Kurdish Studies
Feb 2024
Volume: 12, No: 2, pp.4638-4654
ISSN: 2051-4883 (Print) | ISSN 2051-4891 (Online)
www.KurdishStudies.net

Received: December 2023 Accepted: January 2024
DOI: https://doi.org/10.58262/ks.v12i2.346

Tuning the Linear and Nonlinear Optical Properties of Copper Oxide Nanoparticles With Rhodamin, Methylene Blue, and Crocus Sativus

Zena Karim[1], Raid Majeed Baiee[2], Ghaleb Ali Al-Dahash[3]

Abstract

This research studied the effect of copper oxide nanoparticles (CuO NPs) on the emission and nonlinear optical properties of three dyes: rhodamine B, methylene blue, and saffron dye.The nonlinear optical response of Rhodamine B dye shows the highest nonlinear response at the impact of the 532 nm laser, where the nonlinear refractive index is large, and at the 405 nm laser, the addition of copper oxide nanoparticles, in contrast to 532 and 650 nm. Methylene blue dye shows the highest nonlinear response at 650 nm, which coincides with the absorption maximum of the dye. This dye absorbs red more effectively, which explains the increased nonlinear refraction. Interestingly, the addition of copper oxide nanoparticles increased the nonlinear response at all wavelengths. Saffron dye showed the highest nonlinear response at 405 nm laser impact, where the nonlinear refractive index is good and decreases at longer lengths.

Introduction

Nanoparticles play An important role in Electronic and biomedical applications in the fields of biosensor and nanoelectronics [1, 2]. Among these nanoparticles, noble metal nanoparticles such as silver, gold, copper and their compound have been of great importance in these applications over the past few decades due to their surface plasmon resonance (SPR) and optical characteristics [3]. pulsed laser ablation in liquid (PLAL) is becoming an attractive technique for producing nanostructures without the use of chemicals and stabilizers [4]. This technique produces a rapid and efficient of high-purity nanomaterial [4]. Moreover, PLAL offers advantages over traditional synthesis methods, enabling the generation of smaller particles with narrower size distributions [5]. Therefore, CuO nanoparticles synthesized using PLAL have attracted interest in various fields including photocatalysis, catalytic applications, and biomedical applications [6, 7]. The study of optical properties is a crucial in the field of optoelectronics. In general, optical phenomena is categorized into linear and nonlinear properties [8]. Linear optics involves the interaction between the distribution of material charge and electromagnetic radiation, leading to optical phenomenas such as absorption, reflection, and transmission [9,10]. On the other hand, nonlinear optics investigate the changes in optical properties that induced by high-intensity light. Materials that exhibiting fast and high nonlinear optical responses are particularly valuable for photonics applications [11]. Understanding nonlinear refraction is vital for applications such as photonic switching , as it influences effects

[1] University of Babylon college of Science for Women laser Physics Department, IRAQ
Email: zina.mohammed.gsci199@student.uobabylon.edu.iq
[2] University of Babylon, college of Science for Women laser Physics Department, IRAQ
[3] University of Babylon – college of Science for Women laser Physics Department- IRAQ

such as autofocus and autofocus deactivation [12]. z-scan technique has proven to be a simple and sensitive method to characterize the nonlinear refractive index and absorption of materials [13]. This technique enables the detection of spatial distortion in a light beam within an optical medium and can be modified to assess the nonlinear absorption of a material [14]. Organic dyes have many outstanding advantages such as high solubility, thermal stability, fast nonlinear response, and ease of preparation, make them suitable for various photonics applications. Until now there has been no comprehensive work presented that compares the effect of CuO nanoparticles on the linear and nonlinear optical properties of dyes. Therefore, in the current work, the CuO nanoparticles have been prepared by laser ablation method and mixed with three different dyes sperately to compare their linear and nonlinear optical properties. Organic dyes, particularly those containing unsaturated hydrocarbon compounds, are commonly used as nonlinear optical materials. These dyes possess double or triple bonds coupled chains of carbon atoms, enabling light absorption and transmission in the visible spectrum

2. Experimental part

2.1. Materials

The dyes rhodamin B (Rhb) and methylene blue (MB) were obtained from Sigma-Aldrich and used without further purification. The natural saffron dye was dissolved in water to prepare a 1 mM solution, from which lower concentration solutions were prepared by dilution. In order to study the effect of CuO nanoparticles on the linear and nonlinear optical properties of methylene blue dye, rhodamine B and saffron dye, 1 mL of CuO nanoparticles was added to 1 mL of each dye with three different concentrations sperately.

2.2. Synthesis of CuO Nanoparticles

A colloidal solution of CuO nanoparticles was synthesized by pulsed laser ablation of a pure Cu metal target (purity >98%, purchased from CBI) placed in a graduated glass beaker containing 6 mL of deionized water. The water level above the target was approximately 2 mm . The experimental setup is shown in Figure 1. The Cu target was irradiated by 1064 nm Q-switched Nd:YAG laser with a pulse duration of 10 ns at a 10 Hz repetition rate. The laser fluence was 200 mJ/cm^2.

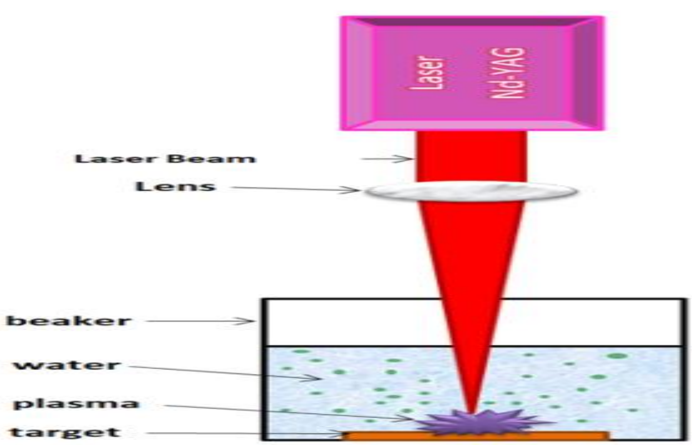

Figure 1: Experimental Setup for the Preparation of Cuo Nps by Plal.

2.3. Characterization Techniques

2.3.1 Z-Scan

Z-scanning was performed in a 1-mm-thick quartz cell using three types of diode-pumped solid-state CW lasers at wavelengths of 405, 532 and 650 nm with beam sizes of 1.28, 1.9 and 2.25 mm, respectively. The laser power was in the range of 13 to 60 mW, a telephoto lens with a focal length of 8.5 cm was used.

2.3.2 Absorption Spectrometry

The linear absorbance of the dye solutions in the range of 190–900 nm was obtained using a UV-Vis spectrophotometer (CECIL CE 7200). Sample scan curves were produced by recording the dye transmittance through a 1 mm diameter aperture located in the far field of the beam as a function of sample position. The sample was moved by an automated stage and data were collected automatically at every 15 μm. In order to check the absorbance of the dye liquid, we put a cell of quartz (cm1) thick, filled with the solvent used, in front of the beam coming from the source, and we put a second cell, the same as the first cell, filled with the dye whose linear absorbance is to be examined, in front of the beam coming from the source as well. After the absorbance values have been examined and recorded in the device, we divide all the results recorded from the absorbance test device by 3 because they are the highest values recorded by the device.

2.3.3 Fluorescence Spectrometry

In order to examine the emission spectra of the used samples, a laser induced emission spectrum examination device was used, by shining a laser beam with a specific wavelength on the sample and using an optical fiber to transfer the fluorescence spectrum to a device measuring the intensity and wavelength of the emitted spectrum, the TID High Resolution Cooled Spectrometer.The dye was excited using a continuous wave laser with a wavelength of 554 nm. The figure shows that the fluorescence intensity increases as the concentration decreases.

2.3.4 (TEM) Transmission Electron Microscope

The TEM image was obtained using a JEM-2100F transmission electron microscope (TEM) operating at 100 kV. The sample for TEM observation was prepared by dispersing the powder of CuO nanoparticles by ultrasonification in water and allowing the dispersion to drop on a copper grid.

3. Results and Discussion

3.1 Cuo Nanoparticles

During the laser ablation process of Cu plate, the deionised water at first appeared colorless and transparent but after a few minutes it began to change to light greenish blue which confirms the generation of CuO nanoparticles (Fig. 2). This is due to the surface plasmon resonance (SPR) Of CuO nanoparticles This was also confirmed by TEM analysis as shown in fig. 3 shows the statistical analysis of particle size distribution. The average sizes of the CuO NPs were obtained to be 24.14

Figure 2: CuO Nanoparticles Produced by Laser Ablation in Distilled Water.

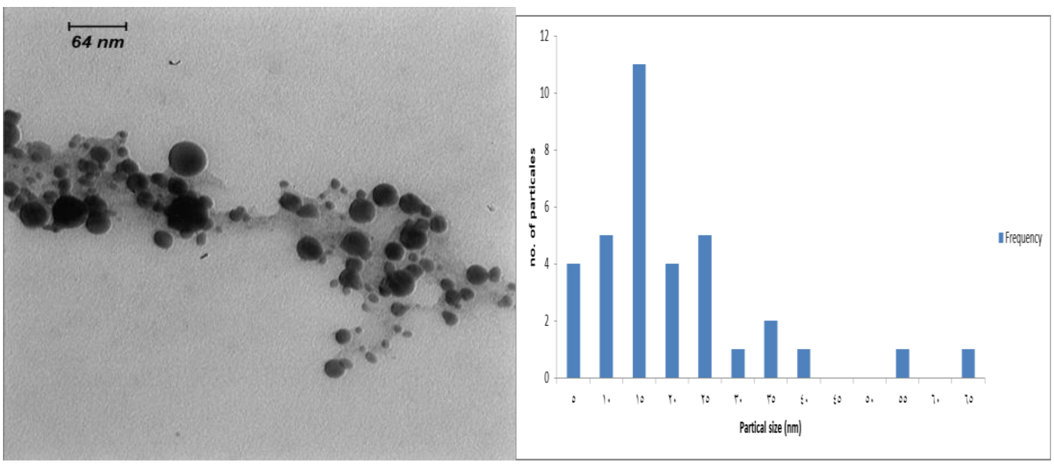

Fig 3: Tem Image of Cuo Nps Synthesized by Laser Ablation in Distilled Water.

3.2 Rhodamine B dye

3.2.1 Fluorescence of Rhodamine B Dye dissolved in Water

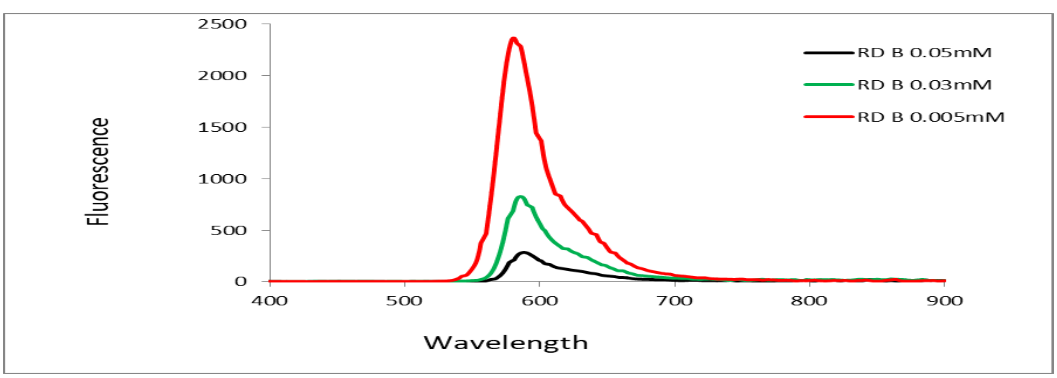

Figure 4: Fluorescence Spectra of Rhodamine B at Different Concentrations.

It is obvious from figure 4 that the fluorescence intensity was increased by decreasing the concentrations of Rhodamine B dye where the fluorescence intensity of the Rhodamine B dye at 0.005 mM concentration was higher than that of 0.03 and 0.05 mM. The fluorescence intensity decreases at the highest concentration of 0.05 mM due to the formation of molecular aggregates, meaning that these aggregates in the dye molecules lead to a decrease in the emission spectrum[15]. at the highest concentration, which leads to aggregations between the dye molecules, there is a suppression in the emission spectrum because in this case the percentage of radioactive decays increases.

Table 1: Characteristics of the Emission Spectrum of Rhodamine B Dye at Different Concentrations.

C (mM)	λ_{max} (nm)	Fluorescence
0.005	579.5	2363.87
0.03	583	826.81
0.05	584	284.88

3.2.2 Effect of Cuo Nps on the Fluorescence of Rhodamine B Dye in Water

Figure 5 shows the fluorescence spectra of rhodamine B dye at different concentrations after addition of copper oxide nanoparticles. The figure shows that the fluorescence intensity of rhodamine B dye Was changed after the addition of CuO nanoparticles. There was a decrease in fluorescence intensity which is more pronounced at lower dye concentrations. For example, the fluorescence intensity at 0.005 mM decreases from 2363.87 to 1587.55 after addition of CuO nanoparticles .At 0.03 mM, the fluorescence intensity decreases from 826.81 to 611.68. However, at 0.05 mM, the fluorescence intensity increases from 284.88 to 334.77 after addition of CuO nanoparticles.

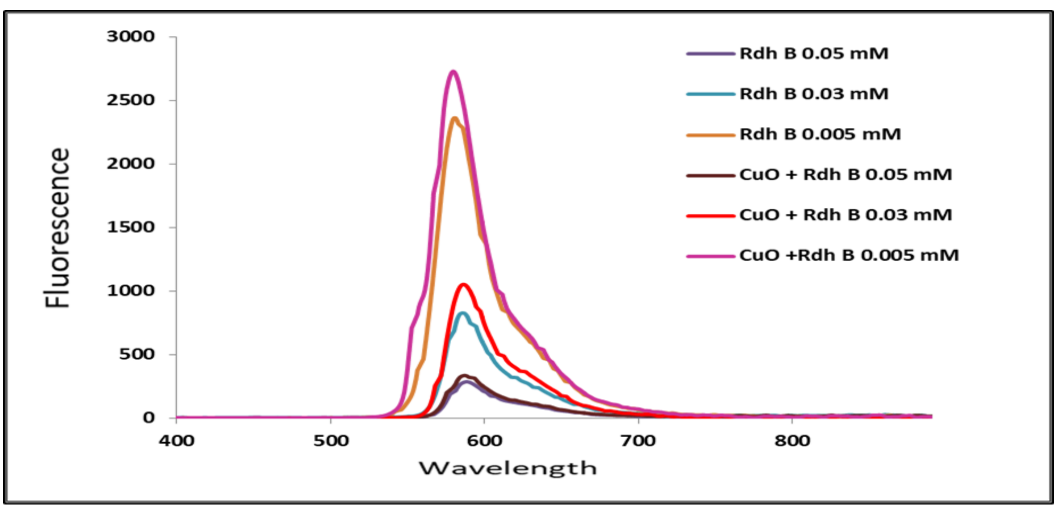

Figure5: Fluorescence of Rdh B at Different Concentrations after Addition of CuO NPs.

The fluorescence intensity of the dye increases when CuO NPs are added. CuO nanoparticles can facilitate energy transfers using dye molecules. The close proximity between nanoparticles and dye molecules can result in efficient energy transfer. And also CuO NPs can act as effective dispersants, resulting in an obvious increase in fluorescence intensity[16]. Table 6 shows the fluorescence spectrum data of rhodamine B dye after adding CuO NPs

Table 2: Emission Spectrum Properties of Rdh B Dye at Different Concentrations After the Addition of Cuo Nps.

C (mM)	λ_{max} (nm)	Fluorescence
0.005	579.6	2730.59
0.03	585.9	1052.09
0.05	586.9	334.77

3.2.3 Nonlinear Properties of Cuo Nps and Rhodamine B

Figure (6) shows the nonlinear refractive index of CuO under the influence of three different Laser wavelengths. We notice that the nonlinear transmittance curves have a peak followed by a trough, meaning that copper oxide nanoparticles have a negative nonlinear refractive index.

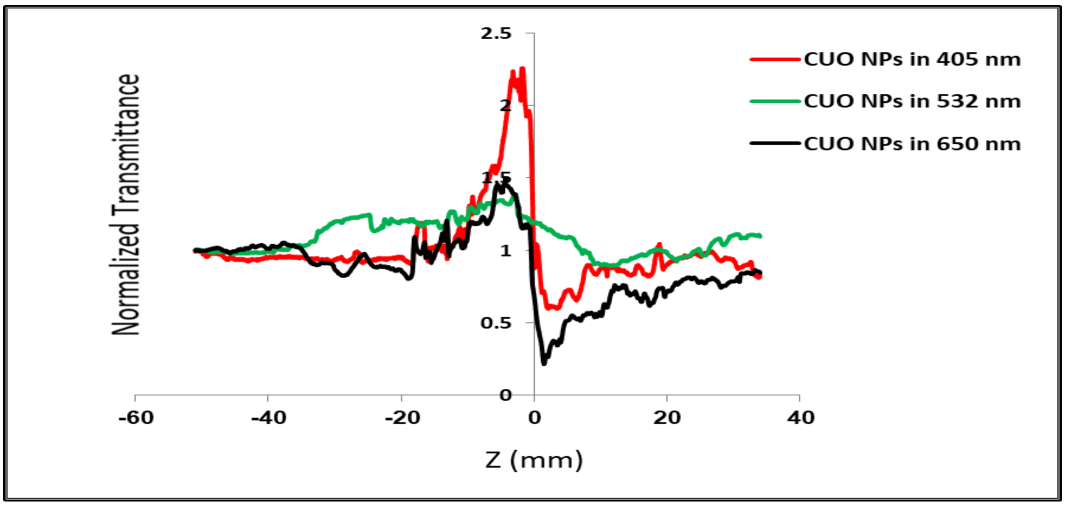

Figure 6: Nonlinear Refraction of Cuo Nps With Effect of Three Wavelengths (405nm, 532nm, 650nm).

Table 3: Nonlinear Properties of Cuo Nps Prepared by Laser Ablation in Water Under the Influence of Several Wavelengths (405nm, 532nm, 650nm).

λ(nm)	P (mW)	I_0(MW/m²)	L_{eff}(m)	ΔT	n_2 (m2/W)
405	5.23	35.27	0.000977	1.663212	$7.91*10^{-12}$
532	33.71	17.75	0.000986	0.493289	$6*10^{-12}$
650	50	35.27	0.000985	1.28535	$6.83*10^{-12}$

From the values in the table, we note that the highest nonlinear refractive index values for the CuO NPs sample were recorded at the wavelength (405 nm) because the wavelength (405 nm) is within the peak of the absorption band of CuO NPs. Light energy is efficiently absorbed and then transferred to the water via non-radiative relaxation processes. This increases the local temperature in the water. The thermal gradient leads to a change in the local refractive index because the local refractive index decreases with increasing temperature for most liquids such as water. The large values of the nonlinear refractive index at short wavelength can be attributed to the high energy of these photons compared to other wavelengths. Higher energy photons can excite samples to higher energy levels. This means more non-radiative relaxation processes, and thus higher temperature, leading to higher associated nonlinearities [17,18].

3.2.4. Nnri of Rhodamine B Before and After Addition of Cuo Nps at 405 Nm

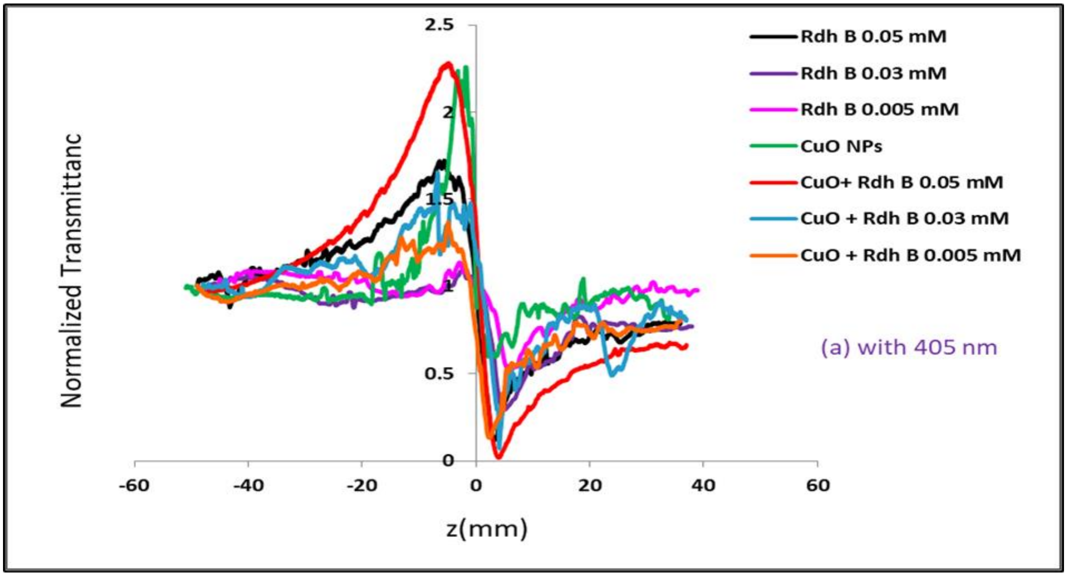

Figure 7: Nonlinear Refractive Index of Rdh B Dye at Different Concentrations Before and After Addition of Cuo Nps.

Table 4: Nonlinear Properties of Rhodamine B Dye at Different Concentrations Before and After Adding Cuo Nps Under the Influence of 405 Nm and a Power of 13.5.

C (mM)	I_0(MW/m²)	L_{eff}(m)	ΔT	n_2 (m2/W)
0.005 Rdh B	91.056	0.00099746	0.61054	$1.10*10^{-12}$
0.03 Rdh B	91.056	0.0009944	0.806861	$1.46*10^{-12}$
0.05 Rdh B	91.056	0.00098994	1.60559	$2.92*10^{-12}$
0.005 Rdh B +CuO NPs	91.056	0.000993	1.240122	$2.25*10^{-12}$
0.03 Rdh B +CuO NPs	91.056	0.0009915	1.58678	$2.88*10^{-12}$
0.05 Rdh B +CuO NPs	91.056	0.0009851	2.265129	$4.14*10^{-12}$

The nonlinear refractive index (NNRI) of rhodamine B dye was studied at different concentrations under the influence of wavelength (405 nm) as depicted in figure 7. It is obvious from figure 7that the NNRI of rhodamine B dye increases as their concentration increases. Figure 7shows the nonlinear transmittance of rhodamine B dye at different concentrations after the addition of CuO nanoparticles. As seen from figure 7, NNRI of Rhodamine B dye was increased by adding colloidal CuO nanoparticles For all samples regardless their concentrations .Nonlinear refraction results From the interactions between dye molecules. Increasing the number of interacting dye molecules, Leads to increasing the intensity of nonlinear refraction. Therefore, the NNRI of rhodamine B dye increases with increasing its concentration [19]. As can be seen from Figure 7, the NNRI of Rhodamine B dye at different a concentration was increased by adding CuO

NPs because the wavelength of laser (405 nm) lies in the absorption spectrum of CuO NPs. This led to an increase in NNRI of rhodamine B dye by heat transfer from CuO NPs to the dye solution [20]. Table 4 presents the values of the nonlinear refractive index of Rhodamine B at 405 nm before and after adding CuO NPs.

3.2.5. Nnri of Rhodamine B Before and After Addition of Cuo Nps at 532 Nm

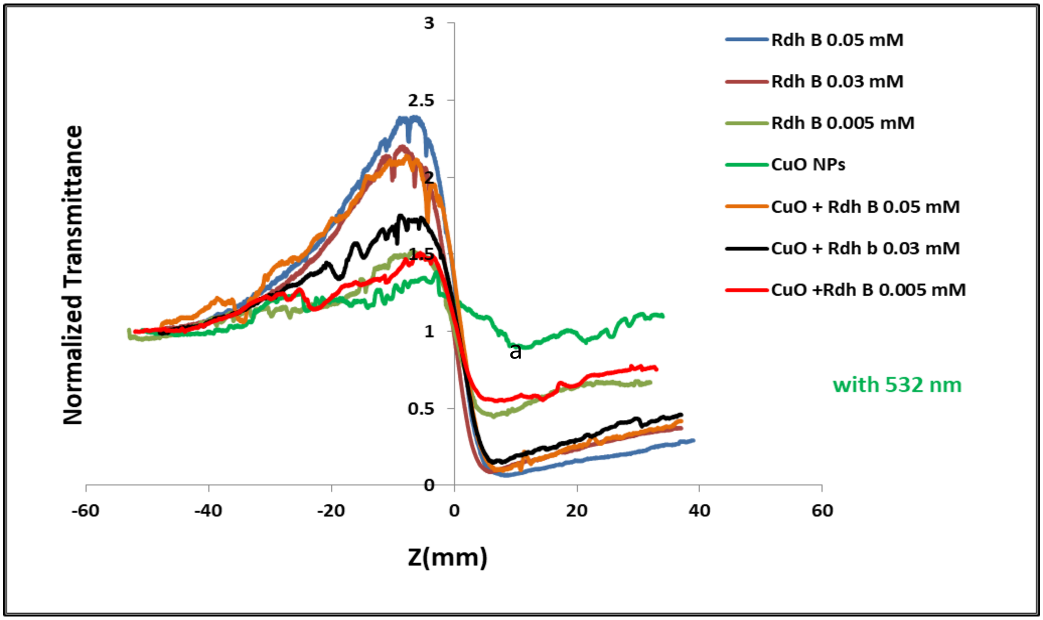

Figure 8: Nonlinear Refractive Index of R Rdh B Dye at Different Concentrations Before and After Addition of Cuo Nps.

Table 5: Nonlinear Properties of Rdh B Dye at Different Concentrations Before and After Adding Cuo Nps Under the Influence of 532 Nm and a Power of 33.71.

C (mM)	$I_0(MW/m^2)$	$L_{eff}(m)$	ΔT	n_2 (m2/W)
0.005 Rdh B	17.751	0.00097859	1.083591	$1.33*10^{-11}$
0.03 Rdh B	17.751	0.00094948	2.117647	$2.67*10^{-11}$
0.05 Rdh B	17.751	0.00090251	2.332386	$3.10*10^{-11}$
0.005 Rd B +CuO	17.751	0.00098695	9.965909	$1.17*10^{-11}$
0.03 Rd B +CuO	17.751	0.0009495	1.606695	$2.03*10^{-11}$
0.05 Rd B +CuO	17.751	0.0009194	2.04878	$2.67*10^{-11}$

Figure 8 shows the nonlinear transmittance of rhodamine B dye at different concentrations Under the influence of 532 nm . The observations indicated that the NNRI of Rhodamine B dye increases as its concentration increases .Figure 8 shows the nonlinear transmittance of Different concentrations of Rhodamine B dye after adding CuO nanoparticles at 532 nm Figure 8 indicates that the NNIR of Rhodamine B at any concentrations was decreased after the adding colloidal CuO nanoparticles**.** The value of nonlinear refractive index is greater than that irradiated by 405 nm wavelength. This could be due to the absorption spectrum of Rhodamine dye which lies within the wavelength of laser (532 nm). Figure 8 indicates that the NNIR of Rhodamine B at any concentrations decreased after adding CuO NPs under the action of 532 nm , This could attributed to the CuO NPs cannot be able to enhance the nonlinear properties of Rhodamine B dye The reason could be that the laser wavelength (532 nm) is out of the region of absorption spectrum of CuO NPs. Table 5 presents the values of the nonlinear refractive index of the redamine B dye before and after adding CuO NPs at 532 [20].

3.2.6. Nnri of Rhodamine B Before and After Addition of Cuo Nps at 650 Nm

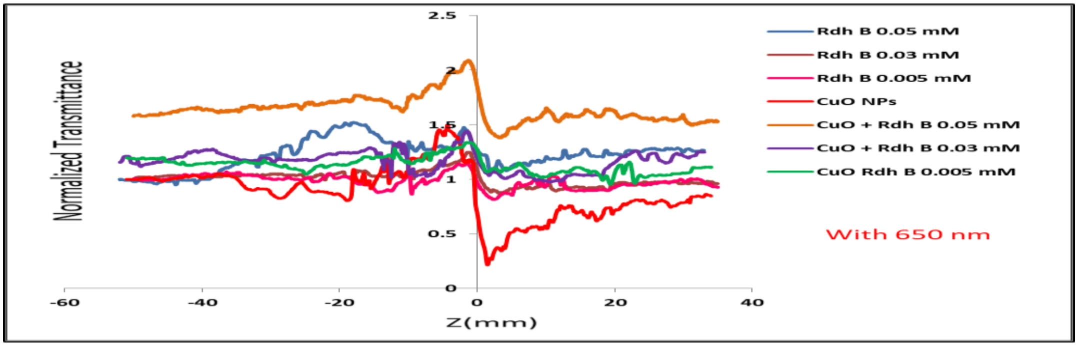

Figure 9: Refractive Index of Rdh B Dye at Different Concentrations Before and After Addition of Cuo Nps.

Table 6: Nonlinear Properties of Rdh B Dye at Different Concentrations Before and After Adding Cuo Nps Under the Influence of a Wavelength of 650 Nm and a Power of 59.55 Mw.

C (mM)	$I_0(MW/m^2)$	$L_{eff}(m)$	ΔT	$n_2(m2/W)$
0.005 Rdh B	58.331	0.000996	0.33653	$1.48*10^{-12}$
0.03 Rdh B	58.331	0.000994	0.38164	$1.68*10^{-12}$
0.05 Rdh B	58.331	0.000996	0.57916	$2.55*10^{-12}$
0.005 Rdh B + CuO	58.331	0.000997	0.38857	$1.71*10^{-12}$
0.03 Rdh B + CuO	58.331	0.000998	0.470219	$2.07*10^{-12}$
0.05 Rdh B + CuO	58.331	0.000994	0.718689	$3.17*10^{-12}$

The NNIR of various concentrations of rhodamine B dye was measured under the influence of 650 nm wavelength as depicted in figure 9. The results showed that the nonlinear transmittance Increased with increasing dye concentrations indicating that the nonlinear optical effects depend on the concentrations of dye. The nonlinear refractive index of different concentrations of rhodamine B dye was studied by adding CuO nanoparticles under the influence of 650 nm light .The results In figure 9b showed that the nonlinear refractive index of rhodamine B dye decreased with the addition of CuO nanoparticles. The results in Figure 9 indicated that the NNRI value for all concentrations of rhodamine B dye increased by adding CuO NPs. This can be attributed to CuO NPs because their absorption spectrum falls within the absorption spectrum of the laser used (650 nm), which leads to an improvement in the refractive index of the dye. Table 6 shows the nonlinear refractive index value of rhodamine B dye before and after adding CuO NPs at 650 nm [20].

3.3. Methylene Blue Dye

3.3.1. Fluorescence of Methylene Blue Dye Dissolved in Water

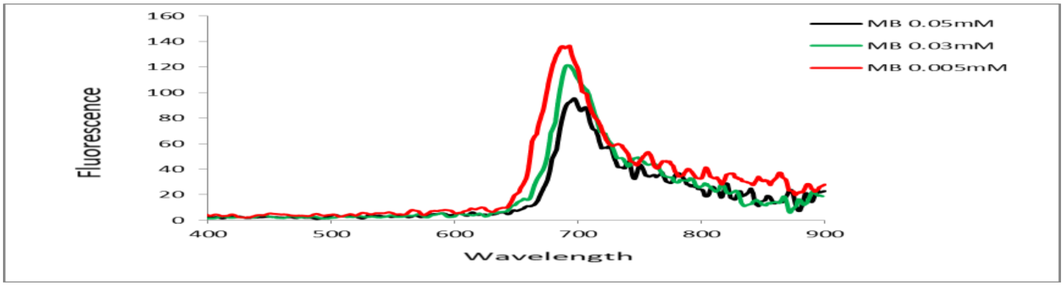

Figure 10: Fluorescence of Methylene Blue Dye at Different Concentrations.

Table 7: Emission Spectrum Characteristics of Methylene Blue Dye at Different Concentrations.

C (mM)	λ_{max} (nm)	Fluorescence
0.005	693	136.72
0.03	691	121.48
0.05	697	95.54

The results In figure 10 showed .that the fluorescence intensity of methylene blue Dye was increased with decreasing The concentration of MB, and the peak of the fluorescence spectrum shifted towards longer wavelengths. The fluorescence intensity increased at the lower concentration of MB dye due to The quenching which resulted from the aggregation of molecules dye [15]. The relationship between the concentration of methylene blue (MB) dye and its fluorescence intensity is generally linear up to a concentration of about 0.01 mM. At higher concentrations 0.05, the fluorescence intensity begins to decrease due to self-quenching. The relationship between the concentration of rhodamine B (RhB) dye and its fluorescence intensity is also generally linear up to a concentration of about 0.05 mM. However, RhB is more susceptible to self-quenching than MB, and the fluorescence intensity begins to decrease at lower concentrations

3.3.2 Effect of Addition of Cuo Nps on the Fluorescence of Different Concentrations of Mb Dye

The fluorescence spectra of methylene blue at different concentrations were studied after the addition of CuO NPs. The results in Figure 11 showed that the fluorescence intensity of the dye increases when CuO NPs are added. CuO nanoparticles can facilitate energy transfers using dye molecules. The close proximity between nanoparticles and dye molecules can efficiently transfer energy, resulting in enhanced fluorescence emission of the dye. Also CuO NPs can act as effective dispersants, leading to an obvious increase in fluorescence intensity. [16]. Table 8 shows the fluorescence spectrum data of MB dye after adding CuO NPs .

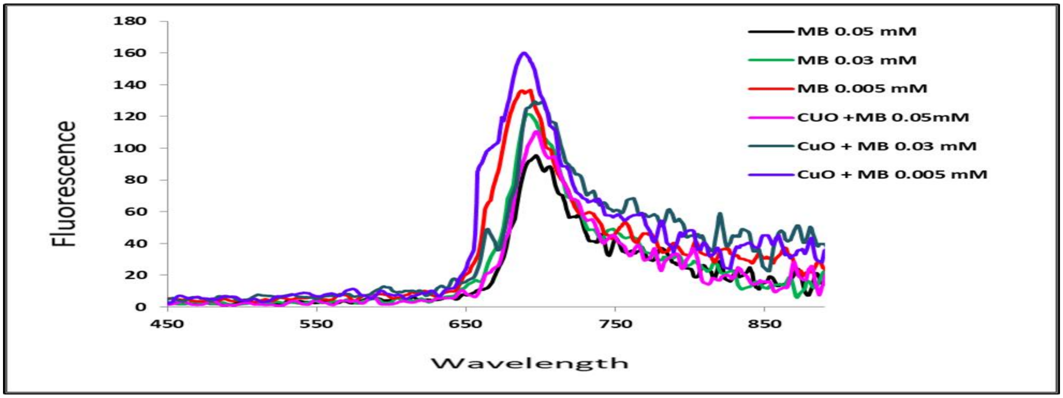

Figure 11: Fluorescence of Mb at Different Concentrations After Addition of Cuo Nps.

Table 8: Fluorescence Characteristics of Mb Dye at Different Concentrations When Cuo Nps Are Added.

C (mM)	λ_{max} (nm)	Fluorescence
0.005	688	160.14
0.03	696.1	129.54
0.05	697	110.71

3.3.3 Nnri of Methylene Blue Dye Before and After Addition of Cuo Nps at 405 Nm

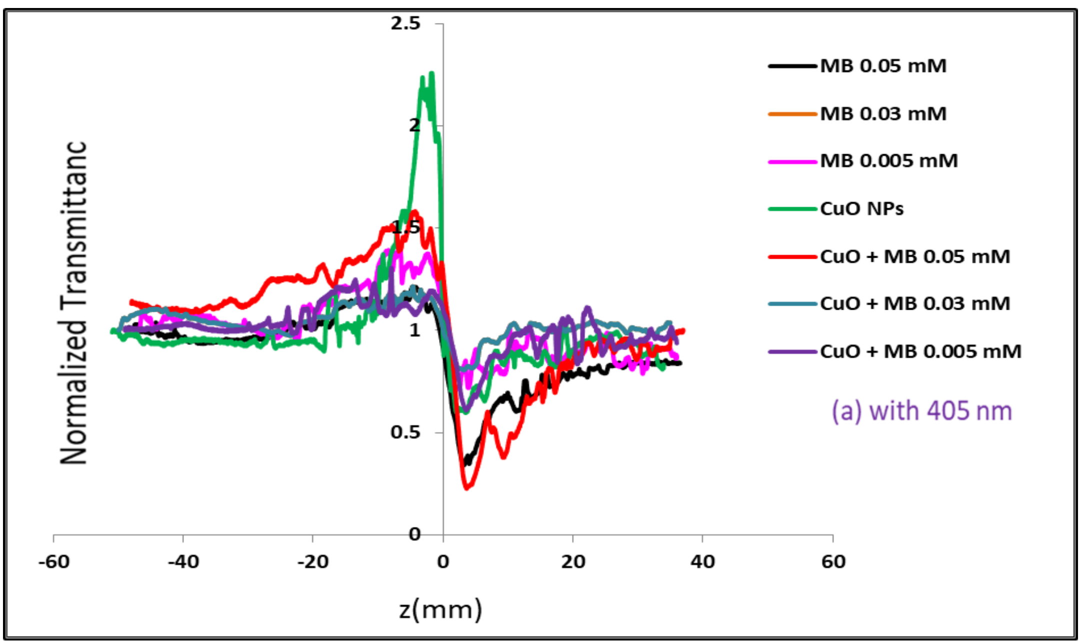

Figure 12.: Nonlinear Refractive Index of Mb Dye at Different Concentrations Before and After Addition of Cuo Nps.

Table 9: Nonlinear Properties of Mb Dye at Different Concentrations Before and After Adding Cuo Nps Under the Influence of 405 Nm and a Power of 13.3 Mw.

C (mM)	I_0(MW/m²)	L_{eff}(m)	ΔT	n_2 (m2/W)

0.005 MB	89.707	0.00099616	0.30387	$5.57*10^{-13}$
0.03 MB	89.707	0.00100001	0.41272	$7.54*10^{-13}$
0.05 MB	89.707	0.00099672	0.877841	$1.61*10^{-12}$
0.005 MB + CuO	89.707	0.00099363	0.698795	$1.28*10^{-12}$
0.03 MB + CuO	89.707	0.00099801	0.707317	$1.29*10^{-12}$
0.05 MB + CuO	89.707	0.00099451	1.358779	$2.50*10^{-12}$

Figure 12 depicts the NNIR of MB dye at different concentrations the results indicate that the nonlinear refractive index of methylene blue was increased by increasing the concentrations of MB dye. Figure 12 presents the nonlinear transmittance Of different concentrations of methylene blue dye after the addition of CuO NPs under the influence of wavelength (405 nm) .As seen from Figure 12, the NNRI of MB dye was increased After adding CuO NPs under the influence of 405 nm. Laser wavelength can be absorbed by CuO NPs because its wavelength (405 nm) lies within the surface plasmon band of CuO NPs added to MB dye, This led to an increase in NNRI of MB dye by heat transfer from CuO NPs to the dye solution. This means that the photon energy was converted to heat when the surface plasmon band of CuO nanoparticles in dye solution was excited by irradiation of a 405 nm laser leading to increasing the NNRI .Table 9 Presents the value of the nonlinear refractive index of the methylene blue dye before and after adding CuO NPs at a 405 nm laser[20].

3.3.4 Nnri of Methylene Blue Dye before and after Addition of Cuo Nps at 532 Nm

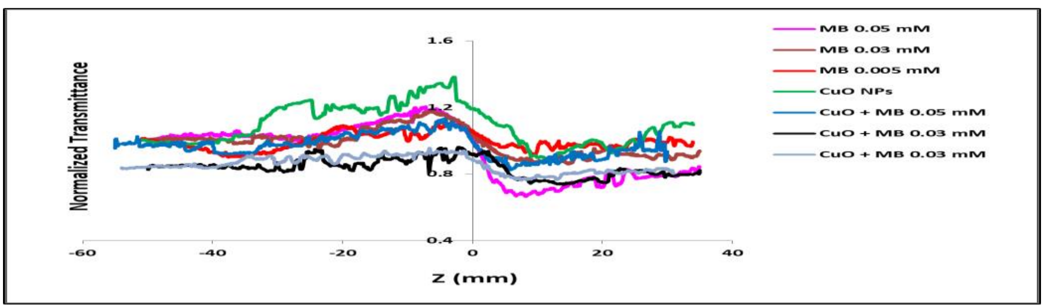

Figure 13: Nonlinear Refractive Index of Methylene Blue Dye at Different Concentrations Before and After Addition of Cuo Nps.

Table 10: Nonlinear Properties of Methylene Blue Dye at Different Concentrations Before and After Adding Cuo Nps Under the Influence of 532 Nm and a Power of 25.8 Mw

C (mM)	I_0(MW/m²)	L_{eff}(m)	ΔT	n_2 (m2/W)
0.005 MB	13.585	0.0009955	0.20858	$3.28*10^{-12}$
0.03 MB	13.585	0.0009959	0.32628	$5.13*10^{-12}$
0.05 MB	13.585	0.00098467	0.54494	$8.67*10^{-12}$
0.005 MB +CuO	13.585	0.00099625	0.19726	$3.10*10^{-12}$
0.03 MB + CuO	13.585	0.00099336	0.230159	$3.63*10^{-12}$
0.05 MB + CuO	13.585	0.00099105	0.31298	$4.95*10^{-12}$

Figure 13 depicts the nonlinear NNRI of the Methylene Blue dye under the influence of wavelength (532 nm) . The results showed that The NNRI of MB dye increases as its concentration increases . The Effect of CuO NPs on the nonlinear transmittance of the Different concentrations of MB dye was studied under the influence of a 532 nm laser It is obvious from table 10 That the value of NNRI was increased by adding CuO NPs for all samples regardless their concentrations. Nonlinear refraction results from interactions between dye molecules. Increasing the number of interacting dye molecules leads to an increase in the intensity of nonlinear refraction. Therefore, the NNRI of MB dye increases as its concentration increases [20]. As can be seen from Figure 13 , we find that the nonlinear refractive index values of the MB dye at different concentrations decrease when CuO NPs are added to it under the influence of the 532 nm wavelength. This is because the laser wavelength (532 nm) falls outside the range of the absorption spectrum of CuO NPs. This resulted in a decrease in the NNRI of MB dye. [20]. Table 4 displays the nonlinear refractive index values of MB at 532 nm before and after the addition of CuO NPs.

3.3.5. Nnri of Methylene Blue Dye before and after Addition of Cuo Nps 650 Nm

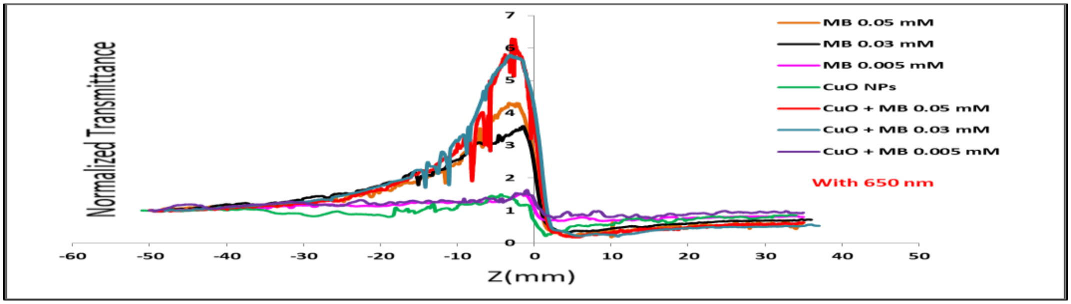

Figure 14: Nonlinear Refractive Index of Mb Dye at Various Concentrations Before and After Addition of Cuo Nps.

Table 11: Nonlinear Properties of Mb Dye at Various Concentrations Before and After Adding Cuo Nps Under the Influence of 650 Nm and a Power of 40 Mw

C (mM)	I_0(MW/m²)	L_{eff}(m)	ΔT	n_2 (m2/W)
0.005 MB	39.181	0.000977	0.84541	$5.66*10^{-12}$
0.03 MB	39.181	0.000941	3.28070	$2.28*10^{-11}$
0.05 MB	39.181	0.000901	4.13901	$3*10^{-11}$
0.005 MB + CuO	39.181	0.000983	0.878613	$5.85*10^{-12}$
0.03 MB + CuO	39.181	0.000931	5.596591	$3.93*10^{-11}$
0.05 MB + CuO	39.181	0.000919	6.12069	$4.35*10^{-11}$

the NNRI of Various concentrations of methylene blue dye under the influence of a 650 nm wavelength depects in Figure 14. The results in figure 14 , indicate that the nonlinear refractive index of methylene blue increase as the Concentration of MB dye increases. the NNRI of Different concentrations of MB dye after the addition of CuO NPs Was examined under the influence of a 650 nm wavelength shown in Figure 14. as shown in Figure 14 , the NNRI of methylene blue dye is increased by adding CuO NPs under the action of 650 nm laser. This wavelength lies within the absorption spectrum of methylene blue dye and within the absorption spectrum of copper oxide, resulting in Increasing the NNRI of MB dye. This can be explained by the fact that laser light can strongly absorbed by MB dye and CuO NPs that led to conversion the photon energy into heat ; as a result, NNIR is increased due to the thermal effects[20]. Table 11 presents the values of the nonlinear refractive index of MB at 650 nm before and after adding CuO NPs .

3.4 Saffron Dye

3.4.1. Fluorescence Spectrum of Saffron Dye Dissolved in Water

saffron does not exhibit an emission spectrum[26].

3.4.2 Nnri of Saffron Dye as Before and After Addition of Cuo Nps 405 Nm

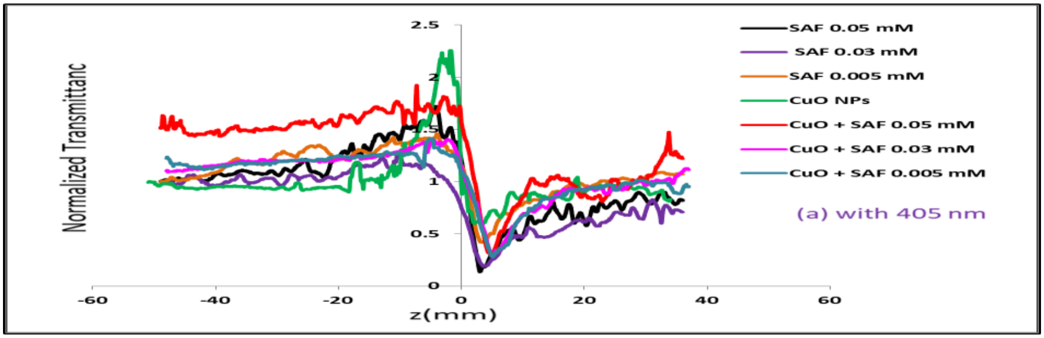

Figure 15: Nonlinear Refractive Index of Saffron Dye at Different Concentrations Before and After Addition of Cuo Nps.

Table 12: Nonlinear Properties of Saffron Dye at Different Concentrations Before and After Adding Cuo Nps Under the Influence of 405 Nm and a Power of 2.75 Mw.

C (mM)	P (mW)	I_0(MW/m²)	L_{eff}(m)	ΔT	n_2 (m2/W)
0.005 SAF	2.75	18.548	0.0009915	1.04624	$9.32*10^{-12}$
0.03 SAF	2.75	18.548	0.0009748	1.09782	$9.95*10^{-12}$
0.05 SAF	2.75	18.548	0.0009572	1.59195	$1.47*10^{-11}$
0.005 SAF + CuO	2.75	18.548	0.0009889	1.141711	$1.02 *10^{-11}$
0.03 SAF + CuO	2.75	18.548	0.00097682	1.117368	$1.01 *10^{-11}$
0.05 SAF + CuO	2.75	18.548	0.00097268	1.629442	$1.48*10^{-11}$

The NNRI of different concentrations of saffron dye was examined under the influence of 405 nm as shown in Figure (15). It is obvious from figure 15 that the NNRI of saffron dye Increases as their concentration increases .The results in Figure 15 show that the nonlinear refractive index of saffron dye decreases with the addition of copper nanoparticles under the influence of 405 nm laser. The nonlinear refractive index values of SAF dye with its different concentrations increase when CuO NPs are added to it under the influence of the wavelength of 405 nm. This is because the laser wavelength (405 nm) falls within the range of the absorption spectrum of CuO NPs and saffron dye. This resulted in an increase in the NNRI of the SAF dye. [22]. Table 12 presents the value Nonlinear refractive index of saffron dye before and after adding CuO NPs at 405 nm.

3.4.3 Nnri of Saffron Dye Before and After Addition of Cuo Nps 532 Nm

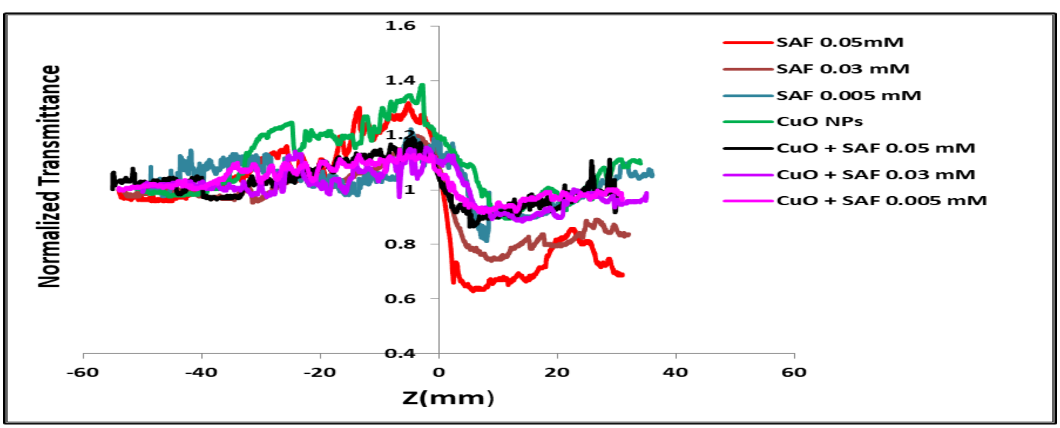

Figure 16: Nonlinear Refractive Index of Saffron Dye at Different Concentrations Before and After Addition of Cuo Nps.

Table 13: Nonlinear Properties of Saffron Dye at Different Concentrations Before and After Adding Cuo Nps Under the Influence of a Wavelength of 532 Nm and a Power of 23.17 Mw.

C (mM)	I_0(MW/m²)	L_{eff}(m)	ΔT	n_2 (m2/W)
0.005 SAF	39.689	0.0008899	0.41379	$8.11*10^{-12}$
0.03 SAF	39.689	0.00099567	0.46222	$8.10*10^{-12}$
0.05 SAF	39.689	0.00098609	0.69298	$1.23*10^{-11}$
0.005 SAF + CuO	39.689	0.00099777	0.23671	$4.14*10^{-12}$
0.03 SAF + CuO	39.689	0.0009959	0.27619	$4.84*10^{-12}$
0.05 SAF + CuO	39.689	0.0009897	0.32863	$4.87*10^{-12}$

NNIR of saffron dye was investigated under the influence of a 532 nm wavelength As depicted in Figure 16 the NNRI of saffron dye increases as its concentration increases .Figure 16 shows the nonlinear transmittance Of different concentrations of saffron Mixed with CuO NPs under the influence of a 532 nm wavelength . It is obviuos from figure 16 that the NNIR of saffron dye Was decreased by adding CuO NPs. It is clear from Figure 16 that the NNIR of saffron dye at any concentration was decreased by adding a colloidal solution of copper oxide to it under the influence of the wavelength of 532 nm because the wavelength of the laser (532 nm) lies outside the range of the absorption spectrum of CUO NPs. This resulted in a decrease in the NNRI of the dye.Table 13 shows Nonlinear refractive index value of saffron dye before and after adding CuO NPs at 532 nm.

3.4.4 Nnir of Saffron Dye as Before and After Addition of Cuo Nps 650 Nm.

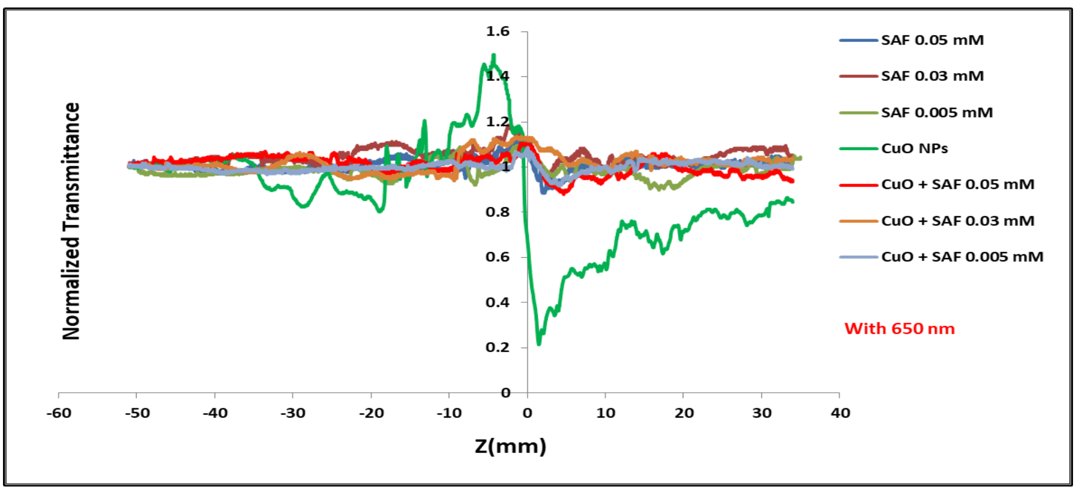

Figure 17: Nonlinear Refractive Index of Saffron Dye at Different Concentrations Before and After Addition of Cuo Nps.

Table 14: Nonlinear Properties of Saffron Dye at Different Concentrations Before and After Adding Cuo Nps Under the Influence of 650 Nm and a Power of 43 Mw.

C (mM)	P (Mw)	I_0(MW/m²)	L_{eff}(m)	ΔT	n_2 (m2/W)
0.005 SAF	43	42.12	0.001001	0.19886	$1.21*10^{-12}$

0.03 SAF	43	42.12	0.000999	0.222892	$1.36*10^{-12}$
0.05 SAF	43	42.12	0.000996	0.241206	$1.47*10^{-12}$
0.005 SAF + CuO	43	42.12	0.000998	0.200354	$1.22*10^{-12}$
0.03 SAF + CuO	43	42.12	0.000997	0.228654	$1.39*10^{-12}$
0.05 SAF + CuO	43	42.12	0.000995	0.253541	$1.55*10^{-12}$

NNIR of Various concentrations of saffron dye was analyzed under the influence of a 650 nm wavelength As depicted in (Figure 17). It is obvious from this figure that the NNRI of saffron dye Slightly increase as its concentration increases. Figure (17) illustrates the nonlinear transmittance Of various concentrations of saffron dye after adding CuO NPs under the influence of a 650 nm wavelength . We can see from this figure that the NNIR of saffron dye was slightly decreased after The addition of CuO NPs .The results in Figure 17b indicate that the NNRI value for all concentrations of saffron dye increases when CuO NPs are added to it under the influence of the wavelength of 650 nm. This is because the wavelength of the laser (650 nm) falls within the range of the absorption spectrum of CuO NPs, which leads to a good increase in the value of the coefficient. Nonlinear refraction of SAF dye. Table 14 displays the nonlinear refractive index value of saffron dye before and after adding CuO NPs.

Conclusions

The behavior of rhodamine B, methylene blue and saffron dyes was studied in terms of fluorescence and nonlinear optical responses. The dyes showed specific absorption peaks and wavelength changes at different concentrations. The addition of CuO NPs affected the fluorescence properties of the dyes. Rhodamine B and methyl blue showed increased fluorescence based on interactions with copper nanoparticles such as energy transfer and dispersion. Rhodamine B showed the highest nonlinear response at a specific excitation wavelength, and CuO NPs enhanced their response at different wavelengths. Likewise, methylene blue showed significant nonlinear responses, especially at the maximum dye absorption wavelength, which was further enhanced by CuO NPs as well as the saffron dye had a good response at the wavelength that falls within the dye absorption spectrum. The results of this study indicate that the addition of nanoparticles can enhance the nonlinear properties of these dyes, as the thermal Kerr effect was demonstrated in all samples studied, which may impact applications that require strong nonlinear optical behavior, ranging from photonic devices to solar energy conversion and optical sensing. And devices for optical reduction or for scientific purposes. It is also possible to benefit from improving the linear properties of dyes by adding nanoparticles as an active laser medium in random lasers.

References

1. Yin, Y., Rioux, R. M., Erdonmez, C. K., Hughes, S., Somorjai, G. A., & Alivisatos, A. P. (2004). Formation of hollow nanocrystals through the nanoscale Kirkendall effect. Science, 304(5671), 711-714.
2. Malhotra, B. D., & Ali, M. A. (2018). Nanomaterials in biosensors: Fundamentals and applications. *Nanomaterials for biosensors*, 1.
3. Malekzad, H., Sahandi Zangabad, P., Mirshekari, H., Karimi, M., & Hamblin, M. R. (2017). Noble metal nanoparticles in biosensors: recent studies and applications. *Nanotechnology reviews*, *6*(3), 301-329. Singh, S., & Gopal, R. (2008). Synthesis of colloidal zinc oxide nanoparticles by pulsed laser ablation in aqueous media. Physics E: Low-Dimensional

Systems and Nanostructures, 40, 724-730.

4. Dell'Aglio, M., & De Giacomo, A. (2021). Optical Diagnostics during Pulsed Laser Ablation in Liquid (PLAL) for the Production of Metallic Nanoparticles. *Applied Sciences*, *11*(21), 10344.
5. Singh, S., & Gopal, R. (2008). Synthesis of colloidal zinc oxide nanoparticles by pulsed laser ablation in aqueous media. Physics E: Low-Dimensional Systems and Nanostructures, 40, 724-730.
6. Hao, W., & Mi, Y. (2016). A Direct Carbon Fuel Cell with a CuO-ZnO-SDC Composite Anode. RSC Adv., 6, 50201-50208.
7. Fazio, E., Gökce, B., De Giacomo, A., Meneghetti, M., Compagnini, G., Tommasini, M., Waag, F., Lucotti, A., Zanchi, C. G., & Ossi, P. M. (2020). Nanoparticles engineering by pulsed laser ablation in liquids: concepts and applications. Nanomaterials, 10(11), 2317.
8. Huang, T., Hao, Z., Gong, H., Liu, Z., Xiao, S., Li, S., & Qin, J. (2008). Third-order nonlinear optical properties of a new copper coordination compound: A promising candidate for all optical switching. Chemical Physics Letters, 4.
9. Aboud, L. H., Mahdi, Z. F., & AlZahra, W. J. (2014). Linear and nonlinear optical properties of the dye laser (Acridine Dye). Academic Research International, 5(4), 135.
10. Bohren, C. F., & Huffman, D. R. (2008). Absorption and scattering of light by small particles. John Wiley & Sons.
11. Garmire, E. (2012). Overview of nonlinear optics. *Nonlinear Optics*, 3-52.
12. Sirleto, L., & Righini, G. C. (2023). An Introduction to Nonlinear Integrated Photonics Devices: Nonlinear Effects and Materials. *Micromachines*, *14*(3), 604.
13. Sheik-Bahae, M., Said, A. A., Wei, T. H., Wu, Y. Y., Hagan, D. J., Soileau, M. J., & Van Stryland, E. W. (1990, January). Z-scan: a simple and sensitive technique for nonlinear refraction measurements. In *Nonlinear Optical Properties Of Materials* (Vol. 1148, pp. 41-51). Spie.
14. Artkin, F. Z-SCAN TECHNIQUE AND ENGINEERING APPLICATIONS FOR NONLINEAR OPTICAL MEASUREMENTS.
15. Tafulo, P. A. R., Queirós, R. B., & González-Aguilar, G. (2009). On the "concentration-driven" methylene blue dimerization. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *73*(2), 295-300.
16. Falamas, A., Marica, I., Nekvapil, F., Stefan, M., Macavei, G. S., Barbu-Tudoran, L., & Farcau, C. (2023). Surface enhanced fluorescence potential of ZnO nanoparticles and gold decorated ZnO nanostructures embedded in a polyvinyl alcohol matrix. Journal of Photochemistry and Photobiology A: Chemistry, 438, 114516.Khandekar, C., Pick, A., Johnson, S. G., & Rodriguez, A. W. (2015). Radiative heat transfer in nonlinear Kerr media. Physical Review B, 91(11), 115406.
17. Shokoufi, N., & Hajibaba, S. N. (2019). The third-order nonlinear optical properties of gold nanoparticles-methylene blue conjugation. Optics & Laser Technology, 112, 198-206.
18. Parvin, U. M., & Ahamed, M. B. (2015). Nonlinear optical properties of methyl blue dye by Z-scan technique. Optik, 126(5), 551-553.
19. Shokoufi, N., & Hajibaba, S. N. (2019). The third-order nonlinear optical properties of gold nanoparticles-methylene blue conjugation. Optics & Laser Technology, 112, 198-206.
20. Khlaif, L. G. (2017). The study of nonlinear optical properties of rhodamine B dye and TiO2 nanoparticles doped in PMMA polymer. *Iraqi Journal of Physics*, *15*(33), 96-100.