  Graphical Analysis 28B

Polarization of Light   
with Rotary Motion Sensor

Perhaps you have seen a display of polarized sunglasses in a store. You can quickly test to see if the glasses are really polarized by looking through the lenses of two pairs of glasses and rotating one pair by 90° (π/2 radians). If both pairs of glasses are polarized, the lenses will appear to go black. Why is that?

To explain the darkened lenses, we need to think of the light as an electromagnetic wave. An electromagnetic wave has varying electric and magnetic fields perpendicular to the direction the wave is traveling. This experiment focuses only on the electric field variation, represented by a vector. Light emitted from a typical source such as a flashlight is randomly polarized, meaning that the electric field vector points in varying directions.

An ideal polarizing filter will remove all but the electric fields that are parallel to the axis of the filter. The light remaining is then said to be polarized. A second filter can be used to detect the polarization; in this case, the second filter is called an analyzer. The transmission through the second filter depends on the angle between its axis and the axis of the first filter. In this experiment you will study the relationship between the light transmitted through two polarizing filters and the angle between the filter axes.

In the 1800’s Malus proposed a law to predict light transmission through two polarizing filters. The relationship is



where I0 is the illumination when the angle θ between the polarizer axes is zero. In this experiment, you will see if this law is useful in describing your polarizing filters.

|  |
| --- |
| Figure 1 |

OBJECTIVES

* Observe the change in brightness of light passing through crossed polarizing filters.
* Measure the transmission of light through two polarizing filters as a function of the angle between their axes and compare it to Malus’s law.

MATERIALS

Chromebook, computer, or mobile device

Graphical Analysis 4 app

Go Direct Light and Color

Go Direct Rotary Motion

Optics Expansion Kit: light source assembly and light sensor holder

Polarizer/Analyzer Set

Vernier Dynamics Track

Preliminary questions

1. Place one Adjustable Analyzer from the Polarizer/Analyzer Set on top of a second Adjustable Analyzer so you can look through both of them. Place the pointer of the polarizer at 0° and rotate the pointer on the analyzer to 90°. What do you notice when the polarizer and analyzer are at right angles to one another?
2. Rotate the analyzer back to 0° and in alignment with the polarizer. Observe the transmitted light as you rotate the analyzer by 180°. Make a qualitative graph of the transmitted light brightness you observed as a function of the angle between the polarizer and analyzer.
3. Based on the graph you just drew, construct a mathematical model for the transmission of light through the polarizer and analyzer as a function of the angle between the polarizer and analyzer. The model should minimally reproduce the observed bright and dark angles and be different from Malus’s law.

Procedure

1. Set up the equipment.
   1. The location of the light source assembly can be read using the notched arrow on the base of the holder. Attach the light source assembly to the Dynamics Track at the 20 cm mark, directed along the track toward higher values. Set the disk to its open circle, to fully expose the LED. Connect power and turn on the LED. Caution: The LED is bright. Note: The brightness of the LED light source varies when it is first turned on. Make a note of the current time so that you can ensure 15 minutes have passed before you begin making the measurements.
   2. Set the pointer to 0° on one Adjustable Analyzer (the one without the Go Direct Rotary Motion Sensor attached) and place it immediately adjacent to the light source, oriented so that the scale is visible. In this experiment, this Adjustable Analyzer serves as the polarizer.
   3. Place a second Adjustable Analyzer (the one with the Go Direct Rotary Motion) further down the track. Orient it so the scale is visible. In this experiment, this Adjustable Analyzer serves as the analyzer. Light will pass through the polarizer and analyzer, with the amount of transmitted light depending on the relative angles of the polarizing sheets.
   4. Attach the sensor cradle to the light sensor bracket, and place the light sensor in the cradle, as shown in Figure 1. Position the light sensor assembly downstream of the analyzer.

If you are not in a dark room, minimize the distance between equipment. This reduces the amount of stray light entering the Light Sensor, ensuring the sensor is only measuring the light source.

* 1. Rotate the analyzer and make a visual observation of how the light transmission varies with angle, reaching two maxima per full rotation.

1. Set up Graphical Analysis.
   1. Click or tap View, , and select 1 Graph.
   2. Adjust the axes of the graph to display illuminance vs. time.
   3. Click or tap Mode and change End Collection to After 30 s duration. Click or tap Done.
2. Zero the sensors.
   1. With both the polarizer and analyzer at 0°, click or tap the Angle meter and select Zero.
   2. Keep the polarizer at 0° and rotate the analyzer to 90° (1.57 rad). In this state, the polarizing axes are at right angles. Very little light should get through the pair. Define the illuminance as zero by choosing Zero from the Sensors menu.
3. You are now ready to collect data.
   1. Return the analyzer to the parallel position, 0°, and start data collection.
   2. Slowly rotate the analyzer through one full rotation. Data will be collected for 30 seconds.
   3. Examine the graph. Does it show a full rotation of the analyzer? If not, re-collect the data.
4. Record the maximum illuminance in the data table.

Data Table

|  |  |
| --- | --- |
| Maximum illuminance |  |

Analysis

1. Describe your graph of illuminance vs. angle, giving important patterns and points.
2. In the 1800’s, Étienne-Louis Malus proposed



to predict the light transmission through two polarizing filters, where I0 is the illuminance when the angle θ between the polarizer axes is zero.

You can use the Curve Fit feature of Graphical Analysis to compare your experimental data with this model.

* 1. Click or tap Graph Tools, , and select Apply Curve Fit. Select Cosine Squared from the Curve Fit menu. Click or tap Apply.
  2. The Cosine Squared curve fit uses the equation y = a \* cos2(bx + c) + d. In this equation, x represents the angle θ between the polarizers, a represents the maximum illuminance I0, and d represents the background illuminance.

1. Compare your data to the fit parameters.
   1. For the fit parameter a, compare the value to the maximum illuminance that you recorded in your data table.
   2. Since you zeroed the light sensor before collecting data, the background light intensity should be zero. Compare the value of parameter d to zero.
2. According to the curve fit on your graph, are your data consistent with Malus’s law?
3. Now compare your data to the model you developed in Preliminary Question 3. Do this in any way you or your instructor chooses. Does your model match the data qualitatively?

Extensions

1. Polarized sunglasses selectively remove glare caused by light reflected by horizontal surfaces; e.g., the hood of a car or a wet highway. For polarized sunglasses to be effective, the glare must be polarized. Devise an experiment to measure how strongly polarized the glare is compared to sunlight or to a flashlight. You will need a smooth horizontal surface to create glare, a bright light source, a polarizing filter, and your light sensor. How is the axis of the polarizer oriented when the glare is minimized?
2. Set two Adjustable Analyzers so that the polarizing axes are at 90°. Insert a third Adjustable Analyzer between the first two and collect data of the transmitted intensity as a function of the angle of the middle filter. Explain the shape of the graph with a vector model.