Experiment 1

Polarization of Light

1.1 Introduction

The polarization of light is an important phenomenon for a couple of reasons. (a) It proves that light is a transverse wave. (b) It provides insight into the structure of transparent materials through the study of the polarizing or depolarizing effect of the material. (c) The polarization of light has found many technological applications, such as the Kerr cell (high-speed shutter), saccharimeter, photo-elastic stress analysis, and sunglasses, to name just a few.

Light is self propagating electromagnetic oscillations. The direction of the oscillating electric and magnetic field vectors is at right angles to the direction of propagation of the light ray as shown in Fig. 1.1. In later figures

Figure 1.1: “Snapshot” of a light ray where $\vec{E}$ is the electric field vector, $\vec{B}$ is the magnetic field vector, and $\vec{c}$ is the direction of the light ray. Note that $\vec{E} \perp \vec{B} \perp \vec{c}$. 

1
we will indicate the polarization direction solely by the electric field vector, $\vec{E}$. The magnetic field vector can be omitted because it is perpendicular to both the electric field and to the direction of propagation of the light.

A beam of light is called unpolarized when the direction of the electric field of the individual light rays that make up the light beam is totally arbitrary as illustrated in Fig. 1.2(b). When the electric-field vector of all light rays points in the same direction we have linearly polarized light as depicted in Fig. 1.2(c). There also exists circularly polarized light when the electric field vector moves in a circle with constant speed, however this will not be discussed here.

Ordinary light is produced by millions of atoms acting independently, and is therefore unpolarized. There are five phenomena that result in polarized light from an unpolarized light beam: (1) absorption, (2) reflection, (3) refraction, (4) birefringence, and (5) scattering.

### 1.2 Linearly polarized light

#### 1.2.1 The Law of Malus

A simple way to obtain linearly polarized light is to filter light through a sheet of polaroid, like $P_1$ in Fig. 1.3. Polaroid contains long, asymmetric
Figure 1.3: Malus's Law. $\mathbf{P}_1$ gives the transmission direction of the polarizer $P_1$, and $\mathbf{P}_2$ of the analyzer $P_2$. $\mathbf{E}_0$ shows the magnitude and direction of the electric field of the incident light. $\mathbf{E}_1$ shows the electric field of the light emerging from $P_1$, and $\mathbf{E}_2$ of the light emerging from $P_2$. Malus's Law states that $I_\alpha = I_{\alpha=0} \cos^2 \alpha$, where $\alpha$ is the angle between $\mathbf{P}_1$ and $\mathbf{P}_2$.

molecules which have been arranged so that the axes of all the molecules are parallel and lie in the plane of the sheet. At optical frequencies the chains of molecules are conducting. When incident light has its electric-field vector parallel to the long molecules, electric currents are set up along the chains and the light is absorbed. The light will be transmitted when its electric-field vector is perpendicular to the chains. The direction perpendicular to the chains is called the transmission axis. An arrangement of two consecutive polaroids as shown in Fig. 1.3 is called a polariscope. The first polaroid is called the polarizer and the second one is called the analyzer.

The electric field vector of a light ray lies in a plane that is perpendicular to the direction of propagation. The orientation of $\mathbf{E}_0$ in this plane for a single ray in unpolarized light is completely arbitrary. A beam of unpolarized light of intensity $I_0 = E_0^2$, that passes through a polaroid emerges as linearly polarized light with its electric field vector along the transmission axis of the polaroid as seen in Fig. 1.3. For an ideal polaroid the amplitude of the transmitted single light ray ($\mathbf{E}_1$) is

$$\mathbf{E}_1 = \mathbf{E}_0 \cos \theta$$  \hspace{1cm} (1.1)

where $\theta$ is the angle between the transmission axis of the polaroid and the electric field vector of the incident light ray. The intensity of the beam after
Figure 1.4: Incident light ray crossing an interface between two media with different refractive indecies $n$. The angle of transmission $\theta_t$ is determined by Snell’s law (1.5), and the angle of reflection $\theta_r = \theta_i$, the angle of incidence. In the case drawn $n_i < n_t$.

the first polaroid is averaged over a uniform distribution of the incident light rays that make up the beam to get the following.

$$I_1 = \langle E_1^2 \rangle = E_0^2 \langle \cos^2 \theta \rangle = E_0^2 \frac{1}{2\pi} \int_0^{2\pi} \cos^2 \theta \, d\theta = \frac{1}{2} E_0^2 = \frac{1}{2} I_0.$$  \hspace{1cm} (1.2)

Consider a second sheet of polaroid located after the first as in Fig. 1.3. The angle between the transmission axes is $\alpha$ and the light emerging from the second polaroid has its electric field vector $(\vec{E}_2)$ in the direction of the second transmission axis. The transmitted intensity $I_2$ is given by

$$I_2 = I_t \cos^2 \alpha.$$ \hspace{1cm} (1.3)

This is called the law of Malus[1]. $I_t$ is the light intensity after $P_2$ when $\alpha$ is zero, that is, when $\vec{P}_1$ and $\vec{P}_2$ are parallel. Ideally $I_t = \frac{1}{2} I_0$ for light that is initially unpolarized. In practice, a polaroid is far from ideal, and absorbs some light that properly would pass.
1.2.2 Snell’s Law

Light in a medium travels slower than in a vacuum. The refractive index, $n$, is defined as the ratio between these two speeds:

$$n = \frac{c}{v},$$  

(1.4)

where $v$ is the phase velocity of light in a given medium. When a light ray encounters a change in refractive index, i.e. it crosses the boundary from one material to another, the ray will refract according to Snell’s Law:

$$n_i \sin \theta_i = n_t \sin \theta_t$$  

(1.5)

where $\theta$ is the angle the ray makes with the normal of the interfacing surface, with subscripts $i$ and $t$ designating the incident and transmitted beams (or the corresponding media) respectively; See Fig. 1.4.

1.2.3 Brewster’s Angle

An important way for obtaining linearly polarized light is based on the reflection of light by a smooth surface. To understand this method, consider Fig. 1.5. The unpolarized incident light may be decomposed into two orthogonal components, one has the electric field vector perpendicular to the plane of incidence and the other has $\vec{E}$ in the plane of incidence. The incident light sets the electrons of the material into dipole oscillation. This creates a new oscillatory electric field which is maximum perpendicular to the oscillation and zero along the direction of oscillation. As a consequence, the reflected and refracted light rays are partly polarized. In the special case that the angle between the reflected and refracted beams is $90^\circ$ as depicted in Fig. 1.5, the reflected light is totally polarized and the refracted (transmitted) beam partially polarized. The angle of incidence for which this occurs is called Brewster’s angle, $\theta_B$. It is left as an exercise to prove that

$$\tan \theta_B = \frac{n_t}{n_i},$$  

(1.6)

where the beam of light, traveling through a medium of refractive index $n_t$ encounters the surface of a different medium of refractive index $n_i$ as described in Fig. 1.5.
Figure 1.5: Unpolarized light incident on a material such as glass or plastic. \( \theta_i \) is the angle of incidence, \( \theta_r \) is the angle of reflection, \( \theta_t \) is the angle of the transmitted ray, and \( \vec{n} \) is the vector normal to the surface. When the angle between the reflected and refracted beams of light is 90°, a special case occurs where the reflected beam is totally polarized in the plane of the surface, perpendicular to the propagation of the light. In this case, the angle of incidence is called Brewster's Angle (\( \theta_i = \theta_B \)). Additionally, the refracted light is partially polarized in the plane of the light rays.

1.3 Chiral molecules & optical activity

Molecules that can not be mapped onto their mirror image are termed ‘chiral.’ Such molecules come in two varieties that are distinguished not by their composition or their general structure, but by their ‘handedness’ only. This is analogous to the left and right hands, which are clearly similar but not equivalent in structure. Nuts and bolts are another example of handedness ('righty-tighty') in everyday life, the spiral pattern on a bolt being an reasonable analogue of the famous double-helix of DNA.

Chiral molecules belong to a group of substances that show optical activity. This means that linearly-polarized light is rotated about the beam axis as it passes through such a substance; see Fig. 1.6. In this figure, plane-polarized light with the electric field vector aligned with the y-axis is incident on a chiral molecule inducing an up-down oscillation of the electrons in the
Figure 1.6: Linearly polarized light passing through a chiral molecule. $\vec{E}_y$ is the electric field vector of the incident light, $\vec{E}$ is rotated vector as a result of the chiral molecule's optical activity.

spiral. The motion of the electrons is constrained to follow a spiral path which causes a small induced electric field, $\vec{E}_x$, along the $x$-axis. The electric-field vector of the emerging light is thus slightly rotated with respect to $\vec{E}_y$. The sign of the rotation is independent of the orientation of the spirals.

### 1.3.1 Saccharimeter

Many biological substances show optical activity, making it an important research and testing tool. For example, optical activity is used extensively in commerce to determine the sugar content of many products. The method is of special importance because it is non-destructive and non-contact. The plane of polarization for a monochromatic beam of light will rotate as a result of the optical activity of the sucrose in a solution through which it travels. The amount of rotation is proportional to the number of sucrose molecules which the light encountered. Thus, it is proportional to the density of the sucrose solution and the path length of the beam inside the solution.

$$\Delta \theta = \alpha CL,$$

where $\Delta \theta$ is the angle through which the plane of polarization is rotated, $C$ is the density of the sucrose solution, $L$ is the path length of the beam inside the solution, and the proportionality constant, $\alpha$, is then called the specific
rotation. Note the units of $\alpha$:

$$[\alpha] = \frac{\text{change-in-angle} \cdot \text{area}}{\text{mass}}.$$  \hfill (1.8)

Furthermore, $\alpha$ is dependent on temperature and the frequency of light used. We will do all of our measurements at room temperature, and use the color filters (and possibly the laser) to select different discrete frequencies.

**Warning: Do not look directly into the laser beam!**

Permanent eye damage (burned spot on retina) may occur from exposure to the direct or reflected laser beam. The beam can be viewed without concern when scattered from a diffuse surface such as a piece of paper, and is harmless to clothing and any part of the body except the eye. Keep your head well above the beam height at all times to avoid accidental exposure to your own eyes. Keep your beam confined to your bench-top to protect your fellow students. Do not insert a reflective surface into the laser beam except as directed in the instructions or authorized by your teaching assistant.

The laser contains a high voltage power supply. Report any electrical hazards (frayed wires, open case, etc.) to your TA.

### 1.4 Program & Procedure

**First session:** Malus's law, Snell’s law, and Brewster's angle.

1. Familiarize yourself with the photometer as discussed in Sec. 1.6 on page 17, the optical bench, and polaroid filters and holders.

2. Align the projector, polarizer, analyzer, and photometer covering any stray light from the projector. This can be facilitated by the leveling screws in the legs of the optical bench. See Fig. 1.7.

3. Measure the stability of the light source and photometer over a 5 minute period taking measurements every minute. Both partners should make the readings independently. Determine the reading error by comparing the results from both sets of measurements.
Figure 1.7: Setup for investigating Malus’s Law (side view). The distance between the light source and the photometer should be about 60 cm. The light beam is produced by a carousel slide projector with an aluminum pinhole collimator inserted where normally the slides go. The beam can be focused onto the photometer’s fiber optic with a button on the side of the projector. *Always keep the radius of curvature of the fiber cable larger than 4 inches to avoid damaging it.*

4. Determine the importance of shielding the probe against background light. For the rest of the lab, you should periodically verify the zero reading by interrupting the light beam.

5. If the light beam is unpolarized the light transmission through a polaroid will be independent of the polaroid angle. However, because the light inside the projector is reflected by a mirror it is slightly polarized. Install a single polaroid on the optical bench, and by rotating the polaroid find the locations and light intensities corresponding to all of the maxima and minima of the transmission. How many are there? In your report determine the degree of polarization (defined as one minus the ratio of the minima to the maxima) produced by the mirror inside the projector.

6. An ideal polarizer transmits 50% of unpolarized light. Because of the optical absorption of the polaroid material, the transmission is less than 50%. Use the measurements just made to determine the transmission-correction-factors, \( F \), defined as the observed maximum intensity divided by the expected intensity. Repeat the measurement with the second polaroid. Compare the transmission-correction-factors of the two polaroids.

7. Verify Malus’s law by determining the intensity \( I \) of the beam of light going through two polarizers as a function of the relative angle \( \theta \) between the two polarizers. Measure in increments of 10° from 0° to 360°, plus the locations of the two minima and two maxima. Make a
Figure 1.8: Setup for measuring the index of refraction of a lucite block. (a) Top view. (b) Side view.

table of \( \alpha \), the relative intensity as measured by the photometer, and the error (which you determine based on your previous measurements of the beam stability, your meter-reading uncertainty, etc.). Always use the scale which gives you a maximum deflection of the needle (but still on the scale!) for each measurement and note that the error is different for different scales. It is always advisable to use a computer such that you can plot the data taken in real time. This will expose many types of errors that would normally have you redo the entire experiment. In your report, in addition to \( I(\alpha) \), present a plot showing the intensity as a function of \( \alpha \) (think cosine — See Eq. 1.3) that will show the data as a straight line. Fit the data to the line and find the free parameters (for example: slope and intercept) and their errors. Optional: calculate \( \chi^2 \) and determine if Malus's law is being violated. For details on how this should be done, see Ref. [2], chapter 6.

8. Make a precision measurement of the index of refraction \( n \) of the lucite block using Snell's law (See Sec. 1.2.2) using the laser (see warning on page 8).
Figure 1.9: Setup for determining Brewster’s angle (top view):

(a) Place the laser on the small magnetic stand to facilitate vertical alignment with the leveling screws.

(b) Place a sheet of graph paper on the support table and align the vertical graph paper axis with the laser beam, as shown in Fig. 1.8, and tape down the graph paper.

(c) Place the lucite block on the graph paper such that incoming and reflected outgoing beams are about 10 cm apart. That is, the distance AC in Fig. 1.8(a) should be about 10 cm.

(d) Mark the outline of the lucite on the paper for reference. Carefully mark the position and direction of the beam at the points of incidence, exits.

(e) Determine $\theta_i$ and $\theta_R$ and calculate $n$.

(f) Using the redundant information on $\theta_i$ and $\theta_R$, evaluate your measuring errors and determine the error of the calculated refractive index.

9. Determine the index of refraction of the lucite block using Brewster’s angle, including error, using either the laser or the projector.

(a) Follow the setup of Fig. 1.9 with a fresh sheet of graph paper and a light source of your choice:

i. Place a polaroid in the incident beam.

ii. Set the lucite block at an arbitrary angle from the beam, say 30°.

iii. Place a movable screen to observe the reflected beam.

iv. Do not place a second polaroid between the Lucite and the screen yet.

(b) Rotate the first polaroid until the intensity of the reflected beam is minimum.
(c) Next vary the angle of incidence by rotating the lucite block until the reflected light is minimum.

(d) Fine tune the polaroid angle and the angle of incidence to get the best minimum. This occurs when angle of incidence is equal to Brewster's angle. Calculate $n$ and repeat at least twice by each partner.

(e) Rotate the polaroid by 90° so that the reflected light is fully polarized vertically, as described in Fig. 1.5.

(f) Determine the absolute transmission direction of the second polaroid by inserting it into the reflected beam and rotating it until the transmission is maximum. Greater accuracy can be achieved by determining the minimum angle of transmission instead. This will yield the normal to the transmission direction.

(g) Repeat step 9f for the first polaroid.

10. Average the two measurements of $n$ for Lucite and determine the error. The expected percentage error is no more than 5%.

11. Strictly speaking, the $n$ you just determined is the relative index of refraction with respect to air. Using the refractive index of air, which is 1.0003, determine if this correction is beyond the accuracy of your measurement. If it is not, then include the correction in your calculations and re-determine the error.

12. Determine the transmission axis of a set of Polaroid sunglasses. Be sure to check both lenses, and to note which type of glasses you are investigating. Explain how this design makes the glasses suitable for their function, be it 3D movie-viewing or blocking glare from, for example, sunlight reflecting off water.

**Second session:** Optical activity.

We want to find the concentration of a mystery concentration of sucrose in water. To do this we need to know the specific rotation $\alpha$ of sucrose for the wavelength of light used. $\alpha$ is determined by measuring the amount of polarization rotation induced by passage through a known path length in a known concentration at a fixed wavelength, and using Eq. 1.7. To get a reliable value, more than one measurement will be taken to determine the specific rotation of the sucrose, and the average of the results will be used when measuring the concentration of the mystery sample.
(c) Next vary the angle of incidence by rotating the lucite block until the reflected light is minimum.

(d) Fine tune the polaroid angle and the angle of incidence to get the best minimum. This occurs when angle of incidence is equal to Brewster’s angle. Calculate \( n \) and repeat at least twice by each partner.

(e) Rotate the polaroid by 90° so that the reflected light is fully polarized vertically, as described in Fig. 1.5.

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**Second session:** Optical activity.

We want to find the concentration of a mystery concentration of sucrose in water. To do this we need to know the specific rotation \( \alpha \) of sucrose for the wavelength of light used. \( \alpha \) is determined by measuring the amount of polarization rotation induced by passage through a known path length in a known concentration at a fixed wavelength, and using Eq. 1.7. To get a reliable value, more than one measurement will be taken to determine the specific rotation of the sucrose, and the average of the results will be used when measuring the concentration of the mystery sample.
Figure 1.10: Saccharimeter (side view).

13. Following Fig. 1.10, assemble the saccharimeter without the sucrose sample.

14. Rotate the analyzer until you have found the minimum transmission angle. As always, record this angle in your log book. Make sure to note which color filter you used.

15. For each of the color filters do the following. Again, you should plot the data taken as you record it. A computer can be especially useful in this respect.

   (a) Insert the first sucrose container, rotate the analyzer until you have found the new minimum transmission angle. The difference is the angle through which the glucose rotates the plane of polarization.

   (b) Using Eq. 1.7, calculate the specific rotation.

   (c) Repeat steps 15a and 15b for the second sucrose container. Time permitting you should exchange sucrose containers of known concentration with other students in the laboratory and obtain more measurements for \( \alpha \) to reduce the statistic error in the final result.

16. Calculate the final result for \( \alpha \) for sucrose at room temperature at the various wavelengths of light used, along with the error.

17. Obtain a mystery sucrose solution and measure the rotation of the polarization at the various wavelengths of light. Use Eq. 1.7 to determine the concentration of the mystery solution along with the error.

18. Using a computer, calculate the wavelength-dependence \((\lambda^{-1}, \lambda, \lambda^2, \lambda^3, \text{etc.})\) of the specific rotation. What is the certainty of this result?

19. Following Sec. 1.5, observe and describe the double refraction of polarized and unpolarized light by a calcite crystal.
Physics 18L

Experiment 1. Polarization of Light

20. Investigate chromatic birefringence as discussed in Sec. 1.5.1.
21. Using the polariscope, investigate the photoelasticity in the Lucite stress samples as discussed in Sec. 1.5.2.
22. Create birefringent pop art and make a class evaluation.

Tips for the report: As a rule, your scientific report aims to communicate your results. In the real world no communication will occur if your report is boring, unattractive, or impenetrable. Including too much uninteresting information, in a report that is too long, is a sure way to lose your reader. Including so little information that your reader must work hard to interpret your meaning is also ineffective. Good scientific writing is concise, striking a balance that communicates economically and effectively.

Figures transmit information very effectively, and should be designed carefully. For this week's report, when you discuss your measurements of the Law of Malus, consider including a figure that plots $I_2(\alpha = \theta_1 - \theta_2)$, $I_0/2$, and $I_1(\theta_1)$ together on the same graph. Also consider a plot showing $I_2(\cos^2\alpha)$, with a linear fit overlaid.

1.4.1 Equipment

1 light source: slide-projector with collimator
1 photometer and fiber-optic cable
1 He-Ne laser, 1/2 mW
1 optical bench with magnetic adhesion
2 Polaroids with angular scale
2 optical bench stands for Polaroids
1 optical bench stand for fiber optic cable
1 lucite block, 20×10 cm
1 pair gloves for handling of lucite block
2 stands for Lucite block
1 small screen
5 color filters: red ($\lambda = 650$ nm), orange (600 nm), green (530 nm), blue (430 nm), violet (400 nm)
3 sucrose samples in holder. Two sizes with defined concentration, one with a mystery concentration.

1 polariscope
2 rulers, 30 cm
1 ruler, 1 m

1.5 Birefringence

The speed of light in isotropic materials is the same in all directions. There are several substances which have a marked anisotropic atomic structure and the speed of light depends on the direction, they are birefringent or doubly refracting. When a light ray is incident on a birefringent crystal not along the optic axis, see Fig. 1.11, it splits into two beams. One is called the ordinary ray which obeys the standard laws of refraction; the other one is the extraordinary ray which follows some modified laws. The two types of rays have mutually perpendicular polarization directions. There is one special direction of a birefringent crystal in which both rays propagate with the same speed. This direction is called the optic axis of the crystal. Nothing unusual occurs when light travels along the optic axis.

Next consider light that is incident on a birefringent crystal perpendicular to the crystal face and perpendicular to the optic axis. The two rays travel again in the same direction but at different speeds. The two rays of the emerging light will have a phase difference which depends on the thickness
Figure 1.12: Rotation of polarization direction by a birefringent material.

of the crystal and the wavelength of the light, see Fig. 1.12. When the phase differences is 180° the crystal is called a half-wavelength plate. If the incident light is linearly polarized the emerging light will also be linearly polarized, with the direction of polarization rotated by 90°. Examples of birefringent materials are cellophane, quartz, lucite-under-stress.

Make a black dot of 1mm diameter on a blank piece of paper. Place a calcite birefringent crystal on top of the dot and observe the dot through the crystal, you should see 2 dots! One dot is due to the ordinary ray and the other to the extraordinary. Rotate the crystal and observe the rotation of the two dots. Write a brief scientific note reporting your observations and add it to your lab report. Also, investigate the polarization of both dots using a polaroid filter.

1.5.1 Chromatic birefringence

A thin plate of a doubly refracting material of suitable thickness can produce dramatic color effects when placed between the polaroids of a polariscope. To understand the physics of this, consider first the case of the doubly refracting quartz plate cut in such a way that it is just a λ/2 plate (‘half-wave plate’) for blue light. The effect of the λ/2 plate in this orientation is to rotate the polarization direction by 90°. The analyzer, when at crossed position to the polarizer, will transmit this blue light. Next consider the case of white light incident on the same polariscope with the λ/2 plate. The blue component of the white light emerging from the λ/2 plate will be transmitted by the crossed analyzer. For all other colors the thickness of the doubly refracting
plate will not be exactly $\lambda/2$, and all non blue light is transmitted elliptically-polarized and consequently will be partly absorbed by the crossed analyzer. The result is that the light that emerges from the polariscope is rich in the blue component and will appear blue-green. When the analyzer is rotated by 90° it will absorb the blue light, while the other wavelengths are being transmitted to some extent. The resulting color will be the complement of blue-green, that is, pink. Finally, consider the case of a doubly refracting material of non-uniform thickness. A particular piece of this material may have the right thickness to act as a $\lambda/2$ plate for red light, another piece for blue light, and so on. The effect of such a material inserted between two polaroids is to produce a psychedelic, kaleidoscopic pattern of colors. It so happens that ordinary cellophane and Scotch transparent tape are both doubly refracting. A few layers of either material amount to just about $\lambda/2$ for various colors and therefore can be used to obtain some very colorful “modern art” pattern.

Insert a crumpled ball of cellophane in the polariscope (see Fig. 1.13) between the analyzer and polarizer and observe the colorful pattern. Rotate the analyzer and watch the colors change to their complementary colors. Replace the cellophane by the “Scotch tape mosaic” and repeat the above. Make a table of the colors and their complements as seen in your experiment.

### 1.5.2 Photoelasticity

Use the polariscope of Fig. 1.13. Set the two polaroids in crossed position and place the lucite stress samples between analyzer and polarizer. Apply various amounts of stress and note the polarization effects. Rotate the analyzer. Make a sketch of the observed stress pattern and interpret the stress pattern.

### 1.6 Photometer

The photometer is a Pasco product, it is model 0S-8020 for the measurement of relative light intensities in the range 0.1 to 1000 Lux. It consists of a selenium photovoltaic cell, a sensitive amplifier and a meter. The front face is shown (see Fig. 1.14). The different components and knobs are identified by a number in the little square frame and they will be explained in the following; in the text they are referred to by the same number in square brackets. The power switch [6] is located on the back panel. It turns the
Figure 1.13: Polariscope (side view). Polarizer and analyzer can be rotated in the horizontal plane.

Figure 1.14: Photometer

(Pasco Model 0S-8020)
unit on and off. When the unit is on the meter [1] is illuminated. The light-probe-input plug [2] contains a selenium photovoltaic cell. The light may be incident directly on the input plug or via a detachable flexible, fiber-optic cable [8]. We will always use the fiber-optic cable. This allows for convenient scanning when attached to a linear translator, which is a small holder for the accurate positioning of the cable input. The fiber optic cable output is made to fit the light input plug.

The sensitivity switch [3] selects the range of the photometer. The variable control knob [4] allows for uncalibrated, continuous adjustment of the range. If the variable control knob [4] is fully clockwise, the sensitivity meter is reproducible. We suggest that you verify that the variable knob is fully clockwise, and then leave it there.

There are two zero adjust knobs. The mechanical one [7] should be used first while the power is still off and the sensitivity switch [3] is in the most sensitive position (0.1).

To adjust the zero electronically first cover the cable input completely with a black cloth. Use the most sensitive position (0.1) of the sensitivity switch. Turn the zero adjust knob [5] until the meter reads zero. The instrument is now served on all ranges. Before starting a measurement turn the sensitivity range knob to the highest range (1000) which is least sensitive.

The meter is a combination of two scales, an upper one from 0 to 10 and a lower one from 0 to 3. When the sensitivity knob is set to 1000, 100, 10, 1, or 0.1 use the upper scale and multiply the reading by 100, 10, 1, 0.1 or 0.01 respectively. When the sensitivity knob is set to 300, 30, 3, 0.2, 0.3 use the lower scale and multiply by 100, 10, 1, or 0.1.

To prolong the life of the fragile fiber-optic cable observe the following:

- The smallest bending radius is 2 inches.
- Do not bend the cable at all within 3 inches of the ends of the cable.
- Do not touch the tip of the cable as it will reduce the transmission efficiency.
Physics 18L

Experiment 1. Polarization of Light