CHAPTER (III)

THEORY AND MEASUREMENT OF INDUCED BIREFRINGENCE

3.1 Introduction

An interferometric method is used to investigate the effect of controlled stress on a transparent material such as plastic and glass. Interference of polarized light transmitted through the transparent material produces interference fringes. The location of each fringe represents a surface of equal stress. Different fringes corresponding to different stresses are recorded on Fortepan photographic plates. A relation between the applied stress and the resulting interferogram is given and confirmed experimentally. A least square algorithm is applied for analyzing the resulting interference fringes and consequently deducing the shape of the applied stress. Optically using compression or tension changes the properties of isotropic transparent solids. In this case the solid acquires the properties of a uniaxial crystal whose optical axis is collinear with the direction of the deforming forces. This effect is known as photoelastic effect and was observed by Browester in 1815 [71].

The photoelastic effect reduces the performance of the optical components by introducing phase distortions. These distortions arise from stress by improper mounting or by non-uniform thermal expansion of the optical components and their mounts [72]. The Photoelasticity is a common method for stress analysis of specimen subjects to load [73,74]. A copy, with reduced scale, of the specimen under investigation is made.

Transparent materials like glass, gelatin, bakelite, acrylic, polymers and epoxy can be used for making such models. Then the stressed models are enclosed between two crossed polarizers and illuminated with a monochromatic light. The stressed regions in the model rotate the plane of polarization of light and a visible interference pattern is produced. The direction and size of the stresses may be deduced from this interference pattern. [43]

3.2 Physical effects of induced birefringence

There are a number of different physical effects invoicing birefringence. In the material that all share single common feature of somehow being externally induced .In these instances one exerts an external influence (e.g., a mechanical force, a magnetic or electric field and a laser effect or laser induced cracks) on the optical medium, thereby changing the manner in which it transmits light.

In 1816 Sir David Browester discovered that normally transparent isotropic substances could be made optically anisotropic by the application of mechanical stress. The phenomenon is variously known as mechanical birefringence, Photoelasticity or stress birefringence. Under compression or tension the material takes on the properties of a negative or positive uniaxial crystal, respectively. In either case the effective optic axis is in the direction of the stress, and the induced birefringence is proportional to the stress. Clearly that if the stress is not uniform over the sample, neither the birefringence nor the retardation will be imposed on a transmitted wave. The retardation is given as in eq. (13) [68].

Photoelasticity serves as the bases of a technique for studying the stress in both transparent and opaque mechanical structures. Improperly annealed or carelessly mounted glass, whether serving as an automobile windshield or a telescope lens, will develop internal stresses that can easily be detected. Information concerning the surface strain on opaque objects can be obtained by bonding photoelastic coating to the parts under study. More commonly, a transparent scale model of the part is made out of a material optically sensitive to stress, such as epoxy, glyptol, or modified polyester resins. The model is then subjected to the forces that the actual component would experience in use. Since the birefringence varies from point to point over the surface of the model, when it is placed between crossed polarizers, a complicated variegated fringe pattern will reveal the internal stresses. Examine almost any piece of clear plastic or even a block of unflavored gelatin between two polaroids; try stressing it further and watch the pattern changes accordingly. The retardance at any point on the sample is proportional to the principal stress difference that is, (σ_1- σ_2), where the sigmas are the orthogonal principal stresses. For example, if the sample were a plate under vertical tension, (σ_1) would be the maximum principal stress in the vertical direction and (σ_2) would be the minimum principal stress, in this case zero, horizontally. In more complicated situations, the principal stresses, as well as their differences, will vary from one region to the next. Under white light illumination, the loci of all points on the specimen for which (σ_1- σ_2) is constant are known as isochromatic regions, and each such region corresponds to a particular color. Superimposed on these colored fringes will be a separate system of black bands. At any point where the E-field of the incident linear light is parallel to either local principal stress axis, the wave will pass through the sample unaffected, regardless of wavelength. With crossed polarizers, that the analyzer will absorb light, yielding a black region known as an isoclinic band. In addition to being beautiful to look at the fringes also provide both a qualitative map of the stress pattern and a basis for quantitative calculations.

Michael Faraday in 1845 discovered that the manner in which light propagated through a material medium could be influenced by the application of an external magnetic field. In particular, he found that the plane of vibration of linear light incident on a piece of glass rotated when a strong magnetic field was applied in the propagation direction, the faraday or the magneto-optic effect was one of the earliest indications of the interrelationship between electromagnetism and light [1].

When an optically isotropic fluid is placed in an electric field it may become anisotropic and exhibit birefringence. This electric field induced birefringence or Kerr effect can be detected by passing a linearly polarized beam of light through the substance. The anisotropy of the sample causes the light beam to become elliptically polarized, with the degree of ellipticity being related to the magnitude of the induced birefringence [30].

When the influence of an input laser pulse is above a certain threshold value and under subsequent cyclic laser shots optical absorption in the material causes microscopic volume changes that give rise to mechanical stresses. These mechanical stresses that result from the expansion mismatch between the deformation zone (crack) and the rest of the matrix induce birefringence is in the fused-silica system [29].

3.3 Theory of induced birefringence

When a polymeric material is deformed, birefringence arises as well as strain. The relation between birefringence and stress has long been a subject of important optical studies. Deformation birefringence arises as a result of a change of bond angles and/or bond length, or a change in packing (a change in the lattice spacing) by an external deformation. For polymer melts and concentrated solutions, the anisotropic part of the refractive index tensor, n (t) is proportional to that of the stress tensor σ (t). This empirical rule is called the stress-optical rule SOR. The SOR for tensile deformation can be written as follows [25].

$$\Delta n\,(t) = C\sigma\,(t) \qquad (40)$$

Here, Δn(t) is the birefringence and σ (t) is the tensile stress. The coefficient of proportionality "C", called the stress-optical coefficient depends upon the properties of the material. The validity of the rule has been examined for many polymeric systems. From a theoretical point of view, the SOR indicates that the molecular origin of the stress as well as the birefringence is attributed to the orientation of the chain. Many molecular theories can predict the validity of the rule in rubbery or liquid states.

Suppose that the stressed model is inserted between two crossed polarizers and illuminated with monochromatic light. The induced birefringence of the model causes the polarized light (from the polarizer) to emerge refracted into two orthogonal planes. The light propagates in the same or different directions but with different velocities and this produces a phase shift between the transmitted light waves. When the analyzer recombines the waves, regions of stress where the differences of the waves are even multiples of π appear dark. The regions of the stress where the phase differences are odd multiples of π appear bright .The difference in phase between the two waves is given by Eq.(13) where n_o and n_e are the refractive indices in the parallel and perpendicular directions to the applied stress. The stress model produces a relative retardation that is equal to:

$$R = 2\pi \, t \, C \, (\sigma_1 - \sigma_2) / \lambda \tag{41}$$

Where $(\sigma_1 - \sigma_2)$ is the difference in the in-plane principal stresses. The transmitted intensity behind the second polarizer is [75]:

$$I = E^2 \, (\sin 2\beta)^2 \, (\sin R/2)^2 \tag{42}$$

Where β is the angle beween the axis of the polarizer and the dirction of the first principal stress in the model. The contours of equal intensity represent contours of equal stress. There are two conditions for the transmitted intensity of light to be zero. The first case is when $\beta = 0, \pi/2, 3\pi/2, \ldots,$. In this case, the axis of the polarizer coincides with any of the two in-plane principle stress directions in the model. The loci of points of equal stress will therefore be dark bands that are called isoclinic, which means that it is of equal inclination. The second case is when $R = 0, 2\pi \ldots m\,(2\pi)$, where "*m*"is the order of interference and an integer number from zero to infinity. It is equal to the number of wavelengths by which the two interfering waves are shifted from each other due to the applied stress. Loci of equal values of "*m*" are also black curves and are known as the isochromatic fringes which are curves of equal principal stress difference.

3.4 Experimental work and discussion

A transparent isotropic material becomes birefringent when subjected to mechanical force. Uniaxial crystals obtained with two privileged directions of the crystal are parallel to the directions of the principal stresses. In general, the direction of the two principal stresses will change from point to point in a crystal. The optical set up is shown in fig.18 and plate 4. S_0 is a monochromatic source of light. G is a glass filter, L_1 is a condensing lens with short focal length 3*cm* to form a minimized image of the source on the pinhole, C is a pinhole to increase the spatial coherence of the light source. L_2 is a collimating lens of focal length 5*cm* to produce a parallel beam of light. N_1 is a linear polarizer to give a linearly polarized light. S is the sample under stress to be investigated, which is a transparent isotropic material such as Acrylic, polymer and glass. N_2 is a linear polarizer. L_3 is a condensing lens with long focal length 15*cm* to form an image on a Fortepan photographic plate F to record the interference pattern. A hydraulic press HY for the compression on the sample is used.

Without a compressive force there are no interference fringes in the field of view, where the polarizer and the analyzer are crossed. By applying a force on the sample the interference fringes start to appear. The number of fringes increases and its shape changes as the magnitude of the applied

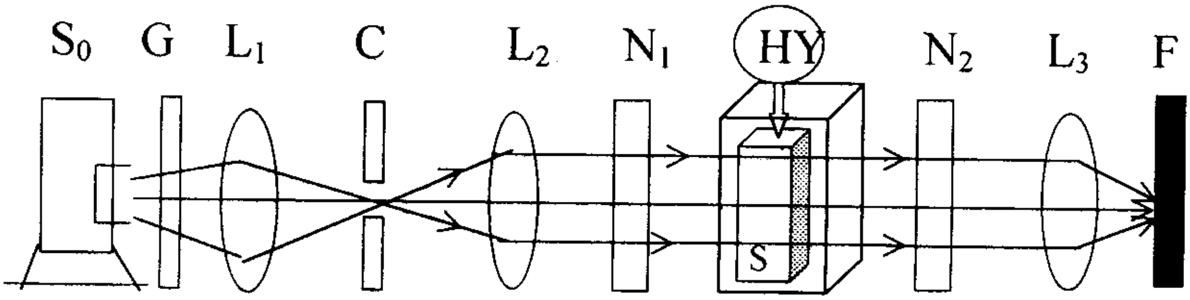


Fig. 18: Optical set-up for investigating the stress distribution in a sample.

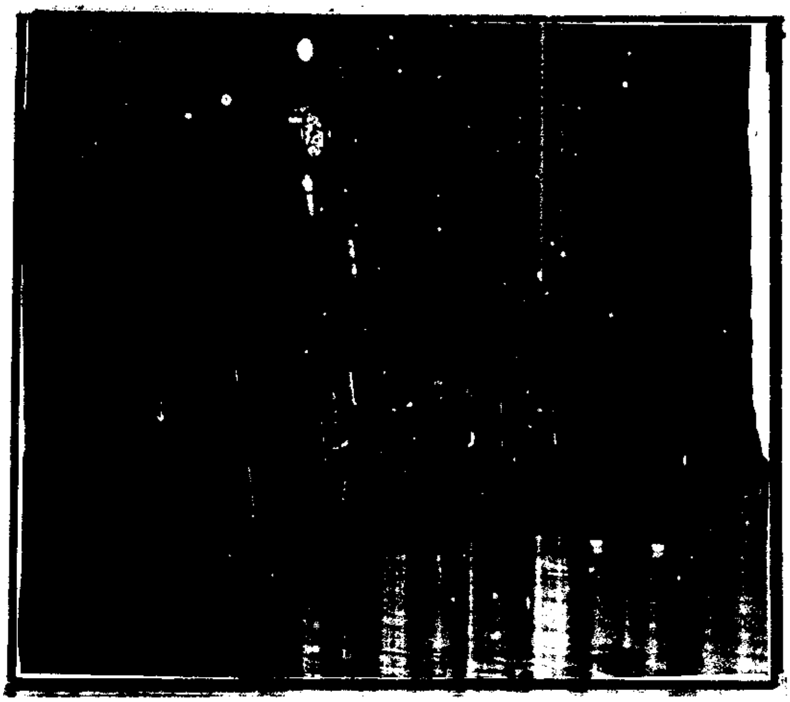


Plate 4: A photographic plate of the optical set-up for investigating the strain distribution in a sample.

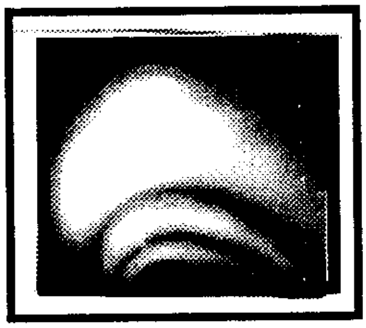
force increases. As the applied force decreases the number of fringes decreases till the fringes disappear when there is no force applied. Starting by an acrylic plate (5cm length and 1.82cm thick.) as a sample placed between two crossed polarizers under a hydraulic press and compressing it with different stresses, the interference fringes with different stresses are shown in plate 5.

3.4.1 Strain distribution and Young's modulus

A method of fitting quadratic forms, by using a PC-computer, for analyzing the resulting interference fringes is adopted to find the distribution of the applied stress as follows. The fringes are numbered according to their orders of appearance. Then, each fringe is traced with equal steps (the steps are chosen approximately equal to the mean fringe separation) to find the positions of x and y on the fringe with reference to the photographic plate F. The (x, y) indices for each step are recorded together with the order of appearance assigned to that fringe as in plate 5. These data are fed to the computer. A least squares algorithm for fitting quadratic forms is designed. The algorithm is then used to determine the coefficients and the residual variance for the fitting of a quadratic equation in the form:

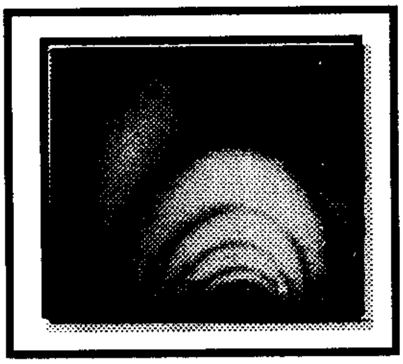
$$Y = A + BX + CX^2. \qquad (43)$$

(a)



(b)

(c)



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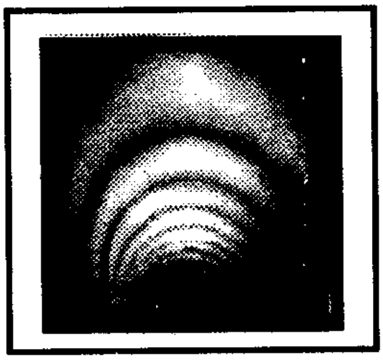


(f)

Plate 5: The interference fringes obtained due to variable stresses on acrylic sample. Stress equal to (a) $49.0 \times 10^4 N/m^2$. (b) $58.8 \times 10^4 N/m^2$ (c) $68.6 \times 10^4 N/m^2$. (d) $78.4 \times 10^4 N/m^2$. (e) $88.2 \times 10^4 N/m^2$. (f) $98.0 \times 10^4 N/m^2$. By using sodium lamp of wavelength (589.3nm).

From the coefficients, A, B and C, the shape of the interference fringes and consequently the shape of the applied stress is deduced. These coefficients indicate that the fringes are of the shape of hyperbolas [76]. This stress is distributed in the form of hyperbolas. The induced birefringence can be obtained from eq.(29) where "m" is the order of appearance of the fringe that exists due to applying the stress.

The value of the constant A represents the displacement of the fringes in the direction of the applied stress (y-axis) at "x = 0" and the values of the constants B & C are useful to find the stress distribution. The coefficient "A" in eq.(43) is directly proportional to the values of the applied stresses on the material used. Since the strain is the fractional change in length of the specimen therefore the ratio of the reduction in the length of the sample, ΔL, to the original length L is the strain of the material. This ratio is a dimensionless quantity. The value of ΔL is found from:

$$\Delta L = (A / \Delta A)\,\lambda \qquad (44)$$

Where ΔA is the average fringe separation. Table3 shows the fitting parameters of eq.(43) for acrylic sample (5cm length and 1.82cm thick.) subjected to different specified stresses. This table illustrates the strain distribution inside the sample. Fig.19 represents the strain distribution in this sample by using sodium lamp of wavelength 589.3 nm. In this figure

Table 3: *Fitting parameters of eq.(43) for acrylic sample subjected to different specified stresses by using sodium lamp of wavelength 589.3 nm.*

Applied stress (10^4 N/m^2)	Fringe order	Fitting parameters		
	m	A	B	C
58.8	1	0.3607919	3.60057E-17	-1.3640308
68.6	2	0.57414719	-1.48243E-17	-1.5658159
78.4	3	0.69117074	1.660833E-17	-1.3444371
88.2	4	0.94880092	-9.13052E-17	-1.370741
98.0	5	1.2588483	-2.10517E-16	-1.3822537

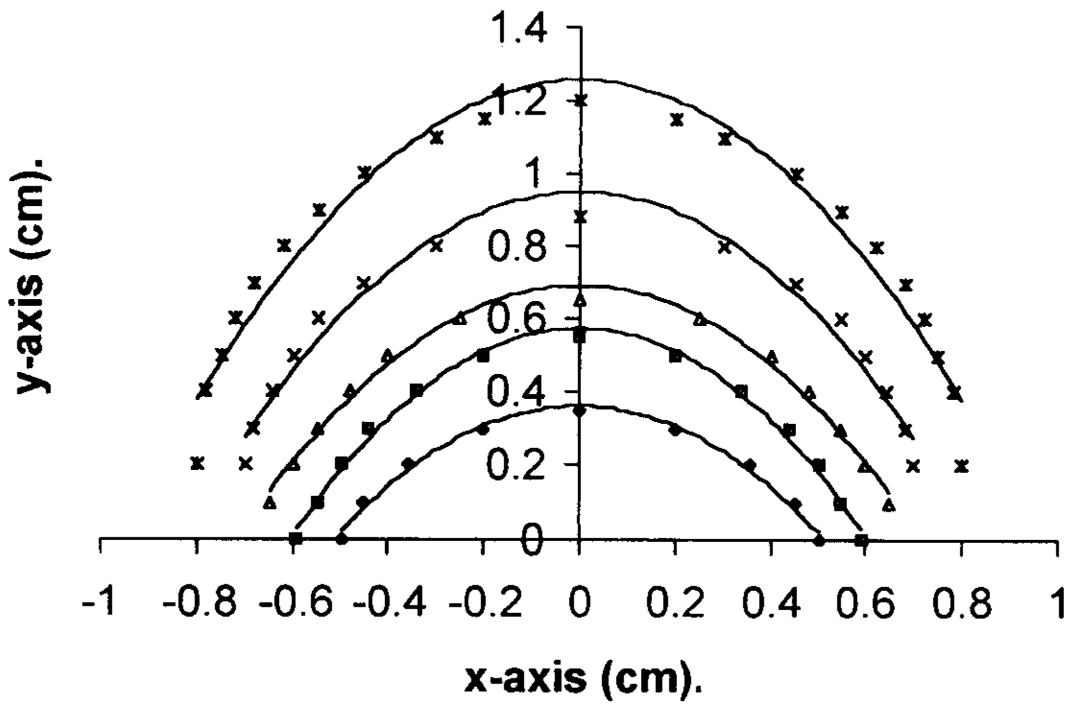


Fig.19: The strain distribution for acrylic sample (5cm length and 1.82 cm thick.) subjected to stress of 98x 10^4 N /m^2 by using sodium lamp of wavelength 589.3nm.

the continuous lines are those of fitting and the doted are the experimental values.

Firstly, a mercury spectral lamp of wavelengths 578.0, 546.1 and 435.8 nm is used as a source. In addition to the mercury lamp the spectral sodium lamp and He-Ne laser source with wavelengths of 589.3, 632.8 nm, are respectively used. The relation between different applied stresses and the produced strain, which is equal to ($\Delta L/L$) or [$(A/\Delta A)\ \lambda\ /L$] are illustrated in fig.20. From the definition of Young's modulus, which is equal to the ratio between the applied stress and the strain, its value can be obtained. Since these figures are straight line, it is fitted to the linear function "$y = a\,x + b$" where "y" represents the stress and "x" the strain, "a" and "b" are constants, where "a" is the Young's modulus and "b" is the intercept with the y-axis. The value of "b" deduces the threshold value of the stress, which should be applied in order to attain detectable strain.

The results of fitting are presented in each figure. The values of Young's modulus corresponding to different wavelengths for acrylic sample is shown in table 4. According to table 4 the Young's modulus depends on the frequency of the light used, actually it should not. Therefore the value at zero frequency is our aim. The relation between Young's modulus and the frequency is shown in fig.21. The true Young's modulus is that corresponding to zero frequency which is (26.368 N / m^2).

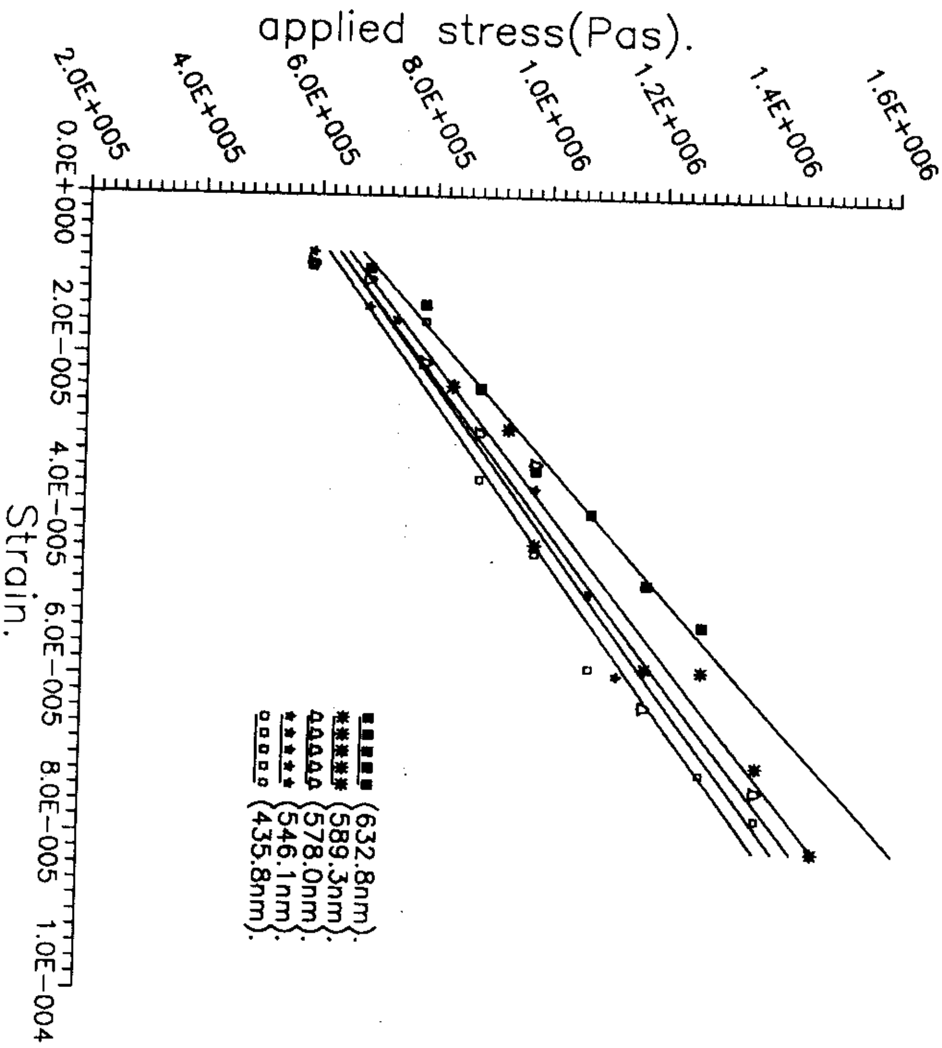


Fig 20: The relation between stress and strain for acrylic sample of length 5cm and thick.1.82cm with different wavelengths (632.8, 589.3, 578.0, 546.1, 435.8 nm)

Table 4: *The values of Young's modulus for acrylic sample with different wavelengths or frequencies (1 λ).*

Wavelength λ (nm)	$1/\lambda$ (nm^{-1})	Young's modulus [10^9 N/m^2 (Pas)]
632.8	0.00158027812	12.5344
589.3	0.00169692855	11.0721
578.0	0.00173010380	10.7730
546.1	0.00183116645	10.4722
435.8	0.00229463056	10.3334

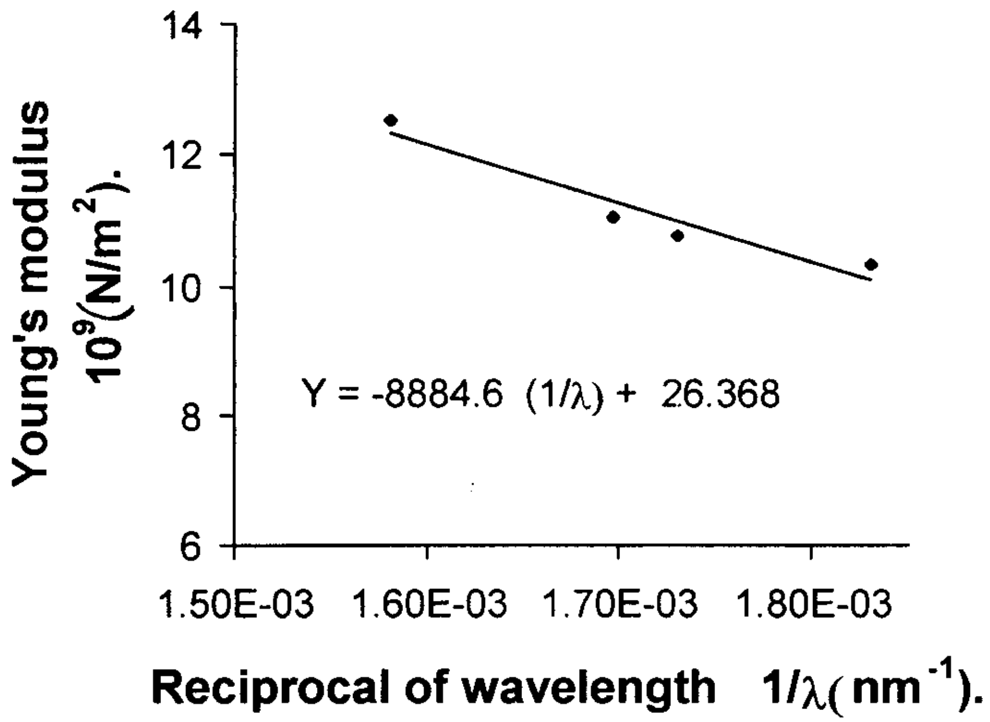


Fig.21: The relation between Young's modulus for acrylic and the frequency of the radiation used.

The same work is applied on a sample of crown glass and Young's modulus is found for it as shown in fig.22. Young's modulus for crown glass sample is 21.4855 x $10^9 N/m^2$ with wavelength 589.3nm.

3.4.2 Measurement of bir :fringence and its dispersion

The induced birefringence "Δn" is obtained by using eq. (29) where the order of interference m is the order of appearance of the fringe, which is equal to "$A/\Delta A$". Since "$Strain = \frac{\Delta L}{L} = \frac{A}{\Delta A} \cdot \frac{\lambda}{L}$", so that by substituting in eq.(29) about "$\lambda \Delta n$" is obtained with different strain at constant stress for the different wavelengths as in fig.20. Dispersion relation is obtained for acrylic sample as shown in fig.23, which represents the relation between the birefringence and wavelengths of light used at constant stress. Birefringence is inversely proportional to wavelength and the relation is in good agreement with normal dispersion of Cauchy equation for natural birefringent materials.

From the relation between applied stress and the induced birefringence in eq. (40), the value of the stress optical coefficient "C" is be obtained as the

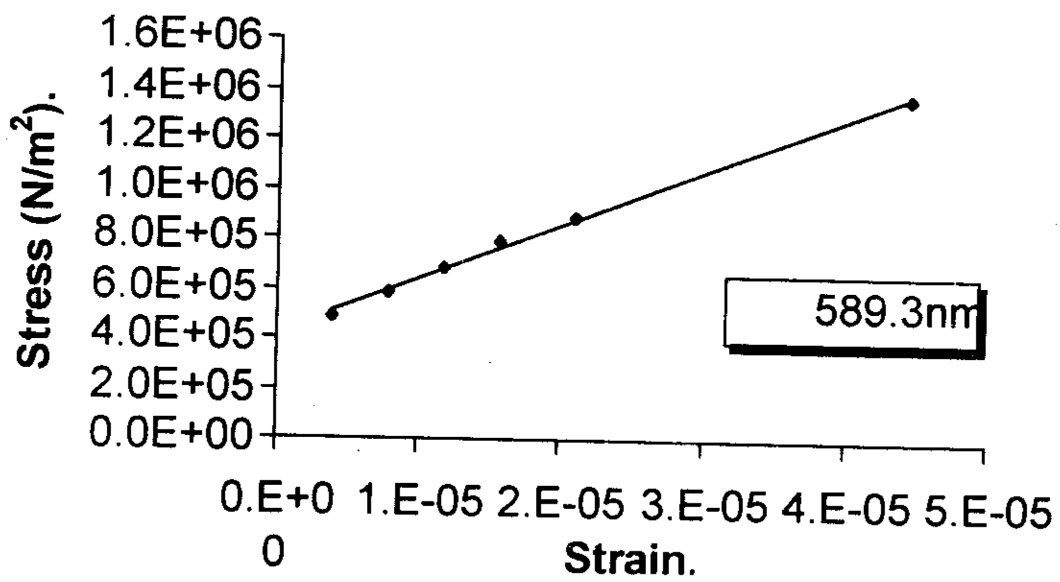


Fig 22: The relation between stress and strain for Glass sample of length 5cm.with sodium lamp of wavelength 589.3nm .

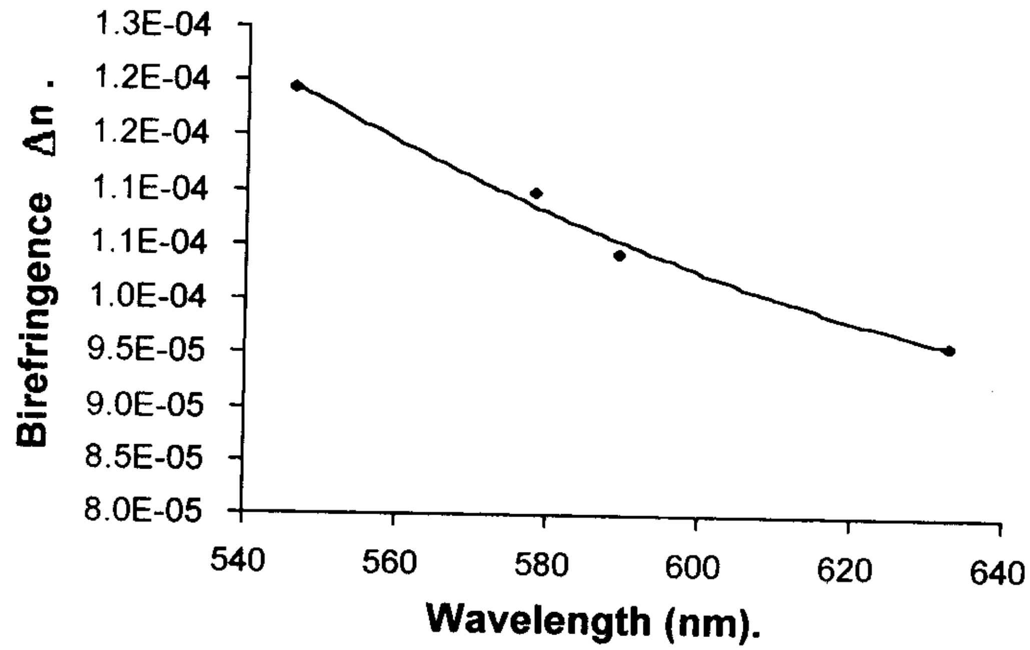


Fig.23: The relation between birefringence and the wavelength of light used for acrylic sample of length 5cm at constant stress of $98.0x10^4$ N/m^2 .

slope of the relations given in fig.24. The value of the stress optical coefficient "C" for the sample of acrylic for different wavelengths is shown in table 5. These values are in good agreement with the published data [13, 29].

Table 5: *The stress optical coefficient C for acrylic sample with different wavelengths.*

Wavelength λ (nm)	Stress optical coefficient C (Brewster)*.
632.8	0.0354802
589.3	0.0330399
578.0	0.0324064
546.1	0.0306179
435.8	0.0244337

* Brewster = 10^{-12} m^2/N

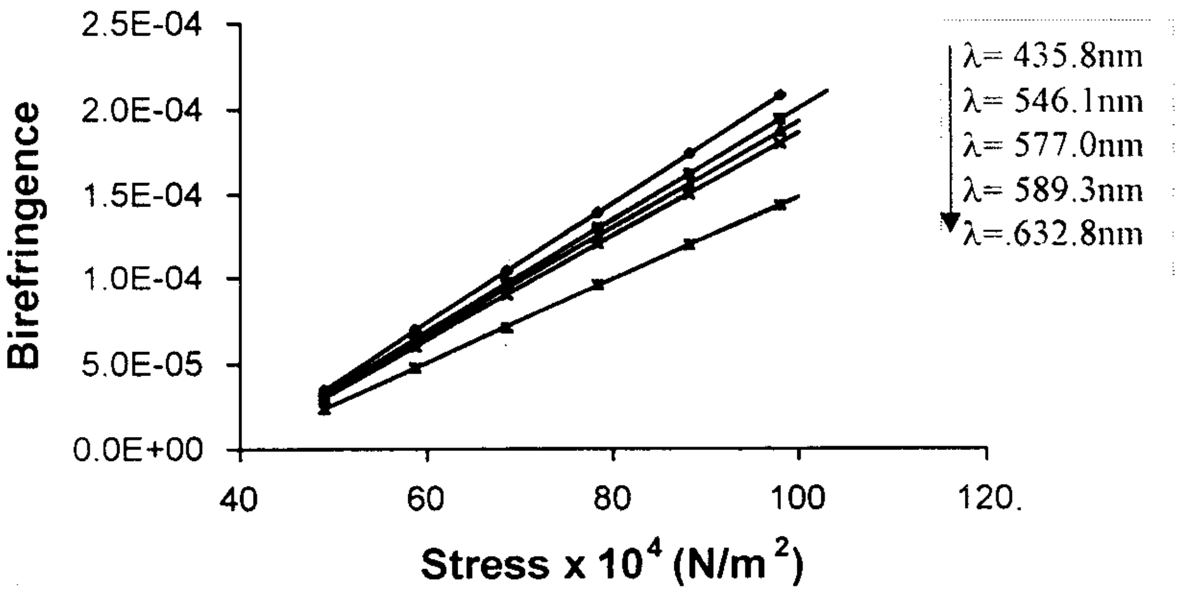


Fig. 24: The relation between applied stress and birefringence for an acrylic sample of thickness 1.82 cm with different wavelengths.

3.5.1 Theory of natural-induced birefringence

In this section localized two-beam interference fringes are produced by bending a thin sheet of transparent photographic film of thickness t, into a complete semi-cylinder of radius r as in fig 25. Due to this curvature there is a stress applied upon it. This means that two kinds of birefringence are included. First, the stored (fixed) birefringence is already present in the sheet and was preimposed to it during its manufacturing. Second, the additional controllable birefringence is induced on the sample sheet by bending it in a curve, where some stresses are imposed on it. The stresses increases by increasing the curvature of the sheet i.e., by decreasing the radius of curvature r. Hence, the measured Δn in presence of stress (through r) is greater than that when no stresses are applied, i.e., when "$r = \infty$" and hence "$1/r = 0$". Therefore, the actual stored "Δn" is that value corresponding to "$1/r = 0$".

A parallel beam of monochromatic light is incident on the concave face of a Fortepan sheet film. Fringes can be seen over relatively wide ranges of both "t" and "r". The refraction effects within the film have been neglected because the film is very thin and "Δn" is small enough.To a close approximation both faces can be considered to have the same radius of

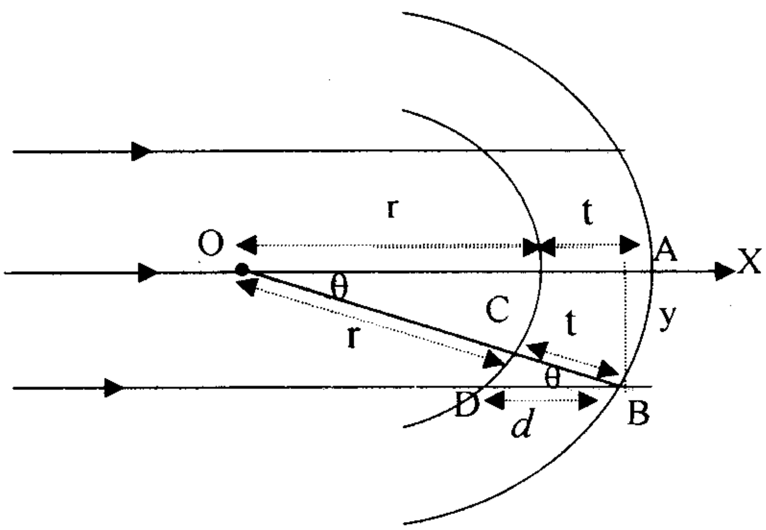


Fig-25: Transparent material in a curved form illuminated with a parallel beam of light.

curvature. An approximate geometrical analysis serves to prove that when the thickness t is different in the path of the monochromatic light, the fringes are localized on a screen behind the sample perpendicular to the axis of symmetry OX, and on either sides of it. Then the distance between a pair of symmetrically situated fringes on either sides of this axis will be called the diameter of the fringe 2y. In fig 25 we have:

$$\text{Cos } \theta \approx (r+t) / \sqrt{(r+t)^2 + y^2} \qquad (45)$$

Where θ is the angle of incidence and y is the distance between the situated fringe and the original axis OX which is equal to AB or is the radius of the fringe. But in Δ BCD:

$$\text{Cos. } \theta \approx t / d \qquad (46)$$

Where t is the thickness of the birefringent sample at the center and *d* is the thickness along the path of the incident parallel beam of light around the center of curvature. From eq. (45) & eq. (46), we get:

$$t / d = (r+t) / \sqrt{(r+t)^2 + y^2} \qquad (47)$$

Eq. (47) can be rewritten as follows:

$$d = (t / r + t) \sqrt{(r+t)^2 + y^2} \qquad (48)$$

Due to the variation of d, the interference pattern occurs. Under this condition the phase difference between the E and the O-ray is given by eq. (13). For the phase difference equal to integral multiples of 2π no light is passed by the analyzer, hence the spectrum is crossed by a dark fringe at each thickness for which;

$$\Delta n\, d = (m + p)\,\lambda \qquad (49)$$

Where $\Delta n = \Delta(n_o - n_e)$, m is the order of appearance and p is the order of interference when y equals zero.

Substituting from eq. (48) in eq. (49) then;

$$(t / r + t)\sqrt{(r+t)^2 + Y^2} = (m + p)\,\lambda / \Delta n \qquad (50)$$

$$[1 + \frac{y^2}{(r+t)^2}]^{\frac{1}{2}} = \frac{m\lambda}{t\Delta n} + \frac{p\lambda}{t\Delta n} \qquad (51)$$

Since at m = 0, then y = 0, so that;

$$p = t\,\Delta n / \lambda\,.$$

By substituting in eq.(46) then;

$$[1 + \frac{y^2}{(r+t)^2}]^{\frac{1}{2}} = \frac{m\lambda}{t\Delta n} + 1 \qquad (52)$$

By using Maclaurin series the left-hand side in Eq. (52) can be written as follows:

$$(1 + \frac{y^2}{(r+t)^2})^{\frac{1}{2}} = 1 + \frac{1}{2}\frac{y^2}{(r+t)^2} + \frac{1}{4}(\frac{y^2}{(r+t)^2})^2 + \ldots\ldots$$

Since $(r + t)^2 \gg y^2$, then

$$(1 + \frac{y^2}{(r+t)^2})^{\frac{1}{2}} \approx 1 + \frac{1}{2}\frac{y^2}{(r+t)^2} \qquad (53)$$

By substituting from Eq. (53) in Eq. (52) we get

$$1 + \frac{1}{2}\frac{y^2}{(r+t)^2} = \frac{m\lambda}{t\Delta n} + 1 \qquad (54)$$

Then;

$$y^2 = [\frac{2\lambda(r+t)^2}{t\Delta n}]m \qquad (55)$$

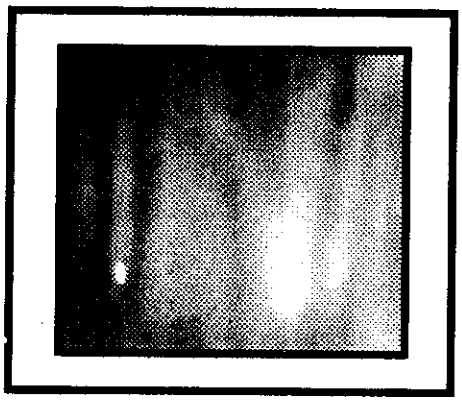
This equation represents the relation between the order of the fringe and the square radius of it. There is a direct proportionality between birefringence "Δn" and the curvature "1/r". By knowing the wavelength of the monochromatic light used, the radius of curvature and thickness "t", induced birefringence "Δn" is obtained for an anisotropic material.

3.5.2 Experimental work and discussion

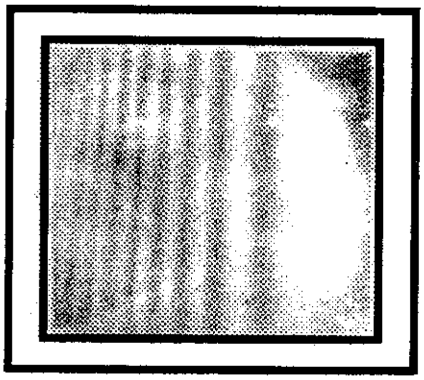
The optical set up used to produce two-beam interference fringes in transmission is shown in fig.1ڤ, but the sample is replaced by a developed Fortepan photographic plate in a curved form as in fig.25. A mercury lamp of wavelength (578.0 nm) is used instead of a white light, and a photographic film at the focal plane of the lens L_3 instead of a grating spectrograph. The fringes are seen on the photographic film F as shown in plate 6.

The resulting two-beam interference fringes are serially numbered from one to *m* and their positions on the photographic film are measured. Thus, for each *m* the value of *y* from eq. (55) is obtained at each radius of curvature. Also, according to this equation, crowded fringes occur by decreasing the radius of curvature r as in plate 6. Fig. 26 shows the relation between y^2 and *m* at different radii of curvature r (i.e., at different stresses) for a developed Fortepan transparent photographic plate as an anisotropic material.

From The relation between induced birefringence Δn and 1/r the value of the natural (stored) birefringence Δn_o is obtained as shown in fig. 27 which is the intersection of Δn-axis at infinity value of r i.e., there is no applied stress and the sheet is plane surface. The value of the natural (stored) birefringence for a transparent Fortepan photographic plate is equal to $(\Delta n)_n = 0.03101$ for $\lambda = 578.0$ nm. This value is in good agreement with the previous value, which was obtained by another method in chapter II.



(a)



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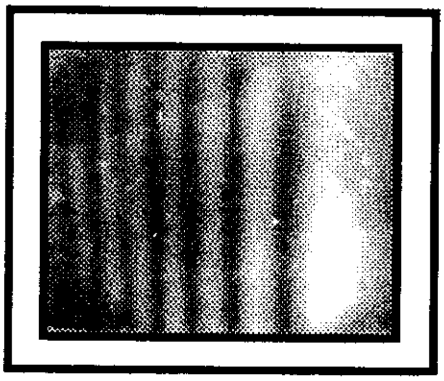

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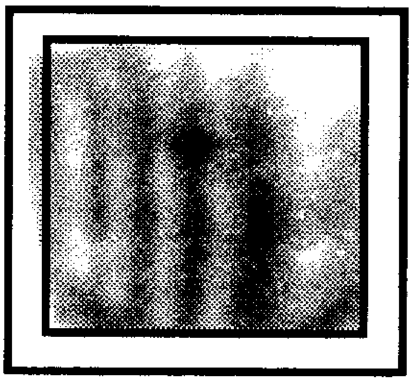

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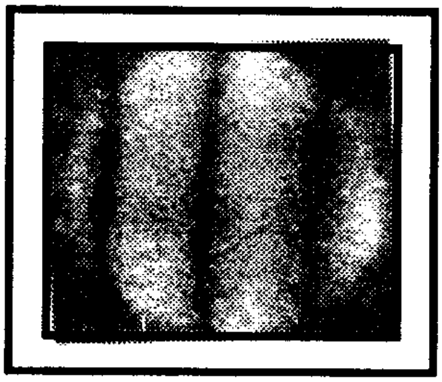

(e)

Plates 6: The interference fringes due to different radii of curvature of Fortepan photographic sheet
(a) Fringes around the center. (b) 2cm. (c) 3cm. (d) 4cm. (e) 5cm.

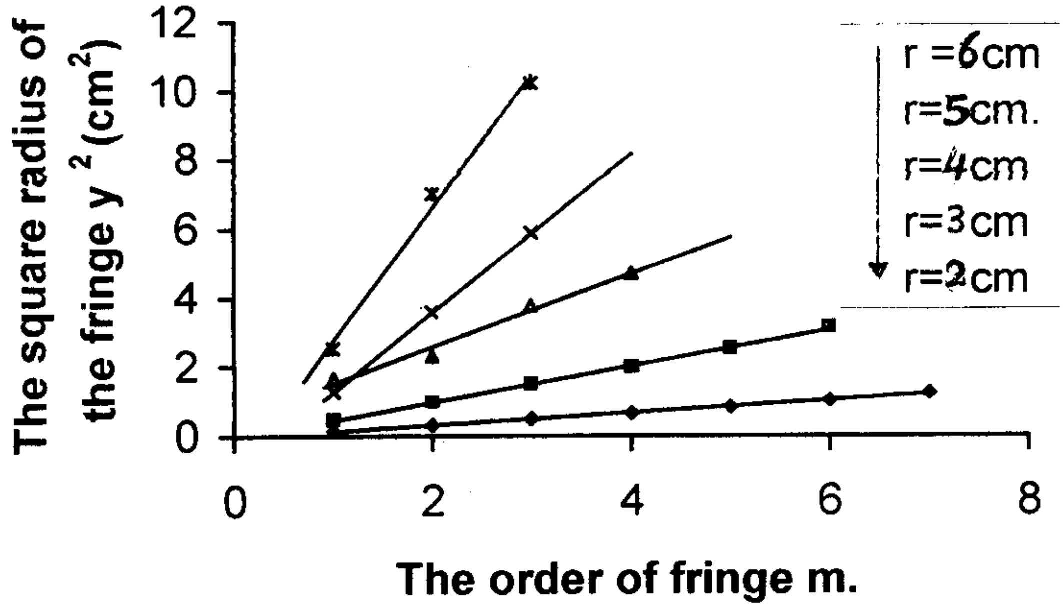

Fig.26 : Relation between squared radius of the fringe y^2 and the order of fringe m at different radius of curvature with a mercury lamp of wavelength 578.0nm.

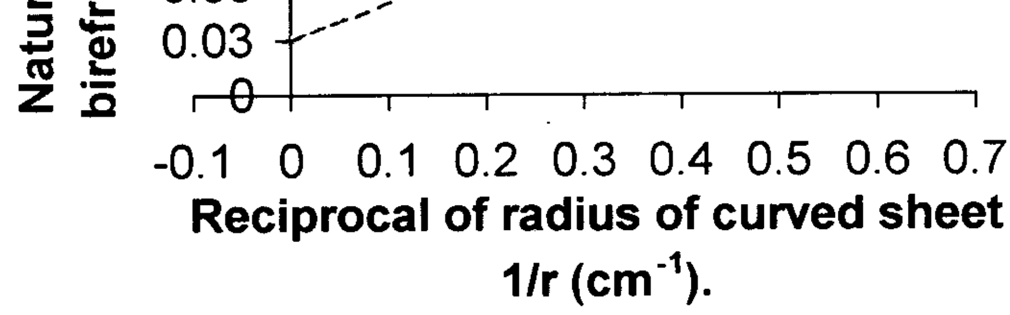

Fig.27: The relation between induced birefringence Δn for a developed Fortepan transparent photographic plate as an anisotropic material by using a mercury lamp of wavelength equal to (578.0 nm), and reciprocal radius of curvature 1/r.

Conclusion

1- In this work a simple and accurate interferometric method for measuring the natural birefringence and its dispersion across the visible region of spectrum is presented.

2- Although the theoretical and experimental background of the method is nearly known, the fields of application and data processing approach are firstly presented. The method is applicable for liquid and solid samples of fixed thickness all over the slit of the spectrograph.

3- A two– term Cauchy dispersion function is most suitable to give accurate values of the birefringence dispersion, because it is simple and time saving.

4- The measured birefringence for both a transparent photographic film and mica sheet decreases with increasing wavelength.

5- The natural birefringence Δn for an anisotropic material is also evaluated for cellophane sheet by changing its thickness, which is another simple method for obtaining birefringence for anisotropic materials.

6- The distribution of the fringes makes it possible to assess the distribution of the stresses inside the plate. This underlies the optical method of studying stresses (photoelastic stress analysis). A model made from a transparent isotropic material is placed between crossed polarizers. The model is subjected to the action of loads similar to those, which the article itself will experience. The pattern observed in transmitted white light makes it possible to determine the distribution of the strain and also to estimate its magnitude.

7- The induced birefringence produced by a certain stress on an isotropic material decreases by increasing wavelength and Cauchy's dispersion function is achieved. The dispersion increases by increasing applied stress upon the sample.

8- From the relation between the applied stress and the resulting strain, which is built upon the displacement in the fringe, Young's modulus is evaluated by a simple and accurate method.

9- The stress optical coefficient is obtained, with different wavelengths, from the relation between the induced birefringence and the applied stress. The stress optical coefficient depends on the wavelength of the light and the material used.

10- The bending of a birefringent plate (Fortepan photographic plate is used in our experiment) introduces additional birefringence. The induced birefringence Δn increases by decreasing radius of curvature (i.e., by increasing the applied stress causing curvature.) and the number of fringes increases and crowds around the center. The natural