General- Physics-2 Q4 Week-3

Fundamental Physics I Laboratory (University of the Philippines System)

DEPARTMENT OF EDUCATION
SCHOOLS DIVISION OF NEGROS ORIENTAL
REGION VII
Kagawasan Ave., Daro, Dumaguete City, Negros Oriental

COMMON PROPERTIES OF LIGHT

(Law of Refraction, Polarization and Their Applications)

for GENERAL PHYSICS 2/ Grade 12/ Quarter 4/ Week 3

SELF-LEARNING KIT

NegOr_Q4_GenPhysics2_SLKWeek3_v2

FOREWORD

This Self-Learning Kit is designed to cater your needs as STEM students for Modular Distance Learning. It is carefully planned to holistically develop your life-long learning skills. This serves as your guide to understand the phenomena of dispersion, polarization as well as their applications.

This module enables you to explain the phenomena of dispersion by relating it to Snell's Law. In addition, they will be guided on how to calculate the intensity of the transmitted light after passing through a series of polarizers applying Malus's Law. With these, you will apply the concepts gained in solving problems involving reflection, refraction, dispersion, and polarization in contexts such as, but not limited to polarizing sunglasses, atmospheric haloes, and rainbows.

OBJECTIVES

At the end of this Self-Learning Kit, you should be able to:

K: relate dispersion phenomenon to Snell's Law;

S: calculate the intensity of the transmitted light after passing through a series of polarizers applying Malus's Law;

: solve problems involving reflection, refraction, dispersion, and polarization in contexts such as, but not limited to, (polarizing) sunglasses, atmospheric haloes, and rainbows; and

A: recognize the importance of refraction, dispersion and polarization in the existence of atmospheric haloes and rainbows.

LEARNING COMPETENCIES

Explain the phenomenon of dispersion by relating to Snell's Law **(STEM_GP12OPTIVb-16).**

Calculate the intensity of the transmitted light after passing through a series of polarizers applying Malus's Law **(STEM_GP12OPTIVc-18)**

Solve problems involving reflection, refraction, dispersion, and polarization in contexts such as, but not limited to, (polarizing) sunglasses, atmospheric haloes, and rainbows **(STEM_GP12OPTIVc-21).**

I. WHAT HAPPENED

PRE-ACTIVITY:

***Quicklab*:** Fill a clear drinking glass with water and place a pencil in the water. Observe the pencil from the side at an angle of about45^0 to the surface. Why does the pencil appear to be bent at the surface? Write your observation and the answer to the question in your notebook/Answer Sheet.

Adapted from https://scientificteacher.com/2011/09/02/bent-out-of-shape-over-refraction/

Figure 1. A pencil is dip in a glass of water

PRE-TEST:

Multiple Choice: Choose the letter of the correct answer. Write it on your notebook/Answer Sheet.

1. What principle is responsible for light spreading as it passes through a narrow slit?
   a. Refraction   c. diffraction
   b. Polarization   d. dispersion
2. The principle which allows a rainbow to form is _________.
   a. Refraction   c. diffraction
   b. Polarization   d. dispersion
3. What principle is responsible for the fact that certain sunglasses can reduce glare from reflected surfaces?
   a. Refraction   c. diffraction
   b. Polarization   d. dispersion
4. A blue sky is caused by the _________ of high frequency light.
   a. Diffraction   c. scattering
   b. Refraction   d. absorption
5. It is a wide range of atmospheric phenomena that result when the sun and moon shines through thin clouds composed of ice crystals.
   a. Rainbow   c. halo
   b. Glass prism   d. water droplet

II. WHAT I NEED TO KNOW

The beautiful colors seen inside a well-cut diamond are part of the allure of this gemstone. It is now possible to create artificial gems that sell at a much lower price but have nearly the same sparkle as a diamond. How can you distinguish a cheap imitation from the genuine article by something you'd find in the kitchen cupboard?

Cubic zirconia also has a high index of refraction and can be made to sparkle very much like a genuine diamond. If a suspect jewel is immersed in corn syrup, the difference in n for the cubic zirconia and that for the syrup is small, and the critical angle is therefore great. This means that more rays escape sooner, and as a result, the sparkle completely disappears. A real diamond does not lose all of its sparkle when placed in corn syrup.

Adapted from https://www.gettyimages.com/photos/diamond?phrase=diamond&sort=mostpopular

Figure 2. A sparkling diamond exhibits refraction

DISCUSSION

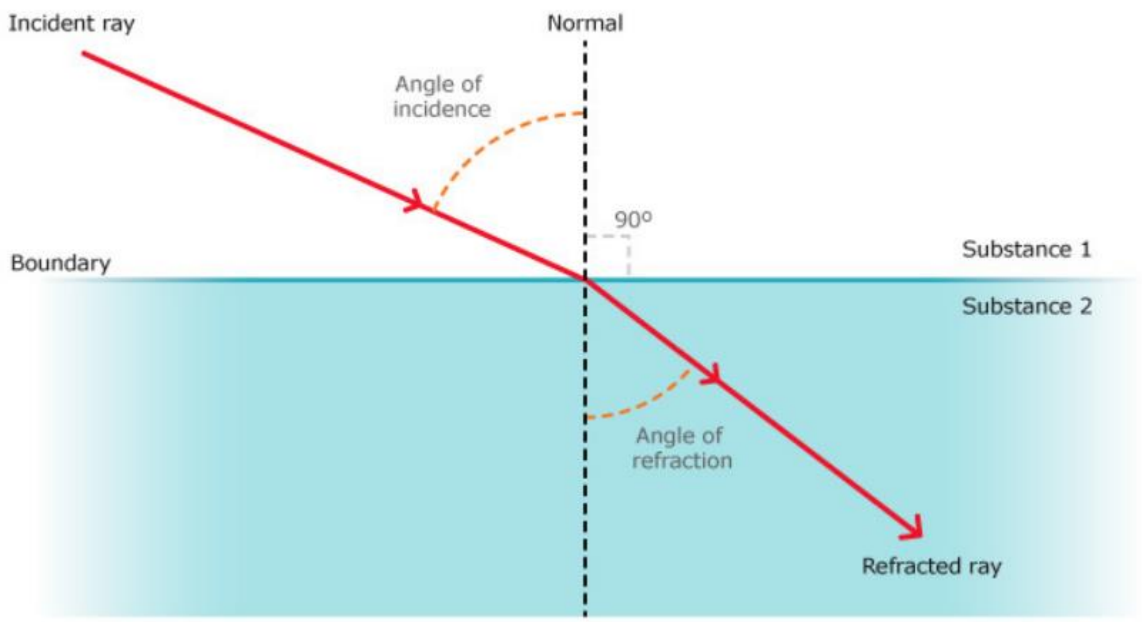
Refraction of Light

Light travels fastest in a vacuum *(c = 2.998 x 10^8 m/s)*. In ordinary air, it travels a bit slower with a speed of *c/1.0003*. In water, light travels at a rate of *c/1.33*; in ordinary glass, it travels at *c/1.5*. These variations in the speed of light as it travels through different media reveal that as the medium becomes denser, light travels at a slower rate. This is the governing principle of refraction. **Refraction** is the bending of light as it enters a different optical medium. This bending of light is associated with the ***absolute index of refraction*** of the medium, which is calculated as follows:

$$n = \frac{c}{v}$$

In this equation, n is the absolute index of refraction, c is the speed of light in a vacuum, and v is the speed of light in the material. Every material has its unique index of refraction. This implies that light will bend in different ways for different materials.

As a ray of light passes obliquely through the boundary between two materials with different indices of refraction, the ray bends (refraction).



Adapted from https://www.sciencelearn.org.nz/resources/49-refraction-of-light

Figure 3. Refraction of light as it bends through substance 1 and 2

Table 1 summarizes how light will bend as it enters a material while Table 2 presents the indices of refraction.

Table 1. How light behaves during refraction

Comparison of the Indices of Refraction	Behavior of the Refracted Ray
$n_2 > n_1$	Refracted ray bends toward the normal as it enters material 2.
$n_2 < n_1$	Refracted ray bends away from the normal as it enters material 2.

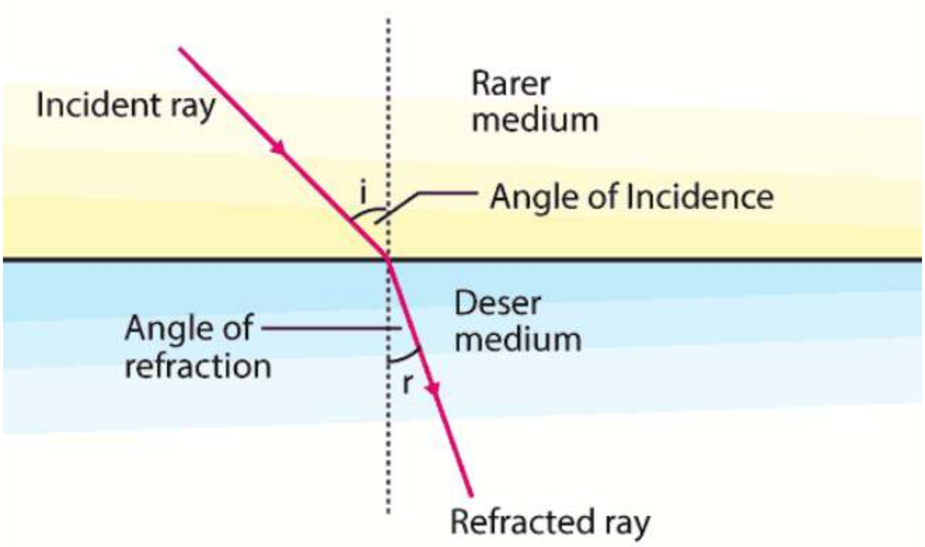
Adapted from DIWA Learning Systems, Inc.

Table 2. Indices of Refraction

Substance	Index of Refraction	Substance	Index of Refraction
Solids at 20⁰C		*Liquids at 20⁰C*	
Cubic Zirconia	2.20	Benzene	1.501
Diamond	2.419	Carbon tetrachloride	1.461
Fluorite (CaF_2)	1.434	Ethyl alcohol	1.361
Fused quartz (SiO_2)	1.458	Glycerin	1.473
Glass, crown	1.52	Water	1.333
Glass, flint	1.66	*Gases at 0⁰C, 1 atm*	
Sodium Chloride (NaCl)	1.544	Air	1.000293
Ice (H_2O)	1.309	Carbon dioxide	1.00045

Adapted from Thomson Learning Inc.

Similar with the law of reflection, the incident ray, the refracted ray, and the normal to the surface all lie on the same plane. Refraction is illustrated in Figure 3 on the previous page and Figure 4 below.



Adapted from https://byjus.com/physics/angle-of-incidence/

Figure 4. The incident ray, the refracted ray, and the normal to the surface all lie on the same plane

In Figure 3 and 4, you will see that the law of refraction is somehow similar to the law of reflection. The incident ray is the light ray that joins the two materials and forms an angle with the normal line or the line perpendicular to it. This formed angle is also called the **angle of incidence** *(θ_i).* The bent light ray that penetrates the other material is referred to as the refracted ray. This ray also forms an angle with the normal line, and this angle is referred to as the **angle of refraction** *(θ_r).*

How a ray is refracted at the interface between two materials of different indices of refraction (n_1 and n_2) is given by the Snell's Law. Snell's Law is mathematically stated as follows:

$$n_1 sin\theta_i = n_2 sin\,\theta_2$$

In this equation, θ_i is the angle between the normal line and the associated ray in medium 1, θ_2 and is the angle between the normal line and the associated ray in medium 2.

***Example 1*:**

A beam of light of wavelength 550 nm travelling in air is incident on a slab of transparent material. The incident beam makes an angle of 40.0^0 with the normal, and the refracted beam makes an angle of 26.0^0 with the normal. Find the index of refraction of the material.

***Solution*:**

Using Snell's law of refraction with these data, and taking n_1 = 1.00 for air, we have:

$$n_1 sin\theta_i = n_2 sin\,\theta_2$$
$$n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2}$$
$$= \frac{\sin 40.0^\circ}{\sin 26.0^\circ}$$
$$= \frac{0.643}{0.438}$$
$$n_2 = 1.47$$

From Table 2, we see that the material could be ***fused quartz*.**

Halo: An Atmospheric Optical Phenomenon

Halo is any of a wide range of atmospheric optical phenomena that result when the Sun or Moon shines through thin clouds composed of ice crystals. These phenomena may be due to the **refraction of light** that passes through the crystals, or the **reflection of light** from crystal faces, or a combination of both effects. Refraction effects give rise to color separation because of the slightly different bending of the different colors composing the incident light as it passes through the crystals. On the other hand, reflection phenomena are whitish in color, because the incident light is not broken up into its component colors, each wavelength being reflected at the same angle.

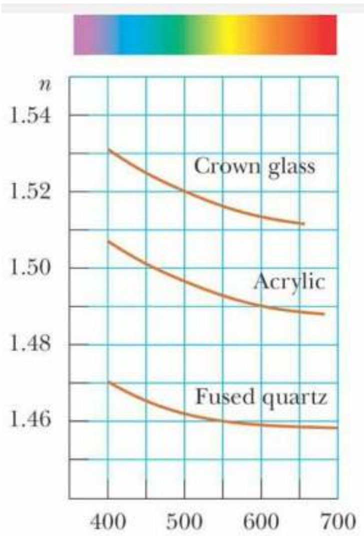
Adapted from https://www.phenomena.org/atmospheric/22halo

Figure 5. Halo, an atmospheric optical phenomenon that results when the Sun or Moon shines through thin clouds composed of ice crystals.

Dispersion of Light

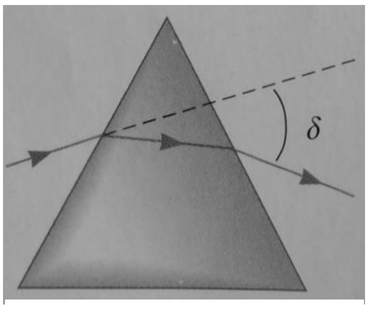
An important property of the index of refraction is that, for a given material, the index varies with the wavelength of the light passing through the material. This behavior is called **dispersion**. Because n is a function of wavelength, **Snell's law** of refraction indicates that light of different wavelengths is bent at different angles when incident on a refracting material.

The index of refraction generally decreases with increasing wavelength (Figure 6). This means that blue light bends more than red light does when passing into a refracting material. To understand the effects that dispersion can have on light, let us consider what happens when light strikes a prism, as shown in Figure 7. A ray of single-wavelength light incident on a prism from the left emerges refracted from its original direction of travel by an angle δ, called the **angle of deviation**.



Adapted from Thomson Learning Inc.

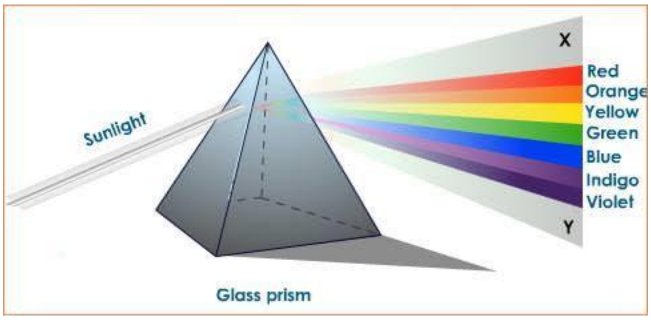
Figure 6. Variation of index of refraction with vacuum wavelength for three materials



Adapted from Thomson Learning Inc.

Figure 7. A prism refracts a single-wavelength light ray through an angle δ

Now suppose that a beam of white light (a combination of all visible wavelengths) is incident on a prism, as illustrated in Figure 8. The rays that emerge spread out in a series of colors is known as the visible spectrum. These colors, in order of decreasing wavelength, are red, orange, yellow, green, blue and violet. Clearly, the angle of deviation δ depends on wavelength. Violet light deviates the most, red the least, and the remaining colors in the visible spectrum fall between these extremes. Newton showed that each color has a particular angle of deviation and that the colors can be recombined to form the original white light.



Adapted from https://www.google.com/amp/s/www.universetoday.com/89411/dispersion-of-light/amp/

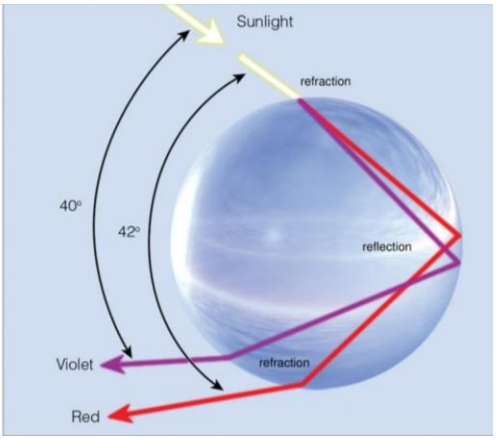
Figure 8. Different colors are refracted at different angles because the index of refraction of the glass depends on wavelength. Violet light deviates the most; red light the least.

The dispersion of light into a spectrum is demonstrated most vividly in nature by the formation of rainbow, which is often seen by an observer positioned between the Sun and a rain shower. To understand how a rainbow is formed, let us consider Figure 9. A ray of sunlight (which is white light) passing overhead strikes a drop of water in the atmosphere and is refracted and reflected as follows:

First: It is first refracted at the front surface of the drop, with the violet light deviating the most and the red light the least.

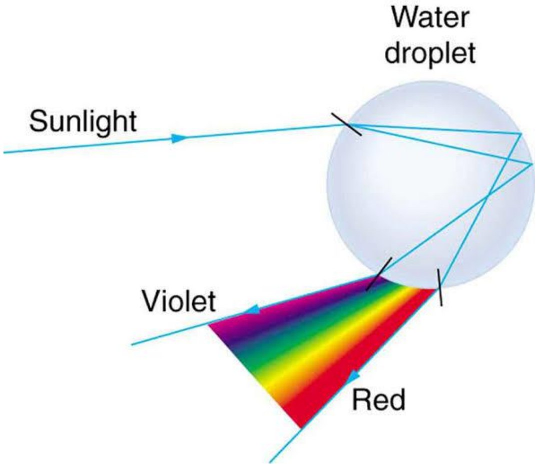
Second: At the back surface of the drop, the light is reflected and returns to the front surface, where it again undergoes refraction as it moves from water into air.

Third: The rays leave the drop such that the angle between the incident white light and the most intense returning violet ray is 40^0 and the angle between the white light and the most intense returning red ray is 42^0. This small angular difference between the returning rays causes us to see a colored bow (Figure 9 and 10).



Adapted from https://slideplayer.com/slide/13459714/

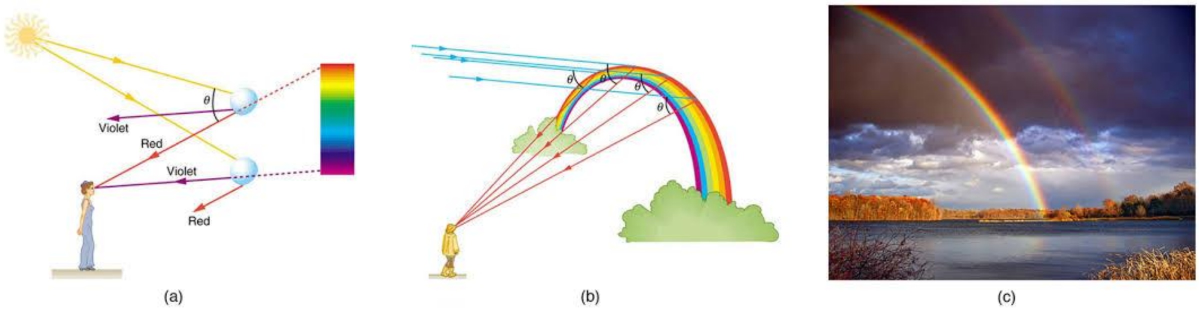
Figure 9. Refraction of sunlight by a spherical raindrop



Adapted from https://courses.lumenlearning.com/physics/chapter/25-5-dispersion-the-rainbow-and-prisms/

Figure 10. Understanding how a rainbow is formed through dispersion

Let us consider an observer viewing a rainbow, as shown in Figure 11. If a raindrop high in the sky is being observed, the red light returning from the drop can reach the observer because it is deviated the most, but the violet light passes over the observer because it is deviated the least. Hence, the observer sees this drop as being red. Similarly, a drop lower in the sky would direct violet light toward the observer and appears to be violet. (The red light from this drop would strike the ground and not be seen). The other colors of the spectrum would reach the observer from raindrops lying between these two extreme positions.



Adapted from https://courses.lumenlearning.com/physics/chapter/25-5-dispersion-the-rainbow-and-prisms/

Figure 11. An observer viewing a rainbow

Polarization of Light Waves

Polaroid sunglasses are familiar to most of us. They have a special ability to cut the glare of light reflected from water or glass. The polarized lenses can improve clarity and reduce eye strain in bright sunny days. Polaroids have this ability because of a wave characteristic of light called **polarization** (See Figure 12 for polarized lenses).

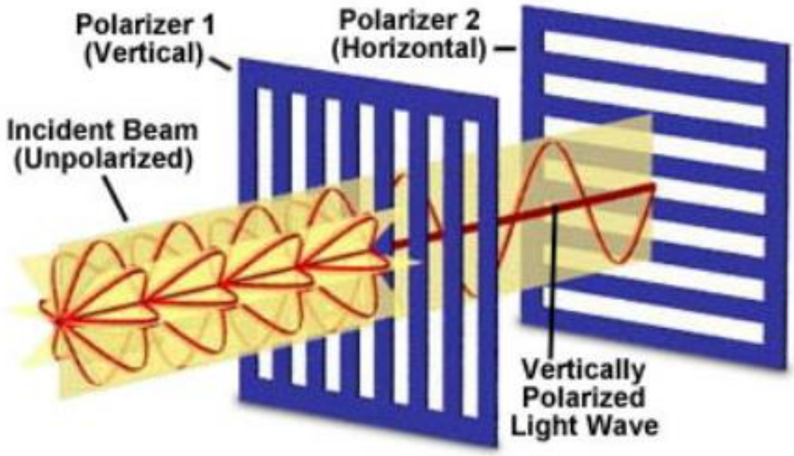
Adapted from https://noblerate.com/best-polarized-sunglasses/

Figure 12. The polarized lenses of polaroid sunglasses

Suppose you are holding one end of a string horizontally, and you are moving the string up and down. This action forms waves that are said to be linearly polarized because each element of the vibrating strings are along the vertical direction. Similarly, if you are holding the string vertically, and you move the string sideways, the waves are still linearly polarized with each vibrating string element along the horizontal direction. **Linearly polarized waves** are those that propagate along a single plane or in the same direction of a particular point at all times. These can be likened to waves drawn on a single sheet of paper.

On the other hand, **nonpolarized waves** are generated either horizontally or vertically if the end of the string will be moved in a random manner. Waves are said to be nonpolarized if these propagate in multiple planes or in any direction at equal times. This can be compared to drawing waves on different sheets of paper wherein you arrange these sheets of paper in a manner where none of them are parallel to each other.

In other words, waves produced by a single source are polarized, whereas multiple wave sources produce nonpolarized waves. A common light source such as a lightbulb contains millions of independently acting atoms that produce nonpolarized light (See Figure 13 for non-polarized incident beam that becomes polarized).



Adapted from https://www.olympus-lifescience.com/zh/microscope-resource/primer/lightandcolor/polarization/

Figure 13. How a nonpolarized incident beam becomes polarized after passing through two polarizers

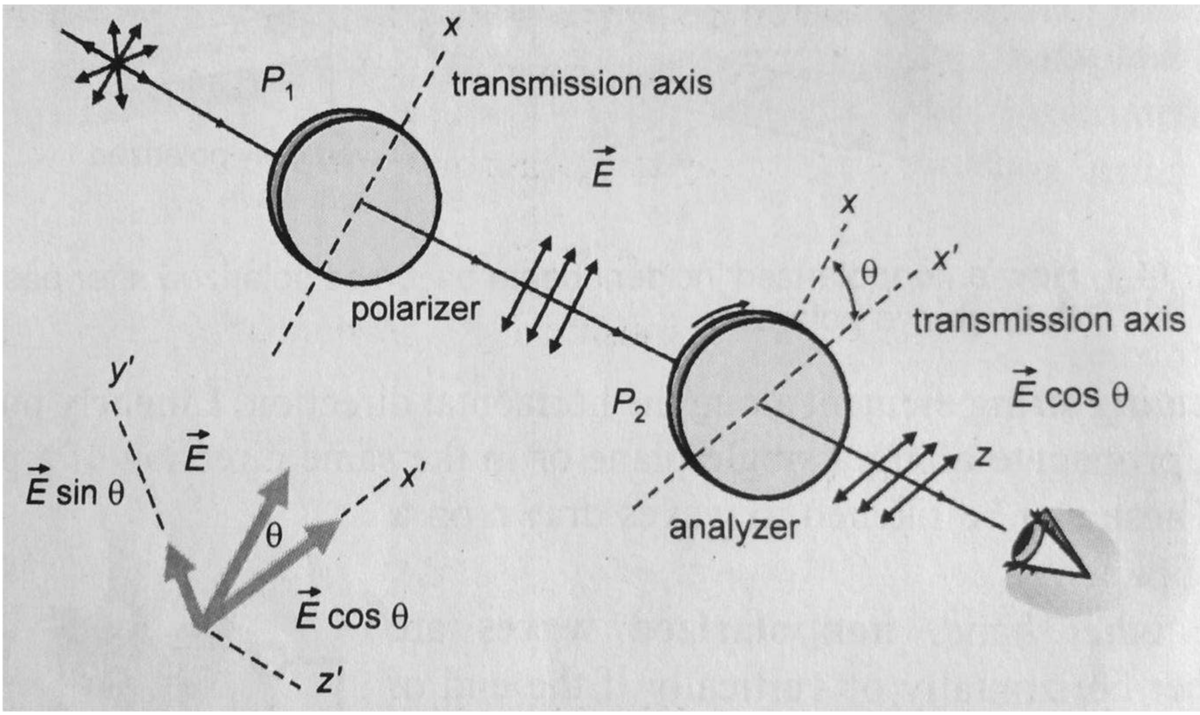
Polarization of light can occur through **absorption**. In this method, a polarizing element is introduced to the path of the light ray. This polarizing element filters the light ray and absorbs some of the light waves that are incident to it. Only waves with a particular propagation emerge from the polarizing element.

Consider introducing a second polarizing element along the path of the light ray, in this setup, the first polarizing element is referred to as the **polarizer**, and the second one is the **analyzer.** This combination of polarizing elements has the ability to control the intensity of the light that emerges through them as given by the equation:

$$I = (I_0)(\cos\theta)^2$$

In this equation, I is the intensity of the light that emerges from the combination of polarizing elements, I_0 is the intensity of the light incident to the polarizer, and θ is the angle formed between the *transmission axes* of the polarizer and the analyzer. This equation is referred to as the **Malus's Law.**

Malus's Law applies to any polarizing elements whose transmission axes form an angle with each other. Malus's Law is used to quantify the intensity of light that emerges from a series of polarization. By the proper alignment of polarizers, you can determine how the intensity of light emanating from these optical devices by virtue of the said law (See Figure 14).



Adapted from DIWA Learning Systems, Inc.

Figure 14. The variation in the intensity of light during polarization is governed by Malus's law

***Example 2*:**

A nonpolarized light with an intensity of 3.0 W/m^2 is incident on two polarizing elements whose transmission axes form an angle of 60. Compute the intensity of light emerging from the second film.

Solution:

The incident light is unpolarized, so the intensity transmitted by the first polarizing sheet is half the incident intensity. The second sheet further reduces the intensity by a factor of $cos^2\ \theta$, with $\theta = 60^0$.

1. The intensity I_1 transmitted by the first sheet is half the intensity I_0 of unpolarized light incident on the first sheet:

$$I_1 = \frac{1}{2}\, I_0$$

2. The intensity transmitted by the second sheet is related to the intensity of the light incident on the second sheet:

$$I_2 = I_1 cos^2\theta$$

3. Combine these results and substitute the given data:

$$I_2 = \frac{1}{2}\, I_0 \, cos^2\, 60^{\circ}$$
$$= \frac{1}{2}(3.0\, W/m^2)\ (0.500)^2$$
$$= \mathbf{0.38\, W/m^2}$$

The second film will transmit an intensity of light at approximately ***0.38 W/m²*.**

Various Practical Applications of Polarization of Light

1. Reducing glare from sunlight using polarized sunglasses.
2. Identifying minerals using polarization microscopes.
3. Checking the chirality of organic compounds.
4. Probing interstellar magnetic fields.
5. Studying the early universe through the polarization of cosmic microwave.
6. Performing selective mage projection for 3D movies.
7. Being integrated in satellite communications to allow separate transmission of different frequencies.

Performance Task:

Directions: Do what is asked below. Be guided with the standards given on how your output will be graded.

The chair of the Physics Department of your University commissioned you, one of the department's best laboratory instructors, to create an experiment that will demonstrate the behaviors of light (reflection, refraction, total internal reflection, and dispersion). The department will include this experiment in its Physics Laboratory Manual. Your initial manuscript should be submitted after a week so that the chair could make an evaluation of its contents based on the following – the appropriateness of the activities included in the experiment with respect to the objectives, the completeness of the contents about the behaviors of light, the inclusion of an accurate answer key that also explains the concepts involved in the activities, and your compliance to the required format of the department, which will be given to you at the start of the project.

III. WHAT I HAVE LEARNED EVALUATION/POST-TEST:

I. Multiple Choice: Choose the letter of the correct answer. Write it on your notebook.

1. What principle is responsible for light spreading as it passes through a narrow slit?
   c. Refraction c. diffraction
   d. Polarization d. dispersion
2. What principle is responsible for the fact that certain sunglasses can reduce glare from reflected surfaces?
   c. Refraction c. diffraction
   d. Polarization d. dispersion
3. The principle which allows a rainbow to form is _________.
   c. Refraction c. diffraction
   d. Polarization d. dispersion
4. On a clear day, the sky appears to be bluer toward the zenith (overhead) than it does toward the horizon. This occurs because __.
   a. The atmosphere is denser higher up that it is at the earth's surface.
   b. The temperature of the upper atmosphere is higher than it is at the earth's surface.
   c. The sunlight travels over a longer path at the horizon, resulting in more absorption.
   d. None of the above is true.
5. A blue sky is caused by the _________ of high frequency light.
   c. Diffraction c. scattering
   d. Refraction d. absorption
6. An example of diffraction is ___________.
   a. Light scattering in the atmosphere.
   b. Light coming through a keyhole and spreading out in a dark room.
   c. Light entering a prism and emerging as a rainbow.
   d. Light bending as it enters a new medium.
7. Sunglasses are vertically polarized in order to block the ______ glare created by sunlight reflecting off the road and other automobiles.
   a. Vertical c. diagonal
   b. Horizontal d. random
8. It is a wide range of atmospheric phenomena that result when the sun and moon shines through thin clouds composed of ice crystals.
   c. Rainbow c. halo
   d. Glass prism d. water droplet

9. Violet light deviates the most and red, the least. This statement is ___________.
   a. True
   b. Neither true nor false
   c. false
   d. undecided
10. Malus's law is expressed in the equation __________.
   a. $I = (I_0)(\cos\theta)^2$
   b. $I = (I_0)(\sin\theta)^2$
   c. $I = (I_0)(\cos\theta)^3$
   d. $I = (I_0)(\sin\theta)^3$

II. Problem Solving: Answer the given problems below. Show the solution in your notebook.

1. Suppose a layer of oil (refractive index is 1.45) floats on water (refractive index is 1.33). If a ray of light shines onto the oil with an incidence angle of 40^0, what is the angle formed between the ray and the surface of the water?
   a. *Given:*
   b. *Formula:*
   c. *Solution:*
   d. *Final answer with unit:*
2. Light that is nonpolarized has an intensity of 6.0 W/m^2. Rays of this light are incident on two polarizing elements whose transmission axes are at an angle of 45^0. What is the intensity of light emerging from the second film?
   a. *Given:*
   b. *Formula:*
   c. *Solution:*
   d. *Final answer with unit:*

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SYNOPSIS AND ABOUT THE AUTHOR

This Self-Learning Kit focuses on refraction, dispersion and polarization of light. Refraction is the bending of light as it enters a different optical medium. Dispersion on the other hand, is the separation of visible light into its different colors while polarization applies to transverse waves that specify the geometrical orientation of the oscillations.

How a ray is refracted at the interface between two materials of different indices of refraction $(n_1 \text{ and } n_2)$ is given by the Snell's Law. Snell's Law is mathematically stated as follows:

$$n_1 \sin \theta_i = n_2 \sin \theta_2$$

Dispersion can be related to Snell's law. Since n is a function of wavelength, Snell's law of refraction indicates that light of different wavelengths is bent at different angles when incident on a refracting material. This behavior of light is called dispersion. Moreover, Malus's Law is used to quantify the intensity of light that emerges from a series of polarization. It is represented with the equation:

$$I = (I_0)(\cos \theta)^2$$

Refraction, dispersion and polarization of light could be best explained in the existence of rainbow, haloes and polarized glasses.

ANSWER KEY

Pre-activity: Answers of students may vary depending on their observations.

Pre-Test:
1. C
2. D
3. B
4. C
5. C

Evaluation/Post-Test

I. Multiple Choice:
1. C
2. B
3. D
4. C
5. C
6. B
7. B
8. C
9. A
10. A

II. Problem Solving:

1. At the interface between the air and the oil, you have:

$$n_{air} \sin 40^o = n_{oil} \sin \theta_{oil}$$

Considering the interface between the oil and the water, you have:

$$N_{oil} \sin \theta_{oil} = n_{water} \sin \theta_{water}$$

Equating the considered equations yields:

$$n_{air} \sin 40^o = n_{water} \sin \theta_{water}$$

Then you have:

$$\theta_{water} = \sin^{-1}\left(\frac{n_{air} \sin 40^o}{n_{water}}\right) = \sin^{-1} \frac{(1)(\sin 40^o)}{1.33}$$

$$\approx 28.9^o$$

The angle formed between the ray and the surface of the water is approximately 28.9°.

2. I = (6.0 W/m²) (cos 22.5)² ≈ **5.12 W/m²**

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