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Studies on natural and induced birefringence using white light interferometry

by

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بسم الله الرحمن الرحيم

"سبحانك لا علم لنا إلا ما علمتنا إنك أنت العليم الحكيم"

صدق الله العظيم

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CONTENTS

ABSTRACT

The effect of thermal annealing on the birefringence of three transparent polymers: polystyrene, polypropylene and cellulose acetate is studied. Thermal annealing at temperatures 80, 60, 40 and 20^{O}C for each polymer sample is applied. The birefringence and its dispersion across the visible region of spectrum for each polymer sample are measured by using the polarized white light interference method. Also, two atomic parameters: the resonance wavelength and the oscillator parameters difference are deduced. The results show that the magnitude of the linear birefringence and the oscillator parameters difference decrease while the resonance wavelength increases with increasing the temperature of thermal annealing.

An interpretation of the experimental results is presented. The birefringence and its dispersion across the visible region of spectrum for the polymer samples are measured by using the polarized white light interference method.

The effect of stress due to bending on birefringence of a cellulose acetate sheet and it's dispersion is studied. Bending effect at radii of curvature 0f 2, 3, 4.5, 5.5 cm is applied. The results show that the magnitude of the linear birefringence increase with increasing the curvature. There is three techniques to measure birefringence from the bended sheet interferogram.

The induced birefringence due to bending shows normal dispersion. Both effects of thermal annealing and bending produce permanent changes which are stored in the sample even if the effect is removed.

Birefringence can completely be controlled by adjusting the temperature of thermal annealing or curvature of bending to, respectively, decrease or increase the birefringence. The relative error in finding the birefringence is $1*10^{-3}$.

Chapter (1)

Introduction and Previous Work

Introduction and previous work

1.1 Birefringence

Light is electromagnetic waves which consist of electric field ”E” perpendicular to magnetic field “B”. The direction of propagation is perpendicular to the plane contains both “E” and” B”. When the electric field “E “vibrates only in one plane the light is said to be polarized light. Fig.1.

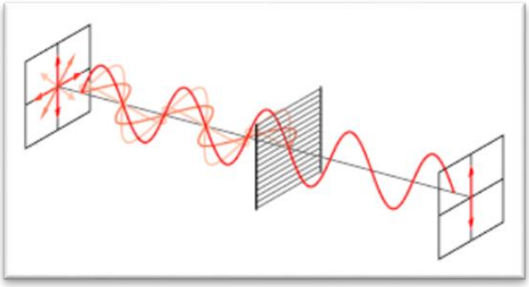

Figure 1: polarized light

Many crystalline substances are solids whose atoms are arranged in some sort of regular repetitive array. They are optically anisotropic, which means that their optical properties are not the same in all directions within any given sample.

The other crystalline substances are optically isotropic, having the same optical properties in all directions.

To understand the difference between isotropic and anisotropic crystals, fig.2 shows mechanical oscillator model of an isotropic medium. A spherically charged shell in which all the springs are the same and the oscillator can vibrate equally in all directions. Amorphous solids, such as glass and plastic, are usually, but not always, isotropic. Fig.3 shows mechanical oscillator model for anisotropic medium, another charged shell bound by springs of different stiffness (having different spring constants).

Anisotropy in the binding force will appear in anisotropy in the refractive index. For example, if plane polarized (p-state) light was to move through some hypothetical crystal so that it encountered electrons its speed would be governed by the orientation of E. If E was parallel to the stiff springs, that is, in a direction of strong binding, the electron's natural frequency would be high (proportional to the square root of the spring constant). In contrast, with E along the direction in which the binding force is weaker, the natural frequency would be somewhat lower.

A material of this type, which displays two different refractive indices, is said to be birefringent. Referring to fig.3, suppose that the crystal symmetry is such that the binding forces in the x- and y-directions are identical (each has the same natural frequency), the z-axis now defines the direction of the optic axis. Fig.4 describes some examples of isotropic and anisotropic materials.

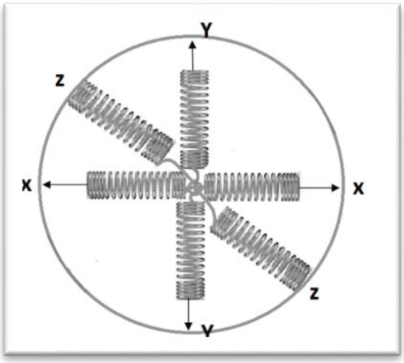

Figure 2 : Mechanical oscillator model for isotropic medium.

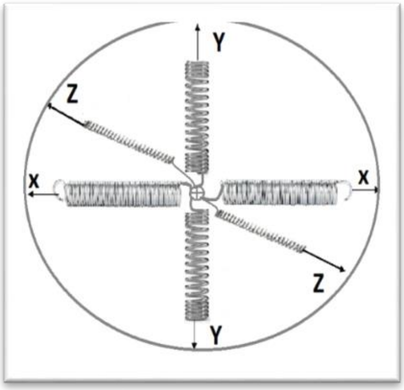

Figure 3: Mechanical oscillator model for anisotropic medium.

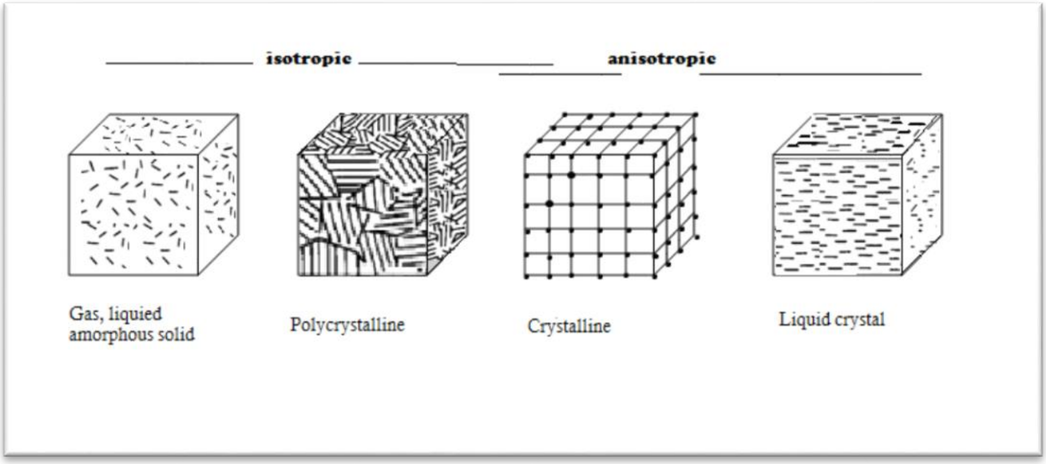

Figure 4: Positional and orientation order in different kinds of materials.

1.2 Birefringent crystals

Cubic crystals, such as sodium chloride have their atoms arranged in a relatively simple and highly symmetric form. Light emanating from a point source within such a crystal will propagate uniformly in all directions as a spherical wave. As with amorphous solids, there will be no preferred directions in the material. It will have a single index of refraction and be optically isotropic. In that case all the springs in the oscillator model will be identical.

Crystals belonging to the hexagonal, tetragonal, and trigonal systems have their atoms coordinated so that light propagating in some general direction will run into an asymmetric structure. Such substance is optically anisotropic and birefringent, like calcium carbonate (calcite) crystal.

The optic axis corresponds to a direction about which the atoms are arranged symmetrically. Crystals like these, for which there is one such direction, are known as uniaxial. Doubly refracting crystals are classified as either uniaxial or biaxial. In uniaxial crystals the refractive indices, and hence the velocities, of the O "ordinary" and E " extra ordinary" waves become equal along a unique direction " optic axis". In biaxial crystals, on the other hand, there are two directions in which the velocity of plane waves is independent of the orientation of the incident vibrations. These two optic axes make a certain angle with each other which is characteristic of the crystal, and depends to some extent on the wavelength. Uniaxial crystals may be thought of as a special case of biaxial crystals where the angle between the axes is zero.

The electric field of the ordinary wave is everywhere normal to the optic axis, so it moves at a speed $V_{\perp}$ in all directions, as in fig.5 ,Similarly, the extra-ordinary wave has a speed $V_{\perp}$ only in the direction of the optic axis ,along which it is always tangent to o-wave. Normal to this direction, E is parallel to the optic axis, and that part of the wavelet expands at a speed $V_{//}$.Uniaxial materials have two principal indices of refraction, $n_o = c/V_{\perp}$, and $n_e = c/V_{//}$, the difference $\Delta n = (n_e - n_o)$ is a measure of birefringence.

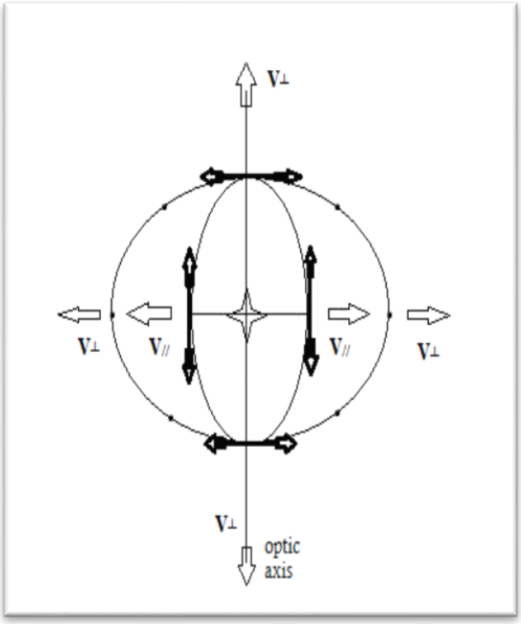

Figure 5: Wavelets in a uniaxial crystal. The arrows and dots represent the E-fields of the extraordinary and ordinary waves, respectively.[1]

1.3 Double refraction in uniaxial crystal

In case of calcite crystal, the cleavage form is a rhomb. Any number of planes can be drawn through the rhomb which contains the optic axis, are all called principal planes. If the principal plane is also normal to a pair of opposite surfaces of cleavage form, it slices the crystal across a principal section, which forms a parallelogram with angles 109° and 71°.

When an unpolarized light incident on the principal section, it splits into two polarized beams, one polarized in a direction normal to the principal section (o-ray), and the other polarized in a direction parallel to it (e-ray), fig.6

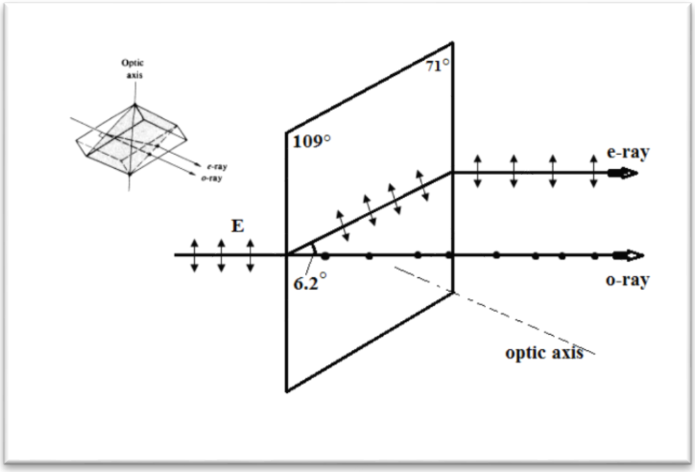

Figure 6: Unpolarized beam traversing a calcite principal section.[1]

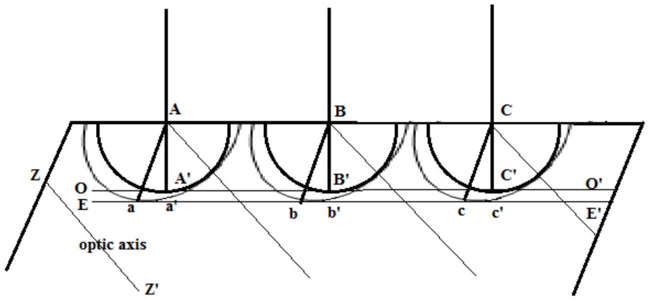

Figure 7: Wave surfaces and normal – velocity surfaces for uniaxial crystals.[2]

The double refraction of light in the calcite crystal can be explained by using Huygens's principle. Fig.7 shows an incident plane wave on the surface of the crystal, if we choose points A, B and C on the crystal boundary as a source of spherical wavelets, then after a time t, the new front wave is found by drawing the common tangents to these secondary wavelets. According to Huygens two plane waves are obtained OO' and EE'.

Since the first is tangent to spherical wavelets, it travels perpendicular to the surface with a velocity proportional to AA', BB' and CC'. This is the ordinary