Physics 319 Laboratory: Optics

Birefringence II

Objective: Previously, we have been concerned with the effect of linear polarizers on unpolarized and linearly polarized light. In this lab, we will explore other optical elements which affect linearly polarized light. These elements are retarders and optically active materials.

Apparatus: You will need the sheet polaroids, scotch tape, a glass slide, a cigarette wrapper, the Pasco optics bench and kit, a light intensity meter and fiber optic, a small beaker of corn syrup, and some kind of stressed plastic (like a plastic protractor or CD case).

Theory:

As we have seen before, unpolarized light can be decomposed into two mutually incoherent, orthogonal polarization states, or P-states, much like a vector can be decomposed into its components along the x- and y- axes. A pure P-state may be decomposed into two coherent, orthogonal P-states, like decomposing the x-axis of one coordinate system into its components along the x'- and y 'axes of a second coordinate system rotated with respect to the first.

(Hecht, section 8.2) A **retarder** is an optical element which can cause one of the coherent P-states of incident linearly polarized light to lag behind the other, causing a phase difference between the two components. This phase difference is given by

$$\Delta\varphi = \frac{2\pi}{\lambda_0}\, d(|n_0 - n_e|)$$

where n_0 and n_e are the indices of refraction of the ordinary and the extraordinary ray, respectively, d is the thickness of the retarder, and λ_0 is the wavelength of the incident light in a vacuum. The light is now circularly or elliptically polarized**.** We refer to the axis of vibration of the faster of the two waves as the fast axis, and the other as the slow axis.

A **half-wave plate** is a retarder which introduces a phase shift of π corresponding to an optical path difference of λ_0 / 2, with the effect that a linearly polarized beam of light with its plane of vibration at an angle θ to the fast axis of the half-wave plate will have its plane of vibration rotated through 2θ.

A **quarter-wave plate** introduces a phase shift of $\pi/2$ between the two components of the incident wave. Light linearly polarized at 45 degrees to either principal axis of a quarter wave plate will be circularly polarized.

(Hecht, section 8.10) An **optically active** material is one which rotates the plane of vibration of incident linearly polarized light

The material may rotate the plane of vibration to the right (dextro-rotatory) or to the left (levo-rotatory). Very often molecules with identical chemical properties can be distinguished by their optical properties, as in d-glucose and l-glucose.

Typical optically active materials will not rotate each wavelength of light equally' leading to some colorful effects. This property is called **rotary dispersion.**

(Hecht, section 8.11.1) Normal transparent materials may develop optical anisotropy when under mechanical stress. This phenomenon is known as stress birefringence or **photoelasticity.** Crossed polarizers may be used to observe this effect to determine stress patterns in clear objects.

Procedure:

I. Half-wave Plate

Ordinary scotch tape may be used to make a half wave plate. During manufacture, cellophane is stretched, aligning the long organic molecules, causing the cellophane to become birefringent. The slow axis of scotch tape is along the length of the tape.

Make a half-wave plate by sticking a piece of tape to a microscope slide. Be sure a small bit of tape sticks out over the end of the slide so that it will be easier to remove. Looking at a light source with the polarizers crossed (90°) insert the slide between them at 45 degrees (see Figure 8.47 on page 303 in Hecht). Try rotating the slide to other angles. ***Why does the tape seem to have no effect when aligned with the polarization axis of the back polaroid?****

Replace the microscope slide and tape with the cellophane wrapper. Determine the slow and fast axes of the cellophane. Which way would you guess the wrapper was stretched during manufacture?

II. Quarter-wave Plate

Set up the optics bench as shown in Figure 1. Place the 2.0 mm light source aperture (9119) onto the incandescent light. Adjust the aperture until the light emerges from the 2.0 mm hole (Note: place a sheet of paper just beyond the aperture to use as a viewing screen). Next, place the variable diaphram (9117) on a place holder about 50mm from the light source. Adjust the diaphram size so that the light beam emerging circular.

Parallel light beam: Put the 18mm focal length lens (9132) and place it on a element holder (the little magnetized stands) and set it about 30mm from the diaphram. Next, take the 127mm focal length lens (9134) and place it about 150mm from the 18mm lens. Now view the beam by taking a sheet of paper and moving it up and down along the bench. Is the beam the same size? If not adjust the 127mm lens until you have a parallel beam (i.e. same size beam no matter where you put the screen).

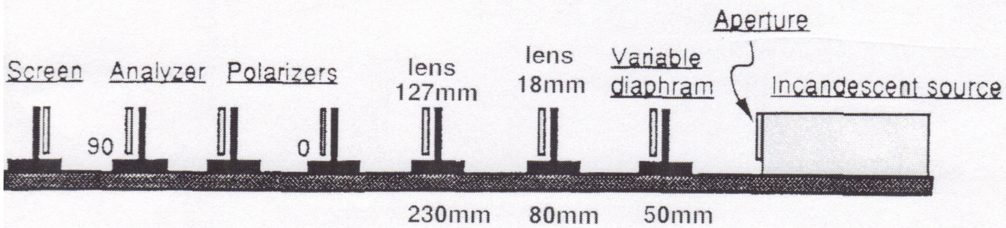

Figure 1.

Now place both the polarizer and analyzer on the bench such that their optical axes are crossed, no light from the beam should be projected on the screen (Note: the analyzer is identical to the polarizer, it sits down beam from the polarizer and is allowed to be rotated, while the polarized has a fixed orientation). Place a third polarizer at 45 degrees on an element holder and place on the bench *between the polarizer and analyzer*. **Suddenly, some light from the beam is projected on the screen. *Use Malus' law to explain why.*****

Replace the center polarizer with the 140 µm retarder (a quarter-wave plate) at 45 degrees. There should be a spot of light on the screen. Rotate the analyzer and pay attention to the brightness of the spot. Why does it not change? Try other orientations of the quarter-wave plate**. *Explain why the brightness of the spot changes as the analyzer is rotated when the retarder is at some angle not equal to 45 degrees*.*****

III. Optical Activity in Corn Syrup

Restore the analyzer to 90 degrees. Remove the retarder and its element holder from the bench and replace it with a rotating table with its arm swung out of the beam path, as in Figure 2. Again, the polarizers are crossed, so no spot should appear on the screen. Place a small beaker of corn syrup on the table in the beam path, making sure none of the markings on the beaker interfere with the beam. A spot should now appear on the screen because the sugar has rotated the plane of vibration of the light.

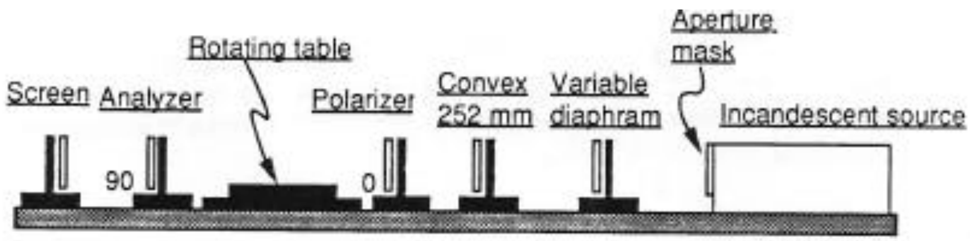

Figure 2.

As one looks toward the source of the light, a d-rotatory substance will rotate the plane of vibration clockwise, and a l-rotatory substance counter-clockwise. Each color has its axis of vibration rotated by a different amount. Remove the screen and look up the beam path. Rotate the analyzer slowly and observe the colors. To what property of optically active materials do you attribute this?

Arrange the optics bench as shown in Figure 3. The red filter (9111) can be mounted on the same holder as the variable diaphram. Insert the fiber optic cable in the set screw on the rotating table, also remove the analyzer holder and place the analyzer on the arm of the rotating table with its optical axis crossed with the polarizer. Setting the intensity meter on the .1 scale, adjust the analyzer for a minimum reading and then turn the zero adjust knob until you get the meter's scale to read zero. Record the analyzer's angle. Insert the syrup the square sided bottle in the beam path and rotate the analyzer until the intensity is minimized according to the meter. Record the angle that the analyzer was rotated and the distance the beam traveled in the syrup (the inner dimension of the bottle). Calculate the specific rotatory power (the angle of rotation divided by the distance) for red light in Karo syrup. Repeat for the green filter (9113) and the blue filter (9114).

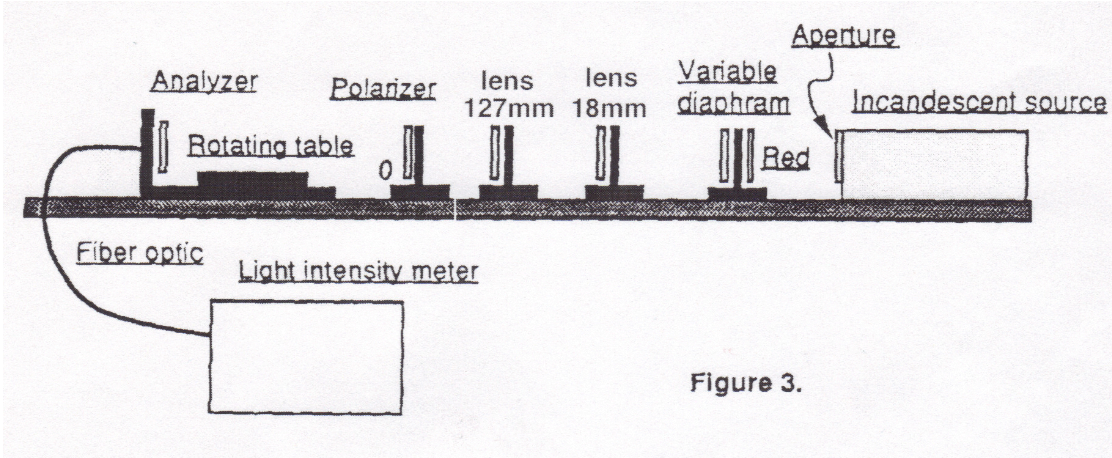

Figure 3.

IV. Photoelasticity

Hold a plastic protractor (or CD case) between two crossed polarizers. Notice the pretty colors. Bend the plastic object and notice how the colors move around.

Questions (taken from text of lab writeup):

1. Why does the tape seem to have no effect when aligned with the polarization axis of the back polaroid?*

2. ******Suddenly, some light from the beam is projected on the screen. Use Malus's law to explain why. *(This question is very important and in one sense constitutes the essence of how polarizers work).*

*3. ***Explain why the brightness of the spot changes as the analyzer is rotated when the retarder is at some angle not equal to 45 degrees*