INTRODUCTION

In the lab today you are going to experiment with some of the “other” polarizations. First the matrix representations are summarized.

JONES VECTORS & MATRICES

I have included the summary tables for various polarizations and devices from the text book Pedrotti[3]. First, the “pure” states of polarization are linear and circular polarizations.

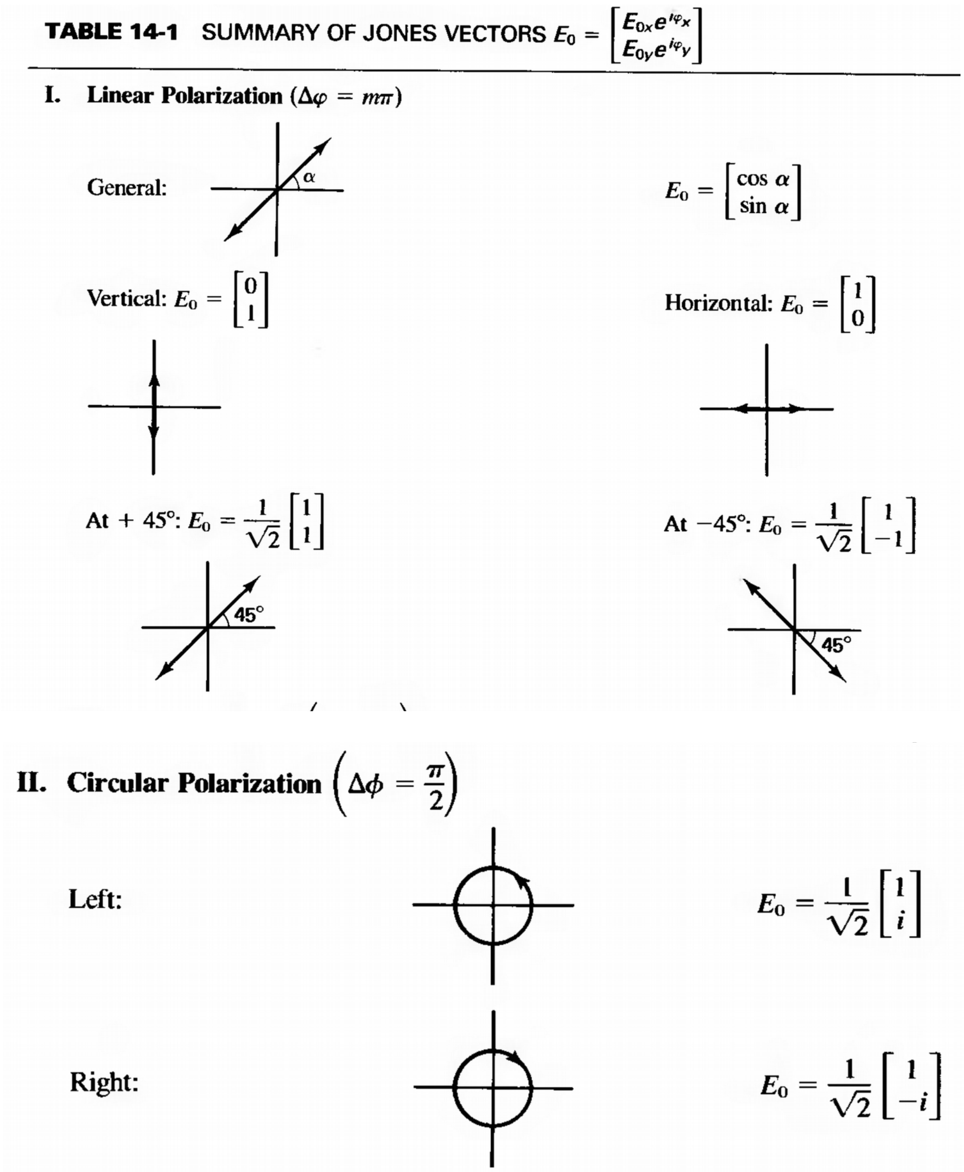

TABLE 14-1 SUMMARY OF JONES VECTORS $E_0 = \begin{bmatrix} E_{0x}e^{i\varphi_x} \\ E_{0y}e^{i\varphi_y} \end{bmatrix}$

I. Linear Polarization ($\Delta\varphi = m\pi$)

General: $E_0 = \begin{bmatrix} \cos\alpha \\ \sin\alpha \end{bmatrix}$

Vertical: $E_0 = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

Horizontal: $E_0 = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$

At + 45°: $E_0 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ 1 \end{bmatrix}$

At −45°: $E_0 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ -1 \end{bmatrix}$

II. Circular Polarization $\left(\Delta\phi = \frac{\pi}{2}\right)$

Left: $E_0 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ i \end{bmatrix}$

Right: $E_0 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ -i \end{bmatrix}$

Then any device that changes the state of polarization can be represented by a 2x2 complex matrix. (See the next page.) Finally to calculate the effect of devices on a polarization state, multiply the polarization vector by the device matrices *from the left*. So if horizontally polarized light passes through a 45^0 polarizer, then a vertical polarizer, the result is

$$\begin{bmatrix}0 & 0\\0 & 1\end{bmatrix}\frac{1}{2}\begin{bmatrix}1 & 1\\1 & 1\end{bmatrix}\begin{bmatrix}1\\0\end{bmatrix}=\begin{bmatrix}0 & 0\\0 & 1\end{bmatrix}\frac{1}{2}\begin{bmatrix}1\\1\end{bmatrix}=\frac{1}{2}\begin{bmatrix}0\\1\end{bmatrix}$$, and the final intensity is ¼.

TABLE 14-2 SUMMARY OF JONES MATRICES

I. Linear polarizers					
TA horizontal	$\begin{bmatrix}1 & 0\\0 & 0\end{bmatrix}$	TA vertical	$\begin{bmatrix}0 & 0\\0 & 1\end{bmatrix}$	TA at 45° to horizontal	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & 1\end{bmatrix}$
II. Phase retarders					
		General	$\begin{bmatrix}e^{i\epsilon_x} & 0\\0 & e^{i\epsilon_y}\end{bmatrix}$		
QWP, SA vertical	$e^{-i\pi/4}\begin{bmatrix}1 & 0\\0 & i\end{bmatrix}$	QWP, SA horizontal	$e^{i\pi/4}\begin{bmatrix}1 & 0\\0 & -i\end{bmatrix}$		
HWP, SA vertical	$e^{-i\pi/2}\begin{bmatrix}1 & 0\\0 & -1\end{bmatrix}$	HWP, SA horizontal	$e^{i\pi/2}\begin{bmatrix}1 & 0\\0 & -1\end{bmatrix}$		
III. Rotator					
Rotator	$(\theta \to \theta + \beta)$	$\begin{bmatrix}\cos\beta & -\sin\beta\\ \sin\beta & \cos\beta\end{bmatrix}$			

1) CIRCULAR POLARIZERS

A circular polarizer only allows light of one pure circular polarization through. For example, no matter what polarization of light goes in, only right circular polarized light comes out.

A circular polarizer can be made by putting a *quarter-wave plate* at 45^0 after a linear polarizer. Light incident on the linear polarizer side comes out circularly polarized, but light incident on the quarter-wave plate side come out linearly polarized. Explain why.

Take the right circular polarizer, marked *RCP*, and figure out which side is the *entrance* side, that is, has the linear polarizer. Hint: *If you look at partially polarized light through the RCP, like a shallow reflection off of a table and rotate the RCP, the reflection will get very dim if the linear polarizer side is facing the reflection*. Make a note of which side (numbered or not numbered) is the entrance side of the RCP.

Mount the RCP in your laser beam in a rotation mount. Predict what the intensity of the transmitted beam will be if you rotate the RCP.

Rotate it by hand and watch the intensity on the screen. Reconcile any difference between your prediction and what you see.

The Left-Circular Polarizer (*LCP*)

Repeat the exercise above using the LCP.

Prediction:

Observation & Reconciliation:

Testing for Circular Polarization

Leave the LCP in your laser beam and predict what will happen if you put a linear polarizer after the LCP and rotate the linear polarizer.

Do the experiment and reconcile what you predicted with what you see.

The Circular Polarizers as Analyzers

If light enters the wave plate side of a RCP, the right circular polarized light gets converted to linear polarization at the angle of the linear polarizer and therefore exits at full intensity, but linearly polarized. However left circularly polarized light get linearly polarized at 90^0 to the linear polarized and so it gets blocked. So *only light of the correct circular polarization gets through*. The RCP can act as an analyzer for circular polarization.

Predict what will happen if a RCP (or LCP) is placed backwards in a linearly polarized laser beam.

Do the experiment and reconcile what you predicted with what you see.

Try the above experiment with the LCP and comment on what you see.

RCP + LCP

There are three ways you can put the RCP & LCP together, face to face, back to back, and face to back. Look through each combination of RCP & LCP and rotate one relative to the other. Record what you see and explain.

1) Back to back (numbers of both facing outward):

2) Front to front (numbers of both facing inward):

3) Front to Back (numbers of one facing in, the other numbers out):

2) A QUARTER-WAVE PLATE

A *quarter-wave plate* (QWP) is *birefringent*, that is the index of refraction for light polarized along one direction is different than for light polarized along an axis at right angles to that axis. These axes are called *fast*- and *slow*- axes because light travels slower or faster depending on its polarization. If light is linearly polarized along one of these two axes, it will exit with the same polarization that it entered. However, if the light is polarized at an angle to these axes, the portion of the light along the slow axis will be delayed or *retarded*. If the amount of delay is ¼th of a wavelength, the light will exit with circular polarization. In between, the light will exit with *elliptical* polarization.

Look at the QWP (labeled *L/4*.) Be very careful with it because it is just a thin plastic film mounted on a rotation mount. Note there is a black dot near 90^0. This dot marks an axis of the QWP. If this axis is either parallel to the polarization of your laser beam or at 90^0 to it, your laser beam should remain purely linearly polarized. You can test this.

1) Place a linear polarizer in the laser beam before the white screen. Rotate it until the beam is extinguished. This should be near 0^0. Record the angle on the mount.

   Angle 90^0 to the beam:

2) Place the QWP on a rotation mount before the linear polarizer. As you rotate it, there should be four angles at which the beam on the screen extinguishes. The beam is extinguished when the light keeps it polarization when passing through the QWP which happens when either the fast or slow axis is along the beam polarization. Record the angles.

   Angles of QWP axes:

3) Now, when the QWP is halfway between these angles, the light should be purely circularly polarized. This means if you rotate the *linear* polarizer, the intensity of the beam on the screen should not change. Test each of these four angle for the QWP.

Angle 1 = _____. Result:	Angle 3 = _____. Result:
Angle 2 = _____. Result:	Angle 4 = _____. Result:

Right- or Left-Circularly Polarized?

Rotate the axis of the QWP marked by the black dot 45^0 clockwise from the laser beam's polarization when looking back along the beam. Use the RCP and LCP to test if this beam is right- or left- circularly polarized. Describe in detail how you reached your conclusion.

3) QUARTER-WAVE PLATE IN A CIRCULARLY POLARIZED BEAM

What do you think the result will be if a quarter-wave plate is placed in a circularly polarized beam? Reason through an answer and write your predictions below:

Set up a circularly polarized beam and place the QWP in the beam. Use a linear polarizer and the other circular polarizer to analyze the beam. Record your observations below. Reconcile your predictions with your observations.

Observations:

Reconciliation:

Rotate the QWP in a Circularly-Polarized Beam

Analyze the beam for several different angles of the QWP to the horizontal.

0^0:

22.5^0:

45^0:

90^0:

Conclusions

How would you summarize the total effect of a circular polarizer followed by a QWP?

What practical use might this device be?

The *half-wave plate* is like a quarter-wave plate, but retards the polarization by ½ of a wavelength. It acts like the device you just constructed but without the linear polarizers. What purpose could a half-wave plate serve?

TASK 1 – REFLECTED CIRCULAR POLARIZATIONS

Describe what you think will happen to a circularly polarized beam when it is reflected from a mirror.

Put the appropriate devices in your laser beam to make a right-circularly polarized beam. Set up a mirror to reflect it more than 90^0. Test the polarization of the reflected beam. Reconcile your observations with your predictions. Show the results to your instructor.

Instructor's initials:

TASK 2 – REFLECTED LINEARLY POLARIZED LIGHT

Describe what will happen if light polarized at 45^0 to the horizontal is reflected horizontally back toward the source.

Put the appropriate devices in your laser beam to make a beam polarized at 45^0. Reconcile your observations with your predictions. Show the results to your instructor.

Instructor's Initials: