

Activity P34: Polarization - Verify Malus' Law (Light Sensor)

Concept	<i>DataStudio</i>	<i>ScienceWorkshop (Mac)</i>	<i>ScienceWorkshop (Win)</i>
Polarization	P34 Malus' Law.DS	(See end of activity)	(See end of activity)

Equipment Needed	Qty	Equipment Needed	Qty
Light Sensor (CI-6504A)	1	Basic Optics System (OS-8515)	1
Rotary Motion Sensor (CI-6538)	1	Polarization Analyzer (OS-8533)	1
Aperture Bracket (OS-8534)	1		

What Do You Think?

If the transmitted light is at maximum intensity when the two polarizers are parallel, and minimum intensity when the two polarizers are perpendicular, what is the relationship of the intensity of transmitted light to the angle of the polarizers between 0 and 90 degrees?



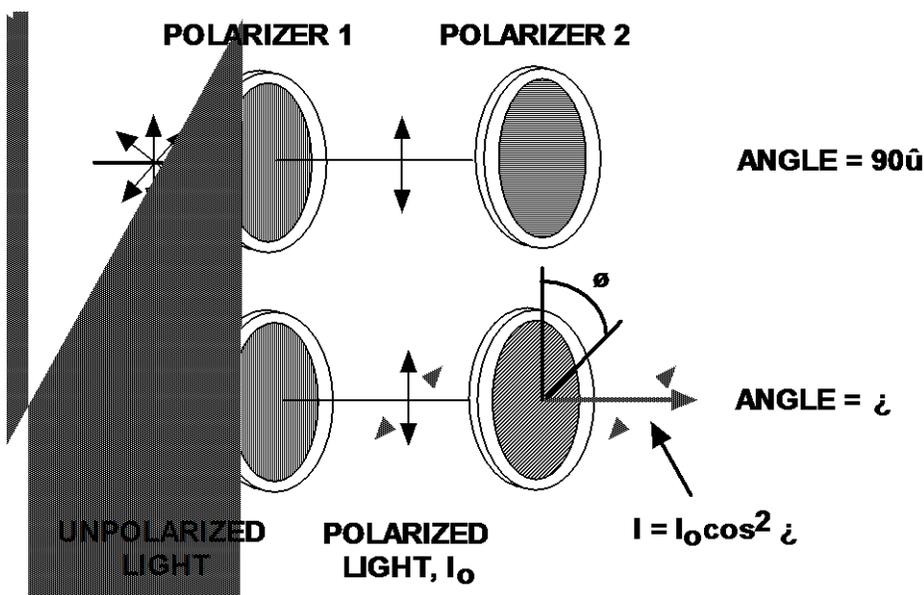
Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

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

Background

A polarizer only allows light that 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 (see the top figure).



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_{θ} , is found by:

$$E = E_{\theta} \cos \phi$$

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:

$$I = I_{\theta} \cos^2 \phi$$

where I_{θ} is the intensity of the light passing through the first filter and θ is the angle between the polarization axes of the two filters.

Consider the two extreme cases illustrated by this equation:

- If θ 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 θ is 90° , the second polarizer is oriented perpendicular to the plane of polarization of the first filter, and the $\cos^2(90^\circ)$ 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.

SAFETY REMINDERS

- Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

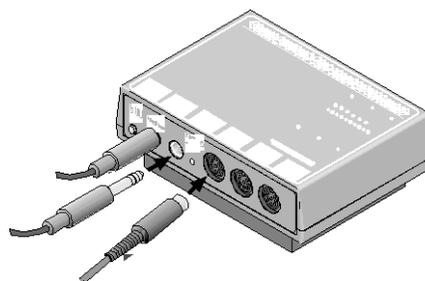
For You To Do

Use the Light Sensor to measure the relative intensity of light that passes through two polarizers. Change the angle of the second polarizer relative to the first polarizer. Use the Rotary Motion Sensor to measure the angle of the second polarizer relative to the first polarizer.

Use *DataStudio* or *ScienceWorkshop* to record and display the light intensity and the angle between the axes of the polarizers. Use the program's built-in calculator to compare the relative intensity to the angle and the cosine² of the angle.

PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Light Sensor into Analog Channel A on the interface.
3. Connect the Rotary Motion Sensor stereo phone plugs to Digital Channels 1 and 2.
4. Open the document titled as shown:



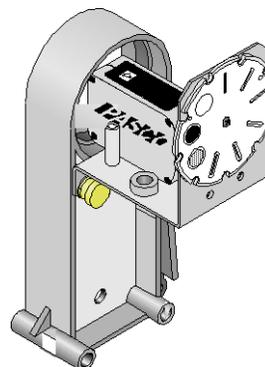
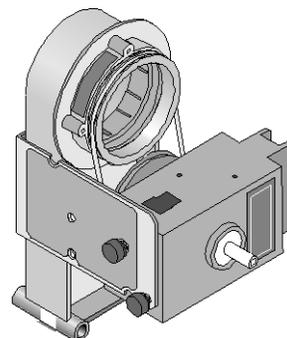
<i>DataStudio</i>	<i>ScienceWorkshop</i> (Mac)	<i>ScienceWorkshop</i> (Win)
P34 Malus' Law.DS	(See end of activity)	(See end of activity)

- The document opens with a Digits display of light intensity, a Graph display of light intensity versus the angle, and a Graph display of light intensity versus the cosine square of the angle.
- Data recording is set at 20 Hz. The Rotary Motion Sensor is set for 1440 divisions per rotation.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.

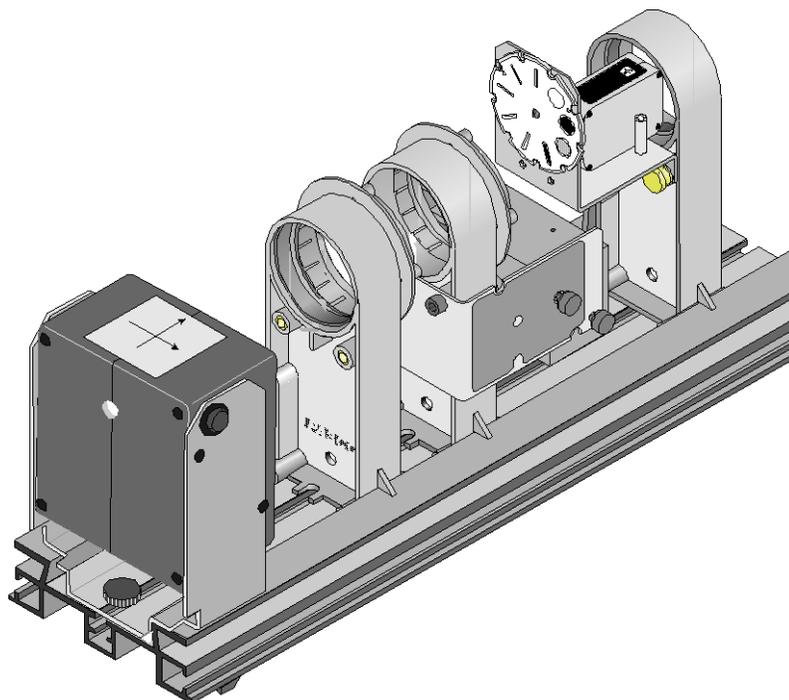
PART II: Equipment Setup and Sensor Calibration

Equipment Setup

1. Assemble the Polarization Analyzer as shown in the instructions that came with the analyzer.
 - Place the polarizer on the accessory holder.
 - Mount the Rotary Motion Sensor onto the bracket.
 - Loop the plastic belt over the Rotary Motion Sensor and the polarizer.
2. Mount the Polarization Analyzer on the Optics Bench.
3. Mount the Light Sensor on the Aperture Bracket and attach the Aperture Bracket to the Aperture Bracket Holder. Put the Aperture Bracket Holder onto the Optics Bench.
4. Rotate the Aperture Disk so the open circular aperture is in line with the opening to the Light Sensor



5. Put the Basic Optics Light Source and another polarizer in an accessory holder onto the



Optics Bench.

6. Turn on the Light Source. Move the Light Source and the Light Sensor so they are as close as possible to the polarizers.

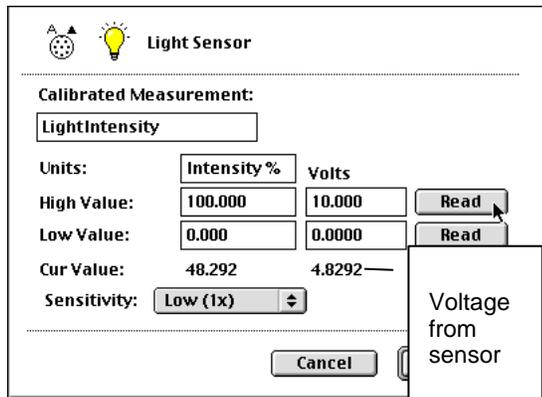
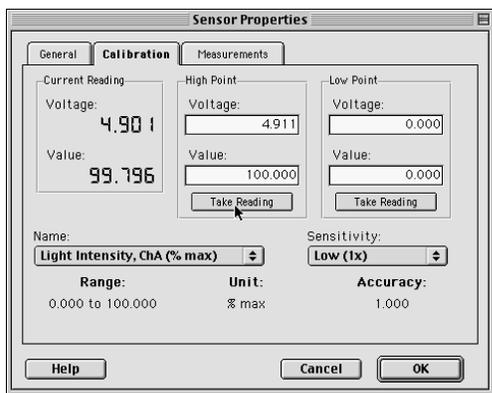
Sensor Calibration

- Calibrate the Light Sensor so that it produces its maximum voltage when axes of the two polarizers are parallel ($\theta = 0^\circ$).
1. Set the GAIN select switch on the top of the sensor to 1. Move the Light Sensor so its port is as close as possible to the light source.
 2. In the Experiment Setup window, double-click the Light Sensor icon. **Result:** The Sensor



Properties window opens in *DataStudio*. The Light Sensor setup window opens in *ScienceWorkshop*. In *DataStudio* click the 'Calibration' tab.

3. Check the voltage from the Light Sensor.
 - Hint: In the *DataStudio* 'Calibration' window, the Current Reading of the voltage from the Light Sensor appears in the upper left corner. In the *ScienceWorkshop* Sensor Setup window, the current value of the voltage from the Light Sensor appears at the bottom of the

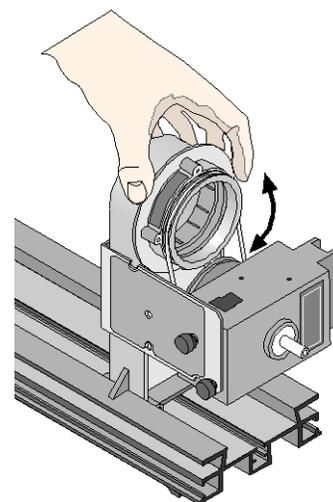


column labeled Volts.

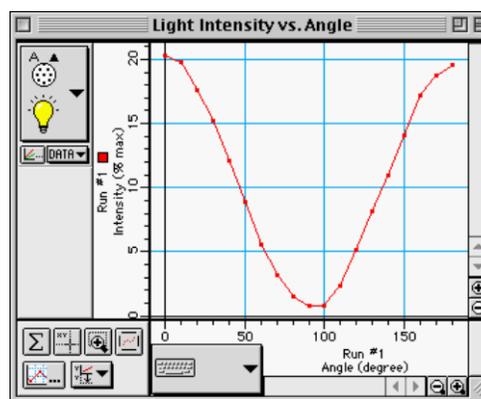
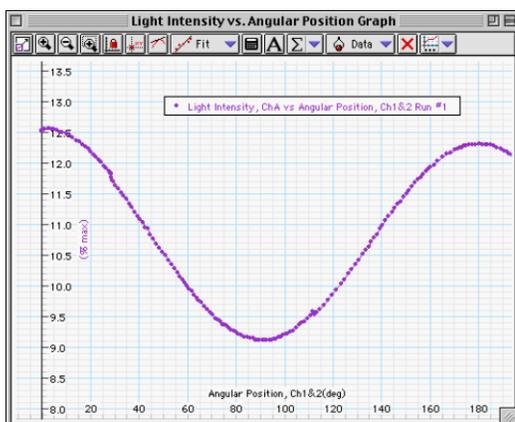
4. Now adjust the polarizers so the light source shines as brightly as possible into the Light Sensor. For example, turn one polarizer so the zero degree mark is next to the reference peg on the accessory holder. Turn the second polarizer so it is parallel with the first polarizer (i.e., also at zero degrees). Adjust the second polarizer until the transmission is maximum as indicated by the voltage in the calibration window.
 - If the value of voltage from the sensor is slightly higher than 4.9 V, slowly move the sensor away from the light source until the value is 4.9 V (or slightly lower).
 - If the voltage value is below 0.49 V set the GAIN switch to 10. If the value is still below 0.49 V set the GAIN switch to 100.
5. Keep this value of voltage as the maximum value (corresponding to 100% intensity). In *DataStudio* click 'Take Reading' below the 'High Point' column. In *ScienceWorkshop*, click the top Read button.
6. Now adjust the polarizers so the light transmission is as dim as possible. Turn the second polarizer to 90 degrees. Adjust the second polarizer so the transmission is minimum as indicated by the voltage in the calibration window.
7. Keep this value of voltage as the minimum value (corresponding to 0% intensity). In *DataStudio* click 'Take Reading' below the 'Low Point' column. In *ScienceWorkshop*, click the bottom Read button. Click 'OK' to return to the Experiment Setup window.

PART III: Data Recording

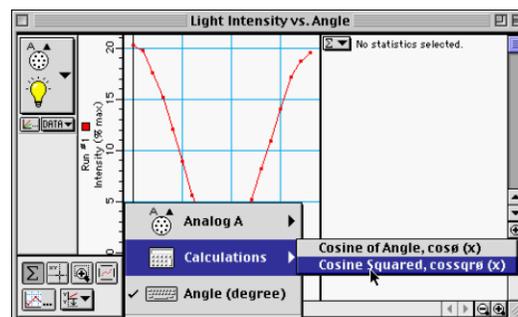
1. Adjust the polarizers for *maximum* transmission of light.
2. When you are ready, start recording data. (Hint: Click the 'Start' button in *DataStudio* or the 'REC' button in *ScienceWorkshop*.)
3. Begin turning the Polarization Analyzer slowly and smoothly. Watch the results in the Graph display. Continue to turn the polarizer for at least one full rotation (360 degrees).
4. After at least one full rotation, stop recording data.
5. Turn off the light source.

**Analyzing the Data**

Use the Graph displays to analyze your data.



1. Examine the Graph display for 'Light Intensity versus Angular Position'.
2. Try to fit the data to a mathematical model.
 - Hint: In *DataStudio*, click the 'Fit' menu button and select 'Polynomial'. In *ScienceWorkshop*, click the 'Statistics' button and then select 'Curve Fit, Polynomial Fit' from the Statistics menu. Note whether or not the 'Polynomial' model is a 'good fit'.
3. Next, examine the Graph display for 'Light Intensity versus cosine (angle)'.
 - In *DataStudio*, click the second graph to make it active. In *ScienceWorkshop*, select 'Calculations, Cosine squared' from the X-axis Input menu.
4. Try to fit the data to a new mathematical model. In *DataStudio*, click the 'Fit' menu button and select 'Linear'. In *ScienceWorkshop*, click the 'Statistics' menu and select 'Curve Fit, Linear Fit'.



Answer the questions in the Lab Report section.

Lab Report - Activity P34: Polarization – Verify Malus' Law**What Do You Think?**

If the transmitted light is at maximum intensity when the two polarizers are parallel, and minimum intensity when the two polarizers are perpendicular, what is the relationship of the intensity of transmitted light to the angle of the polarizers between 0 and 90 degrees?

Questions

1. What is the shape of the graph of the Light Intensity versus the Angular Position?
2. What is the shape of the graph of the Light Intensity versus the square of the cosine of the angle?
3. Theoretically, what percentage of incident plane polarized light would be transmitted through three polarizers which each have their axes rotated 17 degrees from each other? Assume ideal polarizers and assume that the first polarizer's axis is 17 degrees from the axis of the second polarizer.

Appendix: Modify a ScienceWorkshop File

Modify an existing *ScienceWorkshop* file to add the Rotary Motion Sensor.

Open the ScienceWorkshop File

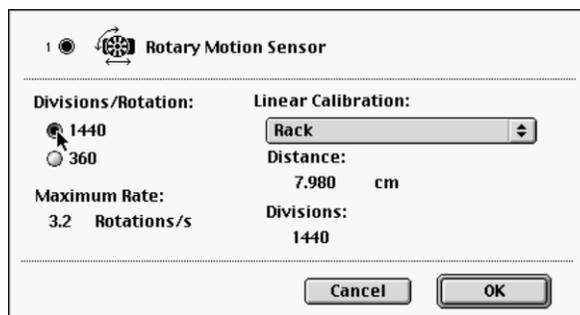
Open the file titled as shown:

<i>ScienceWorkshop</i> (Mac)	<i>ScienceWorkshop</i> (Win)
P57 Malus' Law	P57_POLA.SWS

- The *ScienceWorkshop* file has a Graph display of Light Intensity versus Angle (where the angle is entered from the keyboard.)
- You need to add the Rotary Motion Sensor to the Experiment Setup window, change the Sampling Options, and create a calculation of 'cosine squared' of the angular position data from the sensor.

Set Up the Rotary Motion Sensor

In the Experiment Setup window, click and drag the digital sensor plug to Channel A. Select 'Rotary Motion Sensor' from the list of sensors. Click 'OK'. **Result:** The Rotary Motion Sensor



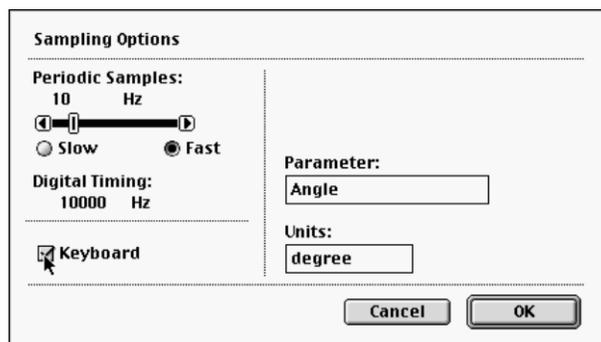
setup window opens.

Click '1440' under 'Divisions/Rotation' and then click 'OK' to return to the Experiment Setup window.

Set the Sampling Options

Click the 'Sampling Options' button in the Experiment Setup window or select 'Sampling Options' from the Experiment menu to open the Sampling Options window. **Result:** The Sampling Options window opens.

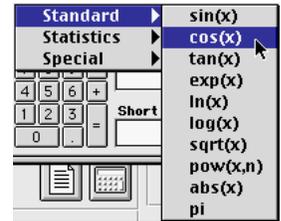
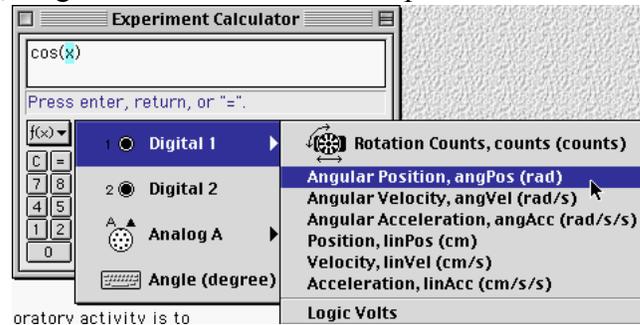
De-select 'Keyboard' by clicking the checkmark. Under 'Periodic Samples' click the right arrow to set the sample rate at '20 Hz' (20 measurements per second). Click 'OK' to return to the Experiment Setup window.



Set Up the Calculation

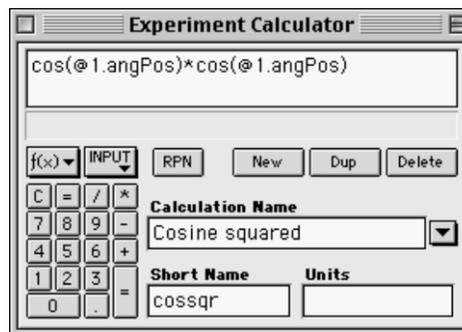
Open the Experiment Calculator window. Select 'cos(x)' from the 'f(x), Standard' menu.

Select 'Digital 1, Angular Position' from the 'Input' menu.



Copy the calculation $\cos(@1.angPos)$ and paste the copy next to the original. Add a multiplication symbol (*) between the original and the copy.

Type 'Cosine squared' for the Calculation Name and 'cossqr' for the Short Name. Click the



'equals' button to finish the calculation.