Lab 2 Polarized Light

EECS 4614 Electro-Optics

Fall 2025

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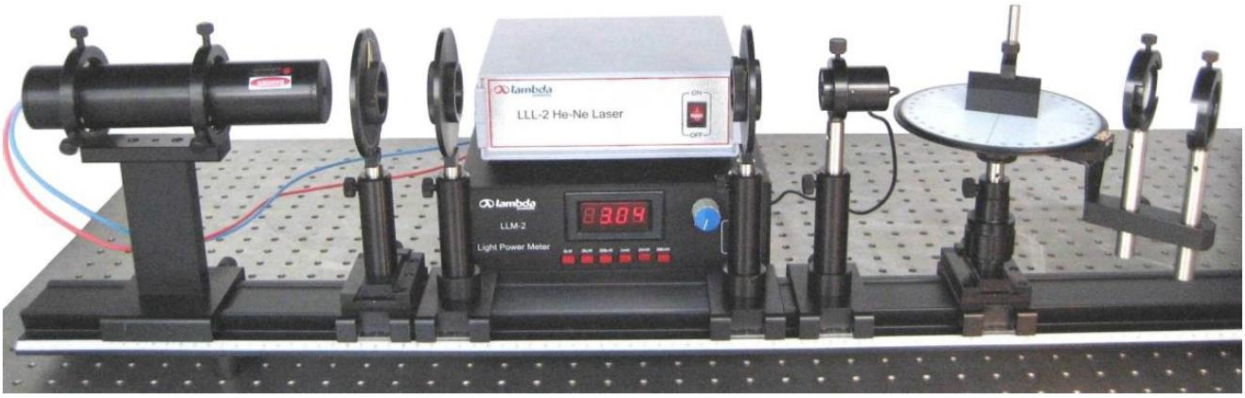

1 Safety

Warning: the He-Ne laser in this lab is a **class IIIa laser**. Avoid direct eye exposure to the laser beam!

Follow the laser safety guidelines discussed by the lab technician and the laser safety training you have completed. If you are unsure about anything, ask your TA.

2 Introduction

A light wave is a type of electromagnetic waves with both electric- and magnetic-field vectors perpendicular to the direction of wave propagation. The polarization property of a light wave describes the direction of oscillation in electric field or the direction of the electric-field vector. This system is designed and developed to help students understand the concept and mechanism of optical polarization. It allows students to measure different types of polarization and the parameters of optical elements that affect polarization.

Acknowledgement: This lab handout is based on the equipment instruction manual provided by Lambda Scientific.

3 Evaluation

Log onto eClass and open the assessment for this lab. You will need to show that you can reproduce **all** processes described in the manual and collect/analyze data as directed. This part of the assessment is for the group. Other parts of the assessment will be answering questions about the experiments. These questions are to be answered individually.

4 Equipment

4.1 Laser specification

Wavelength	632.8 nm
Output Power	~1.5 mW
Polarization	Linearly polarized
Power Stability	Roughly 5% ~ 10%
Working Voltage	1200 V
Divergence Angle	<1.3 mrad

4.2 List of parts

Optical Rail (1 m) *1 piece*		**He-Ne Laser** 1.5mW@632.8nm *1 piece*	
LEPO-54-2/DGL-1-01 Carrier Z-adjustable *3 pieces*		**LEPO-54-3/DGL-1-02** Carrier Y,Z –adjustable *1 piece*	
LEPO-54-3/DGL-1-03 Carrier X,Y,Z-adjustable *1 piece*		**LEPO-44** Laser Tube Holder *1 piece*	
LEPO-9/SZ-08 Lens Holder *2 pieces*		**LEPO-52/SZ-51** Polarizer Holder *3 pieces*	
LEPO-13/SZ-12 Plate Holder *1 piece*		**LEPO-10/SZ-09** Extension Adapter *1 piece*	
LEPO-49/SZ-47 Optical Goniometer *1 piece*		**Alignment Aperture** *1 piece*	
λ/4 Wave Plate @632.8nm *1 piece*		**λ/2 Wave Plate** @632.8nm *1 piece*	
Mounted Polarizer *2 pieces*		**Beam Expander** *f* = 4.5 mm *1 piece*	
Collimating Lens *f* = 150 mm *1 piece*		**Black Glass** *1 piece*	
Photocurrent amplifier with detector head *1 piece*			

5 Polarization Theory

Apart from interference and diffraction, polarization is an important property of light. Without special equipment, human eyes cannot identify the polarization of a light wave as a transverse wave. We define the direction of polarization by the direction of the electric field vector E. Light from common sources such as light bulbs is unpolarized, meaning that the plane of vibration of the electric field vector changes rapidly in a completely random fashion.

However, when light interacts with matter, the plane of vibration of the electric field vector may become fixed in a particular direction (linear polarization) or the plane of vibration may rotate or otherwise vary in a uniform manner (circular or elliptical polarization).

Polarized light can be described by the two orthogonal components of its electric field, Ey and Ez,

$$E_y = E_{oy}\cos(\omega t - kx)$$
$$E_z = E_{oz}\cos(\omega t - kx - \delta) \qquad (1)$$

Where E_{oy} and E_{oz} are the amplitudes of the electric field along y and z axes, respectively; and δ is the phase delay between these components. The value of the phase delay determines the type of the polarization of a light wave as

$\delta = 0$, linear

$\delta \neq 0$, elliptical

$\delta = \delta(t)$ random, unpolarized

$\delta = \pi/2$, $E_{oy} = E_{oz}$, circular

$\delta = \pi/2$, $E_{oy} \neq E_{oz}$, elliptical, major/minor axes aligned along y and z axes.

A polarizer is a special device that selectively passes only the component of the electric field parallel to the optical axis of the polarizer. When unpolarized light passes through a polarizer, it becomes linearly polarized parallel to the direction of the optical axis of the polarizer.

6 Brewster's Angle – for reference only, you completed this in part 1 of the lab

When unpolarized light travels from a transparent medium with a refractive index n_1 to another one with a higher refraction index n_2, part of the light is refracted into the second medium while the other part of the light is reflected back into the first medium. If the angles of incidence and refraction are θ_1 and θ_2, respectively, then the following condition exists, known as Snell's law

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \tag{2}$$

According to Sir David Brewster, at a specific angle of incidence, θ_b, called Brewster's angle, the reflected ray and the refracted ray are perpendicular to each other, so the sum of the incident angle and the refractive angle is 90° as

$$\theta_b + \theta_2 = 90°, \text{ namely } \theta_2 = 90° - \theta_b \tag{3}$$

By substituting equation (3) into equation (2), we get

$$n_1 \sin\theta_b = n_2 \sin(90° - \theta_b) = n_2 \cos\theta_b$$

$$\tan\theta_b = \frac{n_2}{n_1} \tag{4}$$

Equation (4) is known as Brewster's Law. When the incident beam is travelling in air, $n_1 = 1.00$, equation (4) becomes $\tan\theta_b = n_2$. The Brewster's angle of a material is sometimes referred to as the polarizing angle of the material.

Using Brewster's Law, one can determine the refractive index of a black glass. This can be achieved by substituting the value of the Brewster's angle into Eq. (4) to obtain n_2.

Figure 1 Experimental setup for measurement of Brewster's angle

Experimental Procedure:

1. Mount the laser tube onto the laser holder and connect the power supply.

2. Turn the laser on and slide the alignment aperture along the rail. Mount a polarizer onto the polarizer holder, place it onto a carrier next to the laser. Rotate the polarizer to set its axis along horizontal direction so that the transmitted laser beam is horizontally polarized. Since the laser is

linearly polarized, you can rotate it around its axis so that the laser light transmitted through the polarized is maximized. Hint: to more accurately set the polarization, set the polarizer to vertical orientation first, look for minimum light transmission by rotating the laser axis, then rotate the polarizer by 90 degrees. **Note:** do not rotate the laser tube anymore after this step.

3. Place the alignment aperture onto a carrier and slide it back and forth along the rail while altering the laser height and tilt by adjusting the six screws of the laser holder to allow the laser beam to pass through the aperture along the rail.

4. Remove the alignment aperture from the rail, insert the goniometer into the post holder on carrier and secure the carrier on the other end of the optical rail. Unpack the black glass and secure it on the center of the dial using the clamping arm. Make sure one edge of the glass just overlaps the 90º axis of the dial as shown in Figure 2. Secure the black glass.

Figure 2 Black glass mounted on goniometer

Note: Handle the black glass with care. Keep the two reflective surfaces from fingerprints and dirt.

5. Insert the detector on the hole next to the dial of the goniometer and connect the detector to the amplifier. Insert the alignment aperture in the holder in front of the detector. Set the amplifier to the 20 μW range and zero the reading when the laser is off. Make sure the detector area faces the point where two axes of the dial intersect.

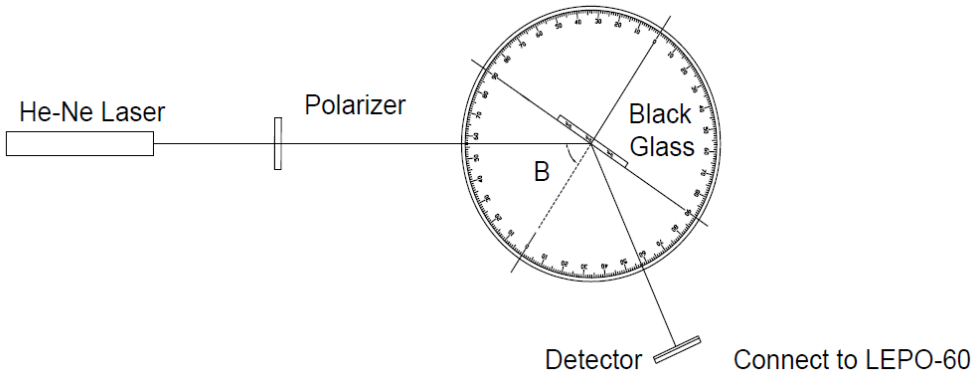

Figure 3 Schematic of experimental configuration

6. Set the angle of incidence to 56º ~57º by rotating the platform and rotate the arm to allow the reflected laser beam to hit the center of the active area of the detector through the alignment aperture. Read the light intensity on the digital display of the photocurrent amplifier.

7. Carefully repeat step 6 to fine-tune the detector arm and rotating platform positions to achieve the minimum possible readout at the detector. Record the angle on the dial. This is the Brewster's angle. **Calculate the refractive index of the black glass.**

7 Malus's Law – for reference only, you completed this in part 1 of the lab

Malus's law defines the transmitted intensity of light through two polarizers with an angle of θ between the transmission directions of the polarizers, as

$$I = I_{\max} \cos^2 \theta \tag{5}$$

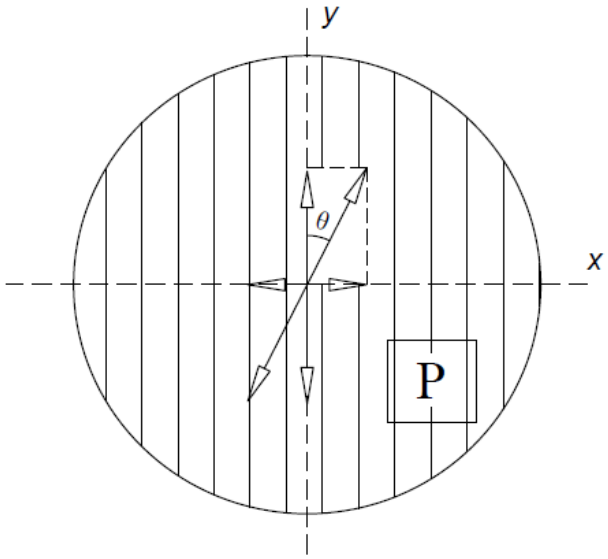

Figure 4 Schematic of Malus's Law

The maximum and minimum transmission occurs when θ = 0º and θ = 90º, respectively.

Figure 5 Experimental setup for verification of Malus's Law

Experimental Procedure:

1. If necessary, repeat steps 1 to 3 in the previous experiment.

2. Place another polarizer after the first polarizer on the rail, and align the polarization axis of the second polarizer parallel to that of the first polarizer.

3. Secure the optical detector on the carrier and connect the detector to the photocurrent amplifier. Turn on the amplifier. Make sure the laser beam hits the central active area of the detector head.

4. Record the relative intensity of the polarized laser.

5. Rotate the second polarizer by 10º while recording the transmitted intensity of the laser.

6. Repeat Step 5 and collect intensity readings for polarizer orientations between 0º and 360 º in steps of 10º in the same direction.

7. **Draw a curve of intensity versus relative angle.** Report the observations on Malus' Law.

8 Half-Wave Plate

When a light beam passes through a birefractive crystal, it is divided into two polarized light beams, one is called the ordinary light *O* because it obeys the 'Law of Refraction'; the other beam is called the extraordinary light *E*, as it does not obey the 'Law of Refraction'. Because *O* light travels in a birefractive crystal with a thickness d at a different speed from *E* light, there will be a phase difference between the two light beams as

$$\delta = \frac{2\pi}{\lambda}(n_0 - n_e)d \tag{6}$$

where λ is the wavelength of light, n_o is the refractive index of *O* light, and n_e is the refractive index of *E* light. A retardation plate whose thickness makes δ=(2k+1)π, k=0, ±1, ±2…is called a half-wave plate while a retardation plate whose thickness makes δ=(2k+1)π/2, k=0, ±1, ±2… is called a quarter-wave plate.

Figure 7 Experimental setup with half-wave plate

Experimental Procedure:

1. If necessary, repeat steps 1 to 3 in the previous experiments.

2. Place another polarizer about 25 cm away from the first polarizer on the rail, and align the polarization axis of the second polarizer parallel to that of the first polarizer.

3. Hold a piece of blank paper next to the second polarizer. A light spot should be observed on the paper. Rotate the second polarizer till the light spot disappears.

4. Assemble the half-wave plate onto a polarizer holder with carrier, and place it between the two polarizers.

5. Rotate the half-wave plate through 360º to observe the brightness change of the light spot on a piece of white paper placed after the second polarizer.

6. Rotate the half-wave plate till the light spot on the paper disappears. Then, rotate the half-wave plate by 15º and rotate the second polarizer until the light spot disappears again. Record the angular change of polarization axis of the polarizer.

7. Repeat Step 6 in step of 15º while recording the corresponding angle of the second polarizer.

9 Quarter-Wave Plate: Circularly and Elliptically Polarized Light

The steps of this experiment are the same as in the previous experiments. The only change you need to make is to replace the half-wave plate with a quarter-wave plate.

You will find that depending on the angle of rotation between the polarized light and the quarter-wave plate, the polarization of the light can be unmodified, circularly polarized or elliptically polarized. Circularly polarized light means that the E vector constantly rotates around the axis of propagation with the same amplitude at every angle. Elliptically polarized light also rotates but with different amplitudes at different angles.

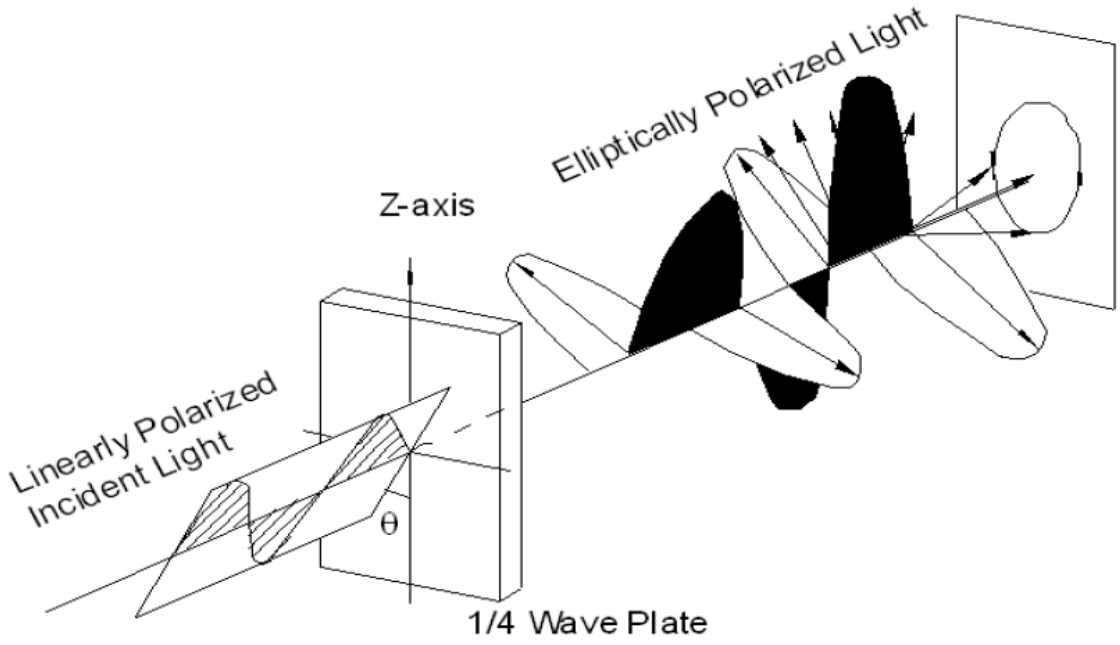

Figure 9 Principle of quarter-wave plate