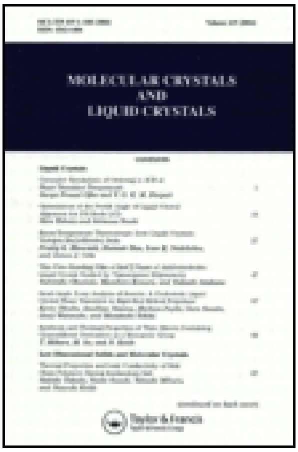

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Differential Conoscopy: Local Birefringence and Molecular Orientation in the Liquid Crystals

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DIFFERENTIAL CONOSCOPY
LOCAL BIREFRINGENCE AND MOLECULAR ORIENTATION IN THE LIQUID CRYSTALS

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Abstract
A new experimental technique of observation and quantitative characterization of interference states in polarizing light is proposed . It permits the determination of the main optical features of the heterogeneous media,namely birefringence, rotatory power, biaxiality ...etc , even of the microdomains . The method consists in superposition of unknown interference state and a standard interference state which presents axial symmetry , and permits observation of extinction zones .

Keywords : conoscopy - birefringence - ring - extinction

1- INTRODUCTION

Classical conoscopy figures show isochromatic lines which are circular for birefringent samples with the optic axis perpendicular to the parallel slide faces .

For calamitic liquid crystals , these rings can be observed only in the case of homeotropic configuration in which molecules are perpendicular to the slides . These rings are centred in the visual field if the optic axis of the observation system coincides with the crystallographic optic axis of the sample .

In white light , these rings are visible due to Newton's colors for path difference δ between 0,3 μm and 3 μm .

In monochromatic light (λ) , they show themselves as black rings on a background of uniform tint of the wave length λ , which appear for the path difference equal to $\delta = k\,\lambda$.

However , in the usual centred system (for example : microscope) , the angular aperture is small and the number of observed rings is limited to 4 or 5 .

Through a polarizing optic microscope magnifying 200 times , a quartz sample of 4 mm thick just allows to see the first ring of extinction corresponding to $\delta = \lambda$.

On the other hand , the direct observation in convergent monochromatic light on a spath sample 3 mm thick can give about ten rings , but one have to use an homogeneous sample of the large surface [1] .

In the case of liquid crystals , 3 difficulties appear :

1- Usually , the thickness of the liquid crystal samples is rather small , and is not sufficient for ring observation .

2- Moreover , thick samples present problem of homogeneity in the bulk and on the surface . In particular , smectic liquid crystals show a number microdomains with different molecular orientations , which make difficult uniform alignment on a sufficiently large surface .

3- The third difficulty is connected with experimental conditions . To study different phases one should vary or stabilize temperature , but the thickness of the heat sheet is incompatible with strongly convergent light beam .

Conoscopic figures presenting 5 or 6 rings have been obtain on the samples of ferroelectric liquid crystals to 200 μm thick with the help of a strongly convergent laser beam [2] , [3] , [4] .

An original conoscopic method using rotation of the observation screen around an axis passing through the sample has been developped in [5] in order to determine the inclinaison of molecules in ferroelectric liquid crystals .

The technique reported in the present paper consist in creating the difference between two states of interference :

- first one given by the known birefringence crystalline slide , which is take as reference . It has axial symmetry .
- second state given by unknown anisotropic slide .

This technique permits to observe simultaneously an image of the texture with the help of polarizing microscope with arbitrary magnitude and conoscopic figure giving local interference state of the sample . In the framework of this method , the observation of the extinction lines gives directly the orientation of the optic axis (orientation of the director in the case of liquid crystals) .

The values of the radius of extinction rings permit also to measure the path difference which makes it possible to know both local and principal birefringencies .

This technique permits also to determine the sens and the value of rotatory power of an actif media , and orientation of the biaxial plane in the case of biaxial structure .

2- EXPERIMENTAL

Reference system formed by convergent lens and a quartz plate with optic axis perpendicular to the slides is placed in the scheme just after polarizing microscope (Figure 1) . Conoscopic figure is formed on the graduated scale situated in the focal plane F of this system . The image of the sample is also formed in the same focal plane F with the help of microscope , everything being illuminated by the white light between crossed polarizers P and A . The images in the focal plane F can be observed either directly in ocular or their photo can be taken .

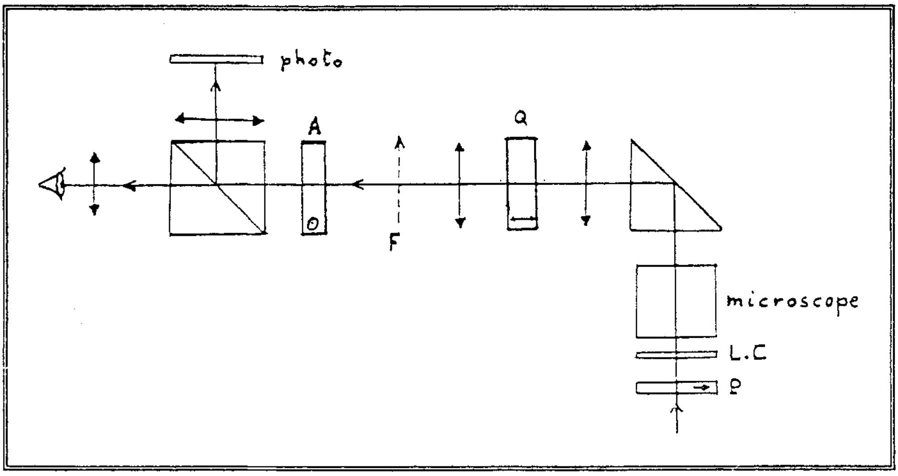

FIGURE 1 - Principe scheme

3- INTENSITY OF INTERFERENCE STATE IN POLARISED LIGHT

Intensity of the light passing through a crystalline plate situated between crossed polarizers P and A , which make angles α and β with the optic axis of the plate (Figure 2) is given by the expression [1] :

$$I = I_0 [\cos^2 (\alpha - \beta) - \sin 2\alpha \sin 2\beta \sin^2(\pi\delta / \lambda)]$$

where δ is the path difference between ordinary and extraordinary waves .

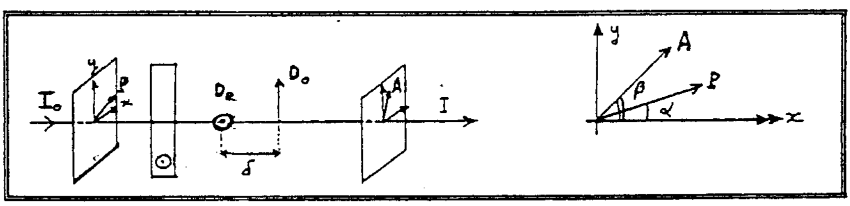

FIGURE 2 - Classical scheme for measures of intensity in polarised light

In the case of the crossed polarizers ($\beta = \alpha + \pi / 2$) , this intensity takes the form :

$$I = I_0 \sin^2 2\alpha \sin^2 (\pi\delta / \lambda)$$

. $\alpha = 0$ or $\pi / 2$ gives : $I = 0$ for all values of δ and corresponds to the neutral lines of the plate .

. $\alpha = \pi / 4$ gives : $I = I_0 \sin^2 (\pi\delta / \lambda)$

- in white light the observed tint is dependent only of δ .
- in monochromatic light $I = 0$ for $\delta = k \lambda$ and the contrast is maximal between dark and clear fringes .

4- REFERENCE SYSTEM

This system is composed of a lens giving a convergent beam on the quartz plate L_1 with parallel slides and optic axis perpendicular to these slides , and of a second lens , which permits to form the conoscopic image in its focal plane F (Figure 3) .

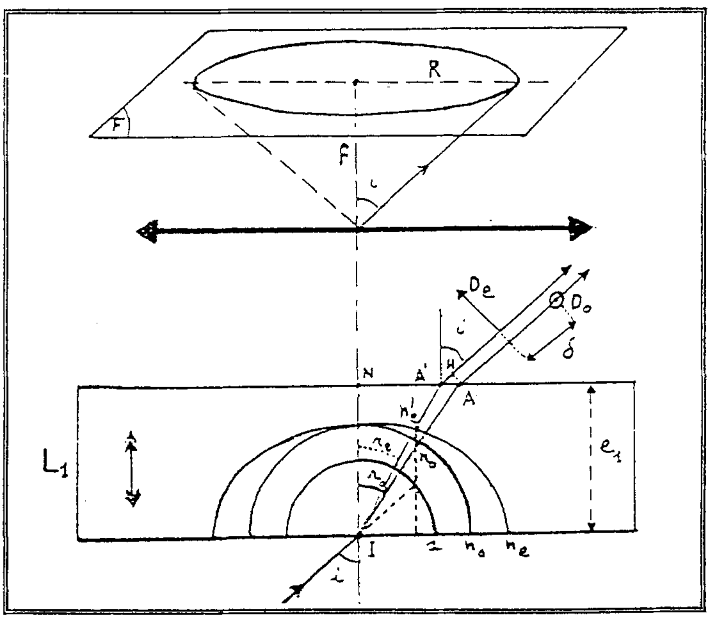

FIGURE 3 - Reference system

In the case when the incident wave arrives on the quartz plate of the thickness e_1 with the incident angle i , two refracted waves -ordinary and extraordinary one can be determined by the Huygens construction with the help of two index surfaces . The sections of these surfaces with the incident plane are the circle of the radius n_o and the ellipsis of the half-big-axis n_e .

Thus : $\sin i = n_o \sin r_o = n_e' \sin r_e$

and $IA = e_1 / \cos r_o$ $IA' = e_1 / \cos r_e$

$NA = e_1 \ tg\, r_o$ $NA' = e_1 \ tg\, r_e$

Taking into account the expressions for propagation velocities $n_o = c / v_o$ and $n_e' = c / v_e'$, we obtain the times necessary for these two waves to cross the plate :

$$t_{IA} = IA / v_o = (n_o . e_1) / (c . \cos r_o) \quad \text{and} \quad t_{IA'} = IA' / v_e' = (n_e' . e_1) / (c . \cos r_e)$$

The time necessary for the extraordinary wave to cross in the air the distance $A'H$ and to arrive in the same wave plane that the ordinary wave , can be expressed as :

$$t_{A'H} = A'H / c = AA' . \cos i / c = e_1 . \cos i . (tg\, r_o - tg\, r_e) / c$$

Thus , the deviation between two waves is :

$$\Delta t = t_{IA'} + t_{A'H} - t_{IA} = [(n_e' / \cos r_e) - (n_o / \cos r_o) + \cos i . (tg\, r_o - tg\, r_e)] . e_1 / c$$

and the path difference ($\delta = c . \Delta t$) :

$$\delta_1 = [(n_e' / \cos r_e) - (n_o / \cos r_o) + \cos i . (tg\, r_o - tg\, r_e)] . e_1$$

As r_o and r_e are always close one to another one has :

$$\boxed{\delta_1 = (n_e' - n_o) . e_1 / \cos r} \qquad \text{where} \quad r = (r_o + r_e) / 2$$

Consequently , in the direction of the incidence angle i with respect to the optic axis , two waves are parallel when leaving the plate . The interference of these waves will take place at infinity with the interference state given by δ_1 . After that they find themselves in the focal plane of the second lens . All the waves situated on the cone of the half-angle i with the axis coinciding with the optic axis of the quartz , present the same interference state . This fact gives the name conoscopic to these figures of interference .

In the white light one obtain coloured ring with the tints characterizing given path difference (Photo 1) .

In monochromatic light the successif black rings are obtained for $\delta = k \lambda$. In the centre $\delta = 0$, first black ring (k = 1) corresponds to $\delta = \lambda$, the second one (k = 2) to $\delta = 2 \lambda$, etc ... Thus , the path difference increase with the distance from the center , as it is illustrated by the formulae : $\delta_1 = (n_e' - n_o) . e_1 / \cos r$

On the other hand , the size of the ring of the fixed order k decreases with decreasing of the wave length λ (Photo 1) .

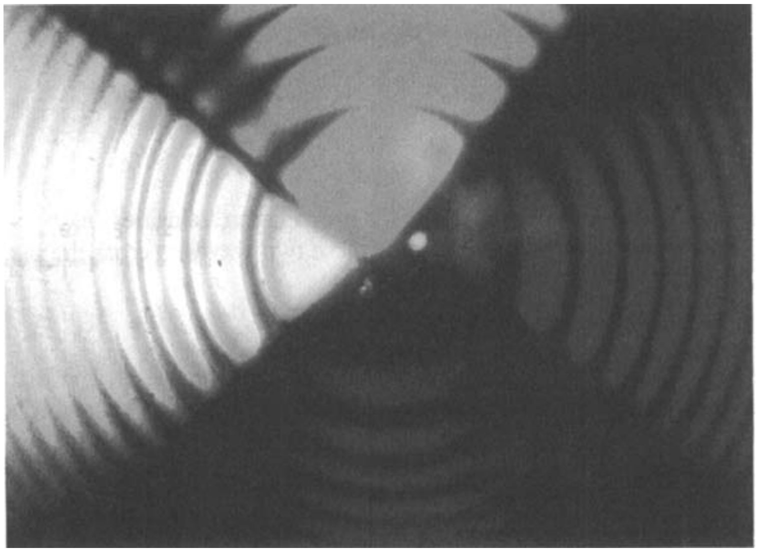

PHOTO 1. See Color Plate I.

Taking into account all the preceding dependencies , we can plot a calibration curve , which gives the path difference δ_1 as a function of the ring radius R (Figure 4) .

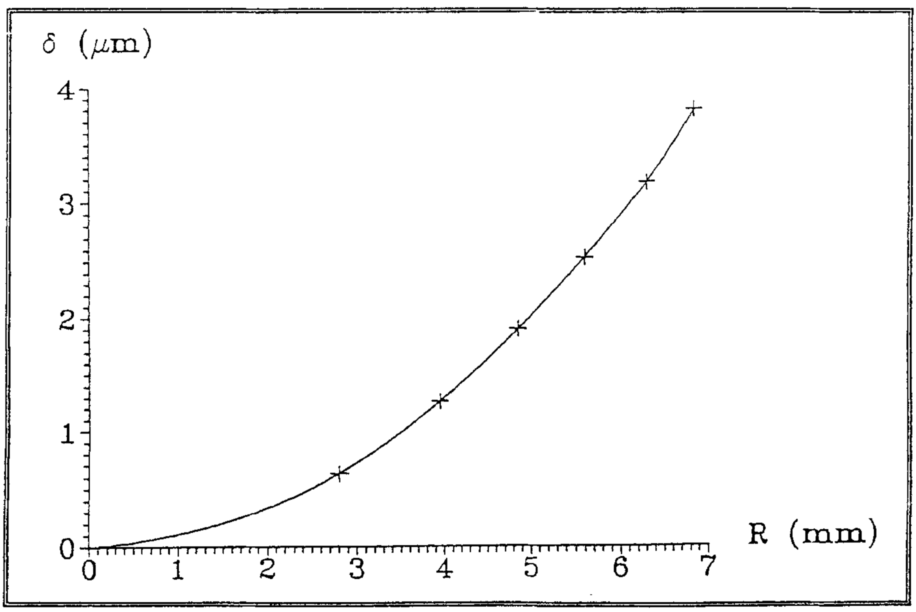

FIGURE 4 - Calibration curve

5- SUPERPOSITION OF INTERFERENCE STATES

If we place another uniaxial crystalline plate L_2 of the thickness e_2 on the optic path of the preceding polarized beam with vibrations presenting already path difference δ_1 , we impose to each vibration additional phase and path difference δ_2 between ordinary and extraordinary vibrations , generated by this plate . It permits us to obtain a superposition of the interference states due to each of the two plates . In the focal plane F of the lens , interference state in a point depends on the characteristics of this plate (thickness , birefringence , direction of the optic axis) but also on the direction of observation i of the incidence wave .

If the optic axis of the plate L_2 is parallel to the slide (in the case of the liquid crystals , this corresponds to the planar configuration of the molecules) , one obtain two extreme situations according to perpendicular or parallel direction of the optic axis with respect to the incidence plane :

a) When optic axis of the plate L_2 is perpendicular to the incidence plane (Figure 5) the intersection of two index surfaces with the incidence plane is represented by two circles of the radius n_o and n_e , ordinary and extraordinary principal indicies of the crystalline plate , respectively .

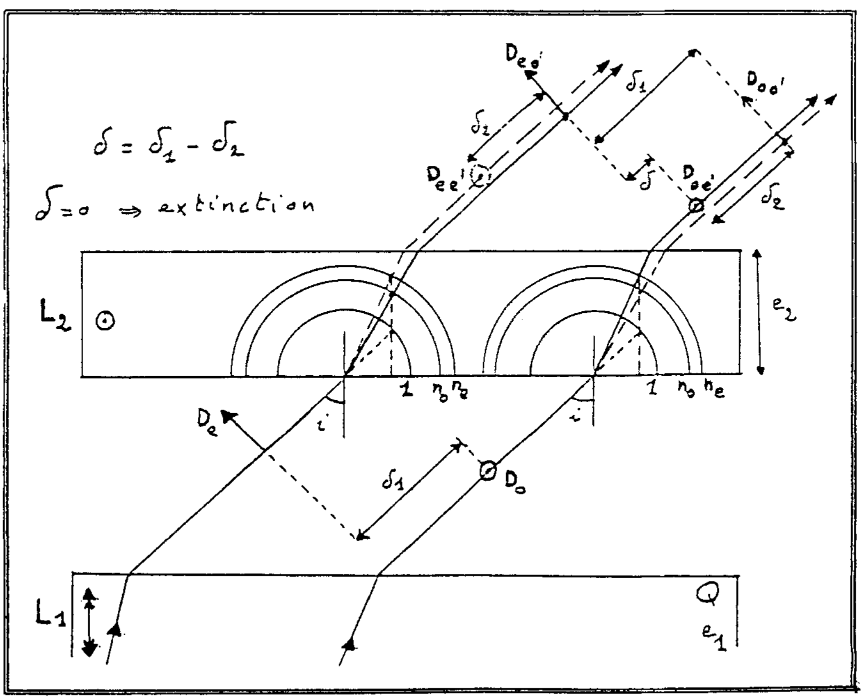

FIGURE 5 - Superposition when the optic axis is perpendicular at the incidence plane

In this case each incident vibration D_o and D_e, parallel and perpendicular to the direction of the optic axis, gives only one component passing through the plate L_2, $D_{oe'}$ and $D_{eo'}$ respectively. The wave D_e which was delayed by for δ_1 when crossing the first plate L_1 is not delayed by the plate L_2. By contrast, the wave D_o which was not delayed by the plate L_1, is delayed for δ_2 by the second plate L_2. So, the path difference between the two interfering waves $D_{oe'}$ and $D_{eo'}$ is $\delta = \delta_1 - \delta_2$. So, we obtain an extinction ($\delta = 0$) in only one direction i_o. Observation of the black arcs (Photo 2.A) permits to determine the direction of the optic axis, and the value of the radius R_o of the corresponding ring gives the possibility to calculate the path difference δ_2 introduced by the plate L_2 which is equal to the path-difference δ_1 of the reference plate L_1.

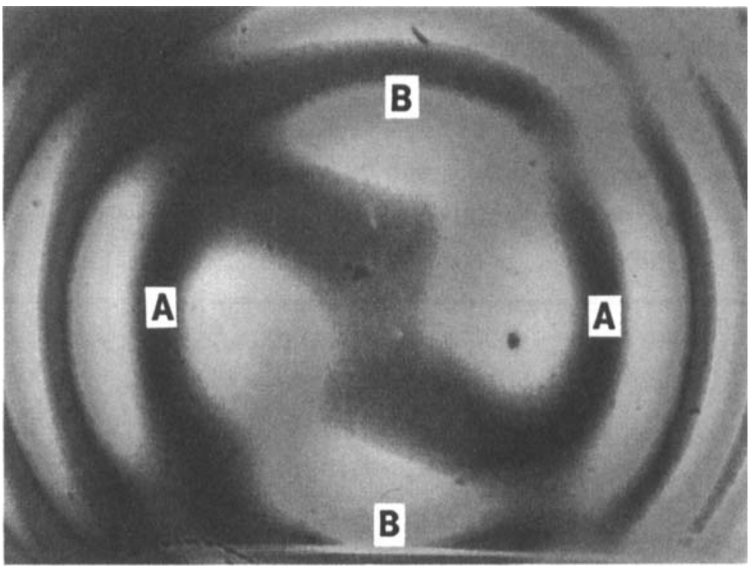

PHOTO 2. See Color Plate II.

b) When optic axis of the plate L_2 is parallel to the incidence plane (Figure 6), the intersection of two index surfaces with the incidence plane is given by one circle of the radius n_o and one ellipsis with half-big-axis n_e. Here, the component D_e, which was delayed for δ_1 by the first plate, is delayed again for δ_2 by the second plate L_2 and gives $D_{ee'}$ vibration. On the other hand, D_o wave which was not delayed by the first plate, is not delayed by the plate L_2 and gives transmitted vibration D_{oo}. Thus, the path difference between these two waves is equal to $\delta = \delta_1 + \delta_2$ (Photo 2.B).

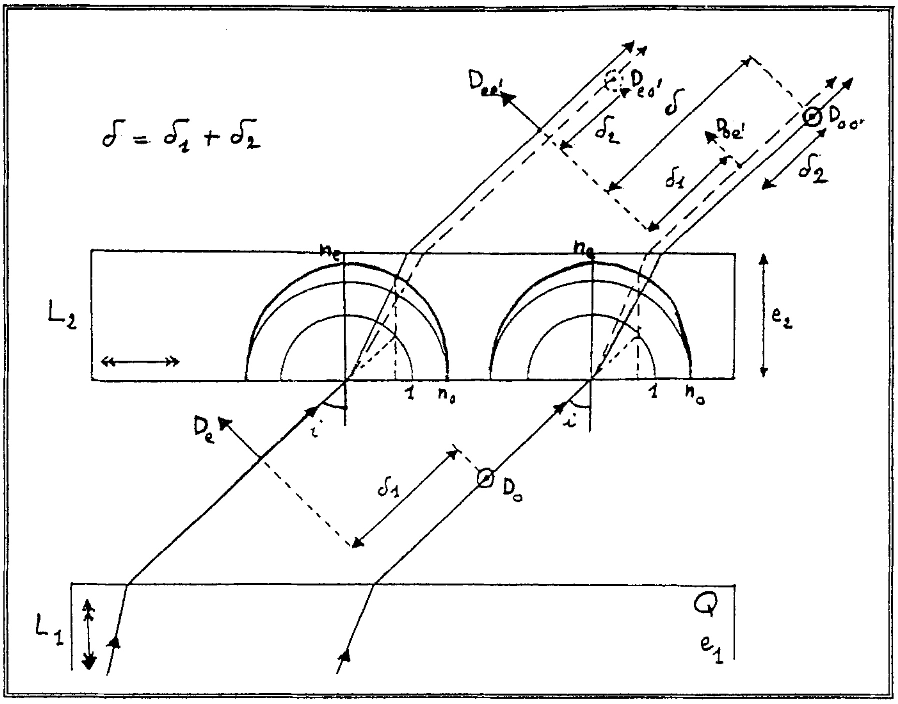

FIGURE 6 - Superposition when the optic axis is parallel at the incidence plane

6- BIREFRINGENCE AND MOLECULAR ORIENTATION

For the liquid crystals in planar configuration we can rapidely determine the average direction of the molecules , represented by the optic axis of the media with homogeneous thickness . This direction is tangent to the extinction rings if the reference plate is made of quartz (positive uniaxial media) , and it is perpendicular to the ring tangente if the reference plate is made of spath (negative uniaxial media) .

On the other hand , using the value of the extinction ring radius R_0 and calibration curve , one can obtain directly the path difference δ_2 introduced by the unknown plate L_2 (Figure 4) : if one know the value of the plate thickness one can deduce principal birefringence , and vice versa if one know the value of the birefringence of material one can get the thickness of the plate .

As a result , we can follow evolution of the radius R_0 and consequently of the birefringence as a function of temperature .

For example , in the case of cyano-biphenyl CB8 , the radius of extinction ring in the nematic phase gives directly the birefringence (Photo 3) , and in the smectic phase

(Photo 4) one can see the orientation of molecules in different microdomains . Photo 5 show the angular displacement of the molecules between S_I and S_F phases of TBDA, which can be easily measured .

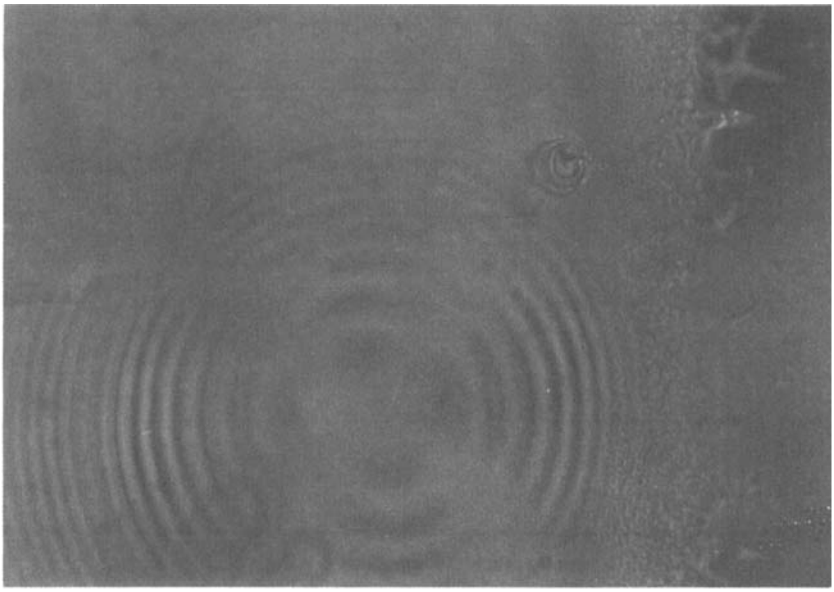

PHOTO 3. See Color Plate III.

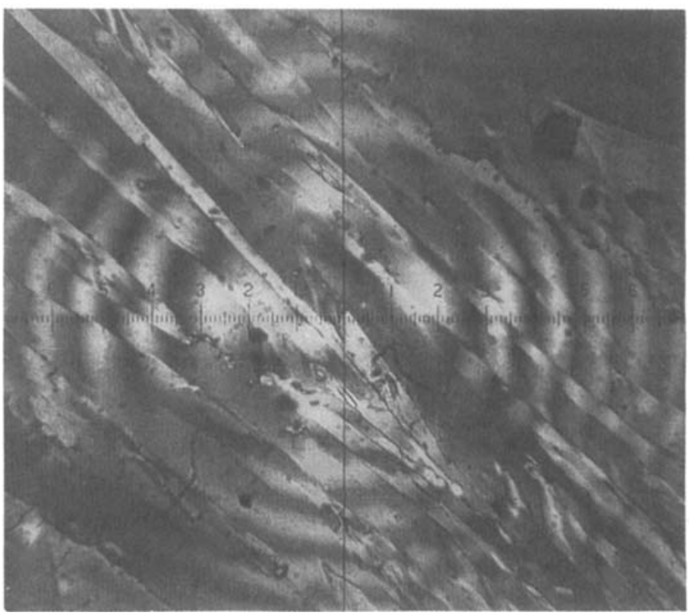

PHOTO 4. See Color Plate IV.

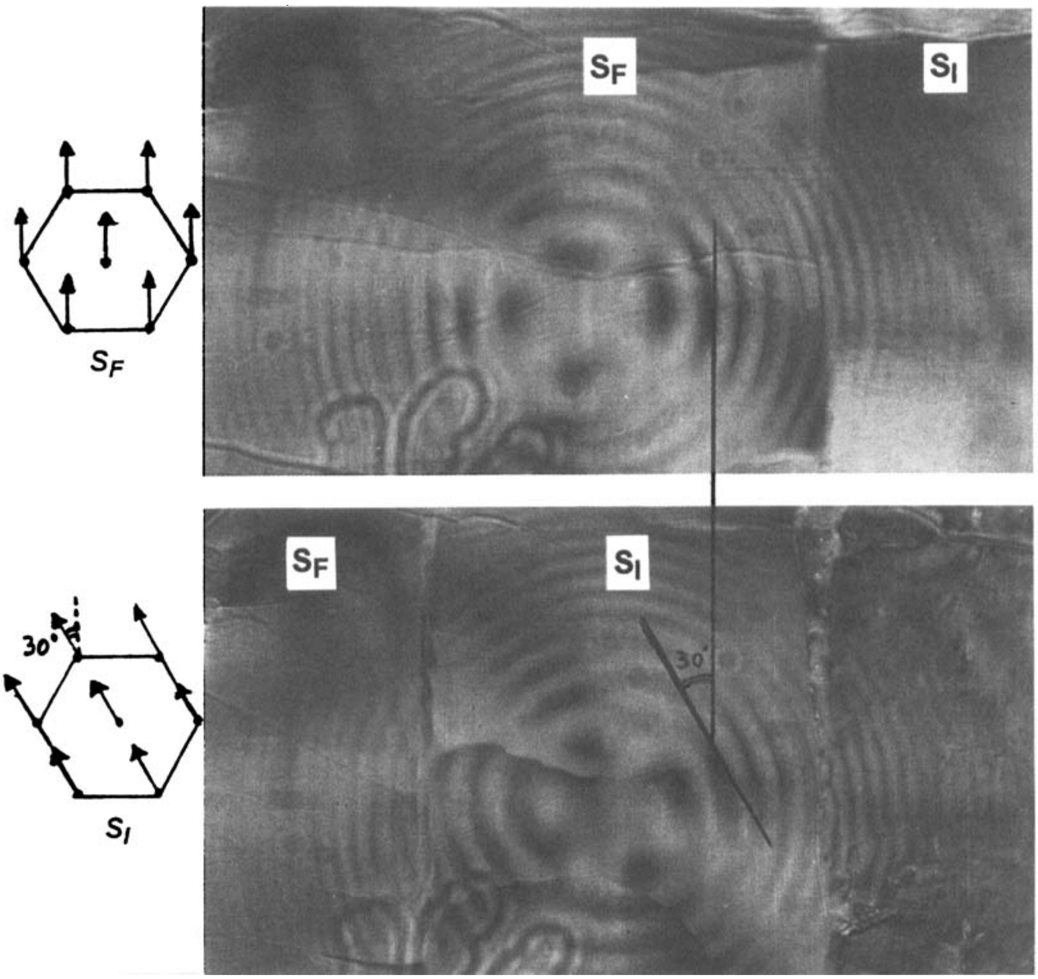

PHOTO 5. See Color Plate V.

7 - BIAXIALITY AND ROTATORY POWER

In the biaxial anisotropic media the isochromatic rings are represented by the ellipses The straight line passing by the two centers of the ellipse defines the trace of intersection of the biaxial plane (Δ' , Δ'') with the observation plane F of the image (Figure 7) .

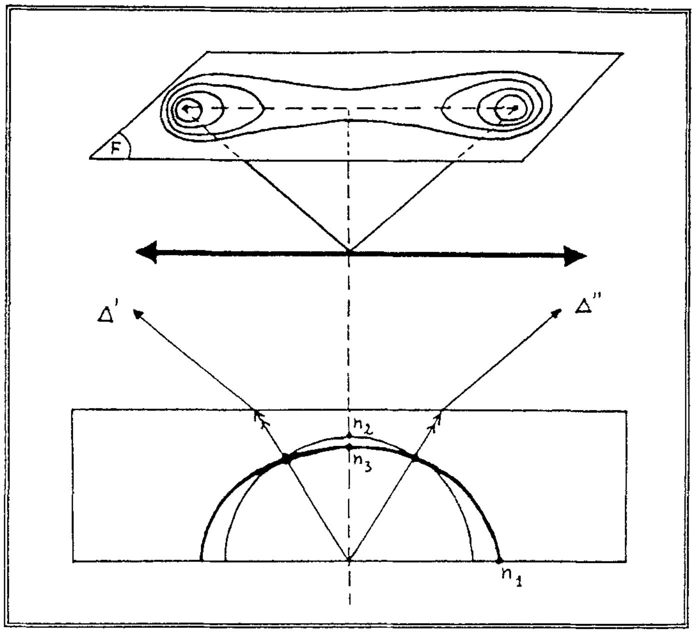

FIGURE 7 - Biaxiality

One can rapidely visualise the biaxiality of the media as , for example , in the mica (Photo 6) .

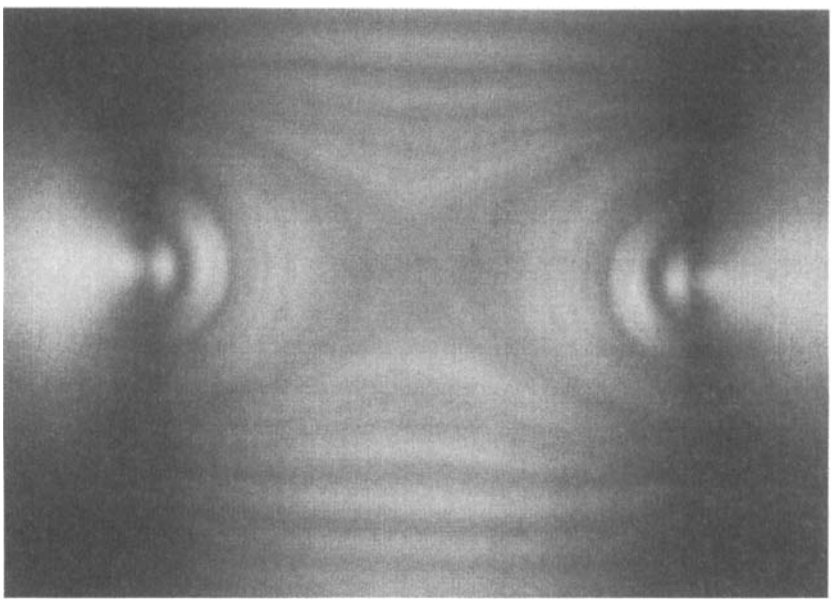

PHOTO 6. See Color Plate VI.

On the other hand , when an anisotropic crystal presents a rotatory power , as it is the case of the quartz , we observe rotation of the extinction lines in the direct or inverse sens , according to right- and left-handed actif media (Photo 7 A and B) .

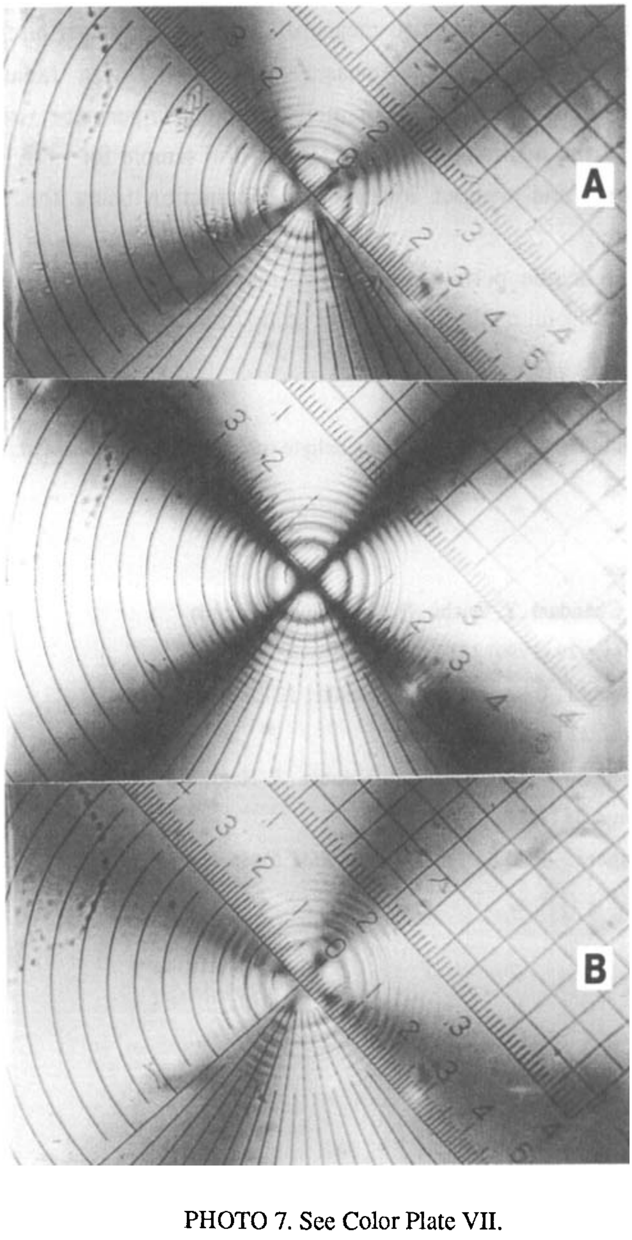

PHOTO 7. See Color Plate VII.

8- CONCLUSION

This new technique of differential conoscopy has an advantage to visualise in optical polarizing microscope the direction of the optic axis in the homogeneous microdomains of several micrometers . It permits to measure locally the principal birefringence of the media with the help of a simple measurement of the ring radius and without inconveniences of the classic method , namely without compensator , without necessity neither to look for the neutral lines , nor to turn the sample for 45° in the direction unknown a priori , and without looking for extinction using the displacement of compensating plate .

The present technique permits also to visualise biaxiality or rotatory power and represents , thus , a useful method for optical study of liquid crystals .

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