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Linear and Nonlinear Optical Properties of Castor Oil

دراسة الخصائص البصرية الخطية واللاخطية لزيت الخروع

Hind K. Abbas
Karbala University, College of Science, Physics Department

Abstract:

In this paper the nonlinear and linear optical properties of castor oil have been found, using a highly sensitive method known as Z-scan technique, experiment was performed depending on He-Ne laser of wave length (632.8 nm). The first part has been done using a closed aperture placed in front of the detector to measure the nonlinear refractive index of castor oil which is found ($-4.5\times10^{-3} cm^2$ /mw) at the employed wavelength. The second part also was done using an open aperture to measure the nonlinear absorption coefficient which was found its value (59.99 cm /mw) ,the linear refractive index was evaluated using a simple technique convergence lens and plane mirror.

الخلاصة :

تم في هذا البحث ايجاد الخصائص البصرية الخطية واللاخطية لزيت الخروع باستخدام طريقة ذات حساسية عالية تعرف بتقنية الماسح على المحور الثالث z scan. انجزت الدراسة بالاعتماد على ليزر هيليوم –نيون بطول موجي (632.8 nm)نانومتر.وتم العمل على مرحلتين الجزء الاول باستخدام الفتحة المغلقة في مقدمة الكاشف لقياس معامل الانكسار اللاخطي لزيت الخروع الذي وجد يساوي.($-4.5\times10^{-3} cm^2$ /mw) في الطول الموجي المسنخدم.والجزء الثاني تم باستخدام الفتحة المفتوحة لقياس معامل الامتصاص اللاخطي الذي قيمته تساوي (59.99cm/mw) وثم حساب معامل الانكسار الخطي باستخدام تقنيه بسيطه (عدسه لامه ومراة مستوية).

Introduction:

Z-scan technique was originally introduced by Sheik Bahae *et al.* [1]. The nonlinear optical properties of castor oil using the Z-scan technique was investigated [2], the experiments were performed for two different excitation wavelengths 514 nm and 810 nm. A large nonlinear optical response of thermal origin was observed. Our results indicate that this oil may be used at several optical applications such as the study of nonlocal nonlinear optical effects opening a wide range of new possibilities. The characterization of the nonlinear optical properties of materials has a great relevance to the possibilities of practical application for optical limiting and optical devices [3]. To achieve this goal it is necessity to find the materials which have large nonlinearities refractive index and small absorption coefficients linear and nonlinear [4] .The Z-scan measurement technique is a simple experimental procedure that gives information on the optical nonlinearities of materials. The technique originally formulated is performed via sending an axially symmetric Gaussian beam through a converging lens, then through a sample of material placed near the beam waist, and finally through an aperture placed in front of a detector in the far field. The sample is moved to one side of the beam waist, the detected power increases to a peak as the sample is moved to the other side of the waist, the detected power decreases to a valley. The difference in power from the peak to the valley has been shown to be proportional to the nonlinear index of refraction [5,6] . Z-scan technique is one of the simplest and effective tools for measuring the third order of nonlinear optics such as nonlinear refraction coefficient and absorption [7]. It has been widely used in material characterization .In this method , the nonlinear sample is scanned along the propagation path of a focus Gaussian laser beam [8].It can provide not only the magnitudes of real and imaginary parts of nonlinear susceptibility ,but also simultaneously can clarify the sign of the real part[9] . This technique is a method which can rapidly measure both nonlinear absorption and nonlinear refraction in solid, liquids and liquid solutions [10] .The main optical properties involved in the light –matter interaction are absorption .It is defined by the absorption coefficient, and refraction which is defined by refractive index [11] . These two parameters were depending on the electric field intensity of laser light .When the material is irradiated, the energy of the absorbed photons makes it possible for the transition from the excited state to the ground state, and this represented a linear absorption [12].

Experimental:

The experimental setup used to measure the nonlinear refractive index and absorption of castor oil in this work is explained in the (closed aperture) Figure 2. He-Ne laser of (632.8 nm) was used as a light source. The laser beam was focused onto the sample by a convergent lens. The light transmittance was measured by a closed-aperture photodetector as a function of the sample position. The detected signal was amplified and then processed by a computer. Nonlinear absorption measurements were performed using the same above experimental setup but using an opened aperture configuration by moving the sample through the focus and without placing an aperture at the detector (open aperture) as shown in figure 1.

Two techniques have been used to measure the nonlinear optical properties of castor oil, closed- aperture used to measure the nonlinear refractive index and open- aperture used to measure the nonlinear absorption coefficient.

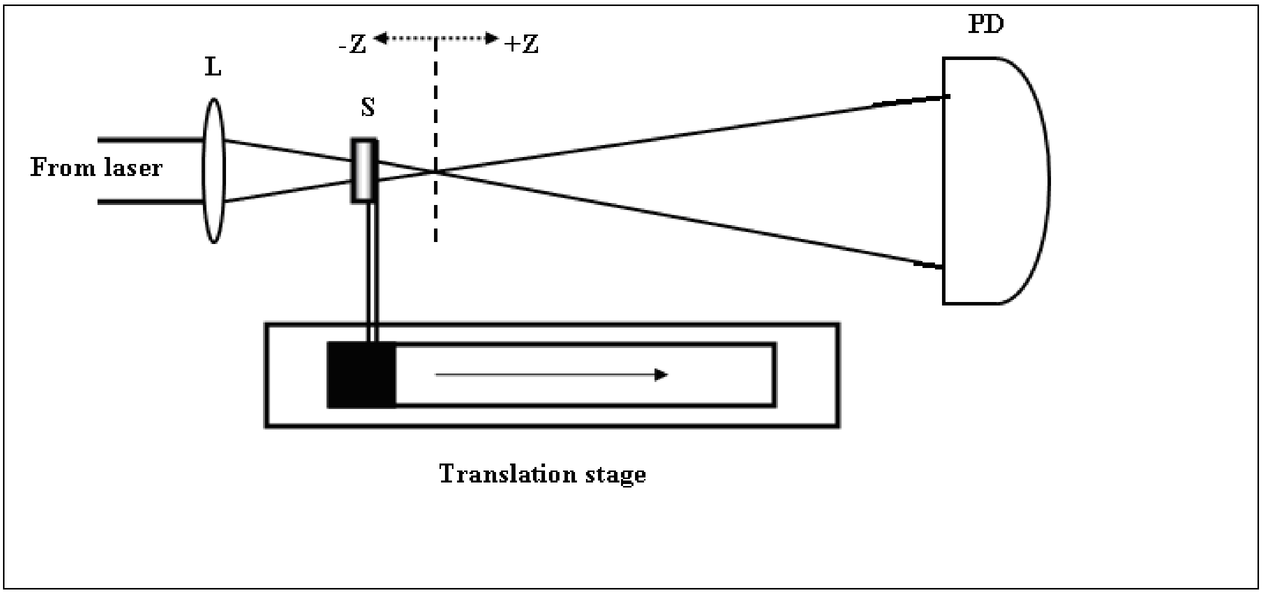


Figure (1) A schematic diagram of open - aperture Z- scan.
L,Lens; S, sample;D,detector.

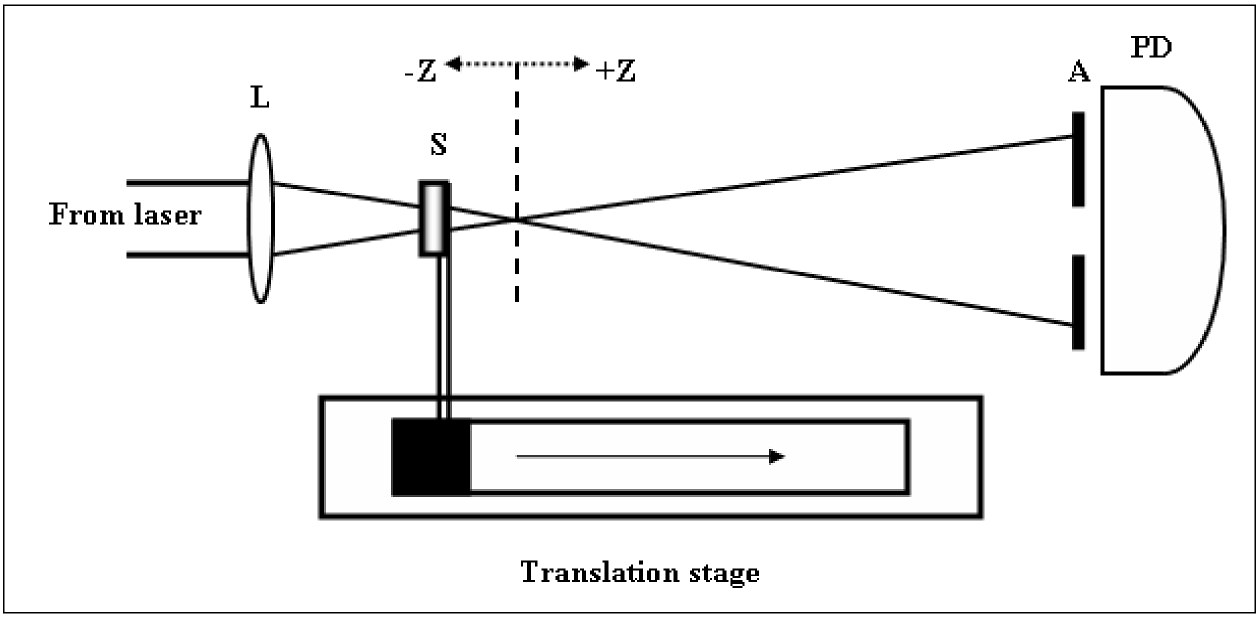
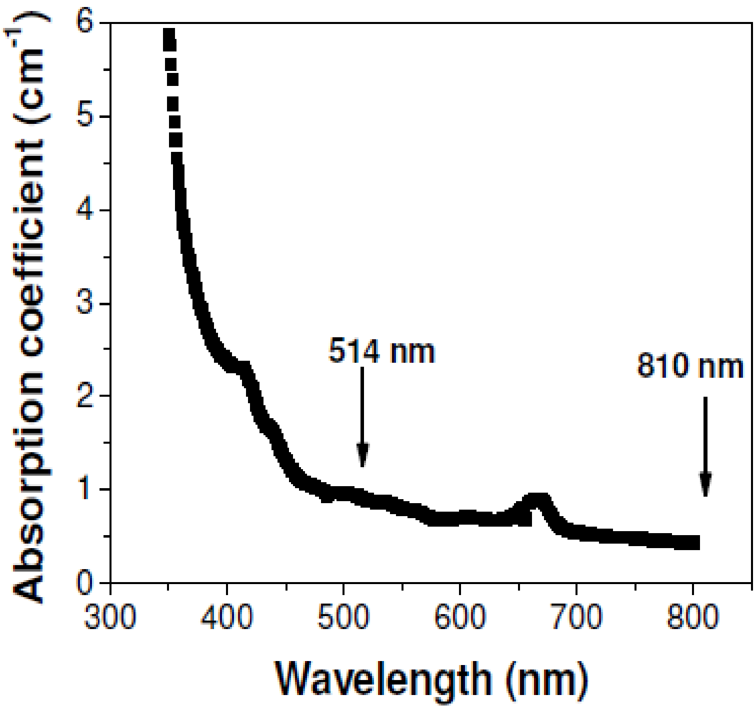


Figure (2) A schematic diagram of closed- aperture Z- scan
L,Lens; S, sample;A,aperture;D,detector.

Results and discussion

The linear UV-VIS absorption spectrum of castor oil is presented in figure (3) .



Figure(3) :Linear absorption spectrum of castor oil [13]

1- Linear optical properties

The optical transmission measurement of castor oil was analyzed using UV-VIS spectrophotometer. The linear absorption coefficient of castor oil at 632.8 nm wavelength was evaluated according to the experimental data of figure(3).
The linear refractive index of castor oil was calculated according to the eq.

$$\frac{F_O}{F_W} = \frac{(n_w - 1)}{(n_o - 1)} \quad \text{……………..(1)}$$

Where F_O the focal length of castor oil lens (0.869)

F_W The focal length of water lens (2.04)

n_w Refractive index of water (1.33)

n_o Refractive index of castor oil

In order to measure linear index coefficient a simple expend is used, a drop of water was putting between the plane mirror and convergence lens and calculated the focal length of water lens, which is making by confined the water drop between plane mirror and the convergence lens .The second part presents, a calculations the focal length of castor oil lens as the same way of water and calculate the linear refractive index of castor oil. Figure (4) [14] explains the above calculations. The linear refractive index of castor oil was evaluated as (1.79).

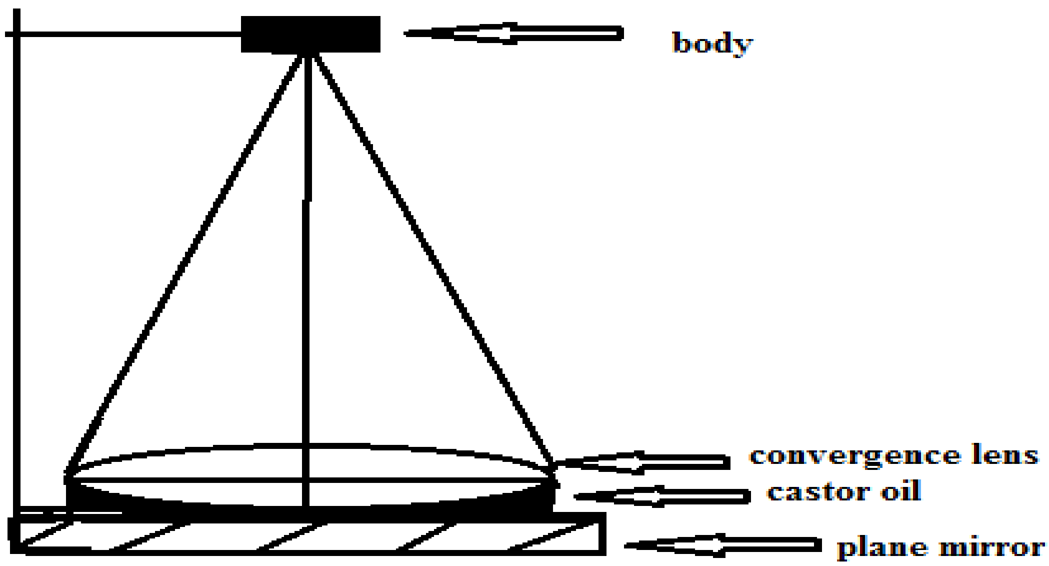


Figure (4) refractive index of castor oil using convergence lens and plane mirror

2- Nonlinear optical properties:-

The nonlinear refractive index and nonlinear absorption coefficient of castor oil were measured by the Z-scan techniques. Two techniques have been used to measure the nonlinear optical properties of castor oil, closed- aperture used to measure the nonlinear refractive index and open- aperture used to measure the nonlinear absorption coefficient. Each technique applied on case of wavelength 632.8 nm[8].

2-1 Refractive index Nonlinear:-

In order to investigate the nonlinear refractive index for He-Ne laser of (632.8 nm) (2 mW power), in this case figure (5) shows the closed- aperture Z-scan curves, which represents the normalized transmittance as a function of position. From the observed transmittance variation, the castor oil nonlinear refractive index was evaluated as (-4.5×10^{-3}). Although this value is smaller than other materials, such as photorefractive crystals and Chinese tea, this linearity is much larger than several organic liquids as DMSO and CS2, [14] .

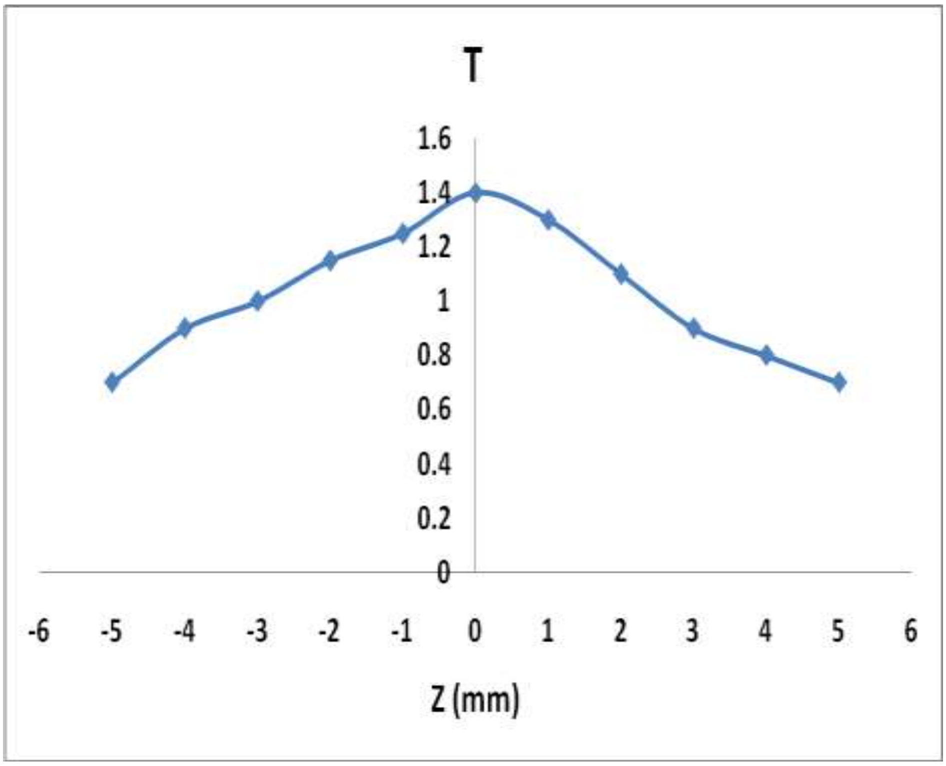


Figure (5) UV-VIS transmission spectrum of open-aperture

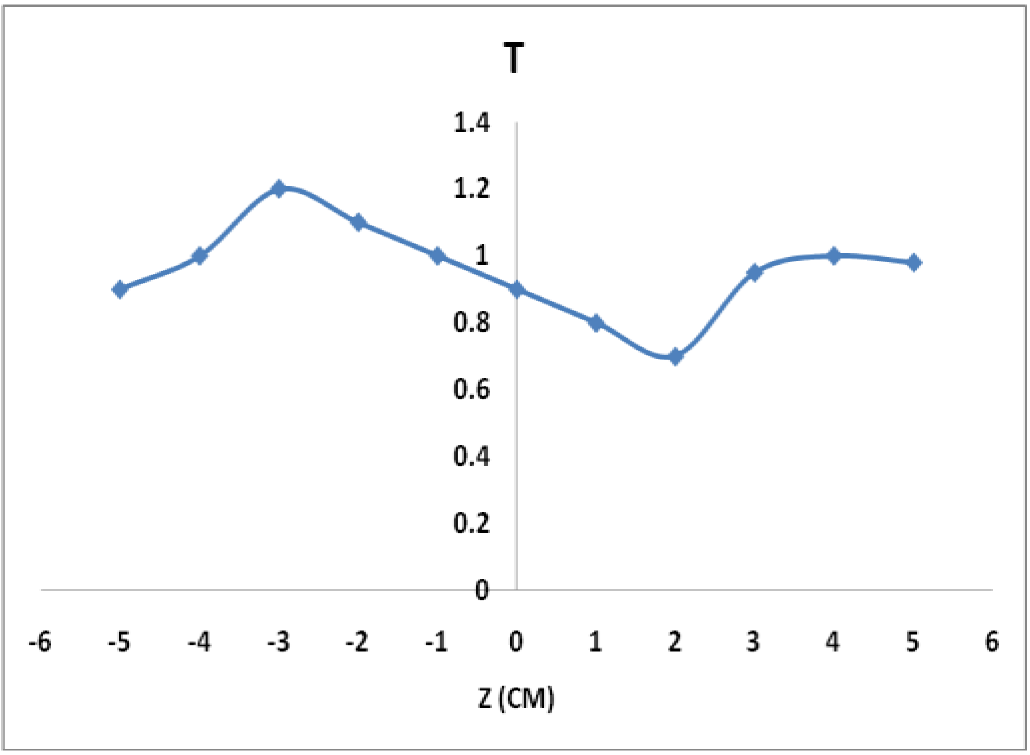


Figure (6) normalized transmittance versus position at 632.8 nm closed-aperture

From the figure (6), it is clear that the normalized transmittance began with slow change (linear) at different positions (Z=-5mm to Z= -1mm) from(T=0.9 toT= 1). After the focal plane, the normalized transmittance begins to increase until it reaches the maximum value (T =1) at approximately Z=4 mm. The behavior of Z-scan curves was in good agreement with that obtained by Sheik-Bahae et al. [12] .As a results, the closed-aperture Z-scan measures the change in transmittance of a beam, as the sample passes through the focal plane, the divergence of the beam is affected by the sample and the detector measures the net change in transmittance. As it leaves the focal plane, the sample will focus the diverging beam. In the far field, this decreases beam divergence and is measured as an increase in power through the aperture. The sample nonlinearity was calculated from the difference between the heights (peak) and the lowest value (valley transmission (ΔT_{P-V}) is written in terms of on axis phase shift at the focus as [15] .

$$\Delta T_{p-v} = 0.406|\Delta\Phi_0| \quad \ldots\ldots\ldots\ldots\ldots(2)$$

The nonlinear absorption coefficient of castor oil was determined for wave length using the formula [11]:-

$$\alpha_0 = \frac{1}{d}\ln\left(\frac{1}{T}\right) \quad \ldots\ldots\ldots\ldots(3)$$

Where d is the thickness of sample and T is the transmittance, and the extinction coefficient is obtained interns of the absorption coefficient,

$$K = \frac{\lambda\alpha}{4\pi} \quad \ldots\ldots\ldots\ldots\ldots..(4)$$

The nonlinear refractive index is given by

$$n = \frac{\Delta\Phi}{KIL_{eff}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where K = 2π/λ and I is intensity of the laser beam at the focus (Z = 0),

$$L_{eff} = \frac{1-\exp(-\alpha L)}{\alpha} \quad \ldots\ldots\ldots(6)$$

, L_{eff} :the effective length of the sample, L: is the sample length, α : linear absorption coefficient[10]

2-2 Nonlinear absorption coefficient:

The nonlinear absorption coefficient β of the samples was evaluated by performing the open aperture Z- scan. Figure (6) shows the open- aperture Z- scan curve, which introduces the normalized transmission as function of position Z.

Figure (5) shows the behavior of transmittance curves at different distances from the far field of the sample position (-Z) the values of transmittance increase slowly and get high value at the zero point (1.4) afterwards, the transmittance begins to decrease toward the linear behavior at the far field of the sample position (+Z), and reaches 0.7 at the position (5mm). The nonlinear absorption coefficient is estimated as

$$\beta = \frac{2\sqrt{2}}{ILeff}\Delta T \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where ΔT is the one peak value at the open aperture Z-scan curve.

Table (1) shows values of nonlinear refractive index, effective length and nonlinear absorption coefficient at wave length 632.8 nm .

λ nm	Thickness (cm)	α_o cm^{-1}	K cm^{-1}	B Cm/mW	n_2 cm^2/mW	L_{eff} cm
632.8	0.0001	43174.88	9.9×10^4	59.99	-4.5×10^{-3}	2.2×10^{-5}

Table (1) measurement details and the results of nonlinear optical properties by the Z- scan.

Conclusion:

The investigation of the nonlinearity optical properties of castor oil using the Z-scan technique for excitation wavelengths, He-Ne laser of 632.8 nm was studied. Large nonlinear refractive indexes were obtained for the wavelengths, however, in the femtosecond regime; it was not possible to observe a typical Z-scan curve for castor oil. This result suggests that this nonlinearity is mainly due to thermal effects. The nonlinear absorption was absent for all experimental configurations.

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