Polarization

Equipment

1	Polarization Analyzer	OS-8533A
1	Basic Optics Bench (60 cm)	OS-8541
1	Red Diode Laser	OS-8525A
1	High Sensitivity Light Sensor	PS-2176
1	Rotary Motion Sensor	PS-2120
Not included but required:		
1	850 Universal Interface	UI-5000
	PASCO Capstone Software	

Introduction

Laser light (peak wavelength = 650 nm) is passed through two polarizers. As the second polarizer (the analyzer) is rotated by hand, the relative light intensity is recorded as a function of the angle between the axes of polarization of the two polarizers. The angle is obtained using a Rotary Motion Sensor that is coupled to the polarizer with a drive belt. The plot of light intensity versus angle can be fitted to the square of the cosine of the angle allowing us to verify the Law of Malus.

As part of the two polarizer experiment, we demonstrate that the diode laser is 100% polarized. We use this to simulate a three polarizer system. The non-rotating polarizer is set perpendicular to the laser polarization so transmission is minimized. The analyzer is then placed between the laser and the fixed polarizer and the student finds that some of the beam is now transmitted. This allows a striking verification of the vector nature of the electric field.
This experiment can be performed with the room lights on.

Theory

A polarizer only allows light which is vibrating in a particular plane to pass through it. This plane forms the "axis" of polarization. Unpolarized light vibrates in all planes perpendicular to the direction of propagation. If unpolarized light is incident upon an "ideal" polarizer, only half of the light intensity will be transmitted through the polarizer.

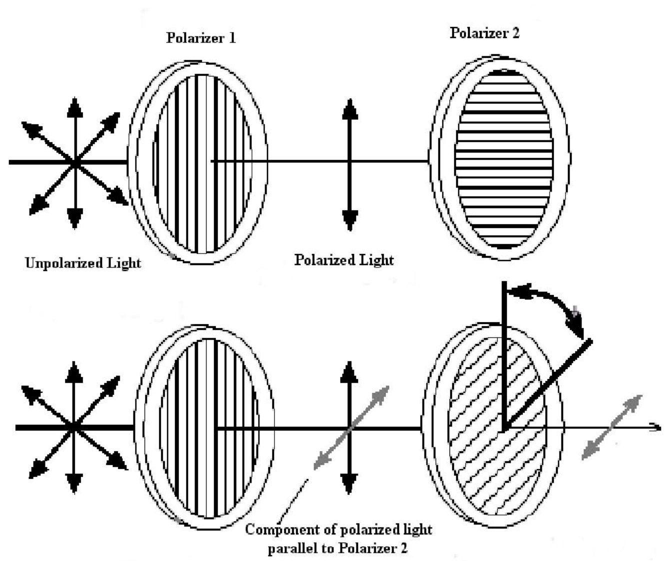


Figure 1: Light Transmitted through Two Polarizers

The transmitted light is polarized in one plane. If this polarized light is incident upon a second polarizer, the axis of which is oriented such that it is perpendicular to the plane of polarization of the incident light, no light will be transmitted through the second polarizer. See Fig.1. However, if the second polarizer is oriented at an angle not perpendicular to the axis of the first polarizer, there will be some component of the electric field of the polarized light that lies in the same direction as the axis of the second polarizer, and thus some light will be transmitted through the second polarizer.

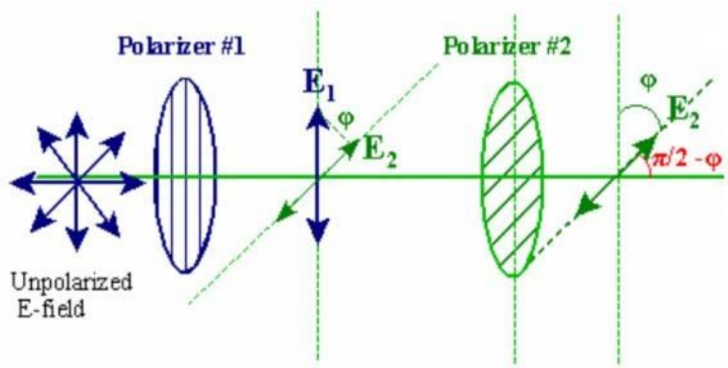


Figure 2: Component of the Electric Field

If the polarized electric field is called E_1 after it passes through the first polarizer, the component, E_2, after the field passes through the second polarizer which is at an angle ϕ with respect to the first polarizer is $E_1 \cos \phi$ (see Fig.2). Since the intensity of the light varies as the square of the electric field, the light intensity transmitted through the second filter is given by

$$I_2 = I_1 \cos^2 \phi \qquad (1)$$

Theory for Three Polarizers

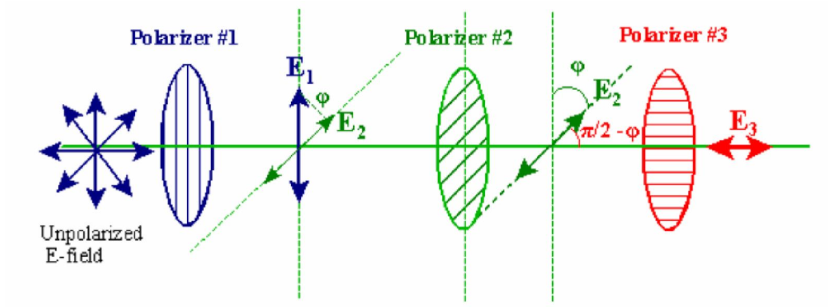


Figure 3: Electric Field Transmitted through Three Polarizers

Unpolarized light passes through 3 polarizers (see Fig.3). The first and last polarizers are oriented at 90º with respect each other. The second polarizer has its polarization axis rotated an angle ϕ from the first polarizer. Therefore, the third polarizer is rotated an angle $(\pi/2 - \phi)$ from the second polarizer. The intensity after passing through the first polarizer is I_1 and the intensity after passing through the second polarizer, I_2, is given by

$$I_2 = I_1 \cos^2 \phi$$

The intensity after the third polarizer, I_3, is given by

$$I_3 = I_2 \cos^2 (\pi/2 - \phi) = I_1 \cos^2 \phi \cos^2 (\pi/2 - \phi) = I_1 \cos^2 \phi \sin^2 \phi \qquad (2)$$

since $\cos(\pi/2 - \phi) = \sin \phi$.

Using the trigonometric identity, $\sin 2\phi = 2\cos\phi \sin\phi$, gives:

$$I_3 = (I_1/4)\sin^2 2\phi \qquad (3)$$

So we predict that the maximum intensity will be four times smaller than the max intensity for the two polarizer case and that intensity will run through its full cycle in $\pi/2$ radians rather than π radians as was the case with two polarizers. This does assume that the polarizers are ideal and transmit 100% of the light aligned with their optical axis and 0% of the light perpendicular to their optical axis. This is not true for real polarizers and we expect that the intensity will not quite go to zero. It also means that the max intensity decreases when more polarizers are inserted in the beam even though all the optical axes are aligned with the beam. This does not affect our results since both the two and three polarizer experiments insert two polarizers in the beam.

Setup

Figure 4: Equipment Separated to Show Components

1. Mount the aperture disk on the aperture bracket holder.

2. Mount the Light Sensor on the Aperture Bracket with the attachment thumbscrew (not the 6 cm rod) and plug the Light Sensor into a PASPORT input on the 850 Universal Interface. Click the low sensitivity (0-10,000) button on the side of the Light Sensor.

3. Rotate the aperture disk so the open aperture is in front of the light sensor (see Fig. 5).

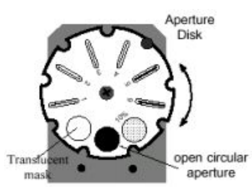


Figure 5: The Aperture Disk

4. Remove the black rod attachment adaptor from the Rotary Motion Sensor (RMS) using the attached tool. Make sure the pulley on the RMS is mounted so the large pulley is toward the body of the RMS. Using the two mounting screws stored on the Polarization Analyzer bracket, mount the Rotary Motion Sensor on the polarizer bracket so the pulley is toward the bracket. Connect the large pulley on the Rotary Motion Sensor to the polarizer pulley with the plastic belt stored on the polarization bracket (see Fig.6).

5. Plug the Rotary Motion Sensor into a PASPORT input on the 850 Universal Interface. Set the common sample rate to 25 Hz.

Figure 6: Rotary Motion Sensor Connected to Polarizer with Belt

6. Push all the components on the Optics Track as close together as possible. See Fig.7. The aperture disk on the light sensor should not touch the Polarization Analyzer. Note that the wrong light sensor shows in the picture.

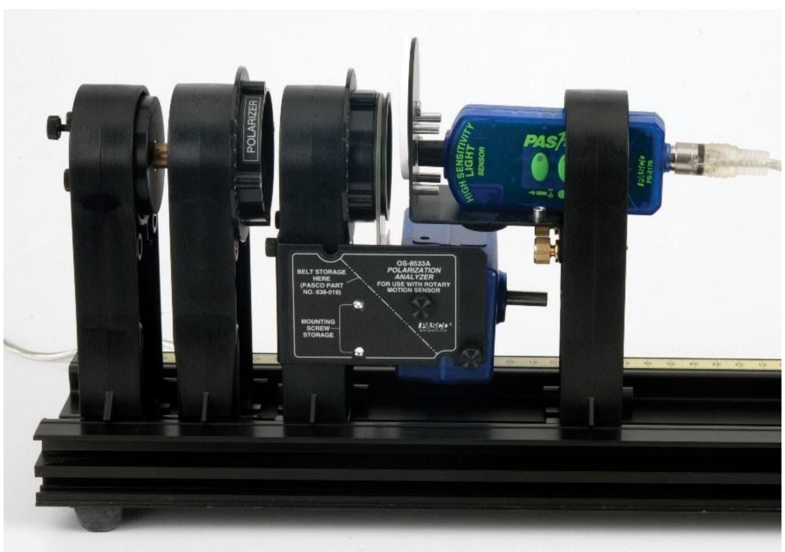


Figure 7: Setup with Components in Position for Experiment

7. In PASCO Capstone, create a graph of Relative Intensity (%) vs. time and another graph of Relative Intensity (%) vs. Angle (°).

Initial Procedure for Two Polarizers

The polarizers are aligned to allow the maximum amount of light through.

1. Since the laser light is already polarized, the first polarizer must be aligned with the laser's axis of polarization. First remove the holder with the Polarization Analyzer and Rotary Motion Sensor from the track. Slide all the components on the track close together. Click RECORD and then rotate the polarizer that does not have the Rotary Motion Sensor through a full 360 degrees. Click STOP. Click the Re-scale tool ( ) on the toolbar above the graph so the graph fills the page. Note that the transmitted intensity drops almost to zero (should be less than 0.5%) twice during the rotation. This proves that the diode laser is 100% (or nearly) polarized. The two maximums will probably not be equally high due to the fact that the polarizer is not quite ideal. Click RECORD and rotate the polarizer until the light intensity on the graph is at its maximum (the higher of the two maximums). Click STOP. Lock the polarizer in place with the brass bolts.

2. Delete all runs.

3. To allow the maximum intensity of light through both polarizers, replace the holder with the polarizer and Rotary Motion Sensor on the track, press RECORD, and then rotate polarizer that does have the Rotary Motion Sensor until the light intensity on the graph is at its maximum (see Fig. 4 under the Setup A tab). Click STOP.

4. Click Delete Last Run at the lower right of the screen.

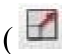
Procedure

1. Note the angle that is at the top of the Polarization Analyzer (should be either 0 or 180 degrees).

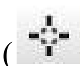
2. Click RECORD and slowly rotate the polarizer which has the Rotary Motion Sensor through 360 degrees (one revolution) in whichever direction gives positive angles. Stop when the Relative Intensity is at a max. Then click STOP. Try to move slowly and steadily through the turning points. You may move faster between the turning points.

3. Click on the Data Summary button on the left of the screen. Click on any Run #1 and re-label it “2 Polar”. Click Data Summary to close it.

Analysis for Two Polarizers

1. If the graph does not fill the page, click the Re-size tool () at the upper left.

2. Position the hand icon over the lowest non-zero number (probably 2) on the left axis. When the hand changes to the parallel plate icon, click and drag until the number is at the top of the graph. This will stretch out the curve so it is easier to see the minimum.

3. Click on the Smart Cursor () from the graph toolbar. Position the cross-hairs directly above the minimums and read the angle (the left number in the box) at each of the minimums. How much has the angle changed going from minimum to minimum to minimum? Why?

   Change in angle = ________

Curve Fit for Two Polarizers

1. In the Capstone calculator, create a calculation for the theoretical curve:

   I=[I zero (%)]*(cos([Angle (rad)]+[A (rad)]))^2+[B (%)]   with units of %
   I zero=15   with units of %
   A=0   with units of rad
   B=0   with units of %

2. On the graph of Relative Intensity vs. Angle, add another vertical axis and select the calculated I.

3. In the calculator, I zero = I_0 = 15. Adjust this value to match your data. A is a constant that may be necessary if you did not start your run from exactly the maximum. It will shift the I plot left or right. Adjust it if necessary. B is a correction if the measured intensity does not go to zero. Adjust it if necessary.

4. How well does the theory work?

Procedure for Three Polarizers

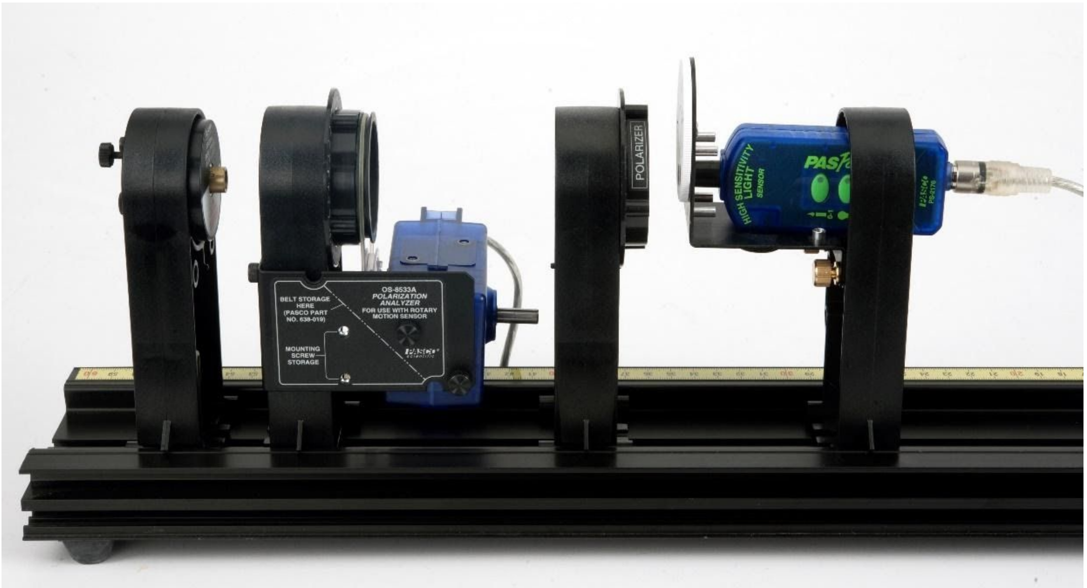


Figure 8: Three Polarizer Setup

1. Now repeat the experiment with 3 polarizers. Reverse the two polarizers so the Polarization Analyzer is closest to the laser. Remember that the laser is polarized so essentially, the fist polarizer is inside the laser.

2. Remove the Polarization Analyzer. Loosen the brass bolts on the other polarizer.

3. Click RECORD and rotate the polarizer until the Relative Intensity is at the minimum. Click STOP. Tighten the brass bolts. Click Delete Last Data Run (caution: don't delete "2 Polar"!!)

4. Place the Polarization Analyzer back on the track. Click RECORD and again adjust the Polarization Analyzer for minimum. Click STOP. Click Delete Last Data Run (caution: don't delete "2 Polar"!!)

5. Open the Procedure tab and repeat as before except re-label the run "3 Polar".

Analysis for Three Polarizers

1. Click on Data Display triangle () to display more than one set of data and then on the black triangle to select “2 Polar” and “3 Polar”.

2. Why are there twice as many cycles of “3 Polar” as “2 Polar”?

3. Equation 3 from Theory predicts that the “3 Polar” maximums should be ¼ as high as the “2 Polar” maximums. Does this check out correctly? Remember that the polarizers are not ideal.

4. What is the angle between the middle polarizer and the first polarizer (the laser polarization axis) to get the maximum transmission through all 3 polarizers?

5. What is the angle between the middle polarizer and the first polarizer to get the minimum transmission through all 3 polarizers?

Curve Fit for Three Polarizers

1. In the Capstone calculator, create a calculation for the theoretical curve:

   I3=[I1/4 (%)]*(sin(2*[Angle (rad)]+[C (rad)]))^2+[D (%)]   with units of %
   I1/4=4.4   with units of %
   C=0   with units of rad
   D=0   with units of %

2. On the graph of Relative Intensity vs. Angle, select the calculation I3 on the second vertical axis.

3. In the calculator, I1/4= $I_1/4$ = 4.4. Adjust this value to match your data. C is a constant that may be necessary if you did not start your run from exactly the minimum. It will shift the I3 plot left or right. Adjust it if necessary. D is a correction if the measured intensity does not go to zero. Adjust it if necessary.

4. How well does the theory work?