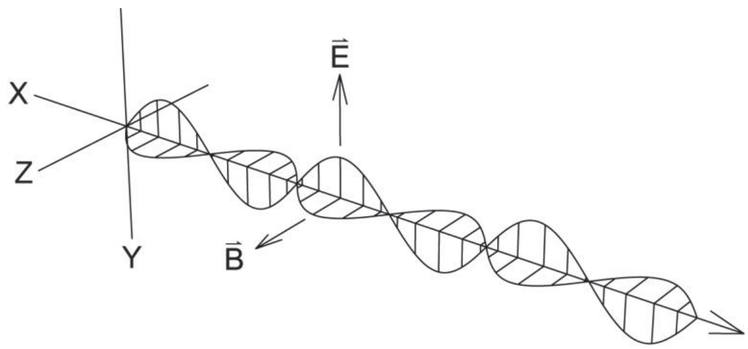
37. Polarization

Driving Question

What does it mean to polarize light?

Background

A photon of light consists of two wave components: an electric field wave component, and a magnetic field wave component. Together they are referred to as a single electromagnetic wave.



The diagram above is a 3-dimensional representation of such a wave traveling along the x-axis. Notice the electric field and magnetic field are both at right angles to the direction of propagation, as well orthogonal to each other.

Electromagnetic energy such as light is generally emitted from sources that produce unpolarized light. Some light sources produce polarized light, like lasers. Polarization of light occurs when the electric field component of the electromagnetic wave is constrained to oscillate in a consistent plane. Light that is unpolarized can be polarized using special pieces of optics such as selective absorption polarizing filters which allow only photons with electric fields oscillating in a particular plane through the filter, while all other photons are absorbed.

Selective absorption polarizing filters are made of a material in which long-chain hydrocarbons are used to absorb electromagnetic radiation. If the long-chain hydrocarbons are aligned in one direction, the material will absorb only photons having electric fields parallel to the hydrocarbon chains, while waves with electric fields perpendicular to the hydrocarbon chains (transmission axis) are transmitted.

An unpolarized beam of light incident upon a linear polarizer will result in a beam of light, linearly polarized in the same direction as the polarizer's transmission axis. However, the intensity of the resultant beam will now be less due to the absorption of all other light in the beam with polarization not matching that of the polarizer. If a second polarizer (usually called an analyzer) is placed in the beam's path after the location of the original polarizer, the intensity of the light that is transmitted through it will decrease, again do to absorption. As the angle between transmission axes on both the analyzer and polarizer gets closer to 90°, the intensity of light transmitted through the analyzer will approach zero. Malus' law states:

$$I = I_o \cos^2 \theta$$

where I_o is the intensity of a polarized beam of light incident on an analyzer, θ is the angle between the light's polarization direction and the transmission axis of the analyzer, and I is the intensity of the light after passing through the analyzer.

Materials and Equipment

For each student or group:

- Data collection system
- Light sensor
- Sensor extension cable
- Basic optics diode laser
- Basic optics aperture bracket
- Basic optics bench
- Polarizing disk (2)
- Polarizing disk accessory holder

Safety

Add these important safety precautions to your normal laboratory procedures:

- Do not look directly into the laser.
- Avoid laser beam reflections that may cause eye damage. Be aware of the laser beam at all times; you may be producing unknown stray reflections.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

◯	◯	◯	◯	◯
Rotate one polarizing disk 10° at a time, and determine the intensity of transmitted light at each angle.	Set up the polarizing disks such that their transmission axes are parallel to each other.	Verify Malus' law by comparing measured intensity values to calculated intensity values.	Plot intensity versus the angle between the transmission axes for the two polarizing disks.	Draw conclusions about the amount of light transmitted and the angle between the transmission axes.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

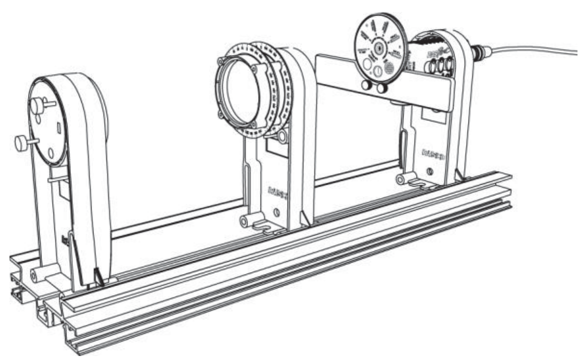
Set Up

1. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Mount the light sensor to the aperture bracket, and rotate the aperture disk until the large circular aperture in front of the light sensor.

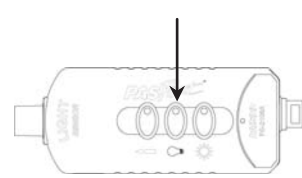
3. ☐ Use the sensor extension cable to connect the light sensor to the data collection system. �(2.1)

4. ☐ Mount the laser, polarizing disk mount, and light sensor with aperture bracket to the optics bench. Align the laser with the beam pointed toward the light sensor.



5. ☐ Plug in and turn on the laser.

6. ☐ Adjust the horizontal and vertical alignment thumbscrews on the laser until the laser beam passes directly through the round aperture hole and strikes the light sensor directly.

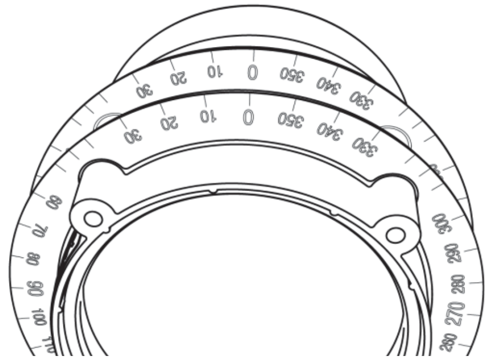


7. ☐ Press the center button on the light sensor to select the middle intensity range setting. A green light will illuminate at the top of that button.

8. ☐ Monitor light intensity in a digits display with your data collection system. �(6.1)

9. ☐ Mount the two polarizing disks to the accessory holder (the first serves as the polarizer and the second serves as the analyzer).

10. ☐ Rotate both polarizing disks independently until the scales on the outside of the disks are aligned.



11. ☐ Rotate the two disks together, observing the light intensity on your data collection system simultaneously, until the transmitted intensity through both disks is greatest.

Note: If the light intensity does not change, try the next higher intensity range setting on your light sensor.

12. ☐ Stop monitoring data.

13. ☐ Put the data collection system into manual sampling mode with manually entered data. Name the manually entered data set "Angle" with units of degrees. �(5.2.1)

Collect Data

14. ☐ Start a new manually sampled data set. �(6.3.1)

15. ☐ Begin with the angle between the polarizing disks set to zero. Record your first point, and enter "0" for the angle between the axes. �(6.3.2)

16. ☐ Rotate the polarizing disk closest to the light sensor 10°.

17. ☐ Record your second data point, and enter "10" as the angle between the two disks.

18. ☐ Continue this procedure, incrementing the angle 10° each time until you have completed a full revolution (360°) for the polarizing disk.

19. ☐ When you have recorded all of your data, stop the data recording. �(6.3.3)

Analyze Data

20. ☐ Display Intensity on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

21. ☐ Change the measurement on the *x*-axis from Time to Angle. �(7.1.9)

22. ☐ Sketch your graph of Light Intensity versus Angle in the Data Analysis section.

23. ☐ Describe, in words, what you have discovered about the intensity of the light, as the angle between the transmission axes of two polarizing disks is changed. Can you draw any conclusions about when the axes are parallel? When they are perpendicular? When they move from parallel to perpendicular? When they move from perpendicular back to parallel (from 90° to 180°)?

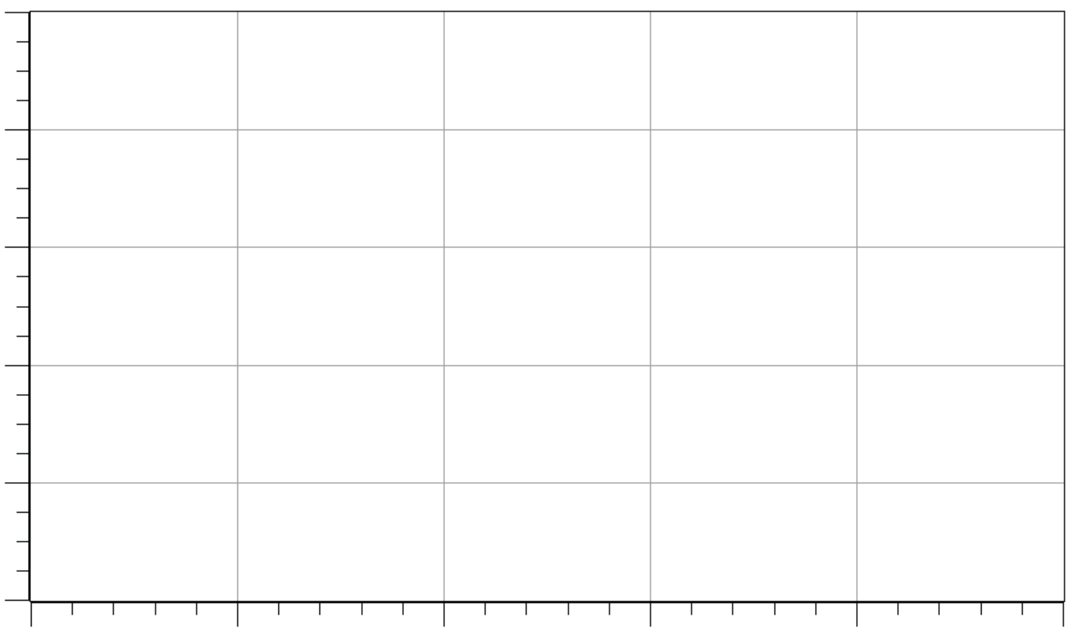
____

____

____

Data Analysis

Light intensity versus Angle



1. ☐ On your data collection system, build the following calculation: �(10.3)

Intensity = *I**(cos([Angle])^2)

where I is the maximum light intensity value you measured at angle zero.

Note: ensure that your data collection system calculator is set to calculate angles in degrees.

2. ☐ Return to the table on your data collection system, and add a new column containing the Intensity calculation. �(7.2.2)

3. ☐ Compare the Intensity calculations to the actual intensities that you measured. To make a quantitative comparison create a new calculation: �(10.3)

PercentDifference = 100*((Intensity-[Light Intensity])/Intensity)

4. ☐ Return to your table, and add a new column containing the PercentDifference calculation. �(7.2.2)

5. ☐ Save your work as instructed by your teacher. �(11.1)

Analysis Questions

1. Polarizing disks, such as the ones used in this experiment, were invented by Dr. Edwin Land. You will recall that the long-chain hydrocarbon molecules in the disk material are made to be electrically conducting. In what direction is the transmission axis for such a disk, relative to the long molecules?

____

____

____

2. Can a sound wave be polarized? Explain.

____

____

Synthesis Questions

Use available resources to help you answer the following questions.

1. In everyday life, radio waves are typically polarized, but light waves are not. Why is this the case?

____

____

____

2. The glare of headlights of oncoming traffic causes many automobile accidents every year. Would it be possible to design a "non-glare" headlight system for cars?

____

____

____

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Polarizing disks, like the ones used in this experiment, polarize light by what method?

- **A.** Reflection
- **B.** Scattering
- **C.** Selective absorption

2. When light reflects off a horizontal surface, such as water, the light waves are much more pronounced in the horizontal plane. So, in order to reduce glare most effectively, what should be the axis of transmission for a pair of polarized sunglasses?

- **A.** Horizontal
- **B.** Vertical
- **C.** 45° to the horizontal plane

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Polarized sunglasses polarize light by the _______________ process. Light waves are made up of two types of fields: electric and _______________ fields. The hydrocarbon chains in Polaroid material absorb the _______________ field component of an electromagnetic wave, so the direction of vibration of the electric field that can be transmitted is _______________ to the hydrocarbon chains. The orientation or direction of the oscillating electric field that can be transmitted is called the _______________ for the Polaroid material. The law that can be used to determine the intensity of the light that passes through two polarizing sheets with their transmission axes at a particular angle to each other is known as _______________.

Key Term Challenge Word Bank

Paragraph 1

Reflection

Parallel

Magnetic

Scattering

Perpendicular

Gravitational

Transmission axis

Electric

Malus' law

Selective absorption

Newton's law