MONOCHROMATIZATION AND POLARIZATION OF THE NEON SPECTRAL LINES IN CONSTANT/VARIABLE MAGNETIC FIELD

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Abstract. As early as the 1980s, a new physical phenomenon was observed in electronegative-electropositive gas mixtures discharges plasma, namely a significant monochromatization effect (called the M-effect) of the emitted visible light. As was established in our previous papers, the generation mechanism of this effect is mainly based on the polar resonant three-body reaction, whose cross- section strongly depends on the energy dissipated in discharge, either by increasing the total gas pressure or the electric current in discharge. In ($Ne+H_2$) gas mixtures, the phenomenon of monochromatization was the most intensive such that the only important spectral line, virtually remaining, was λ=585.3nm that belongs to the neon emission spectrum. This paper deals with the study of way in which a constant/variable magnetic field has influenced the monochromatization and polarization degree, in regard with the neon principal spectral lines: 614.30, 640.22, 692.94, 703.24, 717.39 and 724.51 nm. Given the dependence of the cross-section of the three-body reaction on the energy reaction, the measurements have been performed for different values of the discharge current. The study reveals that the presence of a constant magnetic field improved the quality of the monochromatization -effect and subsequently of the polarization degree for the neon spectral lines, particularly λ=585.3nm, compared with the situation when the magnetic field has been zero or a variable one.

Key words: the M-effect, polarization degree, neon emission spectrum, magnetic field.

1. INTRODUCTION

The monochromatization of visible light is an important physical effect whose appearance can be observed only in noble gas-electronegative gas mixtures plasma, at moderate to high total pressures [1]. The effect consists in a great reduction of the noble gas emission spectrum at one single line, (sometimes a few lines) very intensive in relation to the other spectral lines intensities. This spectacular change in aspect of the noble gas emission spectrum appeared upon addition of a little quantity of electronegative gas (Fig.1). However, there are combinations of gas mixtures in which the M-effect has no appeared, as was indicated in [2].

The magnitude of the M-effect is obtained by introducing the *M* parameter, defined as the intensities ratio of two emission lines from the noble gas spectrum, namely that of the λ_1 monochromatized line, called the dominant line, and that of a λ_2 reference line, chosen at random:

$$M(\lambda_i,\lambda_j)=I(\lambda_i)/I(\lambda_j) \qquad (1)$$

For example, λ_i =585.3 nm and λ_j = 614.3 nm in neon emission spectrum.

The generating process of the M-effect is produced *via* the polar resonant three-body reaction having its general form as follows:

$$P^+ + N^- + N^{met} \to P^* + N^{ground\quad state} + \left(N^{met}\right)^* + \Delta E \qquad (\Delta E \approx 0) \qquad (2)$$

where P and N are the symbols of the atoms of electropositive and electronegative gases respectively, 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 having a higher energy that the metastable level, P^* is the electropositive atom in an excited state, and ΔE is the reaction energy defect.

The energy defect is given by the difference in the energy of the participating particles before the three-body interaction and after it: the positively ionized and excited neutral atoms, P^+ and P^* respectively, and the metastable-state atoms N^{met} and $N^{met}*$ have, by convention, positive energy values while the negative ions have, suitably, negative energy values.

Numerical calculation of the energy balance implied in reaction (2) compared with the experimental observations proves that the M-effect is obtained only for the combinations of P^* and $N^{met}*$ that give a very small energy defect (near to 0 eV). The results of this calculation suggest that values of ΔE in the range of (−1, 1) eV should be considered as an important possibility for the appearance of the M-effect. For example, based on this calculation, the spectral lines of the neon emission spectrum, with the highest probability within the frame of the M-effect, should be: λ= 585.3 nm and λ= 540.1 nm.

The compound of gases in which the M-effect was the most significant was formed by neon and hydrogen. In this specific case, the eq. (1) takes the following form:

$$\begin{aligned} &Ne^+ + H^- + H^*(n=2) \rightarrow (Ne^* H^-) + H^*(n=2) \rightarrow \\ &\rightarrow Ne^*(2p_1) + H^*(n=3) + H(n=1) \pm \Delta E \end{aligned} \tag{3}$$

As we can see from the eq. (3), the particles involved in reaction are ions, excited and neutral atoms of electronegative and electropositive gas, respectively. The spectral line λ_1=585.3 nm is generated by the transition $2p_1 \rightarrow 1s_2$. Hence, is obviously that mostly of the neon excited atoms, reported in monochromatization effect, must be on $2p_1$ energy level because the emitted radiation intensity of spectral line λ_1=585.3 nm is directly proportional to the population of the initial level in Fig. 2.

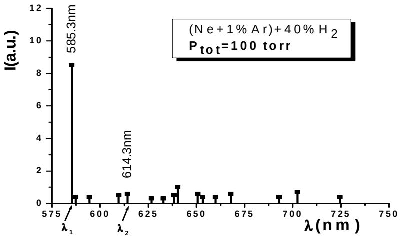

Fig. 1 - Emission spectrum of (Ne+1%Ar) + 40%H_2) gas mixture plasma.

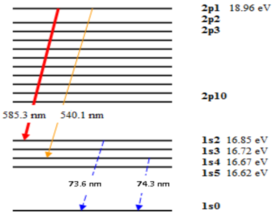

Fig. 2 - The neon energetic levels simplified structure in Paschen notation (The energy levels $1s_2$ and $1s_4$ are resonant while $1s_3$ and $1s_4$ are metastable).

A second permitted transition starting on this level is $2p_1 \rightarrow 1s_4$ with the wavelength of the emitted radiation λ_2= 540.1 nm. In this case, the spectral line is not a dominant one (even the result of calculation would allow it) because its probability of emission is about one hundred time smaller than for the first transition. The levels $1s_2$ and $1s_4$ that are resonant levels for neon atom, are having a theoretical life-time of $\tau_{s2}=2\text{x}10^{-8}$ s and $\tau_{s4}=1.5\text{x}10^{-9}$ s, respectively. The excited atoms standing on these levels return to the fundamental energy level either by radiative dezexcitation or non radiative by collision processes (see Fig. 2).

The wavelengths of the resonance radiation are λ=73.6 nm and λ=74.4 nm, respectively, corresponding to the following two transitions: $1s_2 \to 1s_0$ and $1s_4 \to 1s_0$ (here $1s_0$ is the denotation for the fundamental energy level). Under a few Torr (mbar) pressures values, due to the resonance radiation trapping phenomenon, the real life-time of the excited neon atoms on the resonance energy levels becomes comparable with the life-time of atoms on the metastable energy levels. Theoretically, this life-time is about one second, but in the real circumstances of discharge, this one could be significantly reduced, close to a 10^{-3} s magnitude order.

Table 1 presents the calculation for the defect energy of the reaction related to the principal spectral neon lines of interest in our paper [3].

Table 1 Calculation of ΔE for the main spectral lines of neon.

(+) P^+ (eV)	(-) N^- (eV)	(+)N^{met} (eV)	(-)P^* (eV)	N (eV)	(-)N^{met*} (eV)	(±) ΔE (eV)	λ (nm)
21.56	0.75	10.2	18.38	0	12.09	+0.54	724.52
21.56	0.75	10.2	18.57	0	12.09	+0.35	717.39
21.56	0.75	10.2	18.38	0	12.09	+0.54	703.24
21.56	0.75	10.2	18.63	0	12.09	+0.29	692.95
21.56	0.75	10.2	18.55	0	12.09	+0.37	640.22
21.56	0.75	10.2	18.63	0	12.09	+0.29	614.30
21.56	0.75	10.2	18.96	0	12.09	- 0.04	585.30
21.56	0.75	10.2	18.96	0	12.09	- 0.04	540.06

The radiative and collision processes that appear between $1s_2$, $1s_3$, $1s_4$ and $1s_5$ levels are described by the following equations:

$$\text{Ne}^*(1s_i)+e \to \text{Ne}^{**}(2p_m)+e; \quad m=1\div 10 \tag{4}$$

$$\text{Ne}^{**}(2p_m) \to \text{Ne}^*(1s_j)+h\nu; \quad i=1\div 4;\ j=1\div 4;\ m=1\div 10;\ i\neq j \tag{5}$$

$$\text{Ne}^*(1s_i)+\text{Ne} \to \text{Ne}^*(1s_j)+\text{Ne}; \quad i\neq j \tag{6}$$

$$\text{Ne}^*(1s_i)+\text{M} \to \text{Ne}^*(1s_j)+\text{M}; \quad i=1\div 4;\ j=1\div 4;\ i\neq j. \tag{7}$$

However, the real life-time of the metastable neon atoms is shorter than 10^{-3} s due to the existence of the Penning-type collisions. These reactions produce a quick extinction of the neon excited atoms from the metastable/resonant levels, as are described in the following equations:

$$\text{Ne}^*(1s_i) +\text{Ar} \to \text{Ar}^+ +\text{Ne}+e \quad ; \tag{8}$$

$$\text{Ne}^*(1s_i) +\text{Xe} \to \text{Xe}^+ +\text{Ne}+e \ ; \tag{9}$$

$$\text{Ne}^*(1s_i) +\text{H}_2 \to \text{H}_2^+(v\neq 0)+e; \qquad i = 2, 3, 4, 5. \tag{10}$$

Figure 2 shows that the energy differences between the levels on neon spectrum are very small, around the value of 0.1 eV, being in the range of ΔE values that allows the appearance of the M-effect. The collision processes between neon atoms having their energy levels values very close, causes a kind of „fragmentation” of colliding particles energy. This process favours the existence of a third body into a convenient energy state that can be involved in the resonant reaction. In our previous paper we have proposed a kinetic model that explained the selective population of the $2p_1$ energy level [4].

Remember that the three-body reaction has a cross-section that depends not only on the energy of colliding particles involved in eq. (2), but also on the total gas pressure. Therefore, the existence of the M-effect can be better observed above a value of 10 Torr (13.3 mbar). Indeed, we shall see there are two types of conditions to be accomplished in order to obtaining the M-effect:

1. *Experimental conditions*: *a)* Electronegative-electropositive gas mixture; *b)* Low gas temperature and elevated pressure of the gas mixture; *c)* The question of a high density of the negative ions: low electric field in the plasma and high electron densities can both increase the density of negative ions, conditions accomplished in the after-glow phase of the dielectric barrier discharge, in very low RF discharge and in negative glow of a dc discharge;
2. *Energy conditions*: a high emission probability of dominant spectral line(s) and a corresponding appropriate value of ΔE.

Given these circumstances, the visible emitted light has a degree of monochromatization measured by the dimensionless parameter M. In our previous work [5] we observed the existence of a certain polarization degree of the emitted dominant spectral lines, fact predictable. As is well known, the degree of polarization is defined as follows:

$$\rho = \frac{P_{00} - P_{90}}{P_{00} + P_{90}} . \tag{11}$$

2. EXPERIMENTAL DEVICE

The photo-view and a schematic diagram of the experimental set-up are presented in [5]. In order to allow the passage of the UV radiation, the discharge is produced in a quartz tube with 15 mm inner diameter and 20 mm outer diameter respectively, between two identical wolfram-thorium cylinder electrodes of 12 mm diameter, spaced at 6 mm distance. In front of the discharge tube is placed a reflection mirror for minimizing the loss of the emitted radiation. The experimental conditions are the following: the total gas mixtures pressure up to the value of 30 Torr (40 mbar) and the electric current in discharge varying within the range of 5 to 11 mA, with an increasing constant rate of 5 mA. The discharge device can be pumped down to a pressure of about 10^{-5} mbar and then filled with various gas mixtures of spectral purity. The RF electrical power supply used in the experiment has the following characteristics: maximum output electrical tension of 2 kV corresponding to an electrical current intensity of 150 mA, very low frequency alternative voltage of 25 kHz and a filling factor between 10 to 20%. The optical emission spectra of the plasma discharges have been registered using OMA (Optical Analyzer Multichannel) with a spectral range between 220 to 900 nm, 0.5 s time of integration and a resolution of 1.5 nm, after the passage of the emitted radiation through a diaphragm, a polarization filter and a focusing lens system. The diaphragm has a variable magnitude starting with a value of 20 mm and up to 40 mm. The registered data have been processed by means of a computer.

3. RESULTS AND DISCUSSION

In order to study the influence of a constant/variable magnetic field on the monochromatization and polarization degree we have chosen the (Ne+42.5% H_2) gas mixture RF discharge plasma, at a total pressure of 22 Torr (29.26 mbar), because these experimental conditions are in the optimum range of values established for obtaining the M-effect. We must remark here that the M-effect was found to be more intensive in ac discharges (of radio frequency and dielectric barrier types) than in dc discharge.

By using two magnets, we have applied a constant magnetic perpendicularly on the drift velocity direction of the electrons, namely on an imaginary line connecting the two electrodes of the discharge tube. The variable magnetic field has been obtained by using a single magnet. We have performed the measurements in a constant magnetic field or a variable one respectively, and then we have compared them with the ones obtained in the situation when the magnetic field has been zero. In all the following graphs, P_{00} and P_{90} represent the intensities of light measured in the oscillation and perpendicular plane of the electric vector respectively, and i is the denotation for intensity of the electric current through the discharge.

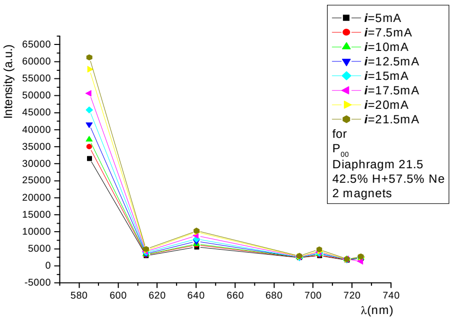

Fig. 3 - The spectral dependence of P_{00}.

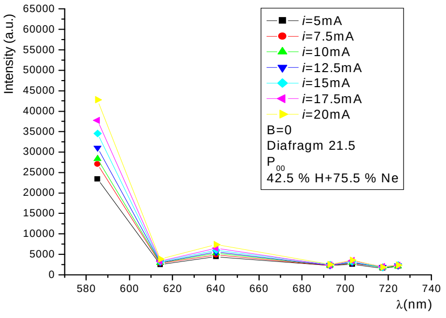

Fig. 4 - The spectral dependence of P_{00}.

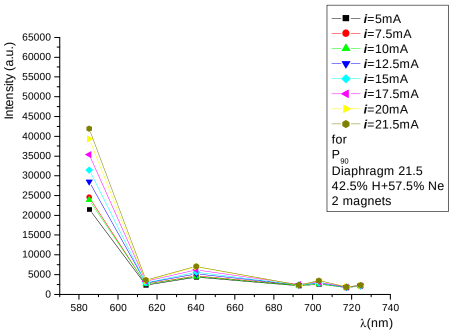

Fig. 5 - The spectral dependence of P_{90}.

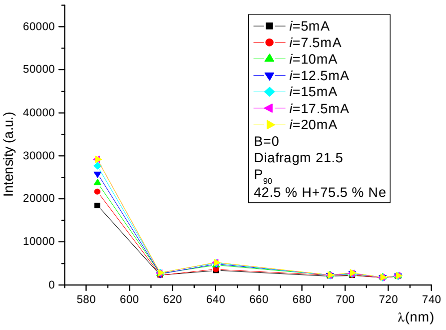

Fig. 6 - The spectral dependence of P_{90}.

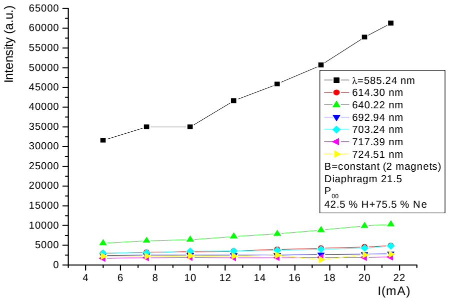

Fig. 7 - The dependence of P_{00} emitted visible light intensity on the electric discharge current.

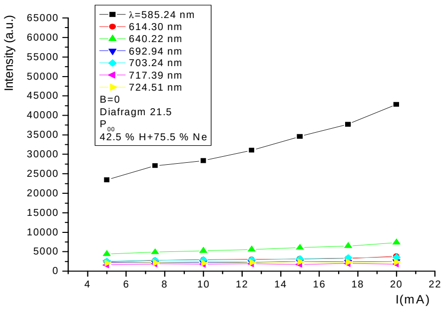

Fig. 8 - The dependence of P_{00} emitted visible light intensity on the electric discharge current.

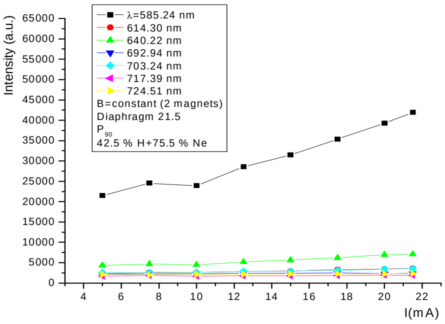

Fig. 9 - The dependence of P_{90} emitted visible light intensity on the electric discharge current.

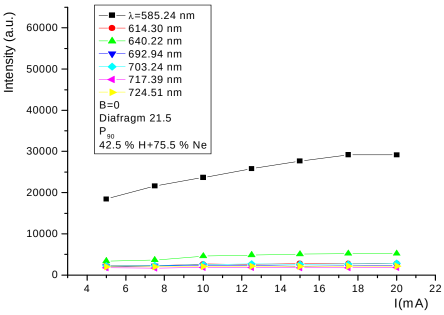

Fig. 10 - The dependence of P_{90} emitted visible light intensity on the electric discharge current.

Let us analyze the Figs. 3÷10 (diaphragm of 21.5 mm), highlighting their following characteristics:

- The intensities of all neon spectral lines have bigger values when is applied a constant magnetic field comparatively with the situation when there is no field.
- The intensities of the component P_{00} of all neon spectral lines are bigger than the intensities of the component P_{90} in both situations, with or without magnetic field.
- The P_{00} and P_{90} components intensities of all spectral lines from the neon spectrum, except the dominant line, keep their values almost constant when the current electric in discharge increases, in both situations, with or without applying a magnetic field.
- The intensity of the dominant spectral line is much higher than any other's line from the neon emission spectrum; however, there are two other spectral lines having a slight increase of their intensities because of the M-effect, namely those with the wavelengths of 640.22 nm and 703.3 nm, respectively.

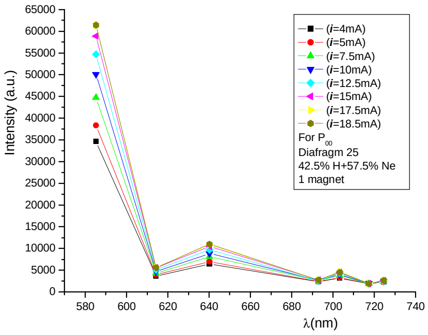

Fig. 11 - The spectral dependence of P_{00}.

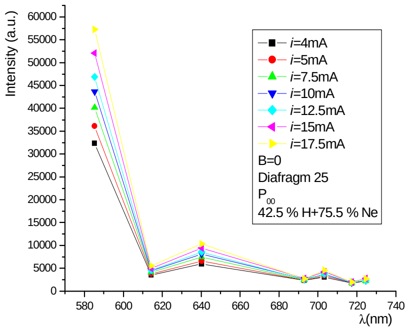

Fig. 12 - The spectral dependence of P_{00}.

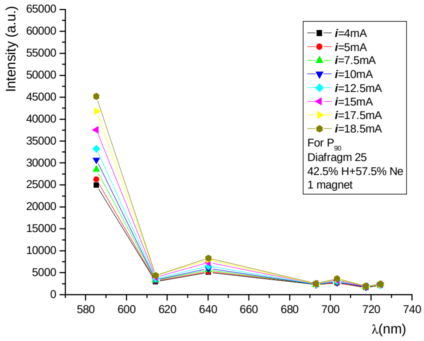

Fig. 13 - The spectral dependence of P_{90}.

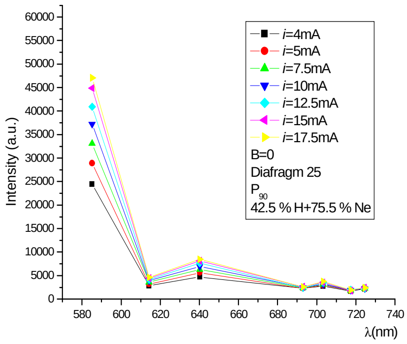

Fig. 14 - The spectral dependence of P_{90}.

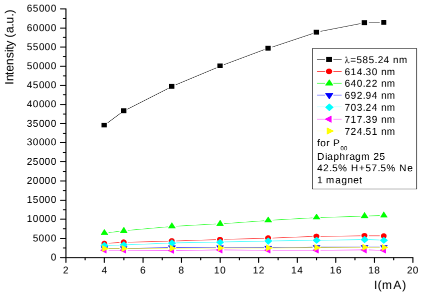

Fig. 15 - The dependence of P_{00} emitted visible light intensity on the electric discharge current.

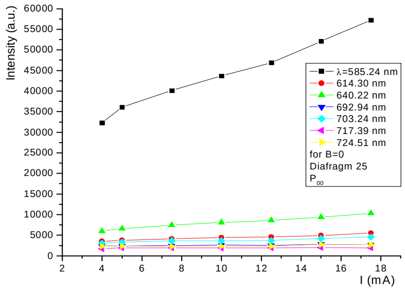

Fig. 16 - The dependence of P_{00} emitted visible light intensity on the electric discharge current.

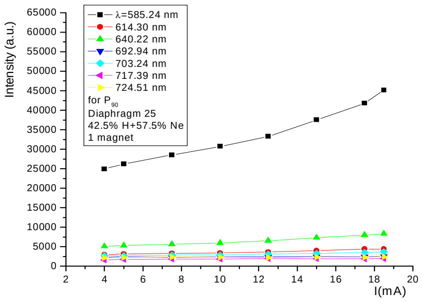

Fig. 17 - The dependence of P_{90} emitted visible light intensity on the electric discharge current.

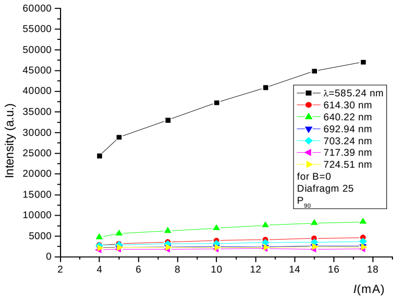

Fig. 18 - The dependence of P_{90} emitted visible light intensity on the electric discharge current.

Figures 7÷10 and 15÷18 show the dependence of the spectral lines intensities on the discharge electric current, in other words, on the energy dissipated in discharge. As we can see, these lines are forming a close-fitting group, except the dominant line λ_1=585.3 nm, that clearly detaches from them. This aspect of the graphs points out that the collision coupling processes between the energetic levels in neon spectrum (within the frame of M-effect), as we have indicated in expressions 5÷8, do not allow the preferential population for any of them with the notable exception represented by $2p_1$ energy level [6].

Figures 11÷14 (diaphragm of 25 mm) show the dependence of intensity for the two components of the visible light, namely P_{00} and P_{90}, on the wavelengths forming the emission spectrum of neon. Similar to the situation presented in figs. 3÷6, the intensities of P_{00} and P_{90} have different magnitudes namely a large values in the presence of the magnetic field compared with the situation in which there is no magnetic field. This behaviour gives us an interesting information about the way in which has been produced the monochromatized light effect in volume of plasma. Thus, when a magnetic field has been applied over the discharge, the Lorentz force acted on the motion of the electrons and negative ions, first generating local irregularities in their distributions. Because of the small dimensions of the tube discharge and the very low frequency alternative supply voltage, the walls of the device in which has been produced plasma rapidly become negative charged. On this line, the negative potential of the wall favours the processes in plasma volume concerning the formation of the negative ions (particles that play an essential role in the appearance of M-effect) and, withal, reduces the possibility of their neutralization on the discharge tube walls; as a result, the life time of the negative ions in plasma volume becomes bigger. This process is not one of having neglected due to the small diameter of the discharge tube (Φ15 mm) and the moderate total pressure value (22 Torr).

We present the Tables 2÷9 that contain data's depending of the polarization degree and the monochromatization parameter on the values of electric current in discharge and on wavelengths, respectively:

Table 2

Dependence of ρ, the polarization degree, on the electric current in discharge for different spectral lines wavelengths (B=0).

λ(nm)	Polarization degree **$\rho=(P_{00}-P_{90})/(P_{00}+P_{90})$** for 42.5%H+57.5%Ne for B=0; Diaphragm 21.5;						
	I = 5mA	7.5mA	10mA	12.5mA	15mA	17.5mA	20mA
585.24879	0.11813	0.11129	0.08973	0.09175	0.11029	0.12693	**0.18949**
614.30626	0.03267	0.09432	0.04801	0.08786	0.05357	0.08482	0.14528
640.2248	0.13261	0.14136	0.06812	0.06907	0.08396	0.10784	**0.17048**
692.94673	0.04834	0.00112	-0.00475	4.26985E-4	0.06692	0.02121	0.03131
703.24131	0.06491	0.094	0.06887	0.04337	0.09234	0.12724	0.11585
717.39381	-0.03978	0.04957	-0.01479	0.02108	0.00909	0.05465	0.0174
724.51666	0.02354	0.03351	0.01164	0.01812	0.06247	0.03091	0.04281

Table 3

Dependence of ρ, polarization degree, on the electric current in discharge for different spectral lines wavelengths (B=ct).

λ(nm)	Polarization degree **$\rho=(P_{00}-P_{90})/(P_{00}+P_{90})$** for 42.5%H+57.5%Ne; for 2 Magnets (B = ct) ; Diaphragm 21.5;							
	I = 5mA	7.5mA	10mA	12.5mA	15mA	17.5mA	20mA	21.5mA
585.24879	0.19018	0.17544	**0.21654**	0.18595	0.18577	0.17802	0.1902	0.18768
614.30626	0.12583	0.10237	0.12313	0.10599	0.15479	0.12804	0.14339	0.15172
640.2248	0.1213	0.13728	0.17691	0.16211	0.16561	0.17988	0.17632	**0.18401**
692.94673	0.06518	0.04364	0.04728	0.02057	0.01983	0.02251	0.09239	0.09598
703.24131	0.08453	0.09569	0.14843	0.11066	0.12913	0.12928	0.1157	0.16259
717.39381	0.03567	0.01418	0.06014	0.02033	0.03815	0.04036	-0.01287	0.02579
724.51666	0.02457	0.06845	0.04663	0.02182	0.05292	-0.24672	0.07625	0.0834

Table 4

Dependence of ρ, the polarization degree, on the wavelengths spectral lines for different values of electric current in discharge (B=0).

I(mA)	Polarization degree **$\rho=(P_{00}-P_{90})/(P_{00}+P_{90})$** for 42.5%H+57.5%Ne for B=0; Diaphragm 21.5;						
	λ_1=585.24nm	614.30nm	640.22nm	692.94nm	703.24nm	**717.39nm**	724.51nm
5	0.11813	0.03267	0.13261	0.04834	0.06491	-0.03978	0.02354
7.5	0.11129	0.09432	0.14136	0.00112	0.094	0.04957	0.03351
10	0.08973	0.04801	0.06812	-0.00475	0.06887	-0.01479	0.01164
12.5	0.09175	0.08786	0.06907	4.26985E-4	0.04337	0.02108	0.01812
15	0.11029	0.05357	0.08396	0.06692	0.09234	0.00909	0.06247
17.5	0.12693	0.08482	0.10784	0.02121	0.12724	0.05465	0.03091
19/20	0.18949	0.14528	0.17048	0.03131	0.11585	0.0174	0.04281

Table 5

Dependence of ρ, the polarization degree, on the wavelengths spectral lines for different values of electric current in discharge (B=ct).

I(mA)	Polarization degree **$\rho=(P_{00}-P_{90})/(P_{00}+P_{90})$** for 42.5%H+57.5%Ne for 2 Magnets (B=ct); Diaphragm 21.5 and different λ_j (nm)					
	λ_j=585.24nm	614.30 nm	640.22 nm	692.94 nm	703.24 nm	**717.39 nm**	724.51 nm
5	0.19018	0.12583	0.1213	0.06518	0.08453	0	0.02457
7.5	0.17544	0.10237	0.13728	0.04364	0.09569	0.01418	0.06845
10	0.21654	0.12313	0.17691	0.04728	0.14843	0.06014	0.04663
12.5	0.18595	0.10599	0.16211	0.02057	0.11066	0.02033	0.02182
15	0.18577	0.15479	0.16561	0.01983	0.12913	0.03815	0.05292
17.5	0.17802	0.12804	0.17988	0.02251	0.12928	0.04036	-0.24672
20	0.1902	0.14339	0.17632	0.09239	0.1157	-0.01287	0.07625
21.5	0.18768	0.15172	0.18401	0.09598	0.16259	0.02579	0.0834

Table 6

Values of *M* parameter (λ_1= 585.3 nm, j≠1) for different values of electric current in discharge (P_{00} component, B=0).

I(mA)	Parameter $M=I_{585.24\ \mathrm{nm}}/I_{\lambda j}$ for B=0; P_{00}; Diaphragm 21.5 and different λ_j (nm)					
	λ_j = 614.30 nm	640.22 nm	692.94 nm	703.24 nm	**717.39 nm**	724.51 nm
5	9.37245	5.31042	10.278	9.20291	14.69115	11.2137
7.5	9.76379	5.52438	12.13581	9.55363	14.2876	12.54053
10	9.6247	5.39958	12.30542	9.74708	15.76654	13.32269
12.5	10.17988	5.59097	13.26035	10.41535	16.44733	13.82688
15	10.81383	5.73246	13.8521	10.84097	19.44907	14.41243
17.5	11.47399	5.82291	15.98771	10.91606	19.35095	16.15203
19	11.12945	5.81173	17.10547	11.94948	22.88348	18.02737

Table 7

Values of *M* parameter (λ_1= 585.3 nm, j≠1) for different values of electric current in discharge (P_{00} component, B=ct)

I(mA)	Parameter $M=I_{585.24\ \mathrm{nm}}/I_{\lambda i}$ for 2 Magnets (B=ct); P_{00}; Diaphragm 21.5 and different λ_j (nm)					
	λ_j = 614.30 nm	640.22 nm	692.94 nm	703.24 nm	**717.39 nm**	724.51 nm
5	10.64902	5.70435	12.97125	10.47595	18.48157	14.15733
7.5	10.8152	5.69722	14.07238	11.114	18.81613	15.35674
10	10.46904	5.45735	13.98242	9.98516	18.04951	15.06586
12.5	11.7865	5.75855	16.75574	11.73328	22.38611	18.11373
15	11.51834	5.81543	18.56744	12.26404	24.06457	18.43305
17.5	11.85654	5.69183	19.22694	12.50012	25.86166	36.7923
20	12.57022	5.80601	21.04812	13.45491	30.11737	22.35192
21.5	12.45619	5.95163	21.20872	12.70413	30.80543	22.35389

Table 8

Values of *M* parameter (λ_1= 585.3 nm, j≠1) for different values of electric current in discharge (P_{90} component, B=0).

I(mA)	Parameter $M=I_{585.24\ \mathrm{nm}}/I_{\lambda i}$ for B=0; P_{90}; Diaphragm 21.5 and different λ_j (nm)					
	λ_j = 614.30 nm	640.22 nm	692.94 nm	703.24 nm	**717.39 nm**	724.51 nm
5	7.89141	5.46904	8.92985	8.26601	10.70029	9.27072
7.5	9.43442	5.87253	9.72686	9.22539	12.61772	10.72412
10	8.85058	5.16976	10.18178	9.34635	12.78629	11.39087
12.5	10.10043	5.34139	11.04101	9.45046	14.27223	11.92755
15	9.64646	5.43572	12.69248	10.45489	15.87106	13.08837
17.5	10.53696	5.6018	12.92304	10.92299	16.72524	13.31162
20	10.16162	5.58782	12.40919	10.27615	16.14499	13.38257

Table 9

Values of *M* parameter (λ_1= 585.3 nm, j≠1) for different values of electric current in discharge (P_{90} component, B=ct).

I(mA)	Parameter *M*=$I_{585.24\,nm}/I_{\lambda j}$ for 2 Magnets (B=ct); P_{90}; Diaphragm 21.5 and different λ_j (nm)					
	λ_j= 614.30 nm	640.22 nm	692.94 nm	703.24 nm	**717.39 nm**	724.51 nm
5	9.33174	4.95298	10.05662	8.4444	12.57519	10.11817
7.5	9.31727	5.26845	10.77271	9.44633	13.57909	12.35581
10	9.16054	5.33088	10.50022	9.19931	13.90867	11.29915
12.5	10.00877	5.48223	11.98446	10.05816	16.00393	12.98817
15	10.80639	5.57842	13.26549	10.91883	17.83513	14.07197
17.5	10.70269	5.71375	14.03374	11.31232	19.56336	15.51163
20	11.41587	5.64153	17.23651	11.55013	19.97051	17.71854
21.5	11.56693	5.90655	17.58582	12.06304	22.18475	18.07115

The figures 19÷26, which were plotted based on the calculations contained in Tables 2÷9, are presented as follows:

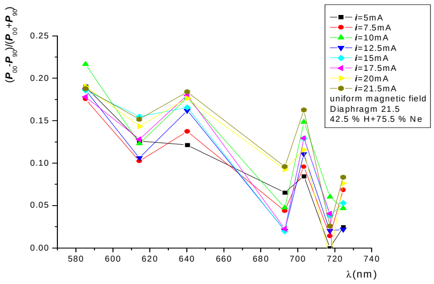

Fig. 19 - The spectral dependence of the polarization degree for different values of the electric current in discharge.

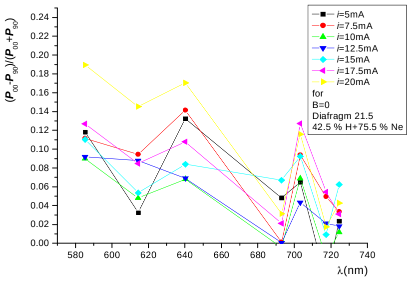

Fig. 20 - The spectral dependence of the polarization degree for different values of the electric current in discharge.

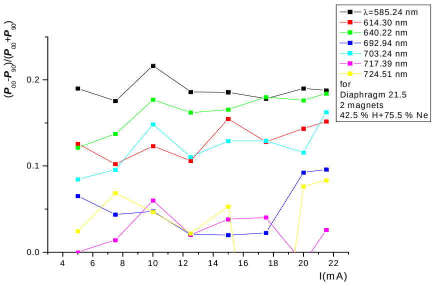

Fig. 21 - The dependence of the polarization degree on the electric current in discharge for different wavelengths.

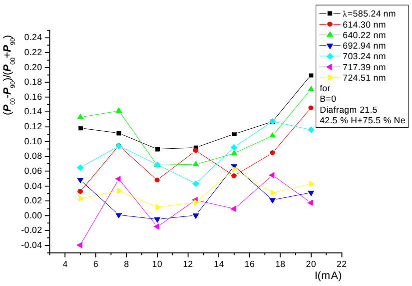

Fig. 22 - The dependence of the polarization degree on the electric current in discharge for different wavelengths.

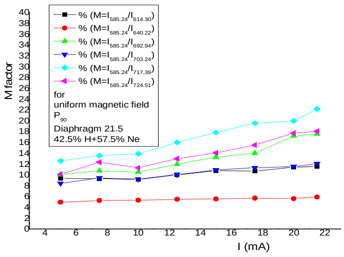

Fig. 23 - The dependence of *M*-parameter on the electric current in discharge (λ_1= 585.3 nm, j≠1, and P_{90} component of electric vector).

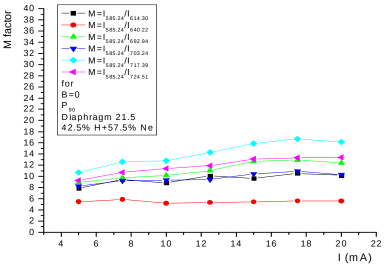

Fig. 24 - The dependence of *M*-parameter on the electric current in discharge (λ_1= 585.3 nm, j≠1, and P_{90} component of electric vector).

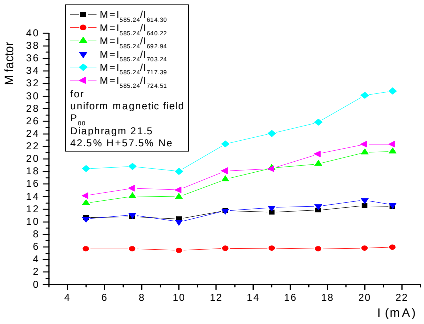

Fig. 25 - The dependence of *M*-parameter on the electric current in discharge (λ_1= 585.3 nm, j≠1, and P_{00} component of electric vector).

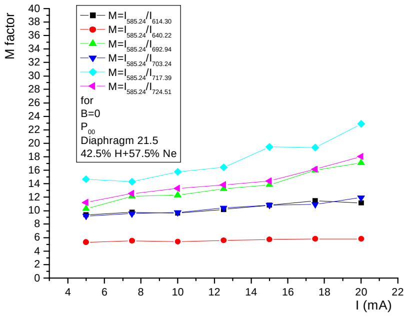

Fig. 26 - The dependence of *M*-parameter on the electric current in discharge (λ_1= 585.3 nm, j≠1, and P_{00} component of electric vector).

Figures 19 and 20 show the dependence of ρ, the polarization degree, on the electric current in discharge for different values of the wavelength, and figs. 21 and 22 the dependence on the wavelengths, for different values of the electric current in discharge. In both cases, the values of the polarization degree are slightly large when is applied a constant magnetic field (ρ= 0÷0.216) compared with the case without magnetic field (ρ=0÷0.189). The figures 19÷20 show that the maximum degree of polarization is reached by the dominant spectral line λ_1=585.3 nm. Hence, when is applied a magnetic field, the polarization degree increases up to a maximum value, corresponding to *I*=10 mA.

In the case without magnetic field, the polarization degree has an opposite behaviour: first it decreases, reaching a minimum at a value of *I* =13 mA, and after that has a continuous increase in the range of variation for the electric current in discharge.

The value of polarization degree for each other spectral line depending on the electric current in discharge is lower than the one for the dominant line.

As we have already explained in our recent work [7-9], this singular aspect of the graphs 21 and 22, that present the dependence of the polarization degree of each wavelength on the electric current (practically, on the energy dissipated in discharge), consisting in multiple points of maximum and minimum, indicates the energy resonant character of the M-effect generating mechanisms.

Consider now the figs. 23÷26, in which is showing the dependence of the *M*-parameter on the electric current in discharge for the two components of the electric vector, namely P_{00} and $P_{90.}$ Here, the *M*-parameter is calculated by dividing the intensity of the dominant line λ_1=585.3 nm to intensity of each other spectral lines belonging to the neon spectrum, considered as reference lines.

The comparative analyze of these graphs provides us the information that there is a value of the *M*-parameter that remains nearly constant with the increase of the electric current in discharge, namely the one calculated having as reference line λ_1=640.2 nm. For all other reference spectral lines, the values of the *M* parameter have, generally, an increasing trend related to the increase of the electric current in discharge. It means that for all these spectral lines, except the line with λ=640.22 nm, the substantial population of the $2p_1$ energy level is realized on account of their depopulation. It is interesting that the line λ=640.22 nm has an equal ΔE defect energy reaction with the one of the dominant line, but a probability of emission less than for this one. This process is carried out by the collision reactions of the type indicated in eqs. 3÷7. The spectral line with the larger transfer of energy to the emission of the dominant spectral line is λ=717.39 nm; which is why its polarization degree is the lowest of all , while the corresponding values of the *M* parameter are the biggest (in both cases, with or without magnetic field). Second in order of contribution are the lines with the wavelengths of 724.51 nm and 692.94 nm.

As in the other cases, the values of *M* parameters increase by the application of the magnetic field: for B≠0, *M*=5.83÷30.89 and for B=0, *M*=5.39÷22.92 (concerning the P_{00} component of electric vector) and for B≠0, *M*=4.95÷22.16 and for B=0, *M*=5.4÷16.2 (concerning the P_{90} component of electric vector).

Consider now the case of a spatially variable magnetic field applied on the discharge device and a diaphragm size of 25 mm that is synthesized by the data from the Tables 10÷17, as follows:

Table 10

Dependence of ρ, polarization degree, on the electric current in discharge for different spectral lines wavelengths (B≠0).

λ(nm)	Polarization degree $(P_{00}-P_{90})/(P_{00}+P_{90})$ for 42.5%H+57.5%Ne; B≠ constant (1 Magnet); Diaphragm 25							
	I= 4mA	5mA	7.5mA	10mA	12.5mA	15mA	17.5mA	18.5mA
585.24879	0.16254	0.18698	0.2211	0.23957	**0.24394**	0.22157	0.18975	0.15246
614.30626	0.10992	0.12101	0.13239	0.16135	0.16661	0.16371	0.13394	0.12022
640.2248	0.11841	0.1382	0.18586	0.19361	**0.19677**	0.17693	0.15192	0.13975
692.94673	0.02107	0.01185	0.05904	0.06889	0.04229	0.05383	0.0651	0.04547
703.24131	0.07364	0.11182	0.13906	0.16939	0.16067	0.16329	0.14707	0.10609
717.39381	0.09158	0.0426	0.00878	0.03811	-5.2356E-4	0.00679	0.03566	0.00624
724.51666	0.04133	0.02063	0.02021	0.04394	0.07152	0.05439	0.08301	0.04553

Table 11

Dependence of ρ, polarization degree, on the electric current in discharge for different spectral lines wavelengths (B=0).

λ(nm)	Polarization degree $(P_{00}-P_{90})/(P_{00}+P_{90})$ for 42.5%H+57.5%Ne for B=0; Diaphragm 25						
	I= 4mA	5mA	7.5mA	10mA	12.5mA	15mA	17.5mA
585.24879	**0.1395**	0.11101	0.09723	0.07973	0.06841	0.07425	0.09747
614.30626	0.10357	0.08939	0.06618	0.06174	0.05013	0.05352	0.08534
640.2248	**0.11634**	0.08029	0.08644	0.07997	0.05901	0.07223	0.09938
692.94673	0.01324	0.02398	0.00702	0.03439	0.03369	0.03562	0.02425
703.24131	0.04672	0.05941	0.08364	0.06727	0.0397	0.08775	0.10035
717.39381	0.00558	0.01115	0.01603	-0.0077	-0.02088	0.04865	0.00823
724.51666	0.03053	0.02204	-0.00308	0.00964	-0.00387	0.05803	0.05199

Table 12

Dependence of ρ, polarization degree, on the wavelengths spectral lines for different values of electric current in discharge (B≠0).

I(mA)	Polarization degree $(P_{00}-P_{90})/(P_{00}+P_{90})$ for 42.5%H+57.5%Ne; B≠ constant (1 Magnet); Diaphragm 25						
	λ_1=585.24nm	614.30 nm	640.22 nm	692.94 nm	703.24 nm	717.39 nm	724.51 nm
4	0.16254	0.10992	0.11841	0.02107	0.07364	0.09158	0.04133
5	0.18698	0.12101	0.1382	0.01185	0.11182	0.0426	0.02063
7.5	0.2211	0.13239	0.18586	0.05904	0.13906	0.00878	0.02021
10	0.23957	0.16135	0.19361	0.06889	0.16939	0.03811	0.04394
12.5	0.24394	0.16661	0.19677	0.04229	0.16067	-5.2356E-4	0.07152
15	0.22157	0.16371	0.17693	0.05383	0.16329	0.00679	0.05439
17.5	0.18975	0.13394	0.15192	0.0651	0.14707	0.03566	0.08301
18.5	0.15246	0.12022	0.13975	0.04547	0.10609	0.00624	0.04553

Table 13

Dependence of ρ, polarization degree, on the wavelengths spectral lines for different values of electric current in discharge (B=0).

I(mA)	Polarization degree $(P_{00}-P_{90})/(P_{00}+P_{90})$ for 42.5%H+57.5%Ne for B=0; Diaphragm 25						
	λ_1=585.24nm	614.30 nm	640.22 nm	692.94 nm	703.24 nm	717.39 nm	724.51 nm
4	0.1395	0.10357	0.11634	0.01324	0.04672	0.00558	0.03053
5	0.11101	0.08939	0.08029	0.02398	0.05941	0.01115	0.02204
7.5	0.09723	0.06618	0.08644	0.00702	0.08364	0.01603	-0.00308
10	0.07973	0.06174	0.07997	0.03439	0.06727	-0.0077	0.00964
12.5	0.06841	0.05013	0.05901	0.03369	0.0397	-0.02088	-0.00387
15	0.07425	0.05352	0.07223	0.03562	0.08775	0.04865	0.05803
17.5	0.09747	0.08534	0.09938	0.02425	0.10035	0.00823	0.05199

Table 14

Values of *M* parameter (λ_1= 585.3 nm, i≠1) for different values of electric current in discharge (P_{00} component, B≠0).

I(mA)	Parameter $M = I_{585.24\ nm}/I_{\lambda i}$ for B≠ constant (1 Magnet) Diaphragm 25; P_{00} and different λ_j (nm)					
	λ_j= 614.30 nm	640.22 nm	692.94 nm	703.24 nm	**717.39 nm**	724.51 nm
4	9.51939	5.38736	14.56968	10.98857	17.86422	14.76867
5	9.66482	5.51302	16.03389	11.60891	20.07386	16.48215
7.5	10.37833	5.47827	17.32133	11.86135	24.32898	18.46513
10	10.66929	5.67763	18.81661	12.48342	25.35241	20.26346
12.5	10.81261	5.6387	21.34257	12.74784	28.65427	21.73262
15	10.69069	5.64291	21.48668	12.99823	30.56305	23.01485
17.5	10.76342	5.66224	22.53047	13.02759	31.07494	23.00337
18.5	10.98551	5.58872	22.26169	13.5585	**31.7416**	23.25634

Table 15

Values of *M* parameter (λ_1= 585.3 nm, i≠1) for different values of electric current in discharge (P_{00} component, B=0).

I(mA)	Parameter $M = I_{585.24\ nm}/I_{\lambda i}$ for B=0; P_{00}; Diaphragm 25 and different λ_j (nm)					
	λ_j= 614.30 nm	640.22 nm	692.94 nm	703.24 nm	**717.39 nm**	724.51 nm
4	9.15991	5.42155	13.61441	10.60289	18.88194	14.07712
5	9.57291	5.47687	15.10205	10.94544	18.95486	15.26808
7.5	9.76069	5.39914	16.47191	10.93793	21.13361	17.75298
10	9.84719	5.39208	16.50623	11.97369	23.37721	18.95531
12.5	10.26998	5.46719	18.415	12.56779	24.39054	20.24299
15	10.54139	5.54273	18.66177	12.41301	26.26576	18.91936
17.5	10.39495	5.54915	21.17832	12.53449	**29.22154**	21.43205

Table 16

Values of *M* parameter (λ_1= 585.3 nm, i≠1) for different values of electric current in discharge (P_{90} component, B≠0).

I(mA)	Parameter $M = I_{585.24\ nm}/I_{\lambda j}$ for B≠ constant (1 Magnet); Diaphragm 25; P_{90} and different λ_j (nm)					
	λ_j= 614.30 nm	640.22 nm	692.94 nm	703.24 nm	**717.39 nm**	724.51 nm
4	8.55129	4.92337	10.9473	9.17446	15.4634	11.55633
5	8.44259	4.98727	11.24593	9.95374	14.97319	11.76513
7.5	8.64033	5.08989	12.43529	10.01017	15.79358	12.26429
10	9.06374	5.15559	13.25151	10.78168	16.78525	13.57357
12.5	9.1995	5.10628	14.11762	10.71447	17.3977	15.24392
15	9.47967	5.1418	15.2499	11.5158	19.74224	16.35294
17.5	9.59747	5.23772	17.48097	11.93177	22.72811	18.50243
18.5	10.28672	5.44533	17.93132	12.33789	**23.63632**	18.73455

Table 17

Values of M parameter (λ_1= 585.3 nm, i≠1) for different values of electric current in discharge (P_{90} component, B=0).

I(mA)	Parameter M=$I_{585.24\ nm}/I_{\lambda j}$ for B=0; P_{90}; Diaphragm 25 and different λ_j (nm)					
	λ_j= 614.30 nm	640.22 nm	692.94 nm	703.24 nm	**717.39 nm**	724.51 nm
4	8.51553	5.17214	10.5569	8.79171	14.41903	11.30014
5	9.16365	5.14751	12.67793	9.86446	15.50886	12.76757
7.5	9.16921	5.28288	13.74428	10.64231	17.95492	14.51691
10	9.49732	5.39461	15.07042	11.67733	19.62013	16.47015
12.5	9.90002	5.36495	17.1764	11.86452	20.39751	17.51478
15	10.11151	5.52023	17.2701	12.75504	**24.94997**	18.31293
17.5	10.14372	5.57058	18.28233	12.60766	24.4302	19.55837

In figures 27÷30 are plotted the graphs presenting the dependence of ρ, polarization degree, on the values of electric current in discharge and of the wavelengths exposed in Table 2, respectively:

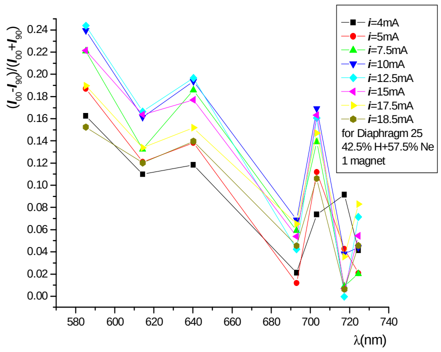

Fig. 27 - The spectral dependence of the polarization degree for different values of the electric current in discharge.

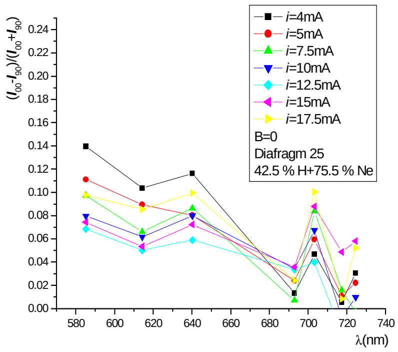

Fig. 28 - The spectral dependence of the polarization degree for different values of the electric current in discharge.

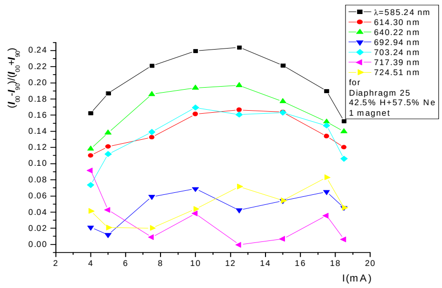

Fig. 29 - The dependence of the polarization degree on electric current in discharge for different wavelengths.

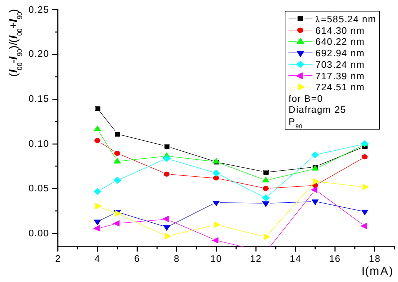

Fig. 30 - The dependence of the polarization degree on electric current in discharge for different wavelengths.

The interpretations of figs. 19÷22 are valid also for the graphs from the figs. 27÷30, because the latter are having the same aspect. However, there are some differences, which clearly appear in the fig. 29. Here, the polarization degree of the dominant spectral line has no more a periodical aspect, like in fig. 21, but a real curve shape, with the maximum value of ρ=0.24 for I=12.5 mA, when B=variable. The lines λ=614.3, 640.22, 692.94 and 703.24 nm have a similar shape, exhibiting a lower value for their corresponding polarization degrees than the one of the dominant spectral line.

The figures 31÷34 are presenting the dependence of *M*, monochromatization parameter, on electric current in discharge, calculated for the two component of electric vector, P_{00} and P_{90}.

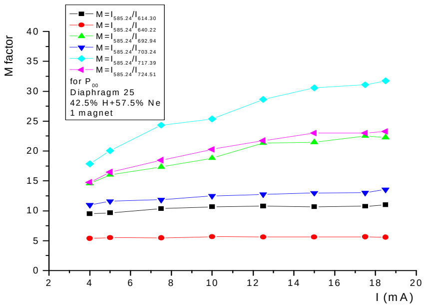

Fig. 31 - The dependence of *M*-parameter on electric current in discharge (λ_1= 585.3 nm, j≠1, and P_{00} component of electric vector).

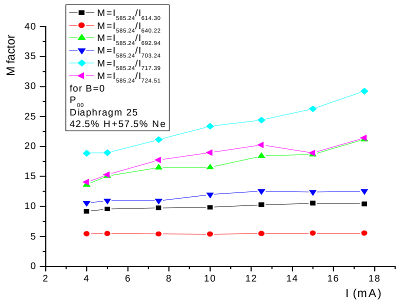

Fig. 32 - The dependence of *M*-parameter on electric current in discharge (λ_1= 585.3 nm, j≠1, and P_{00} component of electric vector).

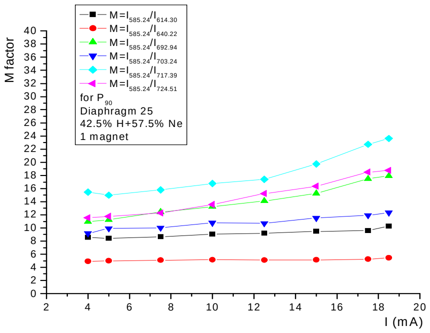

Fig. 33 - The dependence of *M*-parameter on the electric current in discharge (λ_1= 585.3 nm, j≠1, and P_{90} component of electric vector).

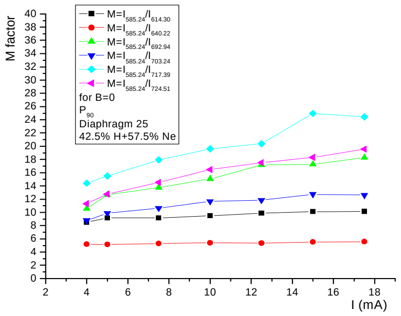

Fig. 34 - The dependence of *M*-parameter on the electric current in discharge (λ_1= 585.3 nm, j≠1, and P_{90} component of electric vector).

The deductions made for explaining figures 23÷26 can be applied for the figs. 31÷34. However, we must notice that the values of *M* parameters calculated over all range of spectral lines intensities, are comparable in the two cases: with or without magnetic field applied. So, related to λ=717.39 nm, for B=variable, *M*=5.38÷31.74, and for B=0, *M*=5.39÷29.22 (concerning the P_{00} component of electric vector), and for B=variable, *M*=4.92÷23.63, and for B=0, *M*=5.14÷24.43 (concerning the P_{90} component of electric vector). This means that a variable magnetic field applied on discharge device, unlike the case of a constant magnetic field, causes no increased values of the *M*-parameter, only of the polarization degree.

4. CONCLUSIONS

In this work, we have treated the spectral emission behaviour of the most remarkable gas mixture plasma, within the frame of the M-effect, under different experimental conditions: zero magnetic field, constant magnetic field and spatially variable magnetic field, respectively. Obviously, we are talking about the combination of neon and molecular hydrogen.

Due to the atomic nature of the generating mechanism that underlies appearance of this effect, we have been led to analyze mostly of the important lines belonging to the neon emission spectrum, by their reporting directly to the best monochromatized line, namely λ=585.24 nm. The large number of experimental data has provided us the following conclusions: when there is a constant magnetic field applied to the discharge gap, the values of both monochromatization-parameters and polarization-degrees, are significantly bigger as against the case when there is no magnetic field. Conversely, the presence of a variable magnetic field, acting in plasma space, causes no notable changes in monochromatization parameter (M) and polarization degree values (ρ).

Now, in the end of this study, we shall briefly present our results in the following table:

Table 18

Resuming data

λ_1 (nm)	λ_j ($j\neq1$) (nm)	Diaphragm (mm)	I (mA)	B (T)	P_{00} (N/C)	P_{90} (N/C)	M_{max}	ρ_{max}
585.24	-	21.5	20.0	0	-	-	-	0.18
585.24	-	21.5	10.0	ct.	-	-	-	0.21
585.24	717.39	21.5	19.0	0	X	-	22.88	-
585.24	717.39	21.5	21.5	ct	X	-	30.80	-
585.24	717.39	21.5	17.5	0	-	X	16.75	-
585.24	717.39	21.5	21.5	ct	-	X	22.18	-
585.24	-	25.0	12.5	Variable	-	-	-	0.24
585.24	-	25.0	12.5	0	-	-	-	0.13
585.24	717.39	25.0	18.5	Variable	X	-	31.74	-
585.24	717.39	25.0	17.5	0	X	-	29.22	-
585.24	717.39	25.0	18.5	Variable	-	X	23.63	-
585.24	717.39	25.0	15.0	0	-	X	24.94	-

This paper presents a complete picture describing the two subsequent phenomena, the monochromatization and the polarization of visible light respectively, regarding the principal spectral lines emitted by the neon and hydrogen gas mixture plasma, in the specified experimental conditions. Further, the study can be extended to other electronegative-electropositive gas mixtures; the interest's being both scientifically and in practical applications.

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