLANATION OF THE INVOLVED ELEMENTARY PROCESSES

G. MUSA[1], R. VLADOIU[1], M. CONTULOV[1], V. DINCA[1]

[1] *Ovidius University, Mamaia 124, 900527, Constanta, Romania*
e-mail: musageavit@yahoo.com

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Abstract. In a number of previously published papers we presented the monochromatization of the noble gas emission spectra at the addition of an electronegative gas to the noble gas discharges. A general character of this new phenomenon was proved by extending the effect not only to selective emission of one line, but also two-spectral lines in a.c. plasmas in special mixtures of one electronegative and two electropositive gases. In the case of hydrogen (electronegative gas) added to neon-argon gas mixtures discharges, there are generated exclusively two intense and monochrome lines with the wavelength at 585.3 nm and 750.4 nm. A synergetic result of three body collisions, metastable states or trapped resonant radiation was found to be the elementary processes that generate the monochrome radiation.

Key words: M-effect, three body collisions, multiple gas discharges.

1. INTRODUCTION

The M-effect (monochromatization-effect) is a powerful tool which can give high intensity monochromatic one line spectra with a certain wavelength depending on the type of used gas mixtures to generate plasma state [1]. The effect consists in the emission of a single spectral line of plasmas ignited in certain binary gas mixtures [2]. A very important step checked by us was to prove the general character of this effect, *i.e.* if the optical emission spectra reduced to nearly one line can be observed also in other gas mixture discharges and which is the correlation between them. There were a lot of coupled gases studied by us, both in the case of AC or DC discharges, with different types of power supplies and various experimental equipment. All these results could be used to list of the requirements for the ignition and running of this type of discharge, namely a discharge with one wavelength light emission.

Recently our new experiments revealed that this effect can be obtained not only at the addition of one electropositive and one electronegative gas but also simultaneously for two or more different monochrome radiation found in the same plasma [3]. The M-effect was continuously studied to find not only new aspects of exceptionally interesting basic physics, but also for its great potential for applications.

The M-effect experiments involving only one electropositive gas and one electronegative gas were performed with DC power supplies generating a few kV, namely in DC from 1.2 kV to 2 kV and respectively a square wave pulsed high voltage source in AC of 1 kV with a frequency in the range of 10 kHz up to 100 kHz [4]. In the case of the simultaneous emission of two spectral lines using a gas mixture of two electropositive and one electronegative gases, *e.g.* Ar, Ne and H_2, respectively, the used power supply was a pulsed high voltage (25kV) with a frequency of 20 kHz.

In this paper, we present a short review on the last results concerning the M-effect, including also a report on the mechanisms at the level of atomic and molecular particles involved in. The three body collision was found to be the elementary process responsible for the full monochromatization effect – one recorded line for the entire spectra.

2. EXPERIMENTAL ARRANGEMENT

The experimental set-up used for our studies on the M-effect of multiple gas mixtures consists from three main parts, namely the discharge device, the air pumping down equipment followed by the multiple gas mixture filling system with in advance established known gas mixtures at known partial gas pressures each one and finally, the third part as we mentioned before an A.C. power supply with a pulsed high voltage (25 kV) with a frecquency of 20 kHz. The *discharge device* consists mainly from a quarz tubing with an inside diameter of 16 mm and 200 mm length (Fig. 1). Just on the axes of this quarz tubing there are mounted axially two

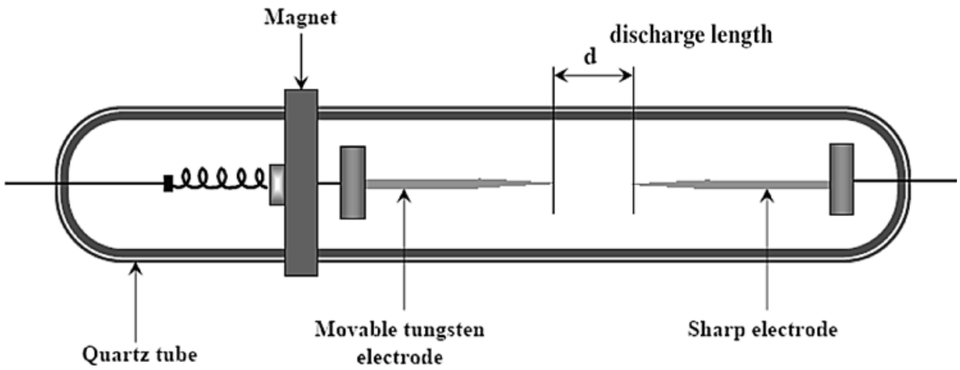

Fig. 1 – The discharge device used for the study of the selective emission of two spectral lines generated in AC plasmas.

metallic electrodes made by tungsten which are movable along the axes of the quarz tubing in order to have the possibility to establish various discharge spaces. The distance between electrodes (d) is quite similar with the active discharge space. Therefore, the distance between electrodes can be changed at will using a permanent magnets system. Usually in present experiment most of the data were taken using an electrodic distance of $d = 100$ mm.

In order to help the ignition and also to ensure a stable discharge, the electrodes – made from tungsten wires with a diameter $\Phi = 1.5$ mm – are sharpened like needles. The tungsten wires – except the active electrodes parts – are covered with glass (or quarz tubing) all along the wire except of the discharge space, tightly bounded to the tungsten wire. In this way are reduced the possible spurions discharges or movable plasma between electrodes due to the very high value of the applied high voltage (25 kV) over the space between electrodes.

To ignite a discharge in the interelectrodic space, the discharge device is filled with a gas mixture of an established composition of the filling gas mixtures. A pulsed high voltage is applied across the electrodes. A bright light in the gas mixture is established in the interelectrodic space, due to the short and powerful applied voltage pulses.

An Optical Multichannel Analyser (OMA) is mounted transversally on quarz glass tubing. Using OMA, with a cross-section of the optically active signal of 2 mm, the discharge spectra is easily recorded. Usually, it is necessary to calibrate the OMA before use but in the case of M-effect the studied emission spectral lines are well known and can be quickly identified.

Using flow-meters we controlled the steady gas flow with different compositions of gases. The spectra were acquired using a computer-controlled Spectral products device SM 242 Spectrometer.

3. RESULTS AND DISCUSSIONS

The main condition to obtain the M effect is the presence of an electropositive and an electronegative gas mixtures. Negative ions density is increasing very fast at the use of a pulsed discharge instead of a d.c discharge [5, 6]. Also, it was proved that excess electrons can increase the negative ions generation. Measured density of negative ions and also electrons in excess over neutrality has been observed in negative glow of simple d.c. discharge device and especially at the use of pulsed discharge to generate plasma [7].

A monochrome radiation was obtained in each of these two-gas mixtures, (*e.g.* Hydrogen and Neon or Hydrogen and Argon) the wavelengths of the emitted lines being 585.3 nm for the emission spectrum of Ne and 750.4 nm for Ar in the cases of $Ne + H_2$ or $Ar + H_2$ [8]. Both recorded spectra were each one unique and monochrome (see Fig. 2).

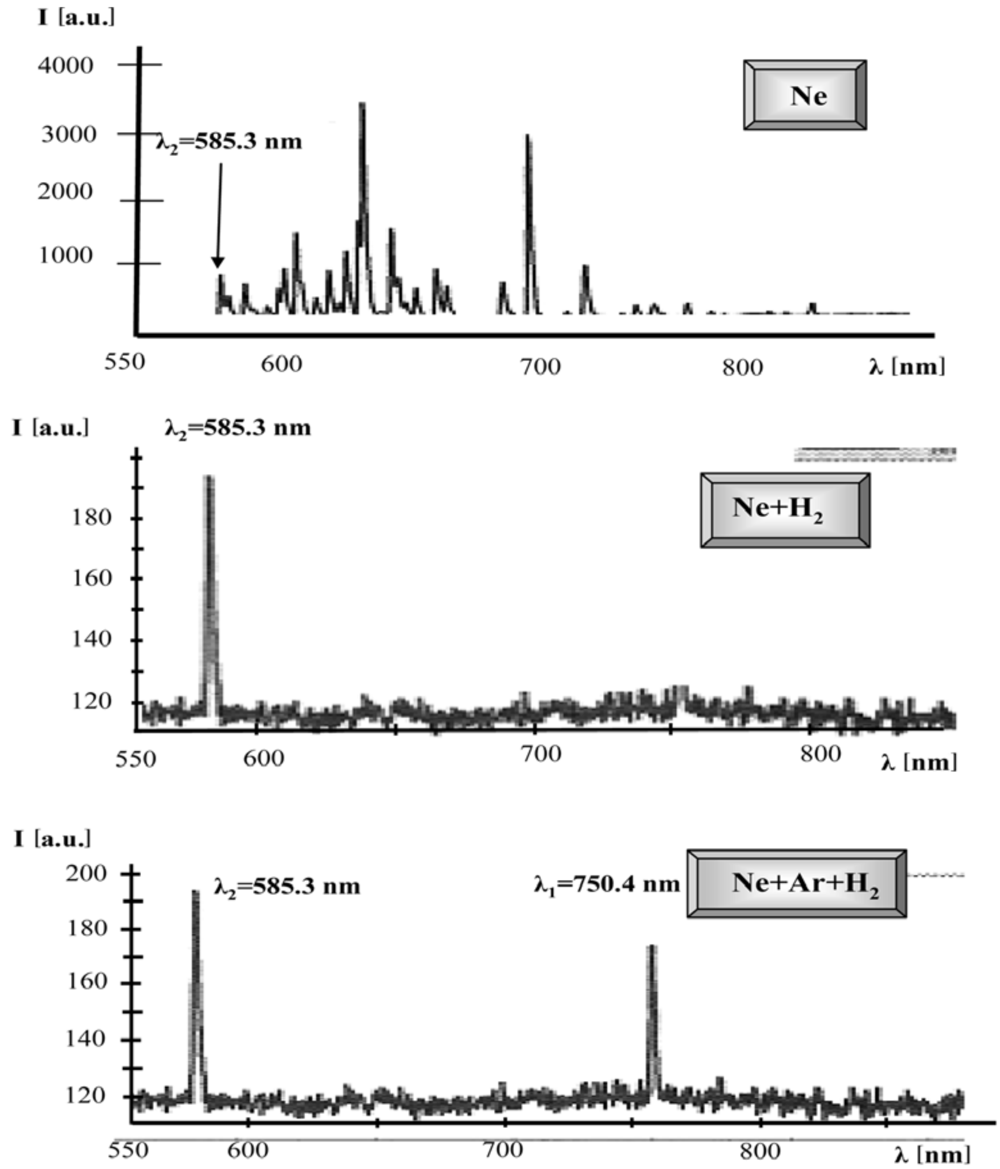

Fig. 2 – Optical emission spectra for illustration of M-effect in different mixtures of gases with Ne as the main component.

This discharge with three elements Ne and Ar with H_2 have proved the existence of the so-called double M-effect. The results suggest that the simultaneous M-effect is independent of total gas pressure as long as the relative concentration of the three gases remains unchanged. The concentration of Hydrogen was 50% in this experiment [9].

Moreover, to illustrate the general feature of the M-effect, in the Table 1 several gas mixtures are revealed with the dominant spectral lines where the M-effect could be noticed [10].

Table 1

The dominant spectral lines for the different gas mixtures with M-effect

Gas mixture	Dominant line λ [nm]
Ne + H_2	585.5
Ar + H_2	750.4
Ar + O	750.4
Ne + O	585.5
Xe + H_2	852.1
Kr + H_2	758.7

Three body collisions do not give alone the clear monochrome spectra as we can observe in published papers. Other elementary processes with high efficiency fully contribute to explain the M-effect as additional effects like **trapped resonant radiation** or **metastable capture**. More details in discussing the M-effect with be presented especially on completely quench of any other compound except one corresponding to M-effect.

All our previous studies on the physical aspects of the M-effect (still not finished) leads to the following partially results: the gas mixture must contain electropositive and electronegative gases. In this case for negative ions generation *via* electron attachment process following conditions must be also fulfilled:

- Nearly zero electric field in plasma region where the negative ions are generated;
- High density of electrons, exceeding the number of ions density;
- Low electron temperature in order to ensure the electron attachment to electronegative atoms or molecules;
- High partial pressure of the gas mixture atomic and molecular partners from the total pressure, because three body collisions involve low density of charges;
- High pressure of the gas mixture (toward atmospheric pressure) in order to sustain triple particle collisions;
- Low temperature of the gas mixture in order to reduce the collisional quenching of the reacting triple particle compound.

As it can be revealed, using a high voltage supply with high frequency of repetition and sharp variation of the pulse, it can be maintained a low temperature of discharge produced plasma, which is one of the main conditions to keep the M-effect. The increase of the discharge gas temperature will decrease quickly the M-effect.

In this way, we can explain the M-effect only due to the additional processes promoting only one (or a few) species interacting until a monochrome spectrum is obtained. So, we have to put together the efeect of three body collisions and resonant radiation trapping or metastable capture process.

For example, to explain this effect for a neon-hydrogen mixture discharge, following three-body equation was assumed to generate the M-effect:

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

where in the left side of equation Ne^{+} is the neon positive ion, H^{*} is the excited hydrogen atom at the level of energy 10.20 eV, H^{-} is the hydrogen negative ion, the value of the corresponding negative energy being (–0.75 eV). In the right side of mentioned equation $Ne^{*}(2p_1)$ is the excited neon atom on the neon energy level $2p_1$, H^{*} is the hydrogen atom excited to the level of energy 12.09 eV and finally H is the hydrogen atom returned to the ground level of energy.

Due to the strong electrostatic forces (Coulombian forces) the reacting particles are quickly attracted to each other gaining energy (both electronegative and

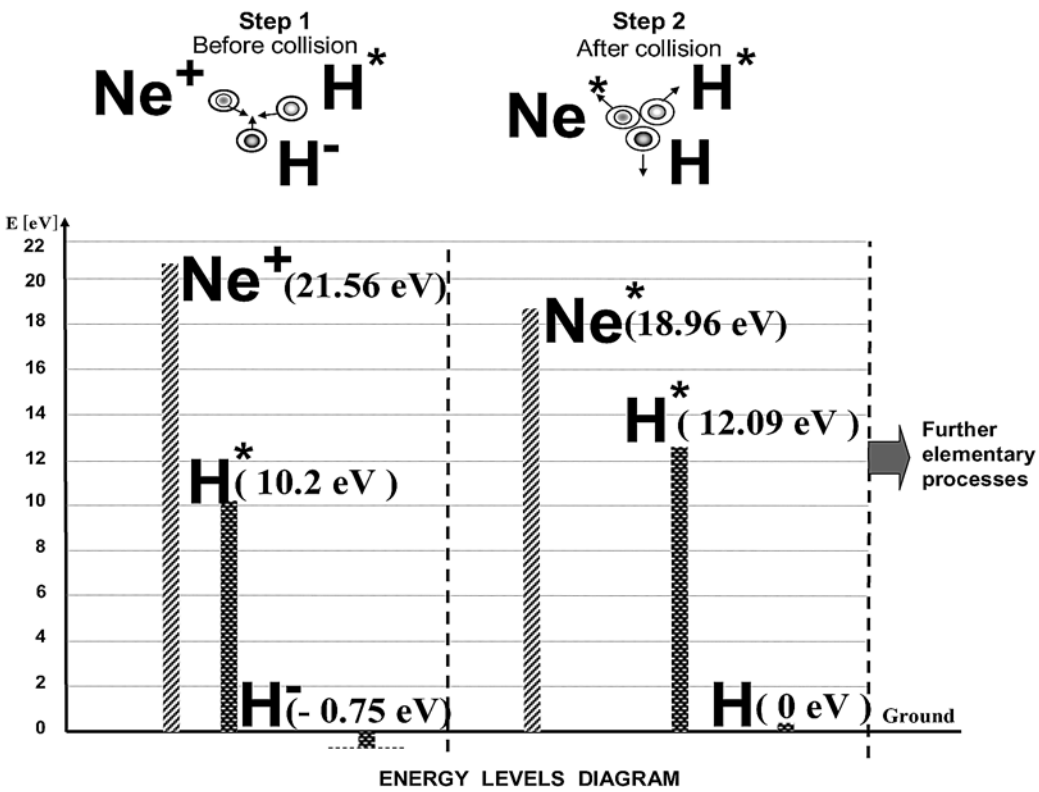

Fig. 3 – Energy levels diagram for the species involved in neon-hydrogen mixture discharge (step 1 – before collision and step 2 – after collision).

electropositive particles). Due to the high value of the recombination of negative-positive ion, in some condition plasma appearance is mainly due to this process.

On the calculation of the energy balance of energetic levels involved in the equation (1) in the left side, the total energy is equal with 31.01 eV while in the right side is 31.05 eV, which means that the difference between these energy is only 0.04 eV, practically zero. The energy defect represents the difference between the energy values of the colliding particles on left side, with those on the right side of this equation (2). Thus, equation (1) is energetically resonant, as it can be noticed from the equation (2).

$$\begin{aligned} &Ne^{+}\,(21.56\text{ eV}) + H^{*}\,(10.20\text{ eV}) + H^{-}\,(-0.75\text{ eV}) = \\ &= Ne^{*}(18.96\text{ eV}) + H^{+}(12.09\text{ eV}) + H\,(0\text{ eV}). \end{aligned} \qquad (2)$$

We must observe that the values of the cross-section from the reported experiments in literature are higher than 0.2–0.3 eV shift.

4. CONCLUSIONS

The mechanism responsible for the generation of the monochrome radiation is based on the elementary process of three body collision together with the resonant radiation of plasma. We explained this with the diagram of energy levels of particles involved in the process. Additional processes including two particle interactions like resonant radiation trapping or metastable state are parts of M-effect. This increased performance extends the area of gas mixtures in which the M-effect can be established, especially ensure the generation of pulsed high voltages with frequencies up to 25 kV.

We proved the general character of the M-effect and we established the conditions to obtain M-effect. These results opened a new research area, with applications involving emission line sources including double M-effect. Further experiments to put in evidence the dependence of the double M-effect on other experimental parameters are under consideration.

The simultaneous controlled emission of multiple lines and in advance established is the next obvious step of research on the M-effect.

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