

Magnetic Field Effect on Refractive Indices for High Birefringence Liquid Crystal (UCF)

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Abstract

Liquid crystals are state of substance possesses characteristics between traditional liquid and crystallization. For instance, perhaps liquid crystal away similar to the crystals. There are different types of crystal in the liquid phase. In this research has been the use of high refractive birefringence as well as the study of the influence of magnetic field on the refractive indices.

The magnetic field of action to urge the molecules of liquid crystals and as a result, we found that when the magnetic field increases when the rate of refraction normal, but not linearly, while the refractive index of the extraordinary (exceptional) decreases, and also found that the refractive birefringence proportional to the square of the value of the magnetic field at room temperature.

Key words : Liquid crystal, birefringence, ordinary refractive index, extraordinary refractive index, magnetic field induced.

الخلاصة

أالبورات السائلة حالة من المادة تمتلك خصائص بين السائل التقليدي و البلورة الصلبة . فللحظة ربما البورات السائلة تتناسب مثل السائل ولكن جزيئاتها تدور بطريقة مشابهة للبلورات . هنالك أنواع مختلفة في أطوار من البورات السائلة ، في هذا البحث أستخدمت البورات عالية الانكسار المضاعف هي (UCF)، كذلك دراسة تأثير المجال المغناطيسي على معاملات الانكسار. أن المجال المغناطيسي حث جزيئات البورات السائلة ونتيجة ذلك وجدنا أنه عندما يزداد المجال المغناطيسي فإن معامل الانكسار العادي يزداد ولكن ليس خطياً بينما معامل الانكسار غير العادي (الاستثنائي) يتناقص، أيضاً وجد أن معامل الانكسار المضاعف (Δn) يتناسب مع مربع قيمة المجال المغناطيسي (H^2) عند درجة حرارة الغرفة .

كلمات دالة: البورات السائلة، الانكسار المضاعف، معامل الانكسار العادي، معامل الانكسار غير العادي (الاستثنائي) ، المجال المغناطيسي.

1 – Introduction

Generally there are three basic states of matter, solid, liquid, and gaseous states. However, this is not true. Now, there exists other new states of matter in nature, such as the liquid crystal state, plasma state, amorphous solid, superconductor, neutron state, etc. [Wang, *etal.*(2004), Germano, *et al.*(2004)]. Liquid crystals are wonderful materials that exhibit intermediate state between liquid and solid (crystal). They possess some typical properties of liquid as well as solid states. Crystalline materials or solids are materials characterized by strong positional order and orientational order. The positional and orientational orders have low values for liquids. The liquid crystal phase is a mesophase, which occurs in the transition from solid to liquid (isotropic). As a result, positional order and orientational order of liquid crystals have values between solids and liquids [Adrienko (2006), Syah (2007)]. There are three distinct types of liquid crystals accordance with physical parameters controlling the existence of the liquid crystalline in phases: thermotropic, lyotropic and polymeric. The most widely used liquid crystals, and extensively studied are thermotropic liquid crystals [Khoo (2007)]. Their liquid crystalline

phases are controlled by temperature. The three main classes of thermotropic liquid crystals are: nematic, smectic and cholesteric.

Liquid crystals are found to be birefringent, due to their anisotropic nature. That is, they demonstrate double refraction (having two indices of refraction). Light polarized parallel to the director has a different index of refraction (that is to say it travels at a different velocity) than light polarized perpendicular to the director.

Thus, when light enters a birefringent material, such as a nematic liquid crystal sample, the process is modeled in terms of the light being broken up into the fast (called the ordinary ray) and slow (called the extraordinary ray) components. Because the two components travel at different velocities, the waves get out of phase. When the rays are recombined as they exit the birefringent material, the polarization state will be changed because of this phase difference [Gray,*et al.*(1973)].

The study of liquid crystals began in 1888 by Australian Botanist F. Reinitzer [Wang,*etal.*(2004)]. Liquid crystal materials are unique in their properties and uses. As research into this field continues and as new applications are developed, liquid crystals will play an important role in modern technology[Nobelprize.org.(2009)].

2-Theoretical background

When the laser beam is polarized at 45 degree to the director of the crystal ,it will pass through the sample and splits itself in an” ordinary ray” and an “ extraordinary ray “ . Because of LC birefringence nature, the two beams will leave the cell in two different directions . By measuring the deviation angle of these two rays with respect to the situation in which the UCF liquid crystal is absent it will be easy to retrieve the two refractive indices of the liquid crystal by means of the refraction laws .

The point where reference ray R_{ref} (see Fig.1) ,emerges from the empty cell , encounters the observation plane π , which is perpendicular to R_{ref} ,is determined experimentally by translating the detector along the X axis by means of the millimetric translator until the peak of the spot is exactly in the center of the detector . After that the cell is filled with the liquid crystal and the two refracted beams R_o and R_e will appear (see Fig.1) .The detector is now translated in order to bring the center of the peak corresponding to the ordinary beam . The displacement X_o from the reference point O is recorded .This procedure is 1 repeated for extraordinary light spot , recording its distance X_e from point O . The accuracy on the measurement of both X_o and X_e is estimated to be (1.6 mm). From the geometrical considerations (see Fig. 1) we can calculate the two refractive indices by the following formulas [Ostapenko,*etal.*(2008), Stefano Brugioni (2006)].

$$n_o = \frac{\sin(\theta + \theta_o)}{\sin(\theta)} \text{ ----- (1)}$$

$$n_e = \frac{\sin(\theta + \theta_e)}{\sin(\theta)} \text{ -----(2)}$$

Where θ is the angle of the wedge formed by the two SiO_2 plates , θ_o and θ_e are the angles formed by the beams R_o and R_e with respect to the beam R_{ref} emerging from the wedge when the UCF is absent (Fig.1) .Note that the lateral shifts of the beams R_o and R_e with respect to R_{ref} at the output of plate B are smaller. These shifts are much smaller than experimental accuracy on the measurements of X_o and X_e and, thus , can be neglected here. From elementary geometry, it follows that:

$$\tan \theta_o = \frac{x_o}{L} \text{ ----- (3)}$$

$$\tan \theta_e = \frac{x_e}{L} \text{-----} (4)$$

$$\therefore \theta_o = \tan^{-1}\left(\frac{x_o}{L}\right) \text{-----} (5)$$

$$\theta_e = \tan^{-1}\left(\frac{x_e}{L}\right) \text{-----} (6)$$

So that

$$n_o = \frac{\sin(\theta + \tan^{-1}(\frac{x_o}{L}))}{\sin(\theta)} \text{-----} (7)$$

$$n_e = \frac{\sin(\theta + \tan^{-1}(\frac{x_e}{L}))}{\sin(\theta)} \text{-----} (8)$$

And the average refractive index $\langle n \rangle$ is [Chien Hut Wen,(2006)].

$$\langle n \rangle = \frac{(2 n_o + n_e)}{3} \text{-----} (9)$$

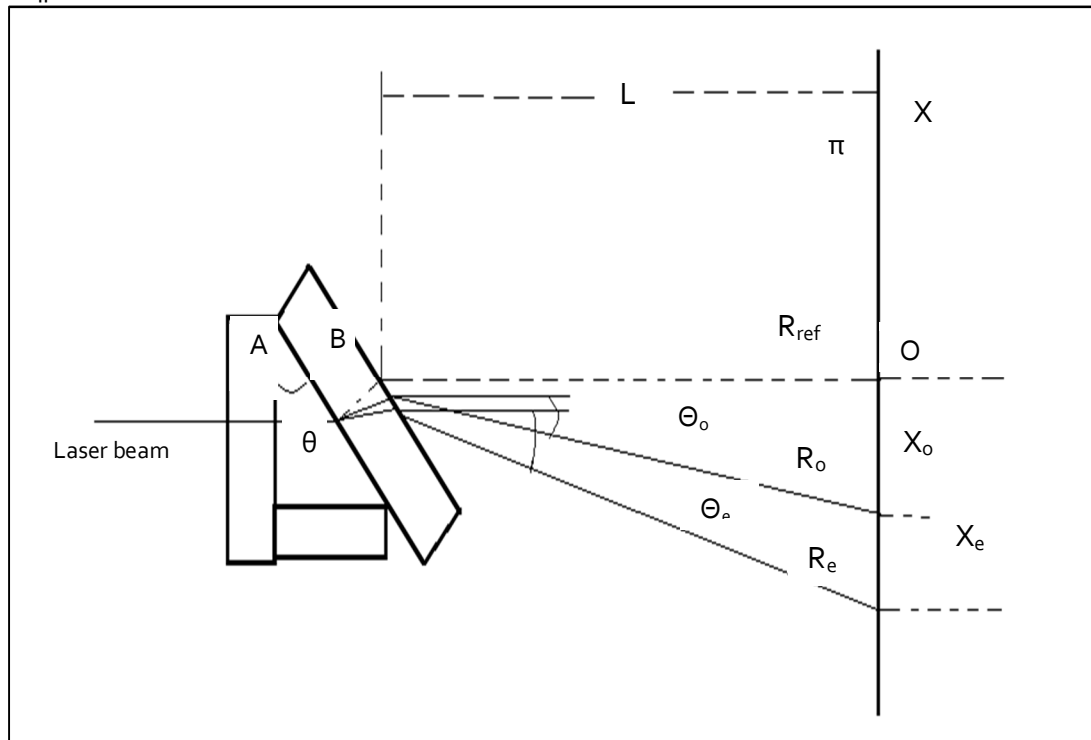
The relationship between birefringence and magnetic field is represented by the following equation

$$\Delta n = \frac{\Delta \epsilon_o \Delta \chi_o H^2}{9 a_o (T - T_c) \sqrt{\bar{\epsilon}}} \text{-----} (10)$$

The parameter a_o is known as Landau coefficient, (T_c) is clearing temperature for UCF liquid crystal is (132 °C) and ($\Delta \epsilon_o$) is saturated dielectric anisotropy and $\bar{\epsilon}$ is the isotropic part of dielectric (at optical frequency) [Chien Hut Wen,(2006),Barbara,J.F.(1989)].

$$\bar{\epsilon} = \frac{2 \epsilon_{\perp} + \epsilon_{\parallel}}{3} \text{-----} (11)$$

$$\epsilon_{\parallel} = n_e^2 \quad \text{and} \quad \epsilon_{\perp} = n_o^2$$



(Fig.1: Liquid crystal wedged cell, the He – Ne laser beam encounters first the substrate A. When the cell is empty only ray R_{ref} emerges. When the wedge is filled the ordinary and extraordinary rays R_o and R_e appear. The angles formed by R_o and R_e with R_{ref} are called θ_o , θ_e)

3 – Experimental set up

The experimental set up is shown in (Fig.2). A c.w.He – Ne laser that operates on the fundamental Gaussian mode at wave length of (623.8 nm) is used a beam condenser formed by two SiO_2 lenses placed in confocal configuration to allow a quite narrow laser spot of a diameter of approximately (2mm) .The laser radiation is polarized along the propagation direction forming an angle of 45 degrees with the LC direction .Such a polarization is obtained by means of a wire grid polarizer .

The beam passes through the liquid crystal cell (UCF).The LC cell is positional inside a coil with the following specifications :

Table (1) : properties of the coil

property	Magnitude and unit
Type of wire	Copper
Value of the Current	1 (A)
Diameter of wire	1 (mm)
Number of turns	6500
Magnetic field	200 (m T)

To avoid the formed heat in coil because of the resistance, we designed the coil from thick wire ,When the operation laser device (see Fig.1) the laser beam is filled on first plate of the LC cell is perpendicular to the wave vector of the incident laser radiation, where the first plate is labeled as (A) . The cell is composed of two SiO_2 windows (2mm) thickness, kept in a wedge – shaped configuration by means of two spacers of different thickness ,the alignment of the (UCF) LC molecules are planar and obtained by coating the inner surfaces of the windows by PVA and rubbing the surfaces with a soft velvet. The quality of the alignment has been checked by means of microscope, observing the sample between crossed polarizers. The angle formed by the two windows of the UCF cell has been evaluated by an optical method, giving the value($\theta = 0.05035$ degrees).

To measure the angle the following method has been adopted. The cell is mounted on rotating goniometer with precision of 0.00001 degrees, then a He – Ne laser beam is sent on substrate (A) of the cell. The beam is partially reflected and multiple reflected sub – beams appear because of multiple reflections at the window surfaces. These beams are visualized on a screen, in order to amplify their separation. It is easy to verify that the angle θ formed by the first two reflected spots (i.e., the more intense) is the same of the angle formed by the two substrates. The position of the first reflected spot is marked on the screen. The cell is then rotated until the second reflected spot superimposes on the position previously marked. The rotation amplitude is measured by the goniometer. The result is the searched angle. By using the detector find the peak of the Gaussian is change in position, therefore, by act to move the vertical millimetric stage in order to change its position in very manner across the observation plane π along the X – axis (see Fig.1). The temperature of the

sample is at the room temperature (25°C) and the distance ($L = 180\text{ cm}$) between the cell and the detector, which plays an important role in our measurements. Each measurement has been repeated many times by changing the magnitude magnetic field in order to study the effect of the magnetic field value on the refractive indices. Every time the magnetic field was changed, we waited about (10 minutes).

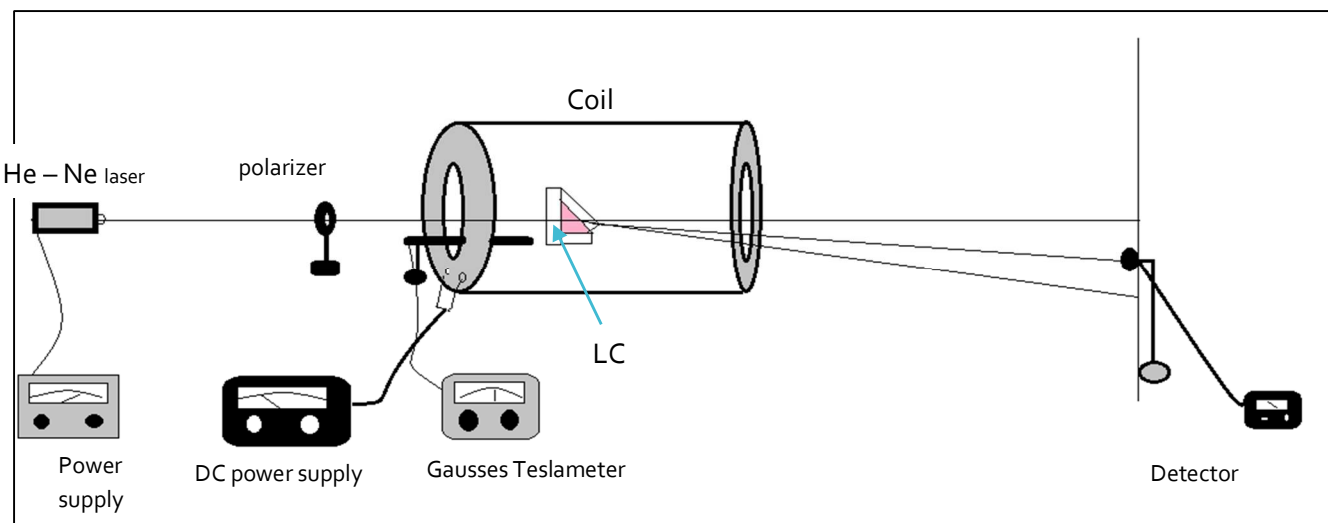


Fig.2: Schematic representation of the magneto – optic system which is used in the search

4 – Results and discussion

4 -1: Magnetic field effect on θ_o and θ_e

By using equations (3) and (4) we find X_o and X_e every 10 minute after the reading of each change in the magnetic field. These data are represented by fig.(3)

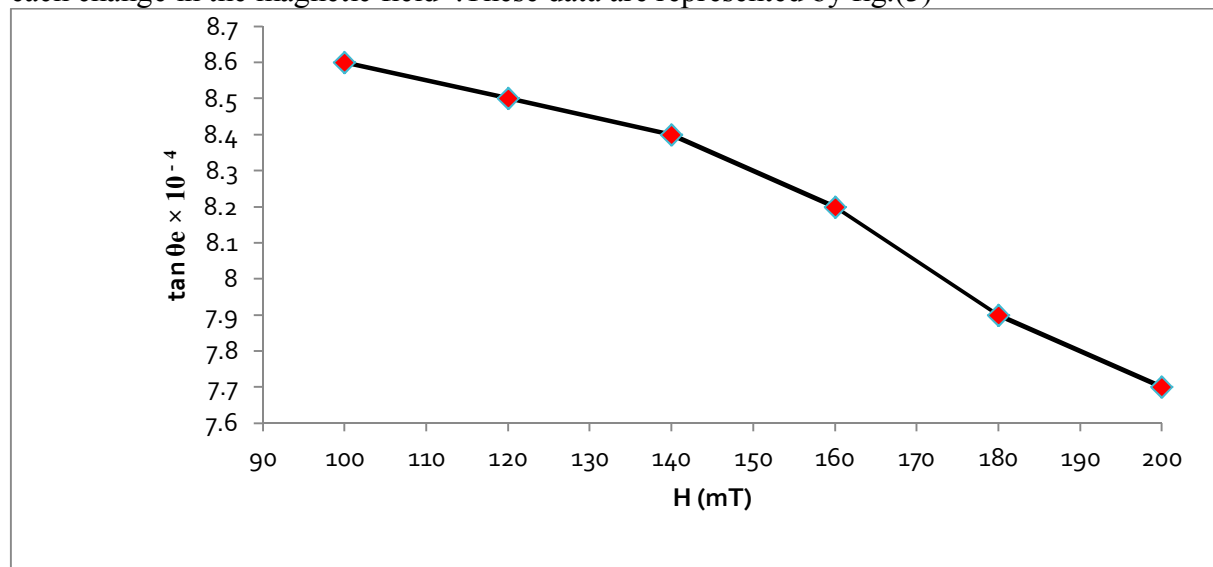


Fig.(3 – a) : The variation of ($\tan \theta_e$) with the magnetic field for mixture liquid crystal (UCF).at wave length (623.8 nm).

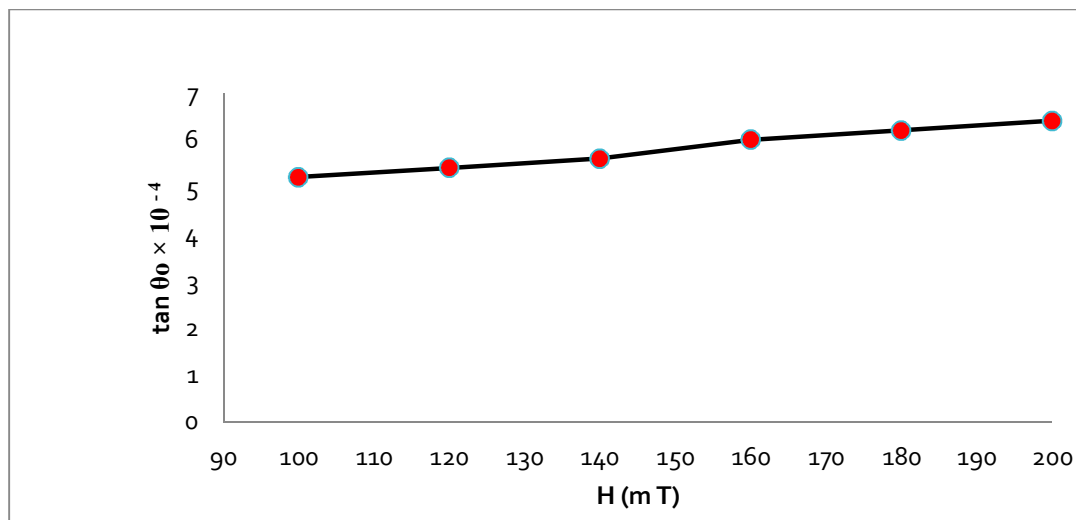
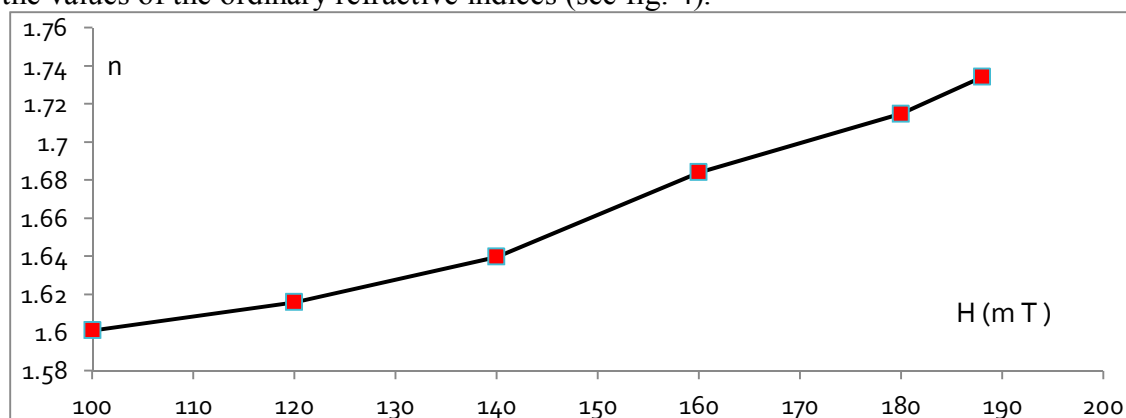


Fig. (3 – b) The variation of ($\tan \theta_o$) with the magnetic field for mixture liquid crystal (UCF), at wave length (623.8 nm)

From above figures we find the magnetic field has effect on the angles of the molecules by change the X_o and X_e , and thus the ($\tan \theta_o$) increases when the magnetic field increases (see fig.3-b). That means the ordinary beam suffers impedance when it travels through the LC ,therefore the parameter X_o takes large value at every time ,while the relation between the magnetic field and the ($\tan \theta_e$) (see fig.3 – a) find the value ($\tan \theta_e$) decreases when the magnetic field increases ,to explain these case we find the extraordinary beam makes small angle at every time ,that means the parameter X_e has been short ,also velocity of this beam decreases through LC.

4 – 2 : Magnetic field effect on the ordinary refractive (n_o)

Applying eq.5 and 7 and changing the mag.field strength value each 10 minutes, we find the values of the ordinary refractive indices (see fig. 4).



(Fig.4) The variation of ordinary refractive index (n_o) with the magnetic field (H), at wave length (623.8 nm)for mixture liquid crystal (UCF).

To discuss the figure (4), shows the ordinary refractive indices for (UCF) liquid crystal increases when the magnetic field increases. More explanation the ordinary beam faces impedance from the medium therefore it takes large value for indices at every time because

the velocity for this beam begins to be less and the result for that takes a big angle divergence (θ_0).

4-3 : Magnetic field effect on the extraordinary refractive indices (n_e)

According to equation (8) and changing the mag.field value every (10) minute and using the equations (6) we find the extraordinary refractive indices, and the results are plotted in fig. (5)

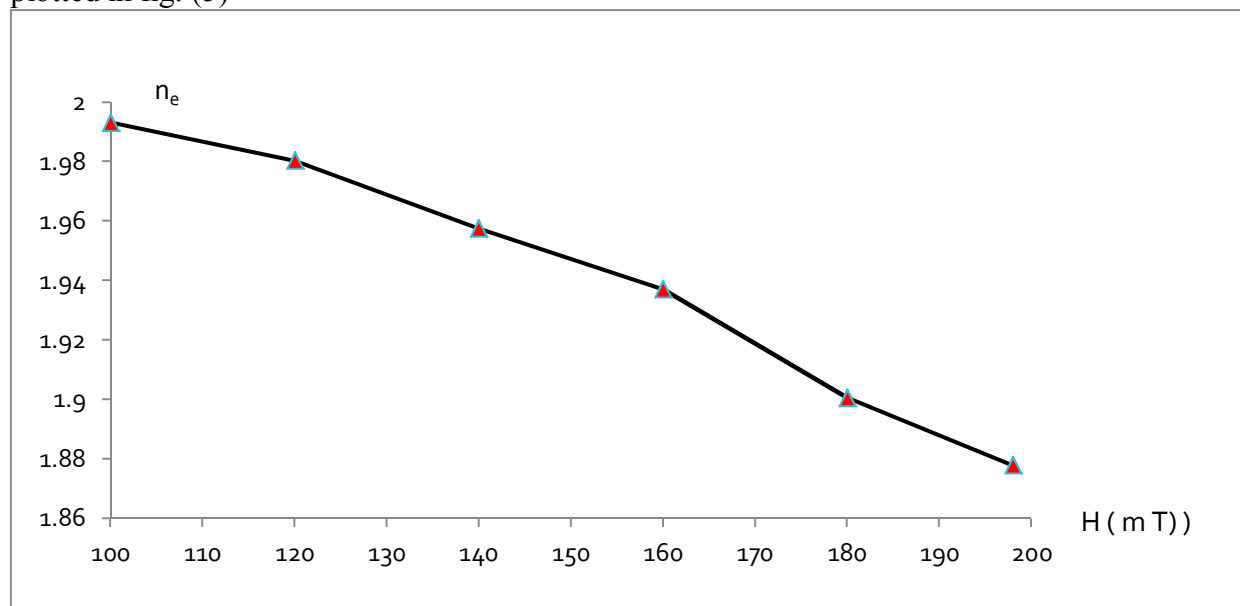


Fig.5: The variation of extraordinary refractive index (n_e) with the magnetic field (H), at wave length (623.8 nm) for mixture liquid crystal (UCF).

To analyze the above figure, we find the extraordinary refractive decreases when the magnetic field increases, from equation (4) the value X_e decreases when the magnetic field values increases.

This also means that the extraordinary beam has fast velocity at any step from increase the magnetic, add for that the impedance of medium LC became less opposite the extraordinary beam.

4-4 : Determine the average refractive indices $\langle n \rangle$

To find $\langle n \rangle$ take the values for ordinary refractive indices which are determined in paragraph (2-4) and the values for extraordinary refractive indices which are determined in paragraph (3-4) and using the equation (9), and determine the average refractive indices for mixture liquid crystal (UCF) (see fig.6).

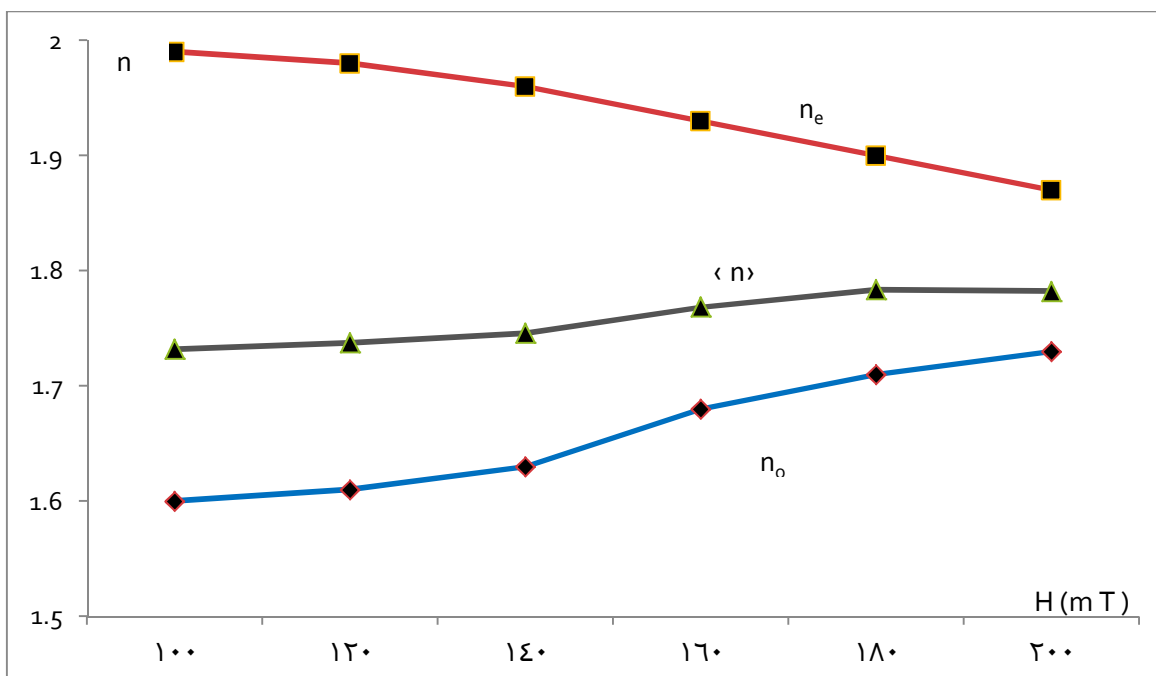


Fig. 6: The variation of average refractive indices $\langle n \rangle$ with the magnetic field for mixture liquid crystal (UCF), at wavelength (623.8 nm)

The value $\langle n \rangle$ can be approximated by the refractive index of the equivalent isotropic medium.

4–5: Magnetic field effect on birefringence (Δn)

By using equation (10) and reparation for all parameters in the same equation and the experience is made at room temperature (25 °C) and (a_0) takes the value (3 / 2) from both the Landau – de Gennes and the Maier – Saupe models [Barbara,J.F.(1989)].After that we find the relationship between the magnetic field and birefringence (see fig. 7).

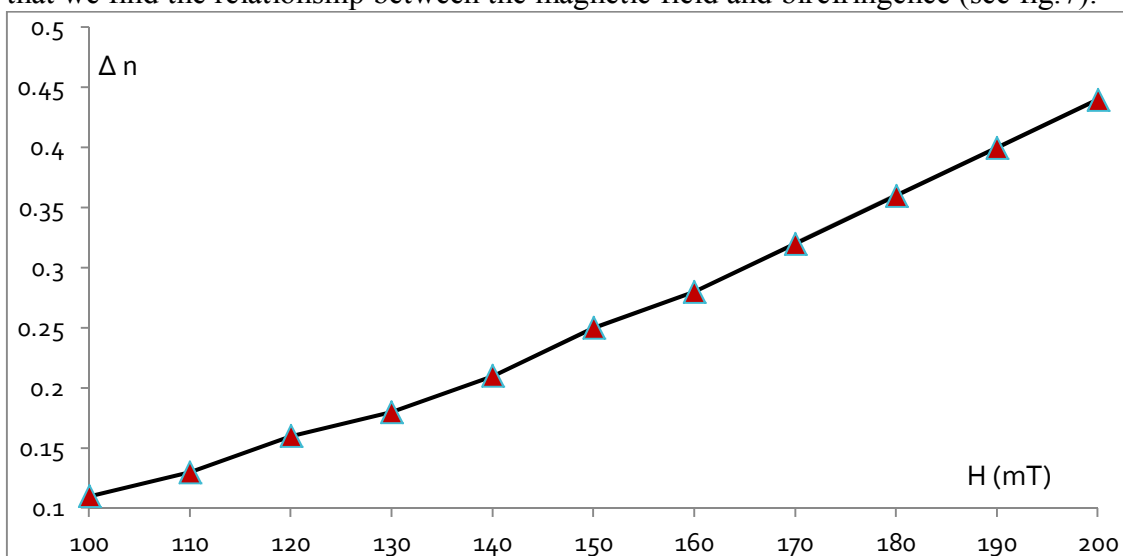


Fig.7: The variation of birefringence with magnetic field for mixture liquid crystal (UCF) at wavelength (623.8 nm)

To discuss fig.7, shows the Optical birefringence (or refractive index anisotropic Δn) is proportional to (H^2) and induced at temperatures above the clearing point .

5 - Conclusions

The study showed that the magnetic field affects the molecules of the liquid crystal (UCF), in this study we find that the extraordinary refractive index (n_e) decreased, while the ordinary refractive index (n_o) increased, increasing the mag.field. Also this study proved that the optical birefringence (Δn) is proportional with the square value of the mag.field at room temperature.

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