Journal of Engineering and Applied Sciences 13 (Special Issue 13): 10780-10784, 2018
ISSN: 1816-949X


# Effect of Gamma Radiation on the Spectral Properties of Laser Organic Dye

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**Abstract:** In present research, the effect of gamma radiation on the absorption and fluorescence spectra of laser organic dye (Rhodamine B) dye which have dissolved in ethanol at different concentrations were studied. The optical properties (absorption, transmittance, linear absorption index, linear refractive index and energy gap) were calculated as well as calculation the lifetime and quantum efficiency of the fluorescence. The results shows the increasing of absorption and fluorescence values after radiation due to decreasing of the energy gap.

**Key words:** Rhodamine B, gamma radiation, spectral properties absorption, fluorescence, laser dyes, energy

## INTRODUCTION

Gamma rays is electromagnetic radiation which arise from the radioactive decay of atomic nuclei. It consists of photons in the highest observed range of photon energy. Paul Villard, a French chemist and physicist, discovered gamma radiation in 1900 while studying radiation emitted by radium. In 1903, Ernest Rutherford named this radiation gamma rays (Aharonian *et al*., 2001). Gamma rays are electromagnetic radiation of nuclear origin with wavelengths in the region of $3\times10^{-11}$-$3\times10^{-13}$ m. It is more convenient to describe the radiation in terms of energy than in terms of wavelength, since, the energy absorbed from the radiation is basically of interest, then the terms of energy of these wavelength range becomes approximately 40-4 MeV. Cobalt-60 is one of the most widely used sources of gamma radiation, gives equal numbers of gamma photons of energy 1.332 and 1.173 MeV (El-Kader, 2007).

Laser dyes are large organic molecules with molecular weights of few hundred mu. When one of these organic molecules is dissolved in a suitable liquid solvent (such as ethanol, methanol or an ethanol-water mixture) it can be used as laser medium in a dye laser. Generally, laser dyes are complex molecules containing a number of ring structures which lead to complex absorption and emission spectra. The laser dyes can be categorized into different classes by virtue of their structures that are chemically similar. Common examples are the coumarins, xanthenes and pyrromethenes. The structure and composition of the molecule have an important influence on spectral emission. However, there are dozens of laser dyes that can be used to span continuously the emission spectrum from the near ultraviolet to the near infrared (Duarte, 2003). Laser dyes, either as solutions or solid are the active medium in pulsed and CW dye lasers as well as ultrafast shutters for Q-switching and passive mode-locking. Thus, a variety of dyes is necessary to cover the entire spectral range (Shanshal, 2005).

### Theoritical part

**Linear optical properties:** When light interacts with matter the optical processes observed in solid state materials can be classified as reflection, refraction, absorption and transmission (Abad, 2007). The intensity $I_o$ of the beam incident to the surface of the solid medium must equal the sum of the intensities of the transmitted, absorbed and reflected beams, denoted as $I_T$, $I_A$ and $I_R$, respectively (Fox, 2006; Kittel, 2005):

$$I_o = I_T + I_A + I_R \quad (1)$$

$$T+A+R = 1 \quad (2)$$

where, T, A and R are transmittance, absorbance and reflectance, respectively. The linear absorption coefficient ($\alpha_o$) and linear refractive index ($n_o$) can be found from transmittance spectrum according to the following Eq. (Ali, 2008):

$$\alpha_o = \frac{\ln(1/T)}{t} \quad (3)$$

$$n_o = \frac{1}{T} + \left[\left(\frac{1}{T} - 1\right)\right]^{1/2} \quad (4)$$

Where:
t = Thickness of sample
T = The Transmittance

Transmittance is the relative percent of light that passes through the solvent. Thus, if half

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the light is transmitted, we can say that the solution has 50% transmittance (Eslamifar, 2013):

$$T\% = \frac{I}{I_o} \times 100\% \tag{5}$$

Where:

$I_o$ = The Intensity of the incident light beam
$I$ = The Intensity of the light coming out of the solvent

The relationship between Transmittance (T) and Absorbance (A) can be expressed by the following (Dehghani *et al*., 2015):

$$A = \log_{10}\left(\frac{1}{T}\right) \tag{6}$$

**Fluorescence quantum yield:** The fluorescence quantum yield $\Phi_F$ is one of the key photophysical quantities which calculated from the relationship (Kuroda *et al*., 2009):

$$\Phi_F = \frac{\text{Number of photon emitted}}{\text{Number of photon absorbed}} \tag{7}$$

where number of photons emitted and absorbed is the area integration under the fluorescence and absorption spectrum, respectively. Then the fluorescence life time is obtained by using the following Eq. 8 (Kuroda *et al*., 2009):

$$\tau_F = \Phi_F \tau_{FM} \tag{8}$$

The stokes shift $\Delta\lambda$ is the gap between the maximum of the first absorption band and the maximum of the fluorescence spectrum (expressed in wavenumbers or wavelength):

$$\Delta\lambda = \lambda_{flu} - \lambda_{abs} \tag{9}$$

This important parameter can provide information on the excited states for instance, when the dipole moment of a fluorescent molecule is higher in the excited state than in the ground state, the stokes shift increases with solvent polarity. The consequences of this in the estimation of polarity using fluorescent polarity probes. From a practical point of view, the detection of a fluorescent species is of course easier when the stokes shift is larger (Birks, 1970).

## MATERIALS AND METHODS

**Rhodamine B organic dye:** RB is a synthetic organic compound available as a dark green crystalline solid. Belong to xanthene family. The molecular formula ($C_{28}H_{31}N_2O_3Cl$), molar mass (479.02 g/mol), solubility in ethanol at 27°C and the structural formula is as shown Fig. 1 (Kurian *et al*., 2005).

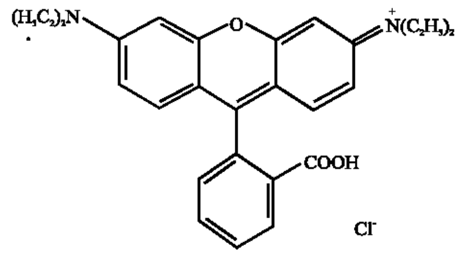


Fig. 1: Chemical structure of Rhodamine B

**Solvent:** Ethanol has been used as a solvent private analyzes spectral purity with a high 99.99% of the highest purity available. It was used as a solvent for both Laser dyes and has solvent at room temperature.

**Radiation source:** In this study, Cobalt-60 ($Co^{60}$) was used as a source of gamma radiation and manufactured in 9/2012 and has a half-life 5.27 years with two energies 1.173 and 1.332 MeV. The activity of the radioactive source is 74 kBq at 1 month. Due to its high activity which allows the emitted gamma radiation to penetrate through almost all materials, the radioactive source is centrally placed inside shield of lead with the samples being directly arranged around it at a distance of 5 cm.

**Preparation of solutions:** To prepare a solution of Rhodamine B dye at a concentration $1\times10^{-3}$ M, we will dissolve 0.0048 g of the dye powder in the volume 10 $cm^3$ of ethanol solvent according to the relationship:

$$W_m = \frac{C \times V \times M.W}{1000} \tag{10}$$

Where:

$W_m$ = The Weight of the dye needed to get the desired concentration
C = The desired Concentration
V = Volume of the solvent
M.W = Molecular Weight of dye used in g/mol

To prepare a different concentrations of the dye solution $3\times10^{-6}$, $5\times10^{-6}$, $3\times10^{-6}$ M From the concentration prepared, the following relationship, called the dilution relationship is used:

$$C_1V_1 = C_2V_2 \tag{11}$$

Where:

$C_1$ = Main Concentration
$C_2$ = New Concentration which calculated from Eq. 11
$V_1$ = The Volume before dilution
$V_2$ = The Volume after dilution

## RESULTS AND DISCUSSION

The spectral properties (absorption and florescence spectra) of all samples prepared for different

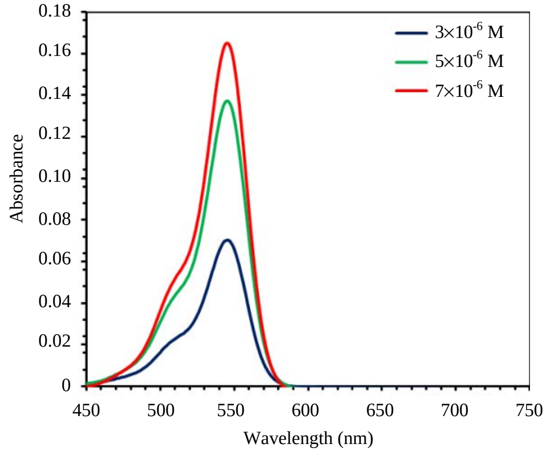


Fig. 2: Curves of the absorbance spectrum for RB dye for different concentration before irradiation

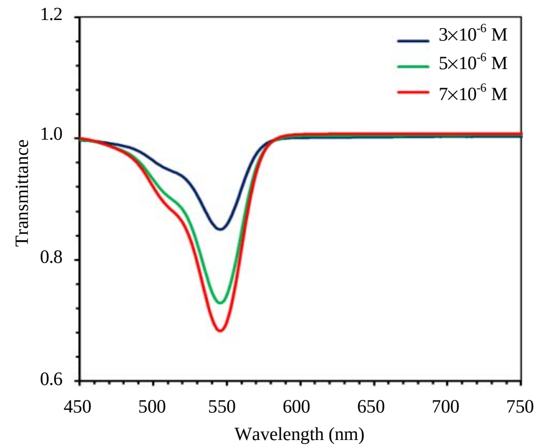


Fig. 4: Curves of the transmittance spectrum for RB dye for different concentration before irradiation

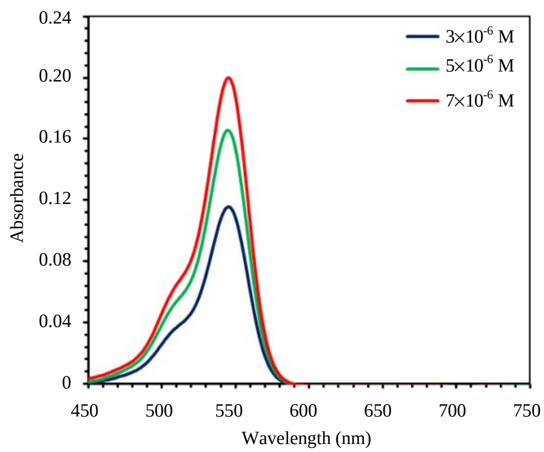


Fig. 3: Curves of the absorbance spectrum for RB dye for different concentration after irradiation

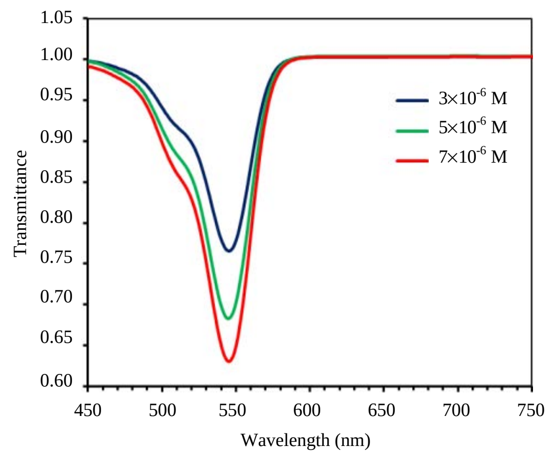


Fig. 5: Curves of the transmittance spectrum for RB dye for different concentration after irradiation

Table 1: The most important properties of samples prepared before and after irradiation

| States/C(M) | $\lambda_{max}$ (nm) | A | T | $E_g$ (eV) | $\alpha_o$ ($cm^{-1}$) | $n_o$ |
|---|---|---|---|---|---|---|
| **Before irradiation** | | | | | | |
| $3\times10^{-6}$ | 545 | 0.070 | 0.859 | 3.22 | 0.162 | 1.795 |
| $5\times10^{-6}$ | 545 | 0.137 | 0.744 | 3.19 | 0.316 | 2.310 |
| $7\times10^{-6}$ | 545 | 0.165 | 0.701 | 3.17 | 0.380 | 2.531 |
| **After irradiation** | | | | | | |
| $3\times10^{-6}$ | 545 | 0.115 | 0.766 | 3.18 | 0.266 | 2.144 |
| $5\times10^{-6}$ | 545 | 0.165 | 0.683 | 3.14 | 0.381 | 2.533 |
| $7\times10^{-6}$ | 545 | 0.200 | 0.630 | 3.11 | 0.460 | 2.814 |

concentrations $3\times10^{-6}$, $5\times10^{-6}$, $7\times10^{-6}$ M before and after exposure to gamma ray from $Co^{60}$ source (for 30 days) were calculated. Figure 2-5 shows the curves of absorbance and transmittance spectra before and after irradiation for different concentrations, from these Fig. 2-5 and Table 1 is observed that the increased concentration increases absorbance and decreases transmittance, this is compatible with Beer-Lambert Law. In addition, absorbance and transmittance are increased when irradiated by gamma rays for all concentrations, this is due to a decrease in the energy gap. The decrease in the value of the energy gap can be explained by the fact that irradiation has created donor levels within the energy gap. The linear absorption coefficient and linear refractive index were calculated from Eq. 3 and 4. Table 1 shows the most important properties of samples prepared before and after irradiation, it is noted from the table that increasing concentration leads to increasing values of linear absorption coefficient and linear refractive index and also notes that irradiation leads to an increase in the values of these and the same reasons for the previous reason.

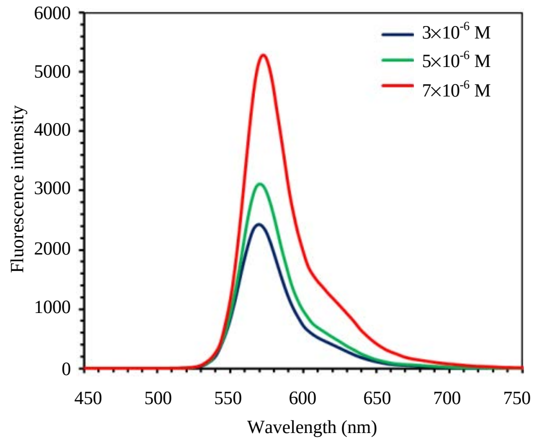


Fig. 6: Curves of the fluorescence spectrum for RB dye for different concentration before irradiation

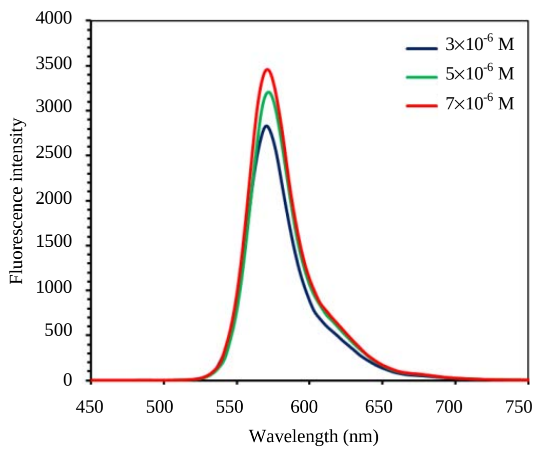


Fig. 7: Curves of the fluorescence spectrum for RB dye for different concentration after irradiation

Figure 6 and 7 shows the fluorescence spectra of RB dye for different concentrations $3\times10^{-6}$, $5\times10^{-6}$and $7\times10^{-6}$ M dissolved ethanol at room temperature before and after. From these figure is observed that the intensity of fluorescence spectra increases with concentration of dissolved dye in solvent used, it also increases with irradiation by gamma radiation, this is due to increased absorption. From the absorption and fluorescence spectrum curves were calculated the fluorescence quantum yield and fluorescence lifetime as show in the Table 2. From the Table 2 is observed that increasing the dye concentration will increase the fluorescence lifetime and decrease the fluorescence quantum yield. Moreover, increased radiation will increase the fluorescence quantum yield, this is very important for organic dyes used in dye lasers.

Table 2: The parameters of spectral properties of samples prepared before and after irradiation

| States/C(M) | $\lambda_{max}$ (nm) | Fluorescence intensity | $\tau_f$ (nsec) | $\Phi_F$ |
|---|---|---|---|---|
| **Before irradiation** | | | | |
| $3\times10^{-6}$ | 570 | 2424 | 0.08 | 0.84 |
| $5\times10^{-6}$ | 570 | 3113 | 0.12 | 0.78 |
| $7\times10^{-6}$ | 570 | 3465 | 0.14 | 0.73 |
| **After irradiation** | | | | |
| $3\times10^{-6}$ | 571 | 2828 | 0.12 | 0.88 |
| $5\times10^{-6}$ | 571 | 3201 | 0.15 | 0.81 |
| $7\times10^{-6}$ | 571 | 5261 | 0.20 | 0.78 |

## CONCLUSION

From this study, we conclude that increasing the concentration of dissolved organic dyes in organic solvents will increase absorption and decrease transmittance and thus, increase linear refractive and absorption coefficients, this is compatible with Beer-Lambert law. It was also observed that increased irradiation of gamma radiation leads to increase the quantitative fluorescence quantum yield, thus, obtain organic dye can be used in dye lasers and high efficiency.

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