

## Polarization of Light – ID: 9599

By Jacklyn Bonneau

Time required  
45 minutes

Topic: Light and Sound

- Describe the production and propagation of electromagnetic waves.
- Describe the formation and detection of linearly polarized light.

## Activity Overview

*In this activity, students use data collected during a lab to explore Malus's relationship for polarized light and light intensity. They will confirm that the relationship is nonlinear and determine the correct mathematical relationship.*

## Materials

*To complete this activity, each student will require the following:*

- TI-Nspire™ technology
- light source
- Vernier Light Sensor with EasyLink™ or Go!@Link interface
- two polarizing filters
- copy of the student worksheet
- pen or pencil

## TI-Nspire Applications

*Graphs & Geometry, Lists & Spreadsheet, Notes*

## Teacher Preparation

*Students may be familiar with polarized lenses because of experience with polarized sunglasses. However, they may not realize that two polarizing filters can be combined to block nearly all light.*

- *The polarizing filters used in this investigation must be able to be rotated relative to one another. Commercially mounted filters can be purchased from science supply companies. Alternatively, you can mount the filters on two pieces of stiff paper or cardboard. One piece of cardboard should be significantly larger than the other. Mark the large piece of cardboard with lines at 15° intervals, and mark a single reference line on the smaller piece of cardboard. Students can rotate the small piece of cardboard to align the reference mark with each of the lines on the larger piece.*
- *The screenshots on pages 2–5 demonstrate expected student results. Refer to the screenshots on page 6 for a preview of the student TI-Nspire document (.tns file). Pages 7–9 show the student worksheet.*
- ***To download the .tns file and student worksheet, go to [education.ti.com/exchange](http://education.ti.com/exchange) and enter “9599” in the search box.***

## Classroom Management

- *This activity is designed to be **student-centered**, with the teacher acting as a facilitator while students work cooperatively. The student worksheet guides students through the main ideas of the activity and provides questions to guide their exploration. Students should answer the questions on blank paper.*
- *The ideas contained in the following pages are intended to provide a framework as to how the activity will progress. Suggestions are also provided to help ensure that the objectives for this activity are met.*
- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

The following questions will guide student exploration in this activity:

- What is the relationship between how much light passes through two polarized lenses and the angle of rotation?
- How can we create mathematical models based on quantitative data for this relationship?

Students will first collect data on light intensity as a function of angle. They will use graph matching and model building to find the relationship between rotational angle in degrees and the amount of light transmitted through polarized filters.

### Part 1 – Observing features of data from polarization filters

**Step 1:** Students should open the file **PhyAct\_9599\_polarization.tns** and read the first two pages. They should connect a Vernier Light Sensor to an EasyLink or Go!Link interface. They should also align the two polarizing filters so that the mark on one filter is aligned with the  $0^\circ$  mark on the other filter. Note: You will need to tell students which setting on the Light Sensor to use (0-600, 0-6000, or 0-150,000). The 0-6000 setting is appropriate for most standard light bulbs. Unless the light source they are using is very dim and/or powered by a DC source, students should not use the 0-600 setting. This setting is sensitive enough that it will detect the fluctuations in intensity caused by alternating current.

**Step 2:** Next, students move to page 1.3. They insert a new data collection box and connect the sensor to their handheld or computer.



**Step 3:** Next, students zero the light sensor. Note: You may wish to dim the lights in the room during data collection.

**Step 4:** Next, students set up the data collection for **Events with Entry**.

**Step 5:** Students turn on the light source and hold the filters between the source and the Light Sensor. They wait for the intensity reading to stabilize, and then record a data point.

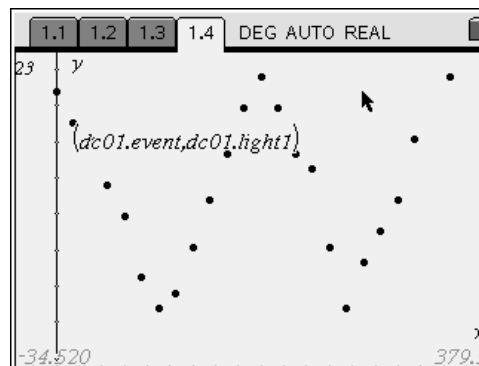
**Step 6:** Students rotate the filters 15° and collect another data point.

**Step 7:** Students repeat step 6 until they have rotated the filters through 360°. Note: Make sure students record the angle of the filters as the “event” when they record each data point. As students collect the data, it will be displayed on the *Lists & Spreadsheet* application on page 1.3. After students have collected the data, stopped the experiment, closed the data collection box, and disconnected the Light Sensor, they should examine the data and then answer question 1.

	A	B	C	D
1	0.	46.8594		
2	15.	42.5995		
3	30.	40.405		
4	45.	33.9505		
5	60.	29.6906		

- Q1.** What features do you notice about the data that may be important in determining the mathematical relationship between angle and intensity?
- A.** *Students' responses will vary. Among the more relevant features of the data are that neither intensity nor angle is ever negative, that intensity seems to have a periodic relationship to angle, and that the relationship appears to be nonlinear.*

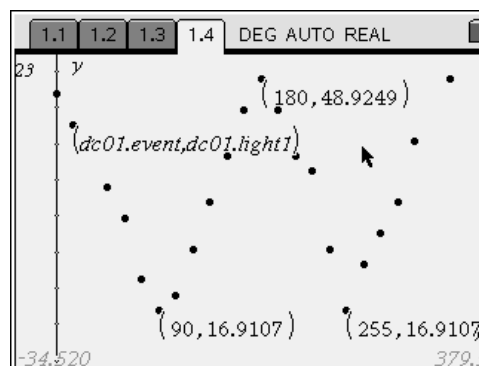
**Step 8:** Next, the students should move to page 1.4 and create a scatter plot of the data. They should use angle (dc01.event) for the x-values and intensity (dc01.light1) for the y-values. Students may need to resize the window (**Menu > Window > Zoom-Data**) to see their data clearly. They should then answer questions 2 and 3.



- Q2.** What mathematical function does this graph resemble?
- A.** *Sine and cosine are possible answers. Discuss the shape of the graph with students. Ask how they could determine what the relationship is. They should reason that attempting to find a best fit to the data using a sine or cosine function would allow them to determine the mathematical relationship between rotation and intensity. You may need to guide them to this conclusion.*
- Q3.** Explain why intensity is never negative.
- A.** *The polarization filters would have to block more light than what shined on the filters for intensity to be negative. In other words, the filters would have to be more than perfect absorbers of light, which is physically impossible.*

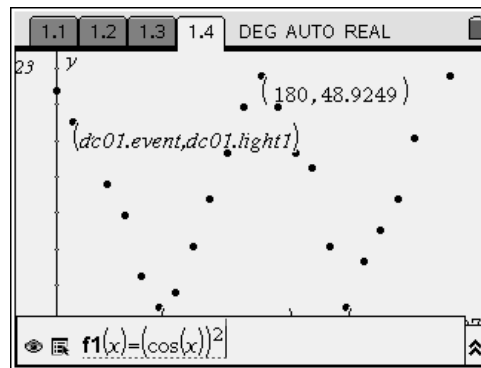
### Part 2 – Building a model for the relationship

**Step 1:** Next, students should use the **Graph Trace** tool (**Menu > Trace > Graph Trace**) to mark the values for the maximum and minimum data points. When the appropriate data point is selected, they should click once to label it with its values. They should then answer question 4.

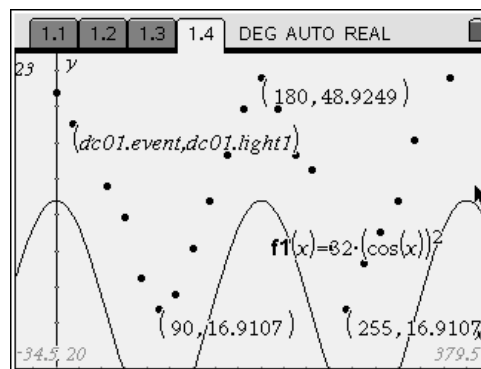


- Q4.** What is the amplitude of the data?
- A.** *Answers will vary. If students struggle with this question, remind them that the amplitude of the wave is the difference between the maximum and the minimum y-values, which they labeled in step 1. If you wish, you may encourage the students to record the maxima and minima on their answer sheets.*

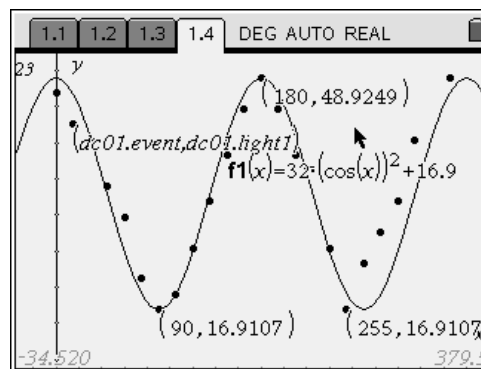
**Step 2:** Explain to students that the relationship between angle and intensity has the form  $y = (\cos x)^2$ . Students should change the graph type on page 1.4 to a **Function** graph and enter the function  $f1(x) = (\cos(x))^2$  in the function line. The function graph will be much larger than the screen.



**Step 3:** Students should now attempt to adjust the equation for **f1** that they entered so that the amplitude of the function **f1** is similar to the amplitude of the data they plotted. Guide students to realize that, to change the amplitude of the **f1** curve, they need to multiply the function  $(\cos x)^2$  by a constant and that that constant is equal to the amplitude of the data. Students should be able to figure out that they need to multiply the function by the amplitude to get the curve to resemble the collected data.



**Step 4:** Next, students should shift the function vertically to align with the data. Guide students to realize that adding the minimum value to the function will accomplish this. Finally, students should answer questions 5–8.

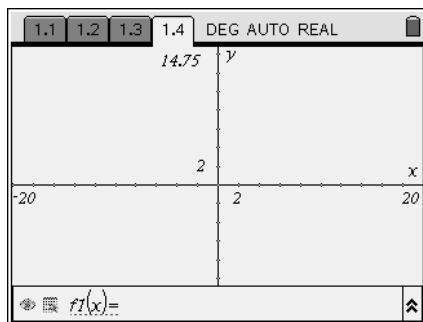


- Q5.** Explain why the graph of the data does not have zero as a minimum.
- A.** *The polarizing filters are not 100% effective.*
- Q6.** What value shifts the function **f1** vertically so that it aligns with the data?
- A.** *The vertical shift factor is equal to the y-value of one of the minima of the data.*
- Q7.** What is the equation that gives a good fit to the experimental data?
- A.** *Answers will vary. Students should be able to justify their best-fit equations.*
- Q8.** In general, what is the equation that describes the behavior of polarization filters?
- A.**  $intensity = ((maximum\ value) - (minimum\ value))(\cos(rotation))^2 + (minimum\ value)$

# Polarization of Light – ID: 9599

(Student)TI-Nspire File: *PhyAct\_9599\_polarization.tns*

The top section of the TI-Nspire interface consists of three panels. The left panel is titled "POLARIZATION OF LIGHT" and is categorized under "Physics" and "Light and Optics". The middle panel contains the following text: "In this activity, you will explore the relationship between the angle of rotation of two polarized filters and the amount of light that is transmitted through the filters." The right panel is a data table with columns labeled A, B, C, and D, and rows numbered 1 through 5. The table is currently empty.



Polarization of Light

ID: 9599

Name \_\_\_\_\_

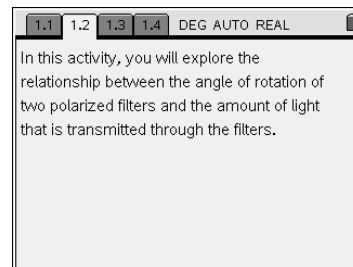
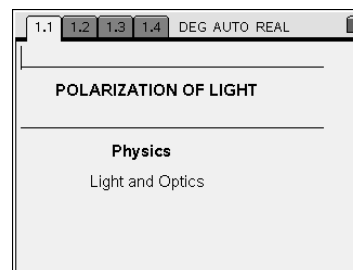
Class \_\_\_\_\_

In this activity, you will explore the following:

- the relationship between angle of rotation of two polarizing filters and the light transmitted through them
- how to make a mathematical model of a physical phenomenon

Open the file **PhyAct\_9599\_polarization.tns** on your handheld or computer and follow along with your teacher for the first two pages. Move to page 1.2 and wait for further instructions from your teacher.

Most light sources produce light waves that oscillate in all directions. A polarizing filter allows only light waves oscillating in a specific direction to pass through it. If a light wave passing through a filter is oscillating perpendicular to the direction allowed by the filter, the filter will not transmit any of the light. In this experiment, you will explore how polarizing filters can be used to control the amount of light that is transmitted.



**Part 1 – Observing features of data from polarization filters**

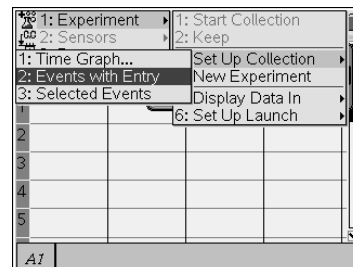
**Step 1:** Connect a Vernier Light Sensor to an EasyLink interface (if using a handheld) or a Go!Link interface (if using a computer). Your teacher will tell you which setting on the back of the Light Sensor to use (0-6000, 0-600, or 0-150,000). Line up the two filters so that the mark on one filter is aligned with the 0° mark on the other filter.

**Step 2:** Move to page 1.3, which contains an empty *Lists & Spreadsheet* application. Insert a new data collection box by pressing **ctrl** **D**. Connect the EasyLink or Go!Link interface to your handheld or computer. Data should appear in the data collection box.



**Step 3:** With the light source turned off, place the Light Sensor about 15 cm away from the light source. (You may need to hold it in place gently.) Wait for the light intensity reading to stabilize, and then zero the sensor (**Menu > Sensors > Zero**).

**Step 4:** For this experiment, you will need to collect data on intensity and angle. To set up the TI-Nspire to collect data in this way, select **Events with Entry** from the **Experiment** menu (**Menu > Experiment > Set Up Collection > Events with Entry**). Click the “play” button (▶) to begin the experiment.



**Step 5:** Turn on the light source. Hold the two filters halfway between the sensor and the light source. Wait until the intensity reading has stabilized, and then click the button in the lower right corner of the data collection box. A dialog box should appear. Enter 0 in the box, and then click OK.

**Step 6:** Rotate the filters so that the mark on one filter is lined up with the 15° mark on the other filter. Hold the filter between the light source and the sensor, at the same place you held it in Step 5. Wait until the intensity reading has stabilized, and then click the button in the lower right corner of the data collection box. A dialog box should appear. Enter 15 in the box, and then click OK.

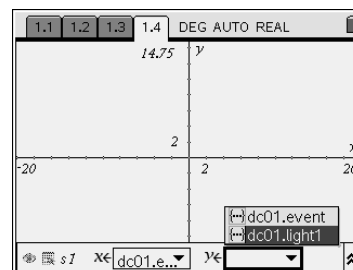
**Step 7:** Repeat step 6 22 more times, rotating the filters 15° each time. Note: Make sure you keep the Light Sensor in exactly the same orientation relative to the light source at all times. Do not raise, lower, or tilt the sensor, or your data will not be accurate. Also, make sure you hold the filters at the same place as you take each reading. When you have finished collecting the data, stop the data collection (click on the top left button in the data collection box) and close the data collection box. You can then disconnect the Light Sensor.

**Q1.** What features do you notice about the data that may be important in determining the mathematical relationship between angle and intensity?

**Step 8:** Page 1.4 contains a blank *Graphs & Geometry* application. Use this application to create a scatter plot of the data in the spreadsheet on page 1.3. Use angle as your x-values and intensity as your y-values.

**Q2.** What mathematical function does this graph resemble?

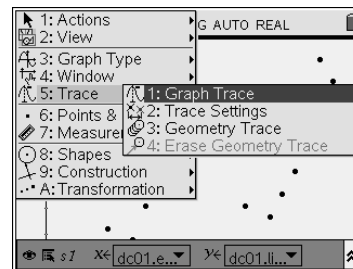
**Q3.** Explain why intensity is never negative.



**Part 2 – Building a model for the relationship**

**Step 1:** Use the **Graph Trace** tool (**Menu > Trace > Graph Trace**) to mark the maximum and minimum intensity values for the data.

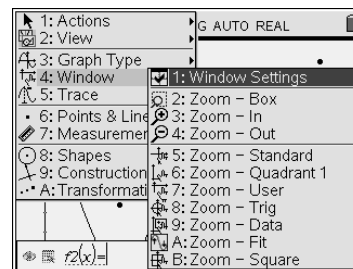
**Q4.** What is the amplitude of the data?



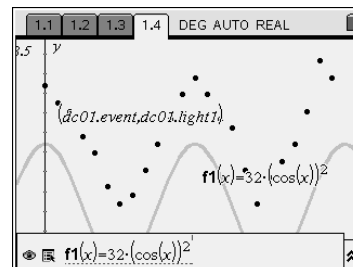
**Step 2:** Change the graph to a function graph. Enter the function  $f_1(x) = (\cos(x))^2$  in the function line of the graph.



**Step 3:** Adjust the equation for **f1** that you entered so that its amplitude is similar to the amplitude of your intensity data. You may need to adjust the window settings (**Menu > Window > Window Settings**) to see your data and the function together.



**Step 4:** Adjust the equation for **f1** so that the graph of the function aligns with your data.



- Q5. Explain why the graph of the data does not have zero as a minimum.
- Q6. What value shifts the function **f1** vertically so that it aligns with the data?
- Q7. What is the equation that gives a good fit to the experimental data?
- Q8. In general, what is the equation that describes the behavior of polarization filters?