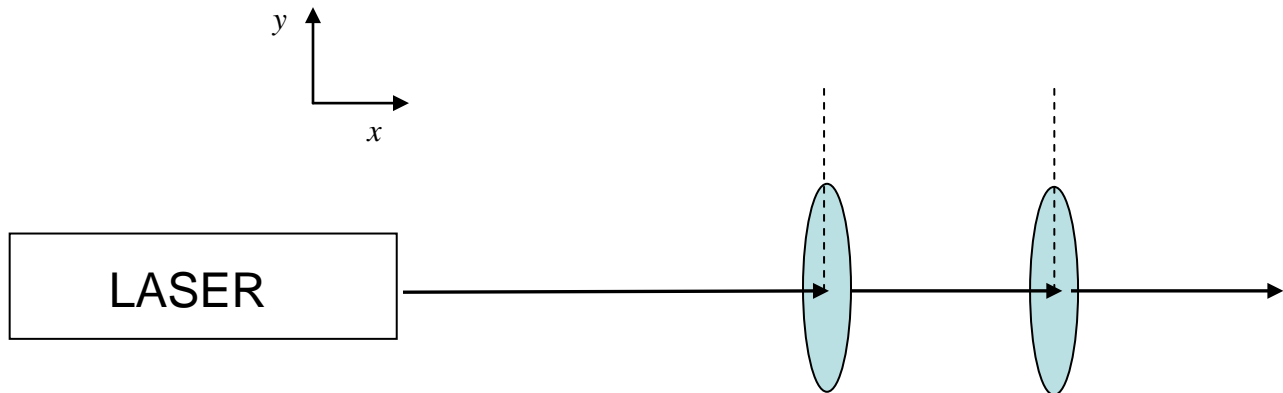
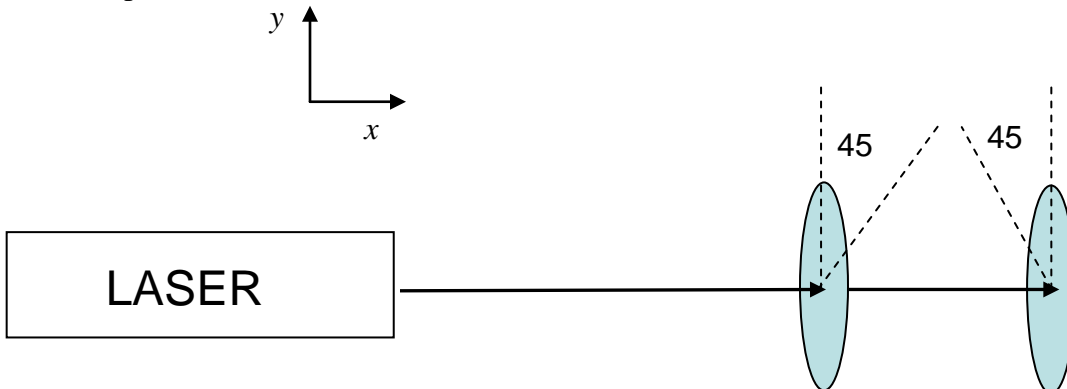


## Physics 345      Pre-Lab 9      Polarization

Light from a laser is linearly polarized along the y-axis. Two linear polarizers are arranged so that the light through both polarizers is maximized.



A student then turns off the laser. Then he/she rotates the first polarizer  $45^\circ$  clockwise and the second polarizer  $45^\circ$  counter-clockwise.



Three different students make different predictions as to how much light will come through the polarizers (assume they are ideal).

Student A: The two polarizers are crossed. Therefore, no light will come out.

Student B: The first polarizer will reduce the light intensity by half and the second polarizer will reduce the intensity by another half. Thus, one quarter of the original light intensity will emerge.

Student C: The only way light will emerge is if a third polarizer at zero degrees is placed between the first two.

Which student (or students) if any, has correctly analyzed these physical circumstances?  
Explain.

**Section 1**

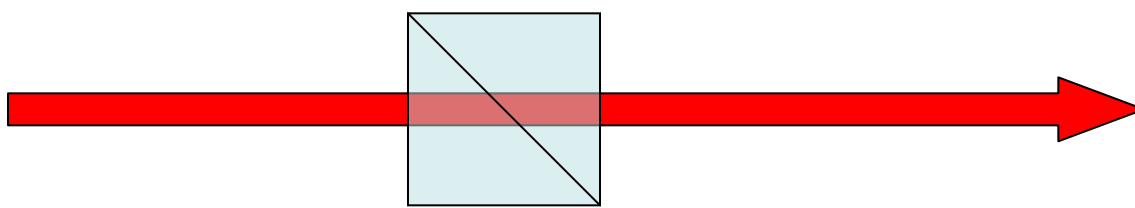
This section's purpose is to familiarize your self with linear polarizers as well as determining the relative orientation of the electric field for linearly polarized light.

For this investigation you will use a He-Ne laser. To begin this experiment, you must first determine the polarization of the laser beam. An easy way to accomplish this is through the use of a Polarizing Beamsplitting Cube (PBC).

**TOP VIEW**

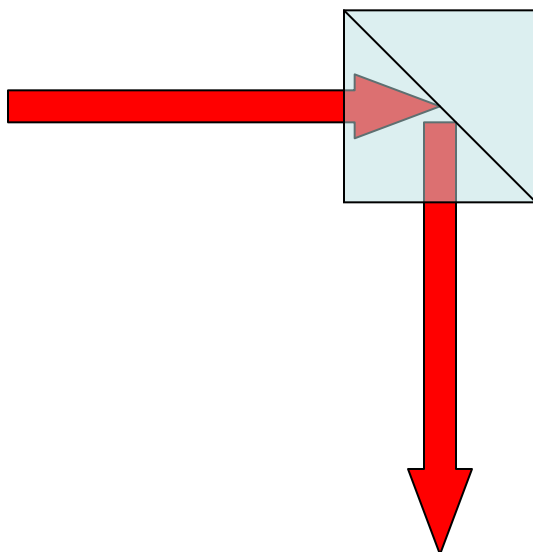
Horizontal Linear Polarization

(the electric field oscillates up/down in the plane of the paper)



Vertical Linear Polarization

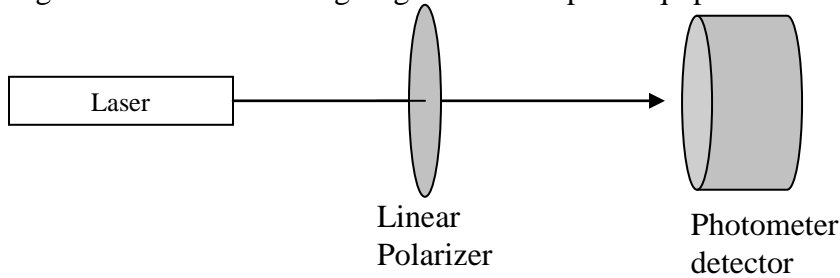
(the electric field oscillates into and out of the plane of the paper)



Put the PBC on a prism holder with double sided tape. One of the frosted sides of the PBC should rest on the prism holder's bottom (double tape here) to protect the clear optical

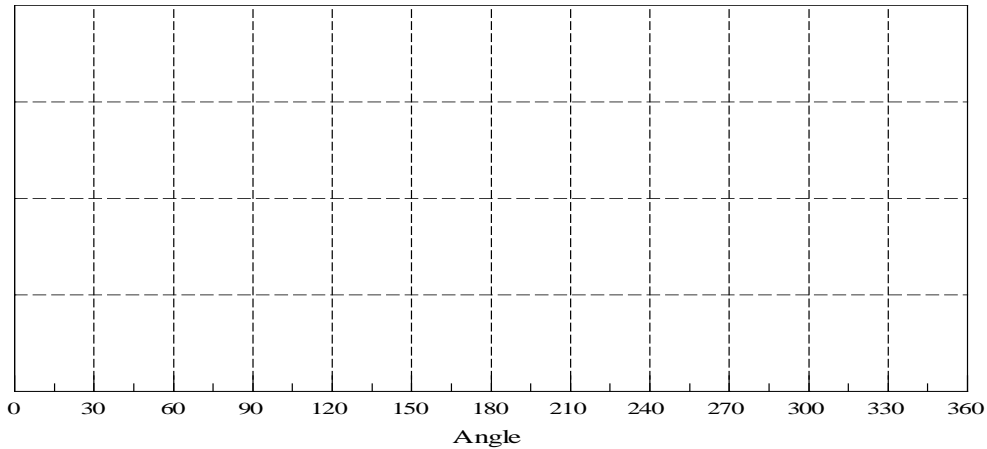
surfaces. Use the PBC to determine the polarization of your laser beam. As always when using lasers, make sure the beam is traveling parallel to the optical table top at all times and terminate the laser beam so that it does not travel off the optical table. How would you describe the polarization of the laser light?

Put a linear polarizer in a hand-turned plate rotator. Make sure you use the spanner wrench to tighten/loosen the locking ring. Then set up the equipment as shown below.



Rotate the linear polarizer to minimize the transmitted laser beam power. We will call this  $90^\circ$ . Rotate the polarizer  $90^\circ$  clockwise. We will call this  $0^\circ$  and we will keep this definition throughout the rest of the investigation. NOTE: This designation more than likely does not agree with the values on the plate rotator. What is the reading on the plate rotator at your defined  $0^\circ$ ?

Predict how the power of the transmitted light will change as a function of the linear polarizer's angle. That is, make a plot of the transmitted laser beam power vs. polarizer's angle.



Explain your reasoning for the your sketch:

Now rotate the linear polarizer by iterations of  $15^\circ$  until you rotate  $360^\circ$ . Complete the table and use Excel to plot your results. Compare to your predictions. Resolve any differences.

$\theta = 0^\circ$		$\theta = 120^\circ$		$\theta = 240^\circ$	
$\theta = 15^\circ$		$\theta = 135^\circ$		$\theta = 255^\circ$	
$\theta = 30^\circ$		$\theta = 150^\circ$		$\theta = 270^\circ$	
$\theta = 45^\circ$		$\theta = 165^\circ$		$\theta = 285^\circ$	
$\theta = 60^\circ$		$\theta = 180^\circ$		$\theta = 300^\circ$	
$\theta = 75^\circ$		$\theta = 195^\circ$		$\theta = 315^\circ$	
$\theta = 90^\circ$		$\theta = 210^\circ$		$\theta = 330^\circ$	
$\theta = 105^\circ$		$\theta = 225^\circ$		$\theta = 345^\circ$	

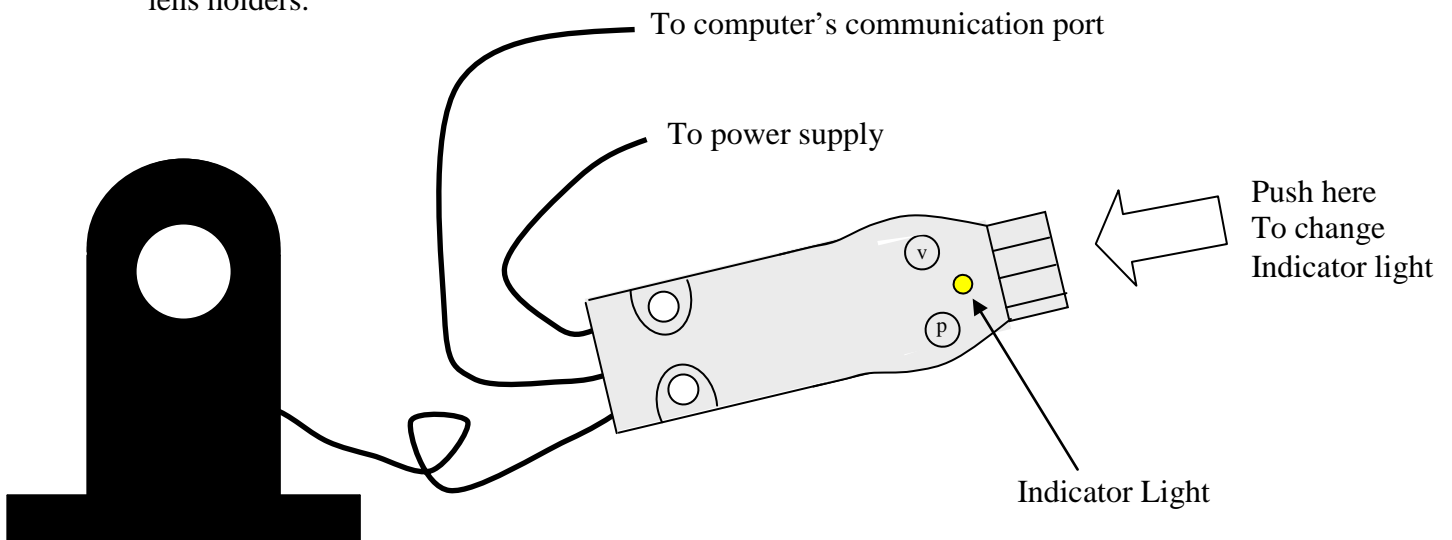
Are the variations in intensity you recorded above a property of the light itself or is it an effect of the polarizer?

SHOW YOUR ANSWERS TO YOUR INSTRUCTOR BEFORE PROCEEDING.

## Section 2

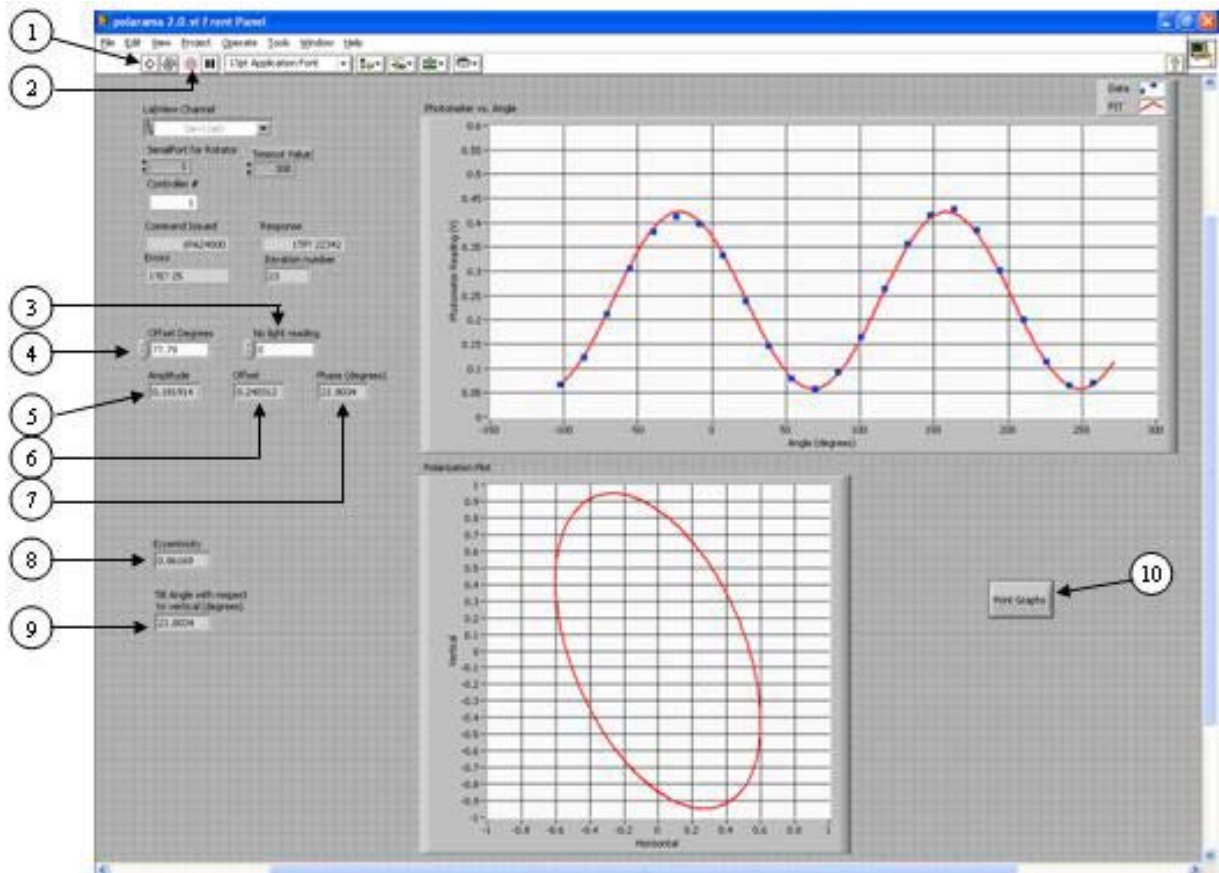
This section is to familiarize you with the motorized plate rotator as well as the software to record/analyze polarizations.

To make the process of examining the polarization easier, we will use a motorized plate rotator with a different linear polarizer. Set the linear polarizer you used above to the side (you will use it again and you will need to have the same orientation in the mount). See the sketch shown below. The motorized plate rotator uses the same type of retainer ring as the lens holders.



Connect the motor control to its power supply. Push the button until the indicator light glows yellow. You will need to plug the cable from the motorized mount into the computer's communication port as well as connect the photometer to channel zero in the LabView interface (make sure its USB cable is plugged in). To operate the rotator (via the computer), you will have to learn how to operate a LabView program called "Polarama 2.1" (it should be on the desktop of the computer).

When you open "Polarama 2.1", you should see...



1. The start button
2. The stop button
3. Location to enter a zero light reading (particularly important if the detector does not read zero when there is no light)
4. Location to enter a phase offset
5. Output for the amplitude of the sinusoid
6. Output for the phase (in degrees) of the sinusoid (assumes a cosine function)
7. Output for the DC offset of the sinusoid in the photometer vs. angle plot
8. Eccentricity (an output) for the polarization plot
9. Tilt angle (an output) for the polarization plot

10. The print graphs button (if one wants a hard copy of the graphs)

NOTE: The graph data shows how "Polarama 2.1" will look after it collects data!

AFTER THE POLARAMA 2.1 PROGRAM FINISHES RUNNING YOU MUST END THE PROGRAM ONE OF TWO WAYS:

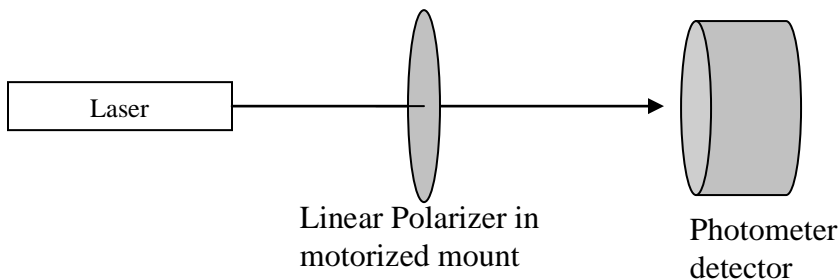
- HIT THE STOP BUTTON
- HIT THE PRINT GRAPHS BUTTON.

“Polarama 2.1” is a computer program that controls the rotation of a linear polarizer (in a motorized mount) and records the photometer reading for each angle. This program then fits a sinusoid to the data, where the sinusoid has the form

$$A \cos[2(\theta + \phi - \alpha)] + DC,$$

where  $A$  is the amplitude (labeled “5” on page 5 figure),  $\theta$  is the angle of the linear polarizer,  $\phi$  is the phase constant (labeled “6” on page 5 figure),  $\alpha$  is a user entered phase offset (labeled “4” on page 5 figure), and  $DC$  is a DC offset (labeled “7” on page 5 figure). The reason the two appears in the cosine function is because the sinusoid will go through two cycles when the linear polarizer is rotated through  $360^\circ$ . The sinusoid fit is then used to generate the polarization plot (the second graph). As you work through Labs 9, 10, and 11 you will gain greater understanding of the meaning behind this graph.

Now set up the same experiment (see below sketch) except a different linear polarizer is in the motorized plate rotator. The label on the motorized mount should face the same direction as the numbers on the hand-turned plate rotator you used on pp. 5 – 6. Run the LabView program 5 times recording the eccentricity and the phase of the sinusoid. NOTE: For now you can consider eccentricity as a measure of the degree of the light’s linear polarization. 1 indicates perfectly, linear polarization. 0 indicates almost no variation in the intensity of the light reaching the detector as the polarizer is turned.



Amplitude	DC Offset	Phase angle	Eccentricity	Tilt angle

Average Amplitude	Average DC offset	Average Phase Angle	Average Eccentricity	Average Tilt Angle
Standard Deviation of the Amplitude	Standard Deviation of DC Offset	Standard Deviation of the Phase Angle	Standard Deviation of the Eccentricity	Standard Deviation of the tilt angle

The purpose for the 5 measurements is to give you an idea of how consistent the LabView program is when measuring the same polarization. This should help you determine what is statistically important and what is not in later experiments. How does knowing the standard deviation help you determine what is statistically important and what is not?

Is the phase of the sinusoid you recorded with the motorized stage consistent with the phase in the Excel graph you previously made? Should the phases be the same? Explain.

Enter the average phase you found above into the box (in the LabView program) called “phase offset”. Run the LabView program once more. How does the phase of the sinusoid you just recorded compare to your Excel graph?

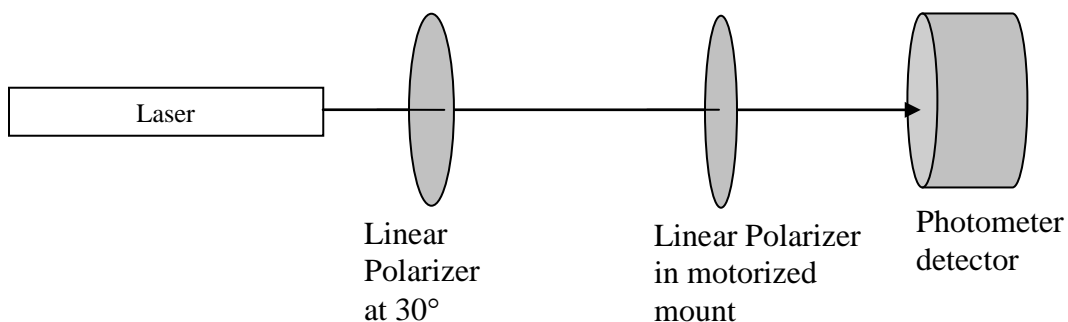
What do you think the “phase offset” does? Why might you want a value there besides zero?

SHOW YOUR ANSWERS TO YOUR INSTRUCTOR BEFORE PROCEEDING.

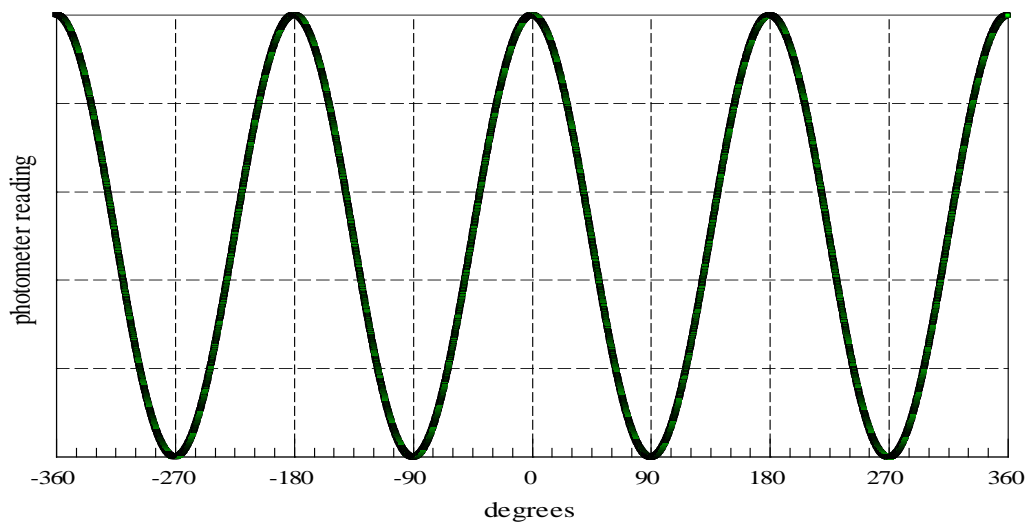
### Section 3

In this section you will examine what happens if a polarized beam of light enters a linear polarizer.

Consider the following experimental set up. Light out of the laser interacts with a linear polarizer turned to an angle of  $30^\circ$  (in the hand-turned mount with the angle defined as described on page 5), a linear polarizer in the motorized mount, and then a photometer detector. The numbers on the hand-turned rotation mount and the label on the motorized mount should face the same direction.



The sketch below shows the photometer reading vs. angle if the first linear polarizer (the one at  $30^\circ$ ) was absent. THIS SHOULD LOOK SIMILAR TO WHAT YOU SAW IN THE PREVIOUS EXERCISE IN SECTION 2. Predict on the same sketch what you expect to see with the linear polarizer present. Explain your reasoning.





Predict values for the following

Amplitude	DC Offset	Phase angle

Using the LabView program (“Polarama 2.1”), produce a graph of photometer reading vs. angle.

Amplitude	DC Offset	Phase angle	Eccentricity	Tilt angle

Resolve any and all differences with your prediction.

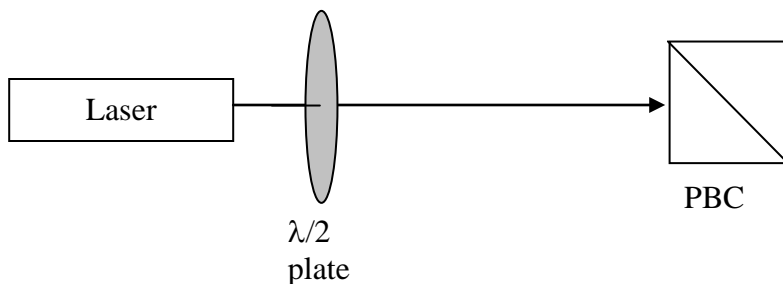
What do you think the polarization plot indicates in the “Polarama 2.1” program?

SHOW YOUR ANSWERS TO YOUR INSTRUCTOR BEFORE PROCEEDING.

### Section 4

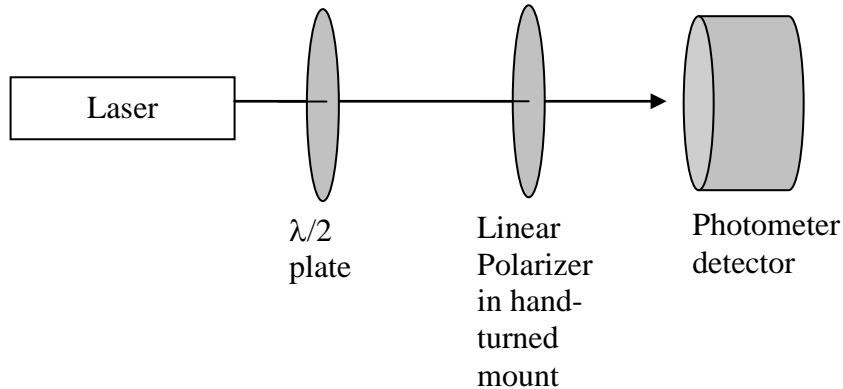
This section introduces the half-wave plate and allows you to discover what it does.

Attach a half-wave plate ( $\lambda/2$  – plate) to a hand-turned plate rotator. Set up the equipment as shown below.

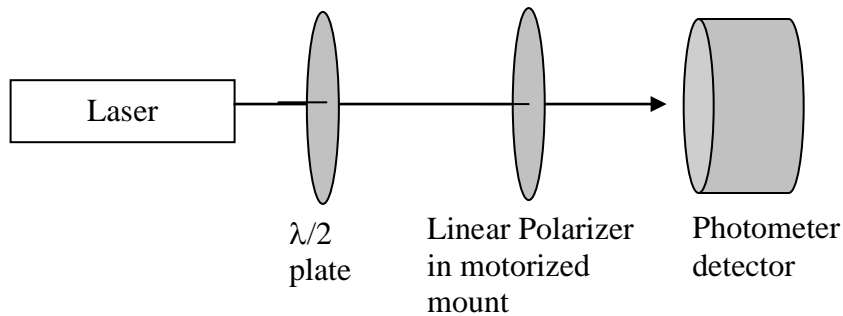


Rotate the  $\lambda/2$  – plate and describe what happens to the transmitted and reflected beams of light through the PBC as you turn the  $\lambda/2$  – plate. What do you think the  $\lambda/2$  – plate is doing to the polarization? How do you think a half-wave plate is different than a linear polarizer?

Set up the equipment as shown below (NOTE: the numbers for each plate rotator should face the same direction). The following procedure is just to choose a convenient zero angle for the half wave plate.



First turn the linear polarizer to its previous zero location (as described on page 5). Next, rotate the  $\lambda/2$  – plate to minimized the light power at the photometer. We will call this  $45^\circ$  for the  $\lambda/2$  – plate and we will keep this definition throughout the rest of the investigation. Turn the half-wave plate to zero degrees by rotating  $45^\circ$  clockwise. NOTE: This designation of  $0^\circ$  more than likely does not agree with the values on the plate rotator. What is the reading on the half-wave plate’s rotator at our defined  $0^\circ$ ? Replace the linear polarizer in the hand-turned mount with the motorized one. Make sure the label on the motorized mount faces the same direction as the numbers on the hand-turned plate rotator.



Using the LabView program, “Polarama 2.1”, produce a graph of the photometer reading vs. angle. After the half-wave plate, how would you describe the linear polarization: horizontal, vertical, or something else (see descriptions on page 4).

Rotate the half-wave plate  $45^\circ$  counter-clockwise. Using “Polarama 2.1”, produce a graph of the photometer reading vs. angle. After the half-wave plate, how would you describe the linear polarization: horizontal, vertical, or something else (see descriptions on page 4).

SHOW YOUR ANSWERS TO YOUR INSTRUCTOR BEFORE PROCEEDING

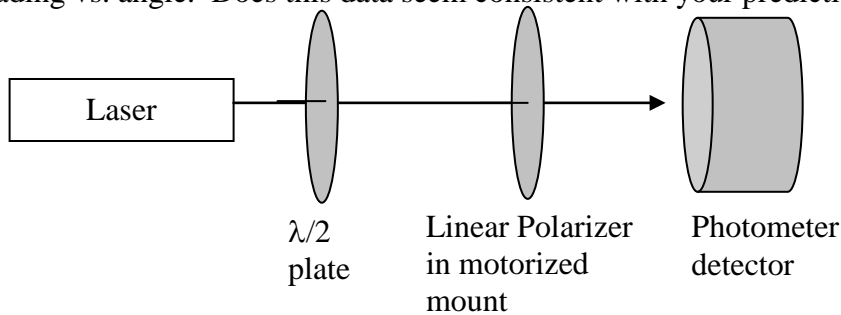
***DO NOT TAKE ANY OPTICAL PIECES OUT OF THEIR MOUNTS.  
LEAVE THEM IN UNTIL NEXT WEEK!***

**Task**

Suppose we want to adjust the laser's polarization so that half the light is transmitted through a PBC and half the light is reflected. PREDICT the angle of the half-wave plate that will accomplish this. Explain your reasoning.

**Show your prediction to your instructor.**

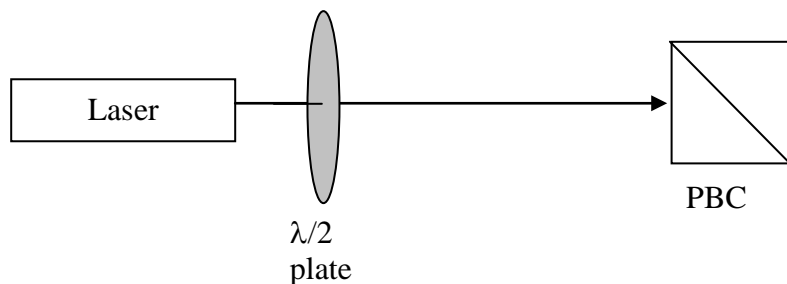
Before checking your prediction with a PBC, use "Polarama 2.1" to record the photometer reading vs. angle. Does this data seem consistent with your prediction?



Amplitude	DC Offset	Phase angle	Eccentricity	Tilt angle

**Show your prediction to your instructor.**

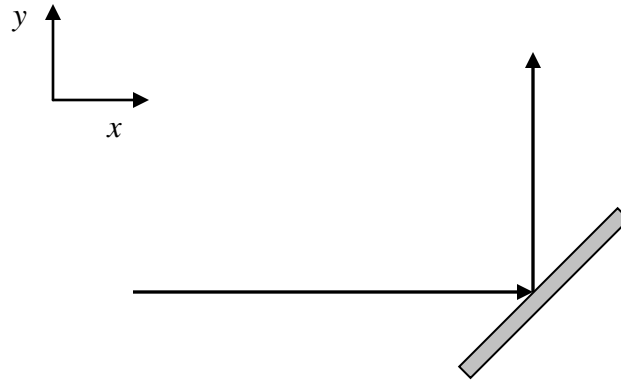
Setup the following to test your prediction. Measure (using the photometer) the transmitted and reflected light power after the PBC.



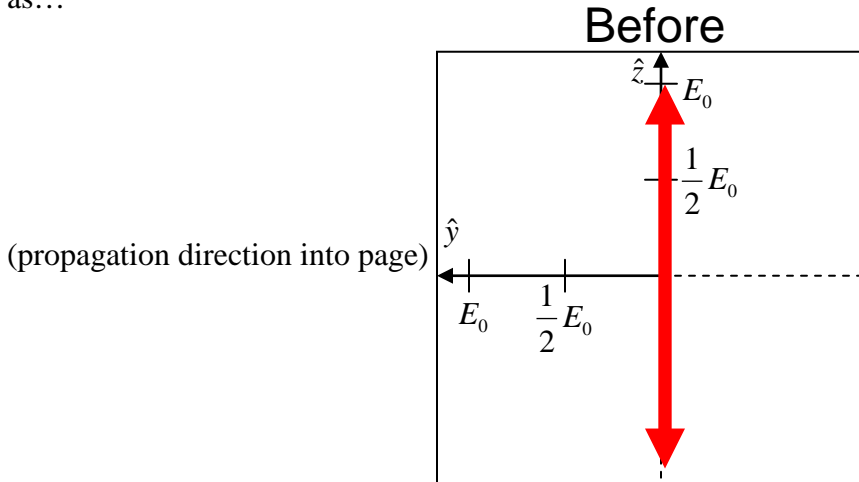
Resolve any differences with your predictions.

**EXTRA STUFF WE HAVEN'T FOUND A PLACE FOR YET**

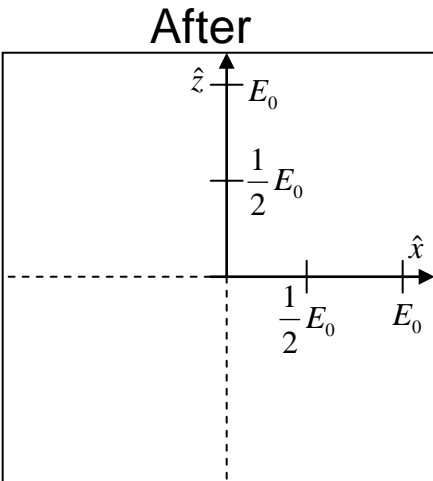
1. A linearly polarized laser beam reflects off an ideal metallic mirror as shown below.



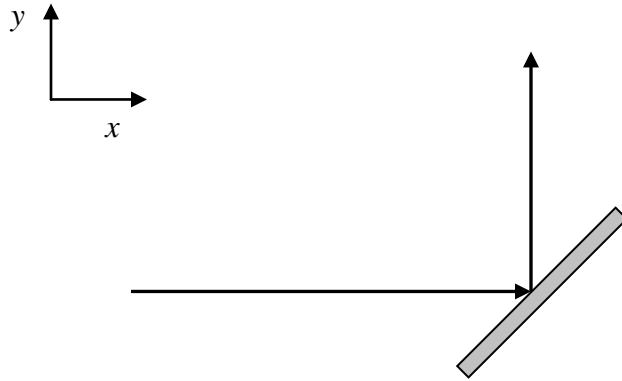
The electric field of the laser beam oscillates in the  $\pm \hat{z}$  direction before the laser beam interacts with the mirror. An observer facing the propagation direction of the laser beam before the mirror would graphically describe the orientation of the electric field's oscillations as...



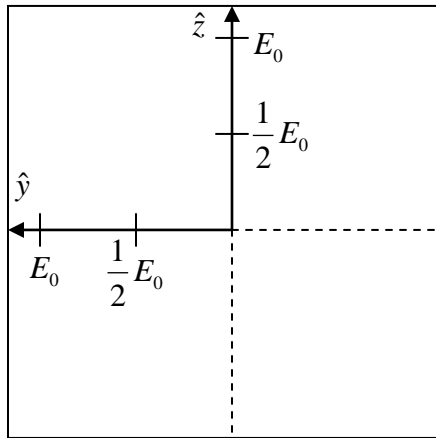
Describe the laser beam's polarization after the mirror. Fill out an equivalent polarization picture (again the propagation direction is into the paper). HINT: You do NOT have to use Fresnel Coefficients. (propagation direction into page for the after picture). Explain!



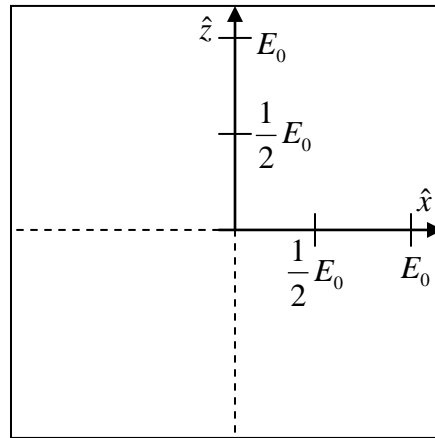
2. Repeat question 1, except now the laser beam's polarization before it hits the mirror is in the  $\pm \hat{y}$  direction. Explain your thinking for both before and after pictures.



Before



After



3. Repeat question 1, except now the laser beam's polarization before it hits the mirror is in the  $\pm \frac{1}{\sqrt{2}}(\hat{y} + \hat{z})$  direction. Explain your thinking for both before and after pictures.

