Verify Malus’ Law of Polarization

EQUIPMENT NEEDED

– Basic Optics Bench (part of OS-8515)  
– Basic Optics Light Source (part of OS-8515)  
– Aperture Bracket (OS-8534)  
– Light Sensor (CI-6504A)  
– Rotary Motion Sensor (CI-6538)

Introduction

The purpose of this laboratory activity is to determine the relationship between the intensity of the transmitted light through two polarizers and the angle, Ø, of the axes of the two polarizers.

Theory

A polarizer only allows light which is vibrating in a particular plane to pass through it. This plane forms the “axis” of polarization. Unpolarized light vibrates in all planes perpendicular to the direction of propagation. If unpolarized light is incident upon an “ideal” polarizer, only half will be transmitted through the polarizer. Since in reality no polarizer is “ideal”, less than half the light will be transmitted.

The transmitted light is polarized in one plane. If this polarized light is incident upon a second polarizer, the axis of which is oriented such that it is perpendicular to the plane of polarization of the incident light, no light will be transmitted through the second polarizer.

However, if the second polarizer is oriented at an angle so that it is not perpendicular to the first polarizer, there will be some component of the electric field of the polarized light that lies in the same direction as the axis of the second polarizer, thus some light will be transmitted through the second polarizer (see the bottom figure).

The component, \( E \), of the polarized electric field, \( E_o \), is found by:

\[
E = E_o \cos \phi
\]

Since the intensity of the light varies as the square of the electric field, the light intensity transmitted through the second filter is given by:

\[
I = I_o \cos^2 \phi
\]

where \( I_o \) is the intensity of the light passing through the first filter and Ø is the angle between the polarization axes of the two filters.

![Figure 1.1: Polarization](image-url)
Consider the two extreme cases illustrated by this equation:

- If $\Theta$ is zero, the second polarizer is aligned with the first polarizer, and the value of $\cos^2 \Theta$ is one. Thus the intensity transmitted by the second filter is equal to the light intensity that passes through the first filter. This case will allow maximum intensity to pass through.
- If $\Theta$ is 90º, the second polarizer is oriented perpendicular to the plane of polarization of the first filter, and the $\cos^2(90º)$ gives zero. Thus no light is transmitted through the second filter. This case will allow minimum intensity to pass through.
- These results assume that the only absorption of light is due to polarizer effects. In fact most polarizing films are not clear and thus there is also some absorption of light due to the coloring of the Polaroid filters.

Procedure

In this activity, the Light Sensor measures the relative intensity of light that passes through two polarizers. You will change the angle of the second polarizer relative to the first. The Rotary Motion Sensor measures the angle. The ScienceWorkshop program records and displays the light intensity and the angle between the axes of the polarizers. You can use the program’s built-in calculator to compare the relative intensity to the angle, the cosine of the angle, and the cosine of the angle.

Equipment Setup

1. Mount the Basic Optics Light Source, Polarizer Holder, Polarizer Analyzer with Rotary Motion Sensor, and Aperture Bracket Holder with Light Sensor as shown. (Refer to the Introduction for more information.)

2. Connect the ScienceWorkshop interface to the computer, turn on the interface. Start Science Workshop.

3. Connect the Light Sensor cable to Analog Channel A. Connect the Rotary Motion Sensor cable to Digital Channels 1 and 2.
Experiment Setup

Select the Sensors and Set the Sample Rate

- Refer to the User’s Guide for your version of ScienceWorkshop for detailed information on selecting sensors and changing the sample rate.

1. In the Experiment Setup window, select the Rotary Motion Sensor and connect it to Digital Channels 1 and 2.
2. Set up the Rotary Motion Sensor for high resolution (for example, 1440 Divisions per Rotation). Select Large Pulley (Groove) for the linear calibration.
3. In the Experiment Setup window, select the Light Sensor and connect it to Analog Channel A.
4. Set the sample rate to 20 Hz, or 20 measurements per second.

Select the Display

- Refer to the User’s Guide for your version of ScienceWorkshop for detailed information on selecting and changing displays.

1. Select a Graph display.
2. Set the axes of the Graph display so light intensity is on the vertical axis and angular position is on the horizontal axis.

Prepare to Record Data

- Refer to the User’s Guide for your version of ScienceWorkshop for detailed information on monitoring and recording data.

1. Turn both Polarizers so they are at the same beginning angle (e.g., zero degrees).
2. Start monitoring data.
3. Rotate one Polarizer back and forth until the transmitted light intensity is maximum.
4. Stop monitoring data.

Record Data

1. Start recording data.
2. Slowly rotate the Polarizer on the Polarization Analyzer in the clockwise direction. Continue to rotate the Polarizer until you have made one complete rotation (360 degrees).
3. After one complete rotation, stop recording data.

Analyze the Data

- Refer to the User’s Guide for your version of ScienceWorkshop for detailed information on creating and displaying calculations and using ScienceWorkshop for data analysis.

1. Use the Experiment Calculator in the ScienceWorkshop program to create a calculation of the cosine of the angle between the Polarizers.
2. Repeat the procedure to create a calculation of the cosine^2 of the angle of the Polarizers.
3. Use the Graph display to examine the plot of light intensity versus angle.
4. Change the Graph display to show the plot of light intensity versus the cosine of the angle, and then change the Graph display to show the plot of light intensity versus the cosine^2 of the angle.
5. Use the ScienceWorkshop program to determine the relationship between the light intensity and the cosine$^2$ of the angle.

Questions

1. What is the shape of the plot of light intensity versus angle?

2. What is the shape of the plot of light intensity versus cosine of the angle?

3. What is the shape of the plot of light intensity versus cosine$^2$ of the angle?

4. Theoretically, what percentage of incident plane polarized light would be transmitted through three Polarizers which have their axes rotated 17 degrees (0.29 radians) from each other? Assume ideal polarizers and assume that the second polarizer’s axis is rotated 17 degrees (0.29 radians) from the first and that the third polarizer’s axis is rotated 17 degrees (0.29 radians) from the second.

5. From your data, determine the answer to Question #4 for the real polarizers.