Study the Effect of Concentration on the Evolution of Far-Field Diffraction Patterns of Bromocresol Purple and Congo Red Solution

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Abstract. Experimental evolution of the diffraction pattern of Bromocresol Purple (BCP) and Congo Red (COGR) Solutions, by diffraction ring technique under CW laser illumination is present. The two azo dyes, COGR dye and COGR dye, were studied for their absorbance spectra, as well as the diffraction rings experimental. The measurement rings were performed when the incident beam propagates through a quartz cell containing dye. Many diffraction rings were observed on the sensitive screen. Among the results we obtained are the diffraction rings at 0.07mM concentration, where the number of rings was 4 at the power of the 50 mW laser beam for the Bromocresol dye and three rings in the congo red dye. The nonlinear refractive index for the Bromocresol dye and congo red dye are found to be in the order of 0.11×10^{-8} cm²/Watt, 3.093×10^{-8} cm²/Watt, respectively. The efficiency of the ring pattern was found to depend on the concentration of the dye and the power of the laser.

Keywords: azo dye; diffraction ring; refractive index; relative phase shift; laser.

1. Introduction

The field of searching for optical materials that exhibit nonlinear optical properties has witnessed wide popularity, due to a large number of applications that rely on nonlinear optical materials [1-4] and the importance of these applications in terms of the high demand for them. Practical applications include, but are not limited to, optical communications that rely on optical fibers [5-8] or photon fibers [9], optical power limiters [10], and integrated optics that include optical information processing [11], perfect optical switches [12] optical modulation [13] and photosensitizer [14]. The optical materials that exhibit nonlinear effects are split into two parts, some of which are inorganic materials, such as volumetric crystals [15] that are suitable for some photon devices because they have high quality, good mechanical and chemical stability and have large nonlinear optical coefficients. However, their high cost and difficulty in adapting them to the devices made researchers find alternatives to them. The organic nonlinear optical materials, such as dyes and polymers, become a wide field of research due to their low-cost and ease of adaptation to the required applications in addition to their large non-linear transactions, wide range and characteristic [16]. The best in it can be mixed with other materials to obtain a new material with high non-linear characteristics [17]. As well as the stability of their chemical and optical properties under normal...
conditions and the high permeability of the largest number of wavelengths and its great resistance to damage to the high intensity of light and the most important characteristic of it is that it possesses a third-order optical effect [18-20].

Among those optical materials that have become an arena for the search for non-linear characteristics are the azo dyes [21], which are distinguished by their containment of a double nitrogen group. Azo dyes are prepared chemically in two ways, one of which produces the corresponding iso-benzene compounds, which we obtain by reducing the nitrobenzene compounds in the presence of zinc. The second produces the asymmetric iso-benzene compounds which are reduced by the reduction of nitro compounds to nitrous by the reaction of the estate [22]. Both methods lead to the formation of a double covalent cluster containing an electron donor and a host group. Azo dyes have distinctive characteristics as they include a wide range of colors (i.e. wide wavelengths), their colors are high intensity compared to other types [23]. The simplicity of the azo dye reaction in which we obtain it, its low-cost, and interacts with water, which occurs at low temperatures, and its toxicity is not high and easy to get rid of [24]. From nonlinear optical studies that dealt with azo dyes such as malachite green [25], Congo red dye [26], Bismarck Brown Y dye [27], 2- (4-Azo) -4-Amino diphey1 Sulfone [28] and others.

There are a number of methods for measuring the nonlinear optical effect, including: mixing the four dissolved waves [29], the optical Kerr gate [30], the laser beam scanning technology on the Z-axis and others [31]. The laser beam scanning technology on the Z-axis has advantages that make it more interesting than others. These include ease of operation, interpretation of results, speed of achievement of results. In addition to the measurement of most nonlinear optical events [32]. The laser beam scanning technology is done on the z-axis in two ways, including the closed aperture and open aperture. The intensity of the light transmitted through the sample was measured of two techniques by power meter device. In addition to some other factors, such as the diameter of the laser beam, the diameter of the closed aperture, and others.

This paper provides experimental evidence of the observation of multiple diffraction rings in Congo red (azo dye) and Bromcresol purple (organic dye) dissolved in Hydroalfuran (THF) at different input power due to irradiation with 635 nm CW laser beams in the visible region. The behavior of the refractive index change, Δn, the relative phase shift, ΔΦ, and effective nonlinear refractive index, n2, have been studied.

2. Experimental work

2.1 Preparing samples

Congo red dye and Bromcresol Purple have been selected as optical material to study linear properties. Congo red dye, and form the molecular (C12H8N2O5S2), is one of azo dyes, used to stain Amyloid. This dye is red and has a molecular weight (652.7 gm / mol) but Bromcresol Purple has the molecular formula C21H16Br2O6S, and has a molecular weight (540.24 gm / mol). A basic dye and a vital colorant because it interacts with the cell’s DNA. Hydroaldfuran solvent C6H12O, which is considered a non-protein organic solvent belonging to cyclic ethers, which has the ability to dissolve many polar and non-polar compounds has been used to dissolve Congo red and BCP dye. Depending on the concentration law, dissolving 0.0013g of Congo red dye in 10 mL of Hydroaldfuran gives us a concentration of 0.2mM, but we get the same concentration when dissolving 0.001g of BCP dye. The two dyes solution will be placed at a temperature approaching 45 °C using a magnetic mixer equipped with a thermal base, after which the solution is left for a period to cool down and then filtered to get rid of residual dyes that have not completely dissolved. The filtration process was carried out in two stages, one using filter paper and the other using a device. A special filtration known as a needle filter with a diameter of 2µm. It is worth noting that applying the dilution law to a concentration of 0.2mM leads us to obtain 0.04mM and 0.07mM, which were also studied.

2.2. Absorption spectra

Each material has a special absorption spectrum through which we can know the substance when it is inside a certain mixture or alloy, so the spectroscopy device of the type reflectance Cecil reflectance-Scan CE-3055 was
used in measuring the absorbance of COGR dye red and BCP dye. Fig. 1 shows the absorbance as a function of wavelength, where the absorbance of COGR dye was close to 0.08 at the wavelength of 510 nm. As for the BCP dye, its absorption was close to 1.75 at the wavelength of 500 nm, knowing that the concentration at which the absorbance was measured was 0.07 mM. The increase in absorbance means an increase in the non-linear behavior, which we note that the absorbance of the BCP dye is much greater than the COGR dye and this is due to the presence of the Bromine component in the dye whose absorption is high, so it shows more nonlinear properties.

![Figure 1: Absorbance spectra of two dyes.](image)  

2.3. Diffraction experiment

We have used the experimental setup depicted in figure 2. A Gaussian light beam of a TEM\(_{00}\) was obtained from a CW laser tuned at 635 nm. The beam intensity of 3.05 KW/cm\(^2\) was focused by a lens of +20 cm of focal length. The laser suffused through a 0.1 cm quartz cell containing the self-defocusing BCP material or COGR material.

![Figure 2. Diffraction pattern experimental setup.](image)

The quartz cell (sample) position could be varied along the beam path and about the focal plane of the convex lens making in this way a convergent or divergent beam impinging on the dye (\(z=0\) is the position of the positive lens focal plane and \(z<0\) (\(z>0\)) the incident beam is convergent (divergent). The approximate radius of the Gaussian incident beam at the quartz cell (sample) of (32.27 \(\mu\)m) was determined using the equation [33]:

\[
D = \frac{1.22 f \lambda}{\omega}
\]
where \( f \) is the focal length of the positive lens. The devices are arranged so that the laser beam falls on the lens, which focuses the laser light on the cell and the model inside. To get the diffraction rings, the distance between the quartz cell (sample) and the screen (35x35cm) was 81.5 cm to observe and record the diffraction ring patterns. The far-field diffraction patterns were recorded by a CCD camera with an exposure time of 30 frames/second.

3. Diffraction rings

The measurements were performed after a 50 mW Gaussian laser beam was focused by a lens of +50 cm through a 1mm cell containing the self-defocusing dye at a concentration of 0.02 mM. We would find that four far-field diffraction patterns were observed on a transparent screen and collected by a cyber-shot CCD camera in the case of BCP dye, while it would display three rings on the Congo red. This means that the non-linear optical properties of the dye containing bromine are greater than the non-linear optical properties of Congo red dye, which contains the same concentration and intensity of the incident light. Furthermore, the diffraction rings are dependent on the ability of the dye molecules to absorbing the incident laser beam. This absorption provides the dye molecules with kinetic energy and as a result of the collisions, they generate thermal energy that recombines the dye material [34]. These new assemblies work on the diffraction of the laser light falling on them, and this light that has suffered diffraction will interfere with the light emitted by the dye particles (which is at the same frequency and amplitude of the incident light) so that constructive and destructive interference will occur depending on the phase angle difference between them. Thus, dark and luminous rings are formed on the screen, the number of which depends on the assemblies of the dye molecules (concentration). Figure 2 represents the number of diffraction rings of the two dyes imaged by a cyber-shot CCD camera.

The induced refractive index change, \( \Delta n \), and the effective nonlinear refractive index, \( n_2 \), for the diffraction rings number can be calculated as follows. Because the incident CW laser beam used in the experiment has a Gaussian distribution, the relative phase shift, \( \Delta \Phi \), suffered by the beam while traversing the cell thickness(sample solution), \( L' \), can be written as [34-36]:

\[
\Delta \Phi = k_w L' \Delta n
\]

To calculate the absorption coefficient, \( \alpha \), of the BCP dye solution sample or COGR dye solution sample we made use of the absorbance (A) spectrum curve Fig.1 and the following relation [37-40]:

\[
\alpha = \frac{2.303A}{L'}
\]

The wave-vector in vacuum can be written as [41]:

\[
k_w = \frac{2\pi}{\lambda}
\]

The relationship between \( \Delta \Phi \) and number of rings, \( N_r \), can be written as [42-45]:

\[
\Delta \Phi = 2\pi N_r
\]

The relationship between the main refractive index, \( n \), and \( n_2 \) can be written as follows [46-48]:

\[
n' = n_0 + \frac{n_2 I}{2}
\]

\[
n' = n_0 + \Delta n
\]

where \( n_0 \) is the background refractive index, and \( I \) is the intensity of incident laser beam. From the numerical given equations and input power of 50 mW, the value of induced refractive index change and third order \( n_2 \) are given in Table 1.
Table 1. The nonlinear value of the pattern rings

| Sample solution | $\alpha$ (cm$^{-1}$) | $N'$ | $n_2 \times 10^3$ (cm$^2$/W) | $\Delta \Phi$ | $\Delta n \times 10^{-4}$ |
|-----------------|----------------------|------|-----------------------------|---------------|--------------------------|
| COGR dye        | 0.46                 | 3    | 0.111                       | 0.32          | 0.34                     |
| BCP dye         | 7.51                 | 6    | 3.093                       | 0.65          | 0.95                     |

Figure 3. Diffraction rings for (a) COGR dye (b) BCP dye, with 0.02 mM concentrations.

3.1. The effect of concentration on diffraction rings

A purple solution of dye (BCP dye) in Hydroaldfuran solvent was chosen for this purpose. After the beam with a power of 100 mW passed through 0.07 mM BCP dye solution, the beam began to diverge into the nested array of diffraction rings, which illuminated the screen. We will find that the number of rings shown on the screen is 23 in the case of the concentration of BCP dye was 0.07 mM, but if the concentration is reduced to 0.06 mM, we will find that the number of rings will also decrease to 19 rings, the same thing happens at 0.05 mM, where the number of rings decreased to 15, and at 0.04 mM the number became 14 rings. For COGR solution, at 0.07 mM we get 20 rings which will decrease to 17 rings at 0.06 mM, 13 rings appear on the screen at 0.05 mM and, then 9 rings at 0.04 mM. The increase in the number of rings with the increase in the concentration in the case of the two dyes leads to an increase in the diameter of the outer diffraction rings due to the move of these rings away from the center of forming the rings. It should not be forgotten that the appearance of the rings also depends on the duration of the laser light shining on the dye. An increase in the exposure time to laser light leads to an increase in the number of rings, but not continuing for a long time leads to a state of saturation or collapse of the dye material. An increase in the number of rings leads to an increase in the nonlinear refractive index. Figure 3 shows the relationship between increased concentration and the number of rings.

Figure 4. Rings number as function of concentration for COGR dye and BCP dye.
Increasing the concentration means an increase in the number of molecules inside the solvent and their distribution more densely within the space occupied by the solvent [49] also the absorbance of the incident laser rays increases and this leads to an increase in the number of molecules that radiate energy with a frequency equal to the frequency of the laser light used, and this leads to an increase in the area at which interference occurs which leads to diffraction rings [50]. This clearly means that increasing the number of diffraction rings and the size of the highest ring with increasing concentration results from the increased aggregation of dye molecules at the point of development at higher concentrations. The diffusivity extends to a larger area, causing more interferences leading to a greater number of rings [51].

3.2. The effect of power on diffraction rings

When the input power of the Gaussian laser was gradually increased, diffraction ring patterns were observed on the sensitive screen. We will find that increasing the power leads to an increase in the number of rings, for the BCP dye at the power of 100 mW and the concentration of 0.07 mM the number of rings was 23, but at the power of 90 mW there is 20 rings number were observed on the screen and when the power was reduced to 80 mW the number became 12 rings. We find the same effect in COGR dye, at 100 mW the number of rings was 20, and when the power was reduced to 90 mW the self diffraction rings number became 14, and 9 rings were observed at 80 mW only. This effect is constant for all the concentrations that were taken in the experiment, which are shown in Figure 4. Increasing the intensity of the incident light means giving more energy to the dye molecules inside the solution, and this causes the particles to emit more energy, which leads to a larger area of radiation interference.

![Figure 5. Laser power viz. ring number with different concentrations.](image)

4. Conclusions

With concentration of 0.07 mM for BCP dye and COGR dye. The diffraction ring technique on the two dyes led to four diffraction rings at 50 mW power in BCP dye and three rings in COGR dye. The nonlinear refractive index for the Bromocresol dye and congo red dye are found to be in the order of $0.11 \times 10^{-8}$ cm$^2$/Watt, $3.093 \times 10^{-8}$ cm$^2$/Watt, respectively. The efficiency of the ring pattern was found to depend on the concentration of the dye and the power of the laser and the dye structure. This is due to the presence of the element bromine, which improved the non-linear properties of the dye, that an increase in concentration leads to an increase in the number of diffraction rings, as well as an increase in the intensity of laser light leads to an increase in the number of diffraction rings, due to the increase in the interaction between light and matter and the participation of the largest number of dye molecules in that reaction, and this leads to an increase in nonlinear optical properties.
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