1A - MALUS' LAW

OBJECTIVES

- To determine the plane of polarization of linearly polarized laser light.
- To measure the intensity of light passing through a polarization filter as a function of the filter's angular position.
- To verify the validity of Malus's Law.

EQUIPMENTS

- He-Ne Laser (1mW, 220 V AC)
- Polarization Filter
- Photocell
- Digital Multimeter

GENERAL INFORMATION

What are the Electromagnetic Theory of Light, Polarization, Polarizer, Analyzer, Brewster's Law, and Malus's Law?

Polarization of light refers to the process by which the oscillations of the electric field vector within an electromagnetic (EM) wave become restricted to a single plane. The plane of polarization is determined by the direction of propagation and the orientation of the electric-field oscillations. Different types of polarization, such as linear, circular, and elliptical, exhibit distinct characteristics and behaviors

1. **Linearly or plane-polarized light**: The oscillations are confined to one plane, and the electric field vector traces a straight line (Figure 1).
2. **Circularly polarized light**: The electric field vector traces a circle.
3. **Elliptically polarized light**: The electric field vector traces an ellipse. This is the most general form of polarized light.

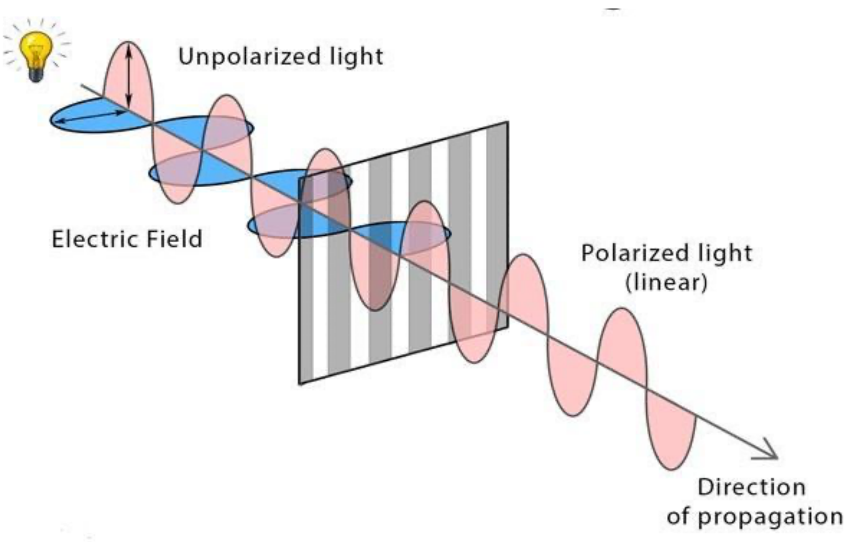

Figure 1: Linearly Polarized Light

All light possesses polarization. Light, commonly termed "unpolarized," lacks organized polarization, instead exhibiting randomized polarization. Randomly polarized light is a type of light in which the electric field vector oscillates in random directions perpendicular to the direction of the light's propagation. Linearly polarized light occurs when the electric field vector oscillates in a single plane perpendicular to the direction of the light's propagation. The direction of polarization is typically denoted as either vertical or horizontal but can be at any angle relative to the viewer. Light can be linearly polarized with a polarizer that selectively transmits light waves in a desired polarization direction while blocking others. Various methods can be employed to generate polarized light, including reflection, refraction, scattering, and absorption.

A polarizer is an optical filter that lets light waves of a specific polarization pass through while blocking light waves of other polarizations. An analyzer is also a polarizer that acts on already polarized light. Let the angle between the analyzer and the polarization angle be θ and the amplitude of the incident waves be E_0.

$$E_0{}' = E_0 cos\theta \qquad (1)$$

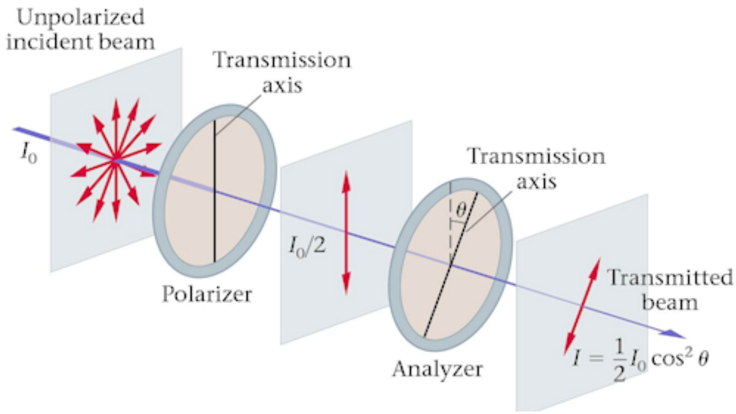

Figure 2: Polarizer-Analyzer System

The intensity of light after it has been through the analyzers proportional to the square of the cosine of the angle θ as described by Malus' Law:

$$I' = I\,cos^2\theta \qquad (2)$$

When the two polarizers are positioned perpendicular to each other, no light is observed.

In Figure 3, the photocell current is shown as a function of the angular position of the analyzer's polarization plane after background correction. The intensity peak corresponds to the angular rotation of the emitted laser beam's polarization plane.

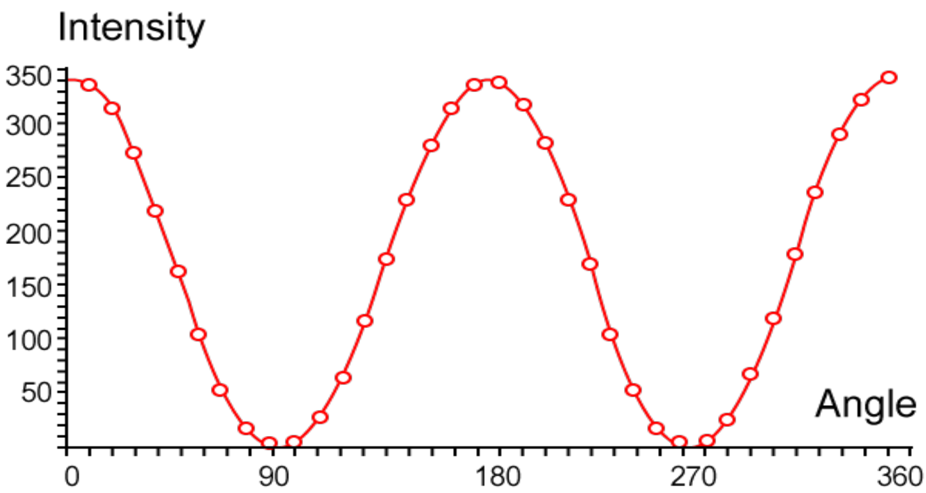

Figure 3: Change in intensity as a function of the analyzer angle

Figure 4 shows the normalized and corrected photocell current as a function of the analyzer's angular position. Malus's Law is verified by the slope of the initial linear section of the graph. (Note: The angular determination of the analyzer for Malus's Law should be done to identify the Malus line in Figure 4).

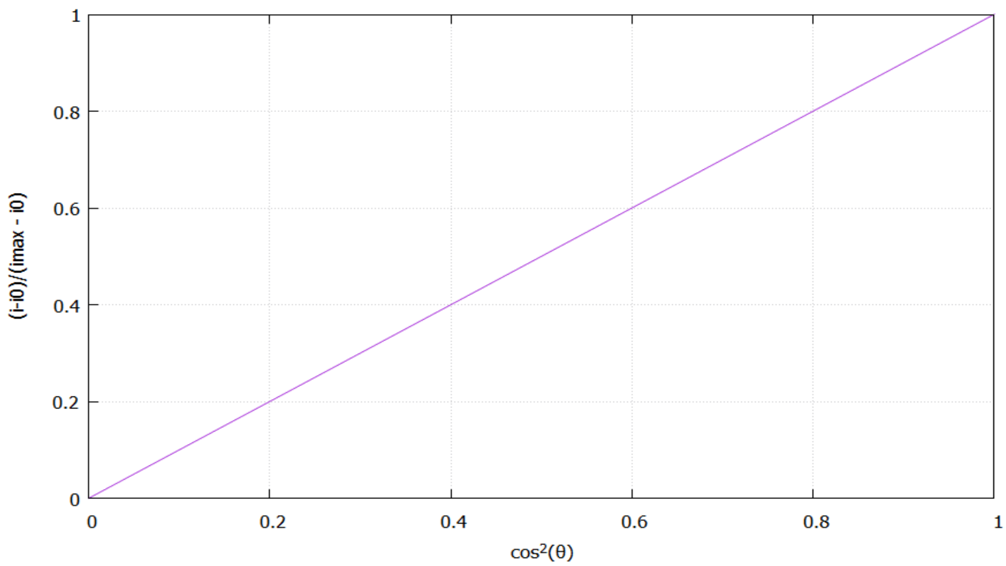

Figure 4: Normalized Photocell Current as a Function of the Analyzer's Angle

EXPERIMENT PROCEDURE

The experiment is set up as shown in Figure 5. Ensure that the polarization filter is correctly positioned so that the photocell is fully illuminated.

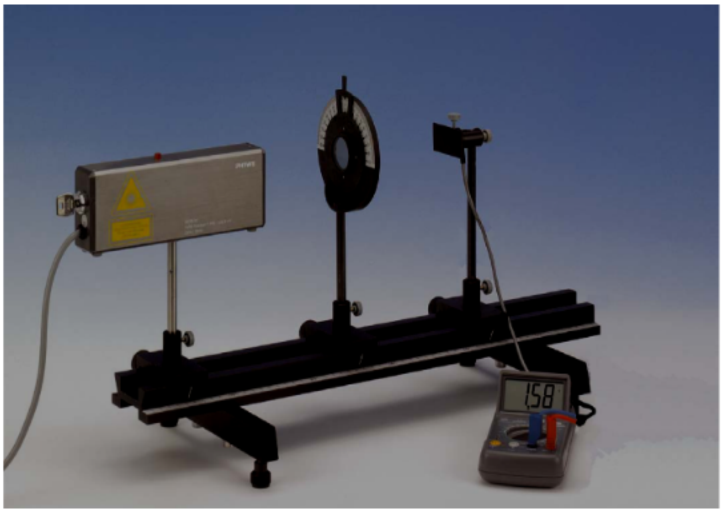

Figure 5: Experimental Setup

If the experiment is conducted in a non-dark environment, background interference current should be measured with the laser off and accounted for during the experiment. Allow the laser to warm up for approximately 30 minutes.

The polarization filter should be rotated at intervals between the positive and negative filter positions, and the corresponding photocell current should be measured using a highly sensitive DC scale on the digital multimeter.

Linearly polarized light passes through a polarization filter. The intensity of the transmitted light is measured as a function of the filter's angular position.

1B - NEWTON's RINGS

OBJECTIVES

- To analyze the interference phenomenon

EQUIPMENTS

- **Newton Ring System**
- **Na Lamp as a Light Source**
- **Viewfinder**
- **A Small Piece of Glass**

GENERAL INFORMATION

The events that confirm the hypothesis that light is an electromagnetic wave are interference and diffraction. Although the interference and diffraction of light appear to be separate events, both are actually similar. Both are special cases of the superposition of waves. Superposition is the ability of two or more waves to exist in the same region of space without affecting each other.

Various setups are viable to observe the phenomenon of interference. In the setup known as Newton's Rings, a plane-convex lens with a large radius of curvature is placed on a flat, parallel glass surface. When the setup is illuminated, the interference pattern appears as concentric rings. The center of these rings is the point where the lens touches the flat parallel surface below it and is dark.

Let the lenses' radius of curvature R, the radius of one of the Newton Rings r and the thickness of the air between the parallel planar glass and the lens be d(r).

$$d = R - R\left[1 - \left(\frac{r}{R}\right)^2\right]^{\frac{1}{2}} \qquad (1)$$

Because $\left(\frac{r}{R}\right) \ll 1$, if the expression is expanded as a series:

$$d = R - R\left[1 - \left(\frac{r}{R}\right)^2 \ \ldots\right] \simeq R - R + \frac{R}{2}\frac{r^2}{R^2} = \frac{r}{2R}^2 \qquad (2)$$

is acquired. Therefore, the optical path difference between the two light rays is:

$$2nd = \left(m + \frac{1}{2}\right)\lambda \quad \text{(max)} \qquad m = 0,1,2,3\ldots$$

$$2nd = m\lambda \qquad \text{(min)} \qquad m = 0,1,2,3\ldots$$

If the refractive index of air is taken as $n = 1$;

$$2d = \left(m + \frac{1}{2}\right)\lambda \qquad \text{(max)} \qquad m = 0,1,2,3\ldots$$

$$2d = m\lambda \qquad \text{(min)} \qquad m = 0,1,2,3\ldots$$

is acquired. If $d = \frac{m\lambda}{2}$ (2) condition is applied

$$\frac{m\lambda}{2} = \frac{r^2}{2R} \Rightarrow r^2 = m\lambda R \qquad (3)$$

is found. The radius of some rings are measured, and a graph is plotted such that r^2 is the y-axis and order is the x-axis. The slope of this graph gives us $R\lambda$, from that;

a. Since the wavelength of used light is known, the lenses' radius of curvature is calculated.
b. If the radius of the lens is known, λ is calculated.

EXPERIMENT PROCEDURE

1. By looking through the viewfinder, the center of the lens is aligned with the crosshair of the viewfinder's eyepiece, i.e., brought to the center of the reticle.
2. The glass plate and sodium lamp are positioned so that the field of view is well illuminated when looking through the viewfinder. The experimental setup is readjusted to make the interference (Newton) rings, formed in the thin air layer between the plane-parallel glass and the plane-convex lens, clearly visible.
3. By looking through the viewfinder, the edge of any m^{th} dark ring is aligned with the center of the reticle. Remembering that the order of the dark ring at the center is $m = 0$, m is determined by counting the dark rings. The radius of the corresponding Newton ring is read from the viewfinder's scale as r_m.
4. The reticle is then aligned with the edge of another dark ring m', and is recorded. The corresponding r_m is read.
5. The same measurements are repeated for different m and m' values. Each measurement is repeated three times, and the average value is taken. By assuming the wavelength of the light used is $\lambda = 5890$ A° and using expression (3), the radius of curvature, R, of the lens is calculated. Then;

$$R_{avg} = \frac{R_1+R_2+R_3+R_4}{4} = \qquad \text{meters}$$

is calculated.

M	r_m	R
1		
2		
3		
4		

From here, the radius of curvature of the lens is found by finding the slope of the previously drawn graph.

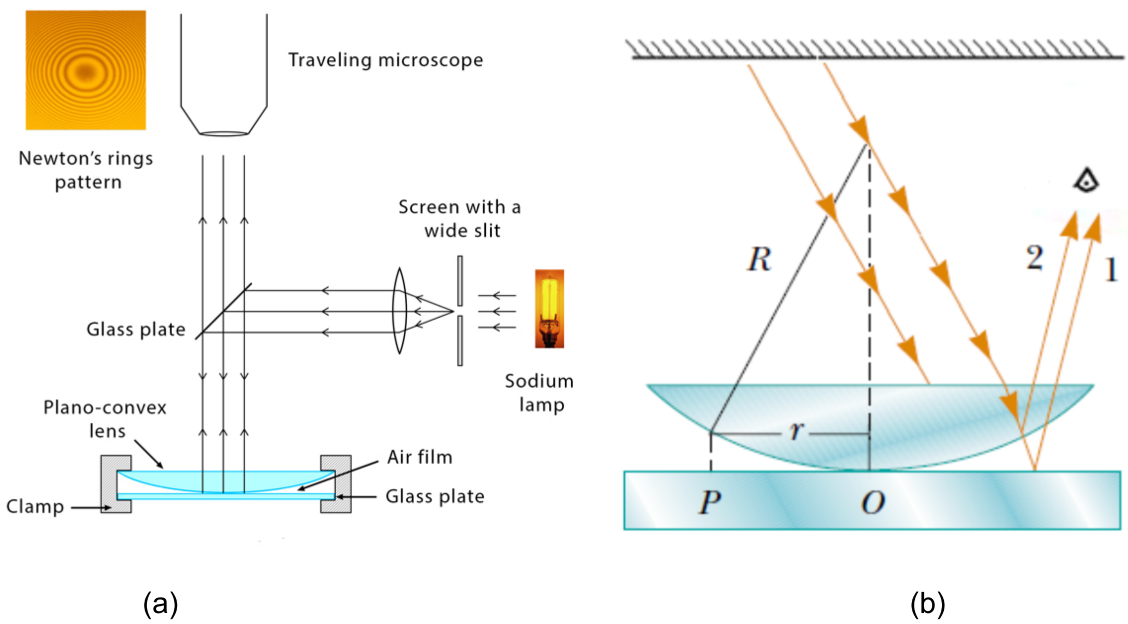

Figure 1: (a) Newton's Rings experiment setup (b) Close-up of the lens and planar glass