Pre-Lab 10

1). It is possible that one can have polarized light that is not linearly polarized. This is called elliptical polarization. Suppose a beam of light was traveling in the $+\hat{z}$ direction and the electric field had the following form…

$\vec{E} = (A\hat{x} + B\hat{y})\exp[i(kz - wt)]$ where A and B are complex constants. (NOTE: this is a generalized form for elliptical polarization).

For the special case where $B = \left(\frac{1+i}{\sqrt{2}}\right)A$ with A = real number, determine the following.

(a) Plot the electric field's projection on the x-y plane for different times (t = $0, \frac{p}{4w}, \frac{p}{2w}, \frac{3p}{4w}, \frac{p}{w}, \frac{5p}{4w}, \frac{3p}{2w}, \frac{7p}{4w}, \frac{2p}{w}$) at $z = 0$.

(b) Plot the magnetic field's projection on the x-y plane for different times (t = $0, \frac{p}{4w}, \frac{p}{2w}, \frac{3p}{4w}, \frac{p}{w}, \frac{5p}{4w}, \frac{3p}{2w}, \frac{7p}{4w}, \frac{2p}{w}$) at $z = 0$.

2). Suppose we had a material that would retard the electric and magnetic fields of light differently for two different axes. As an example, we will consider what will happen to linearly polarized light as it passes through a material with this property. For this example, assume that the light has the following electric field $\vec{E} = E_0\hat{x}\exp[i(kz - wt)]$ as it enters the material.

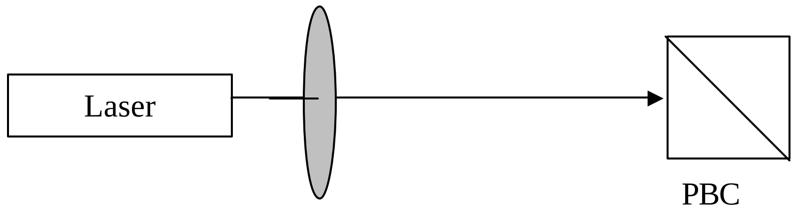
(a) The component of the electric field along the axis defined by $\pm\hat{x}$ will be phase shifted by f and will be polarized in the $\pm\hat{x}$ direction after the light exits the material. The component of the electric field along the axis defined by $\pm\hat{y}$ will be phase shifted by $\left(f + \frac{p}{2}\right)$ and will be polarized in the $\pm\hat{y}$ direction after the light exits the material. Describe the polarization before and after the light exits the material.

(b) The component of the electric field along the axis defined by $\pm\frac{1}{\sqrt{2}}(\hat{x} + \hat{y})$ will be phase shifted by f and will be polarized in the $\pm\frac{1}{\sqrt{2}}(\hat{x} + \hat{y})$ direction after the light exits the material. The component of the electric field along the axis defined by $\pm\frac{1}{\sqrt{2}}(-\hat{x} + \hat{y})$ will be phase shifted by $\left(f + \frac{p}{2}\right)$ and will be polarized in the $\pm\frac{1}{\sqrt{2}}(-\hat{x} + \hat{y})$ direction after the light exits the material. Describe the polarization before and after the light exits the material.

(c) The component of the electric field along the axis defined by $\pm(\cos q\hat{x} + \sin q\hat{y})$ will be phase shifted by f and will be polarized in the $\pm(\cos q\hat{x} + \sin q\hat{y})$ direction after the light exits the material. The component of the electric field along the axis defined by $\pm(-\sin q\hat{x} + \cos q\hat{y})$ will be phase shifted by $\left(f + \frac{p}{2}\right)$ and will be polarized in the $\pm(-\sin q\hat{x} + \cos q\hat{y})$ direction after the light exits the material. Describe the polarization before and after the light exits the material.

Lab 10

Attach a quarter-wave plate ($\lambda/4$ – plate) to a plate rotator. Set up the equipment as shown below.

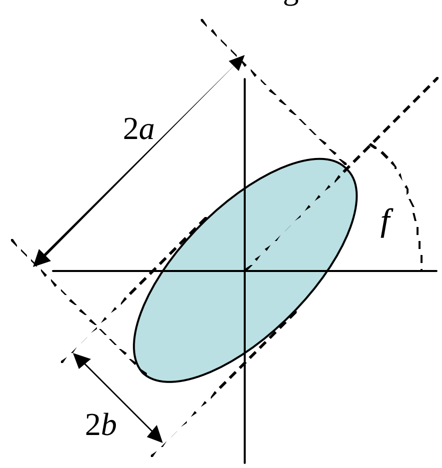


Rotate the $\lambda/4$ – plate and describe what happens to the transmitted and reflected beams of light through the PBC as you turn the $\lambda/4$ – plate.

If light is polarized, one can always consider it a form of elliptical polarization. (Note: perfectly linear polarization is an extreme form of elliptical polarization, e = 1). If one traces the electric field (or magnetic field) of a polarized electromagnetic wave about the propagation axis, it will trace out an ellipse (see problem 1 of the pre-lab). $\lambda/4$ – plates transform one type of elliptical polarization into another type of elliptical polarization.

For any ellipse, we can define it by 3 parameters: the semi-major axis a, the eccentricity e, and the tilt angle f. Eccentricity is the distance between the two foci divided by the semi-major axis. The eccentricity is zero for a perfect circle and one for a line (infinitely narrow ellipse). The eccentricity can also be found using the semi-minor axis b (see the below sketch).

$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

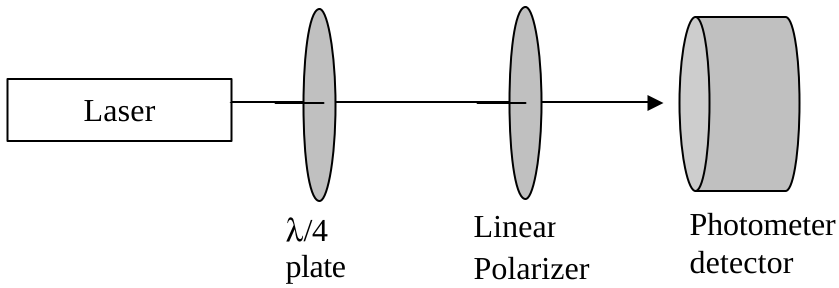


For elliptical polarization we can determine the tilt angle as well as the eccentricity by rotating a linear polarizer. The tilt angle is determined by angle at which the maximum amount of light passes through the linear polarizer. The eccentricity is found by

$$e = \frac{Max - Min}{Max}$$

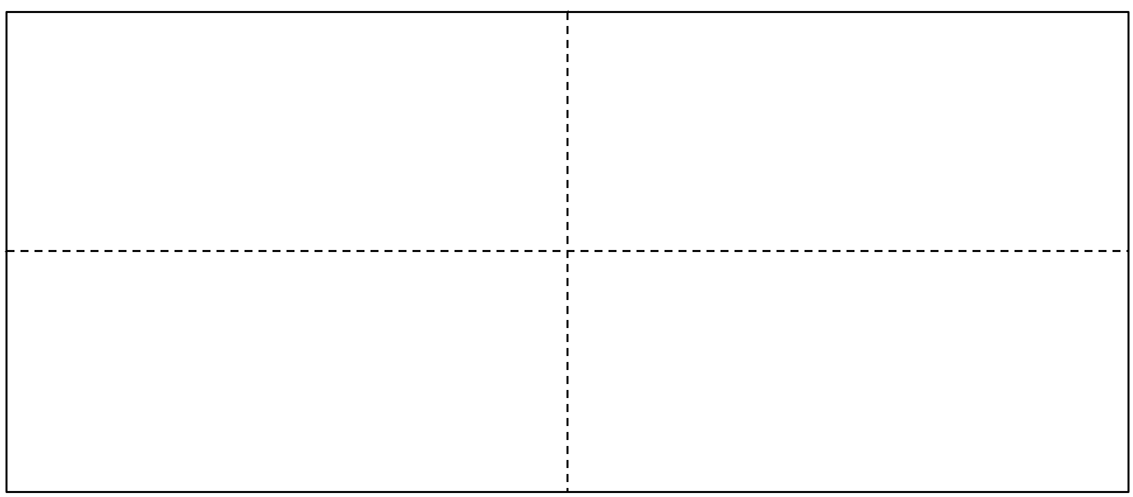
where Max is the maximum power through an ideal linear polarizer and Min is the minimum power through an ideal linear polarizer.

Turn a linear polarizer to the angle that minimizes the light reaching a photometer. We will call this angle 0°. Set up the equipment as shown below.



First turn the linear polarizer to its zero location (where it minimized the light from the laser). Next, rotate the λ/4 – plate to minimized the light power at the photometer. We will call this 0° for the λ/4 – plate 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 rotation stage.

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



Explain your reasoning for the above sketch:

Rotate the linear polarizer by iterations of 15° until you rotate 360°. Complete the table and then using Excel plot your results (make sure that zero power is on the graph). Compare to your predictions. Resolve any differences.

θ = 0°		θ = 120°		θ = 240°	
θ = 15°		θ = 135°		θ = 255°	
θ = 30°		θ = 150°		θ = 270°	
θ = 45°		θ = 165°		θ = 285°	
θ = 60°		θ = 180°		θ = 300°	
θ = 75°		θ = 195°		θ = 315°	
θ = 90°		θ = 210°		θ = 330°	
θ = 105°		θ = 225°		θ = 345°	

How is the light elliptically polarized? Draw a sketch that shows the eccentricity and the tilt angle of the elliptical polarization.

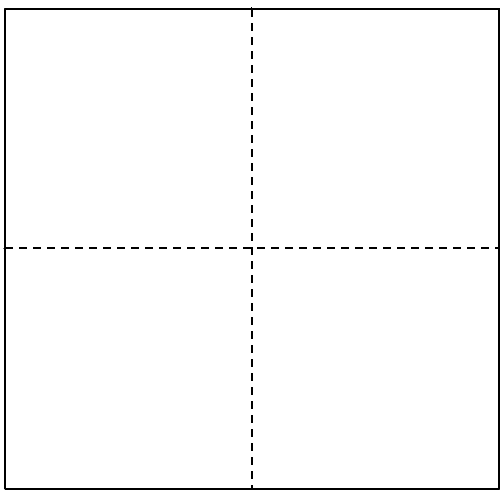
Rotate the $\lambda/4$ – plate by 22°. Predict how the light power reaching the photometer will change as a function of the linear polarizer's angle. That is, make a plot of the transmitted laser beam power vs. the linear polarizer's angle.

Explain your reasoning for the above sketch:

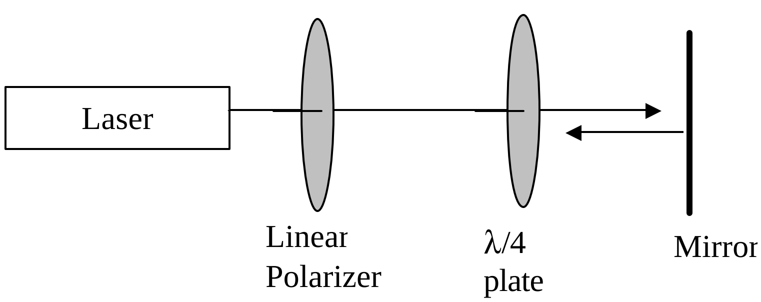
Rotate the linear polarizer by iterations of 15° until you rotate 360°. Complete the table and then using Excel plot your results (make sure that zero power is on the graph). Compare to your predictions. Resolve any differences.

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

How is the light elliptically polarized? Draw a sketch that shows the eccentricity and the tilt angle of the elliptical polarization.

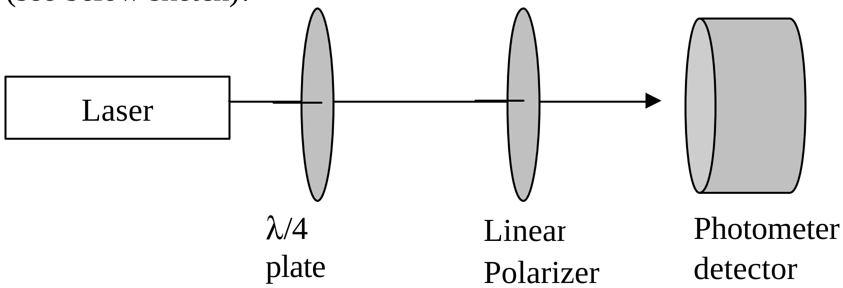


Set up the equipment as shown below.

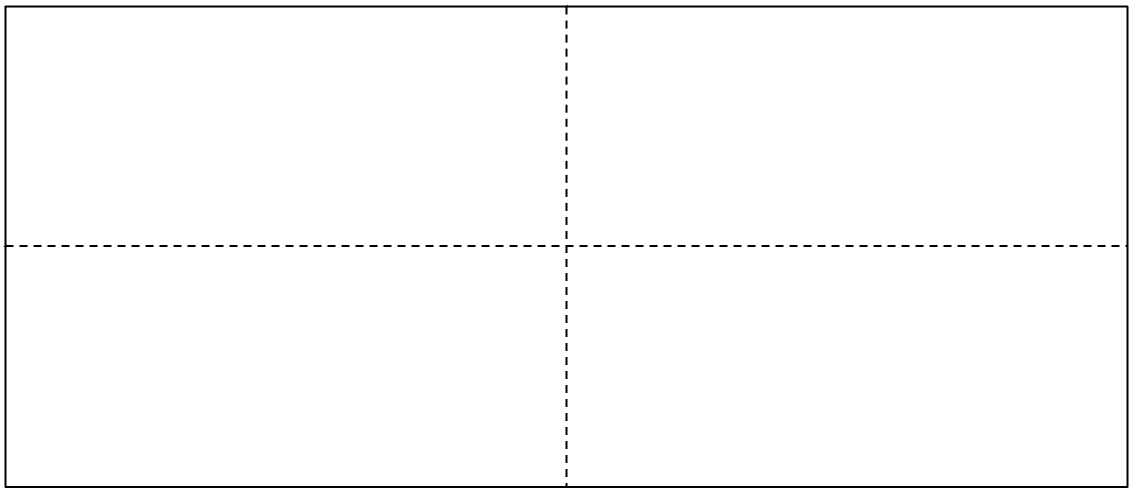


First turn the linear polarizer to 90° (where it should allow the most light to pass through). Reflect the laser light back towards the laser so that you can see the returning laser spot just to the side of the emission hole. Next, rotate the $\lambda/4$ – plate to minimize the returning light power. What is the angle of the $\lambda/4$ – plate?

Keeping the λ/4 – plate at its previous angle, move the linear polarizer behind the λ/4 – plate (see below sketch).



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

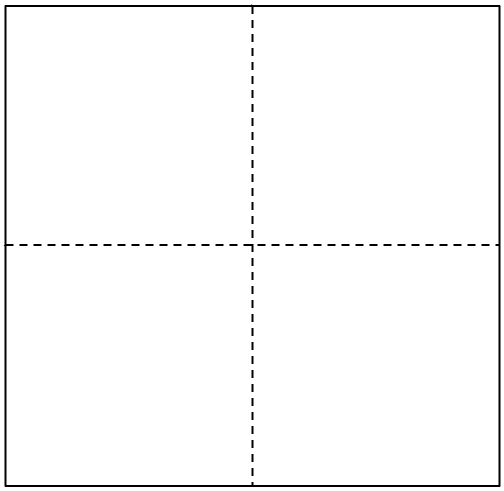


Explain your reasoning for the above sketch:

Rotate the linear polarizer by iterations of 15° until you rotate 360°. Complete the table and then using Excel plot your results (make sure that zero power is on the graph). Compare to your predictions. Resolve any differences.

θ = 0°		θ = 120°		θ = 240°	
θ = 15°		θ = 135°		θ = 255°	
θ = 30°		θ = 150°		θ = 270°	
θ = 45°		θ = 165°		θ = 285°	
θ = 60°		θ = 180°		θ = 300°	
θ = 75°		θ = 195°		θ = 315°	
θ = 90°		θ = 210°		θ = 330°	
θ = 105°		θ = 225°		θ = 345°	

How is the light elliptically polarized? Draw a sketch that shows the eccentricity and the tilt angle of the elliptical polarization.

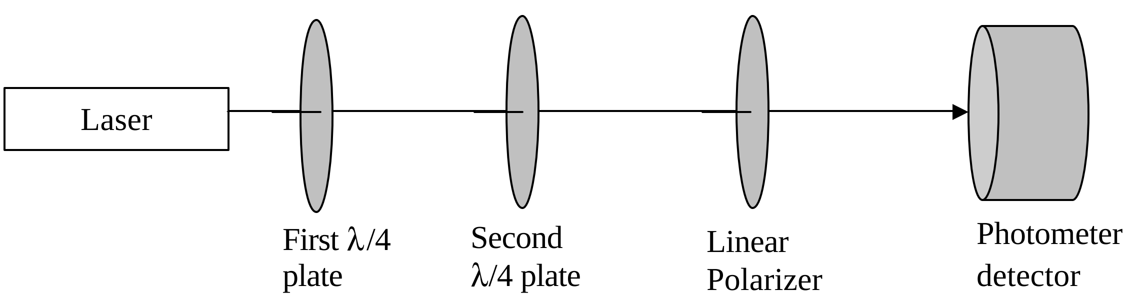


Recall question 2 on the pre-lab. From what you observed, how does a λ/4 – plate differ from the material described in question 2 of the pre-Lab?

For what reason is a λ/4 – plate called a quarter wave plate?

How do you think a λ/4 – plate effects the electric and magnetic fields associated with the light passing through the λ/4 – plate? How does the data from this investigation support your answer?

Connect a second λ/4 – plate to a plate rotator. Set up the equipment as shown below.



First turn the linear polarizer to its previous zero location (where it minimized the light from the laser). Next, rotate the first λ/4 – plate to its previous zero location. Now rotate the second λ/4 – plate to minimize the light power reaching the photometer. We will call this 0° for the second λ/4 – plate and we will keep this definition throughout the rest of the investigation. Add a small piece of masking tape to the second λ/4 – plate's rotator so that you can distinguish your two λ/4 – plates.

Now rotate the first λ/4 – plate to 45°. Rotate the linear polarizer and the second λ/4 – plate to minimize the light power reaching the photometer. Keep rotating these two devices until you nearly extinguish the laser light reaching the photometer. What is the best description of the polarization (linear, elliptical, circular) between the first and second λ/4 – plates? How do you know?

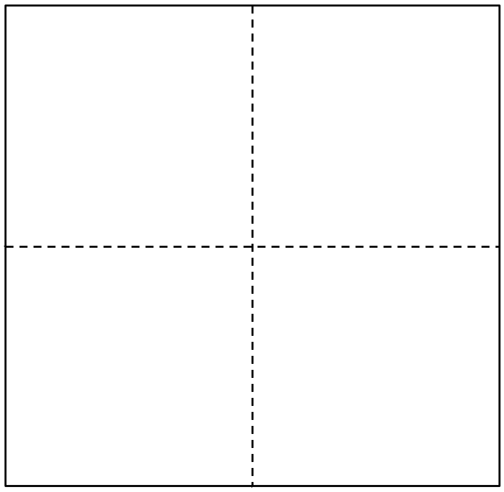
Predict how the light power reaching the photometer will change as a function of the linear polarizer's angle. That is, make a plot of the transmitted laser beam power vs. the linear polarizer's angle.

Explain your reasoning for the above sketch:

Rotate the linear polarizer by iterations of 15° until you rotate 360°. Complete the table and then using Excel plot your results (make sure that zero power is on the graph). Compare to your predictions. Resolve any differences.

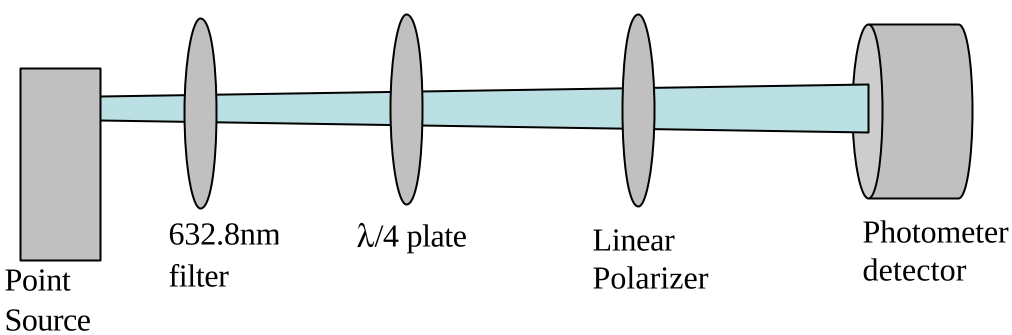
θ = 0°		θ = 120°		θ = 240°	
θ = 15°		θ = 135°		θ = 255°	
θ = 30°		θ = 150°		θ = 270°	
θ = 45°		θ = 165°		θ = 285°	
θ = 60°		θ = 180°		θ = 300°	
θ = 75°		θ = 195°		θ = 315°	
θ = 90°		θ = 210°		θ = 330°	
θ = 105°		θ = 225°		θ = 345°	

How is the light elliptically polarized? Draw a sketch that shows the eccentricity and the tilt angle of the elliptical polarization.



Quarter wave plates are useful in transforming one form on elliptical polarization into another. Quarter wave plates can transform linear polarization into elliptical polarization and elliptical polarization into linear polarization. If one had perfectly circular polarized light ($e = 0$), one would find that a linear polarizer always cuts the intensity in half no matter its angle. This is the same relation one would have for unpolarized light. Is there a difference between unpolarized light and circularly polarized light?

Using a point source (which is unpolarized) and the 632.8nm light filter (held with either a plate rotator or lens mount) construct the below set up. Since the beam is spreading out, try to keep all the components as close together as possible.



Try to minimize the light reaching the photometer by rotating the λ/4 – plate and the linear polarizer. Keeping rotating the λ/4 – plate and the linear polarizer until you are sure you cannot make the beam and dimmer.

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

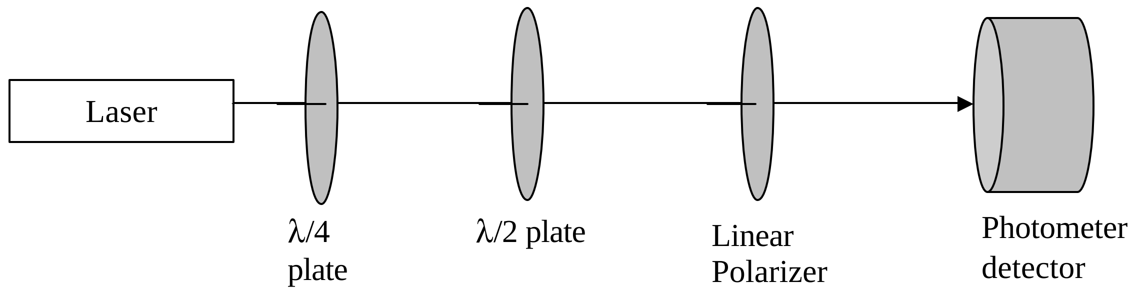
Explain your reasoning for the above sketch:

Rotate the linear polarizer by iterations of 15° until you rotate 360°. Complete the table and then using Excel plot your results (make sure that zero power is on the graph). Compare to your predictions. Resolve any differences.

θ = 0°		θ = 120°		θ = 240°	
θ = 15°		θ = 135°		θ = 255°	
θ = 30°		θ = 150°		θ = 270°	
θ = 45°		θ = 165°		θ = 285°	
θ = 60°		θ = 180°		θ = 300°	
θ = 75°		θ = 195°		θ = 315°	
θ = 90°		θ = 210°		θ = 330°	
θ = 105°		θ = 225°		θ = 345°	

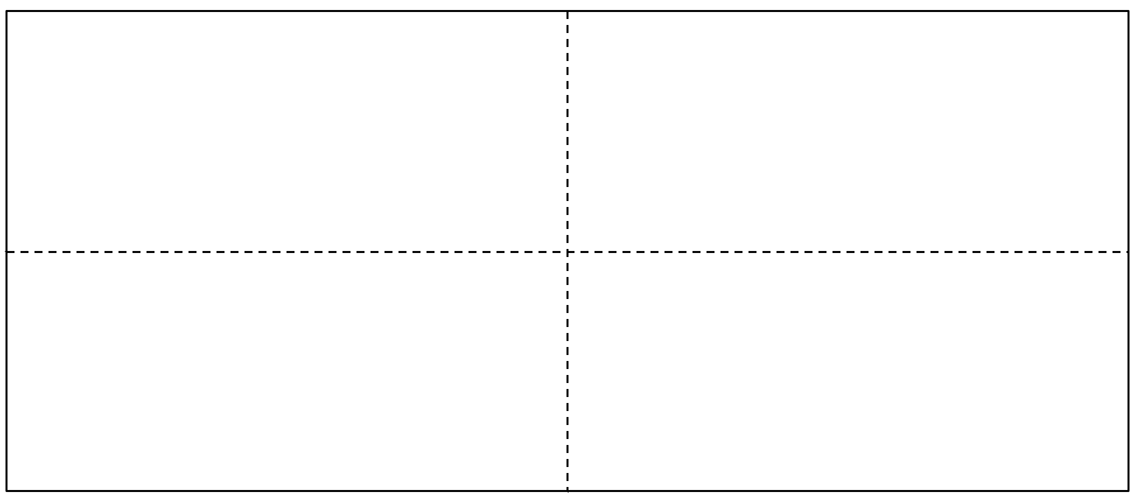
Is the light coming through the first 632.8nm filter polarized (as opposed to unpolarized)? Explain your reasoning.

Set up the equipment as shown below.



First turn the linear polarizer to its previous zero location (where it minimized the light from the laser). Next, rotate the first λ/4 – plate to 22°. Finally, rotate the λ/2 – plate to 0°.

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



Explain your reasoning for the above sketch:

Rotate the linear polarizer by iterations of 15° until you rotate 360°. Complete the table and then using Excel plot your results (make sure that zero power is on the graph). Compare to your predictions. Resolve any differences.

θ = 0°		θ = 120°		θ = 240°	
θ = 15°		θ = 135°		θ = 255°	
θ = 30°		θ = 150°		θ = 270°	
θ = 45°		θ = 165°		θ = 285°	
θ = 60°		θ = 180°		θ = 300°	
θ = 75°		θ = 195°		θ = 315°	
θ = 90°		θ = 210°		θ = 330°	
θ = 105°		θ = 225°		θ = 345°	

How is the light elliptically polarized? Draw a sketch that shows the eccentricity and the tilt angle of the elliptical polarization.

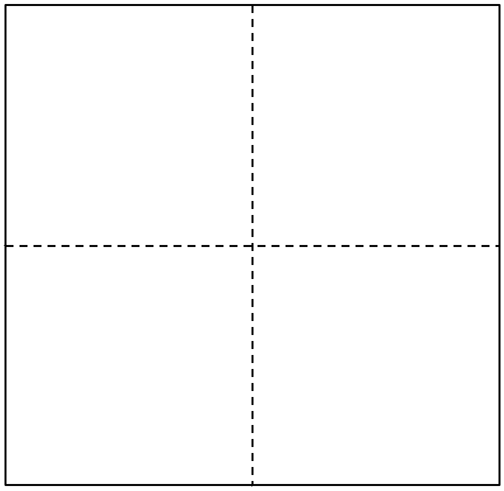
Now rotate the $\lambda/2$ – plate to 45°. Predict how the light power reaching the photometer will change as a function of the linear polarizer's angle. That is, make a plot of the transmitted laser beam power vs. the linear polarizer's angle.

Explain your reasoning for the above sketch:

Rotate the linear polarizer by iterations of 15° until you rotate 360°. Complete the table and then using Excel plot your results (make sure that zero power is on the graph). Compare to your predictions. Resolve any differences.

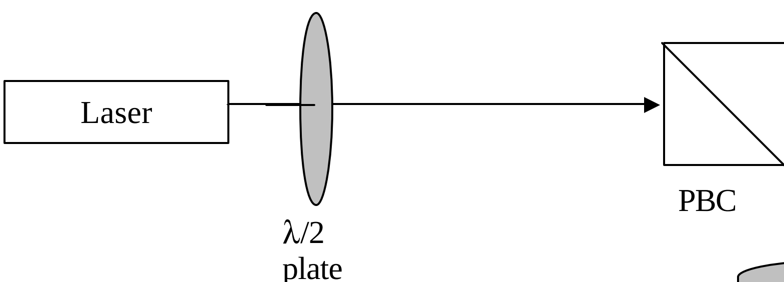
θ = 0°		θ = 120°		θ = 240°	
θ = 15°		θ = 135°		θ = 255°	
θ = 30°		θ = 150°		θ = 270°	
θ = 45°		θ = 165°		θ = 285°	
θ = 60°		θ = 180°		θ = 300°	
θ = 75°		θ = 195°		θ = 315°	
θ = 90°		θ = 210°		θ = 330°	
θ = 105°		θ = 225°		θ = 345°	

How is the light elliptically polarized? Draw a sketch that shows the eccentricity and the tilt angle of the elliptical polarization.

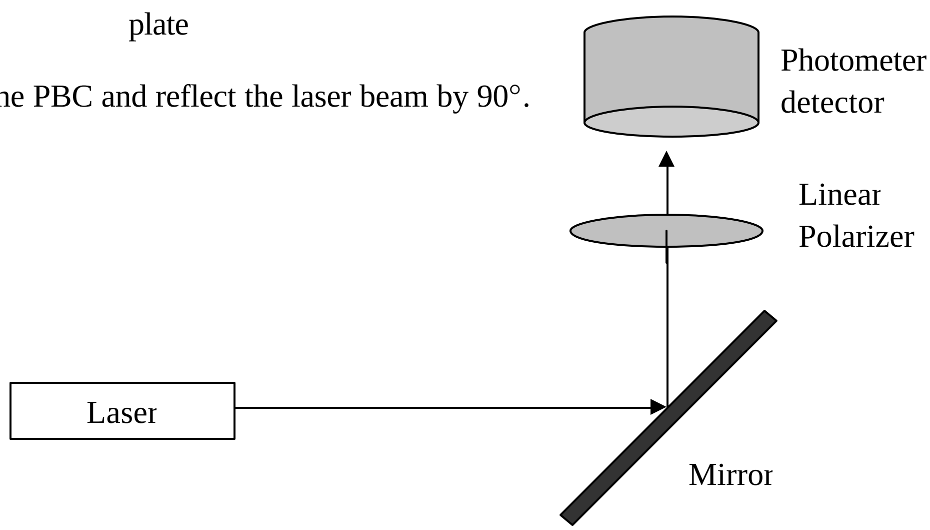


In general, what does a λ/2 – plate do to polarized light?

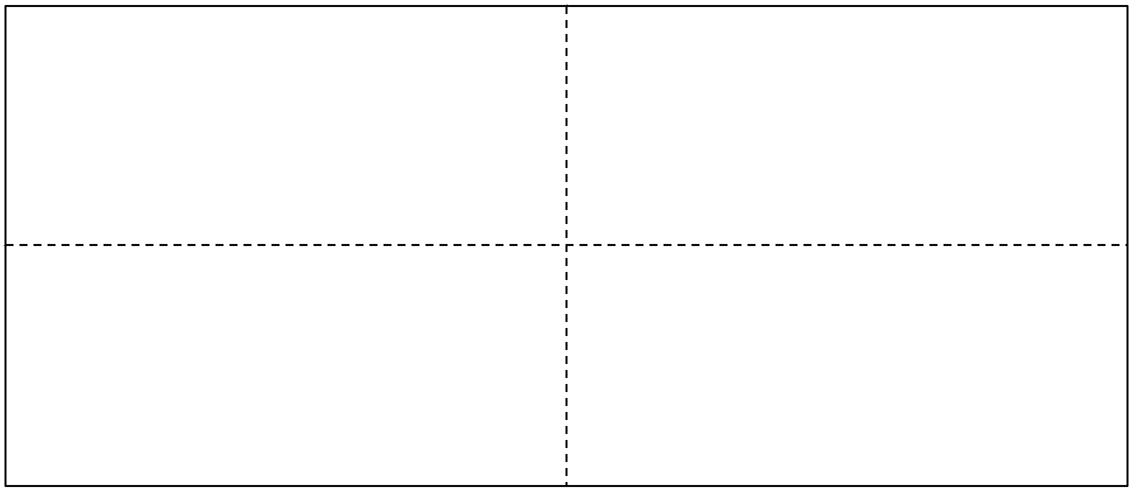
Adjust a λ/2 – plate so that half of the light is transmitted and half the light is reflected by a PBC.



Next, remove the PBC and reflect the laser beam by 90°.



Predict the shape of a plot of the transmitted laser beam power vs. the linear polarizer's rotation angle.

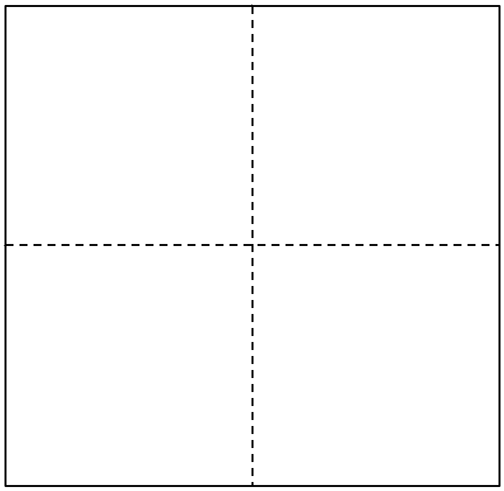


Explain your reasoning for the above sketch:

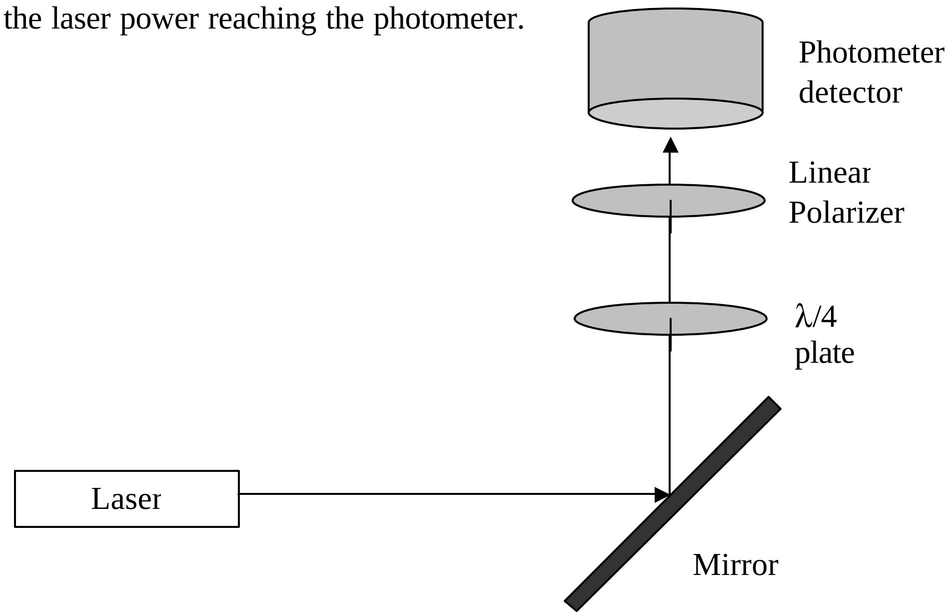
Now set up the above condition and test your predictions. Complete the table and then using Excel plot your results (make sure that zero power is on the graph). Compare to your predictions. Resolve any differences.

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

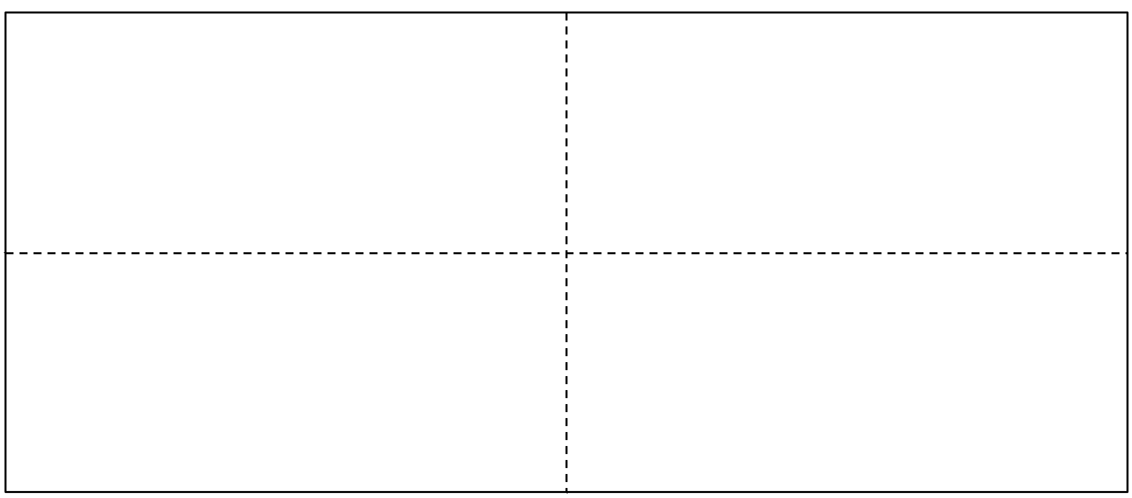
How is the light elliptically polarized? Draw a sketch that shows the eccentricity and the tilt angle of the elliptical polarization.



Next, add a $\lambda/4$ plate as shown below. Repeatedly rotate the linear polarizer and $\lambda/4$ plate to minimize the laser power reaching the photometer.



Predict the shape of a plot of the transmitted laser beam power vs. the linear polarizer's rotation angle.



Explain your reasoning for the above sketch:

Now set up the above condition and test your predictions. Complete the table and then using Excel plot your results (make sure that zero power is on the graph). Compare to your predictions. Resolve any differences.

θ = 0°		θ = 120°		θ = 240°	
θ = 15°		θ = 135°		θ = 255°	
θ = 30°		θ = 150°		θ = 270°	
θ = 45°		θ = 165°		θ = 285°	
θ = 60°		θ = 180°		θ = 300°	
θ = 75°		θ = 195°		θ = 315°	
θ = 90°		θ = 210°		θ = 330°	
θ = 105°		θ = 225°		θ = 345°	

How is the light elliptically polarized? Draw a sketch that shows the eccentricity and the tilt angle of the elliptical polarization.

Is the light reflected off a mirror polarized? How can you tell?