PHYSICS 2204
Unit 4: Waves
Worksheet #11: REFRACTION OF LIGHT

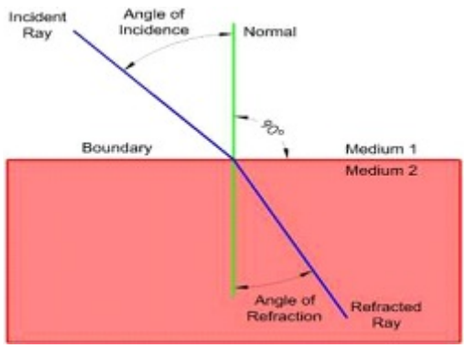
Student Name: _____

REFRACTION

When light rays cross from one material to another they bend. This bending is called refraction. Refraction is a useful phenomenon. All kinds of optics, from glasses to camera lenses to binoculars depend on refraction.

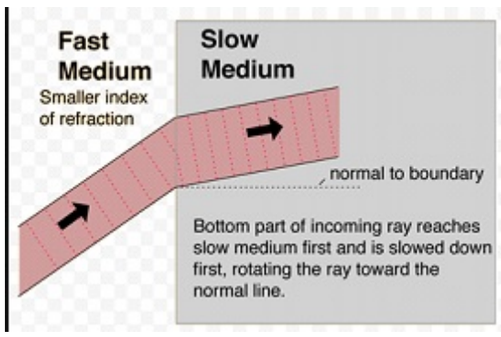
The speed of light in a vacuum is 2.997924 x 10^8 m/s. The speed of light in air is 2.997050 x 10^8 m/s. These speeds are so close that we use 3.00 x 10^8 m/s as the speed of light in both a vacuum and air.

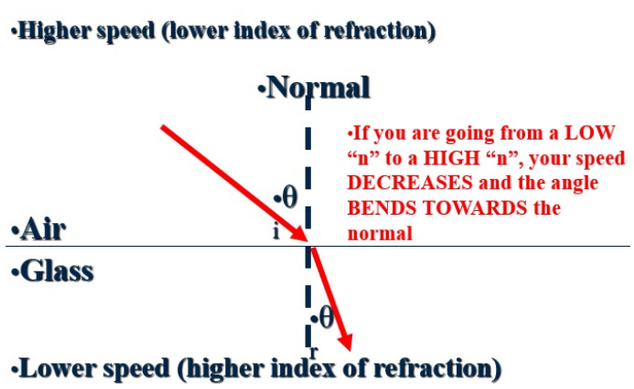
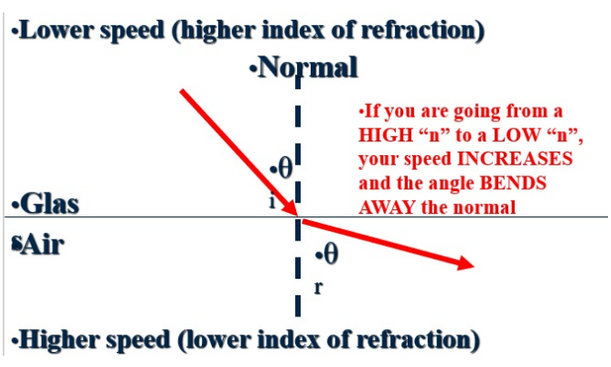
The symbol for the speed of light in a vacuum (or air) is "c". We will use the symbol "v" for the speed of light in any other substance



- The frequency of the waves in both mediums remains the same.
- The speed changes as the waves moves from one medium to another. Hence, if the frequence remains the same, the wavelength must change .

  -speed up, then the wavelength is longer
  -slow down, then the wavelength is shorter



As light travels from a less dense medium to a more Dense medium :The ray bends towards the normal.	As light travels from a more dense medium to a less dense medium -The ray bends away from the normal.
	

Index of Refraction

The Index of refraction is a number that describes how much light slows down when it passes through a certain material. For example, the index of refraction of glass is about 1.5. This means that light travels 1.5 times faster through a vacuum than it does through glass. The index of refraction of air is approximately 1. Light travels through air at just about the same speed as it travels through a vacuum.

Material	Index of Refraction (η)
Vacuum	1.0
Air	1.0001
Water	1.33
Glass	1.5
Diamond	2.42

The Index of refraction is represented by Using the symbol η [greek letter eta] or n. It can be determine by:

Method 1:

Index of refraction for a substance is the ratio of the speed of light (c) in a vacuum or in air to the speed of light v in the substance:

$$\eta = \frac{c}{v} \qquad \text{Or} \qquad n = \frac{c}{v}$$

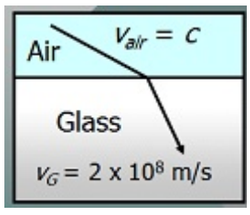
- Note that η has no units because m/s cancel.

Example 1:

The speed of light in a piece of glass called crown glass is 1.97 x 10^8 m / s. What is the index of refraction of crown glass?

Example 2:

What is the speed of light in a diamond if its index of refraction is 2.419?



Method 2:

Index of refraction is defined as "The ratio of the angle of incidence of one medium with respect to the angle of refraction of another medium."

$$\eta = \frac{\sin\theta_i}{\sin\theta_r}$$

where,

θ_i is the Angle of incidence
θ_r is the Angle of refraction

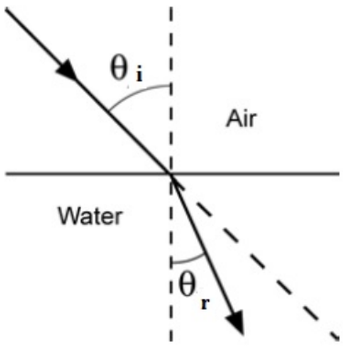
Example 3:

A laser shines from air into a diamond. If the θ_i = 52 and the angle of refraction is 19^0, Calculate the Index of refraction from air to diamond.

Example 4:

A type of diamond has an index of refraction of 2.42 (n_0 = 2.42). If light is incident in air, at 60^0, what will be the angle of refraction?

Which way does the light ray bend?



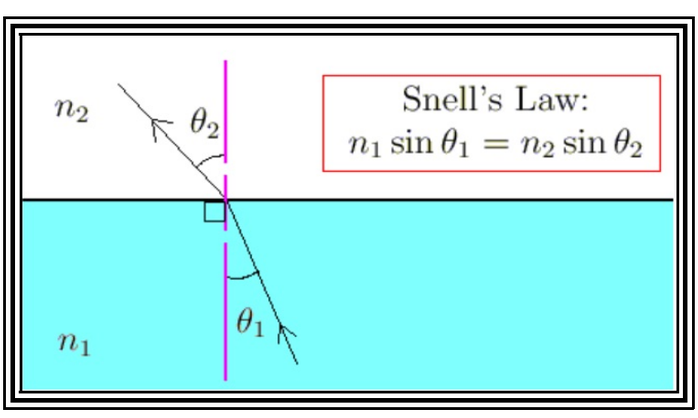
Now let's look at some ray diagrams showing refraction. To make a refraction ray diagram, draw a solid line to show the boundary between the two materials (water and air in this case). Arrows are used to represent the incident and refracted light rays. The normal is a dashed line drawn perpendicular to the boundary between the surfaces. It starts at the point where the incident ray hits the boundary.

As you can see, the light ray is bent toward the normal as it crosses from air into water. Light rays always bend toward the normal when they move from a low-η to a high-η material. The opposite occurs when light rays travel from a high-η to a low-η material. These light rays bend away from the normal. The amount of bending that occurs depends on the difference in the index of refraction of the two materials. A large difference in n causes a greater bend than a small difference

Snell`s Law

Snell's law (also known the law of refraction) is a formula used to describe the relationship between the angles of incidence and refraction, when referring to light or other waves passing through a boundary between two different media, such as water, glass and air.

Like with reflection, refraction also involves the angles that the incident ray and the refracted ray make with the normal to the surface at the point of refraction. Unlike reflection, refraction also depends on the media through which the light rays are travelling. This dependence is made explicit in Snell's Law via refractive indices, numbers which are constant for given media



Example 5:

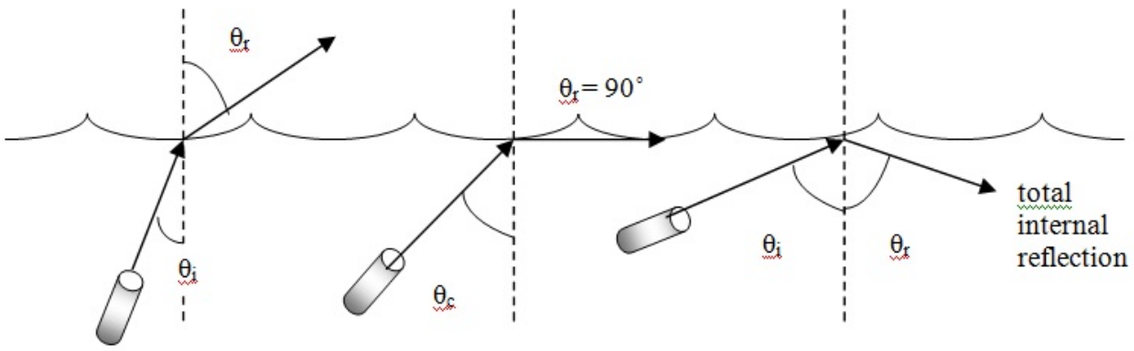
A ray of light is incident from air on a block of glass (η=1.55) at an angle of 53^{O}, calculate the angle of refraction in the block.

Example 6:

A ray of light is incident from a block of diamond (η=2.42) to a block of glass (η=1.55). The angle of incidence is 35^{O}. What is the angle of refraction in the glass?

Total Internal Reflection

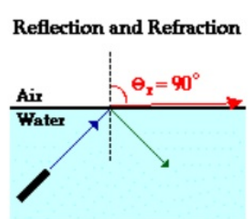
Consider a waterproof laser that you can put under the water and shine a beam of light up out of the water into the air. If you shine the light at a small angle relative to the normal, the light will emerge from the water and bend away from the normal as it enters the air.



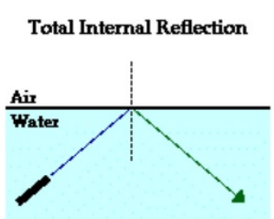
As you increase the angle at which the laser is pointed at the surface of the water, the refracted angle also increases, eventually causing the refracted ray to bend parallel to the surface of the water:

The angle θ_c is called the **critical angle**. Critical Angle refers to when the angle of incidence reaches a critical value, the refracted ray lies along the boundary, having an angle of refraction of 90-degrees. It is the largest angle of incidence for which refraction can still occur.If the laser is pointed at an angle greater than the critical angle, the beam will not emerge from the water, but will reflect back into the water.

This phenomena is called **total internal reflection**. For any angle of incidence greater than the critical angle, light will undergo **total internal reflection.** Total internal reflection, or TIR as it is intimately called, is the reflection of the total amount of incident light at the boundary between two media. The inside surfaces of a glass prism in a pair of binoculars can become like mirrors, reflecting light inside the prism if the light is pointed at the surface at an angle greater than the critical angle. Total internal reflection is the also the principle behind the transmitting of light waves through transparent fiber optic cable for communication purposes.



When the angle of incidence equal the critical angle, the angle of refraction is 90-degrees.



When the angle of incidence is greater than the critical angle, all the light undergoes reflection.

Example 7:

The index of refraction of honey is 1.49. What is the critical angle for a ray of light passing from honey into air?

Example 8:

Find the critical angle for light traveling from glycerine (n = 1.473) into water (n = 1.333).

PART A: MULTIPLE CHOICE

General Instructions

Select the best correct response and shade the appropriate letter on the Scantron card

1. Refraction is the bending of a wave disturbance as it passes at an angle from one ____ into another.

   (A) Area
   (B) Boundary
   (C) Glass
   (D) Medium

2. When light travels from a vacuum into a glass block, its speed

   (A) Decreases
   (B) Increases
   (C) Stays the same
   (D) Not information provided

3. The ____ of light can change when light is refracted because the velocity changes.

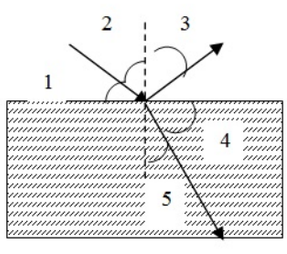
   (A) Frequency
   (B) Medium
   (C) Transparency
   (D) Wavelength

4. Which characteristic of a wave changes as the wave travels across a boundary between two different media?

   (A) Frequency
   (B) Phase
   (C) Speed
   (D) Period

5. A beam of light passes from the air through a thick piece of glass as shown. Which of the following angles is the angle of refraction?

   (A) 1
   (B) 2
   (C) 4
   (D) 5



6. A beam of light passes from air into water. Which of the following statements is true?

(A) The angle of incidence is greater than the angle of refraction in the water
(B) The angle of incidence is less than the angle of refraction in the water
(C) The angle of incidence is equal to the angle of refraction in the water
(D) The frequency of the light decreases

7. When light passes at an angle to the normal from one material into another material in which its speed is lower,

(A) It is bent toward the normal to the surface
(B) It always lies along the normal to the surface
(C) It is unaffected
(D) It is bent away from the normal to the surface

8. When viewed straight down (90° to the surface), an incident light ray moving from the water to air is refracted

(A) Away from the normal
(B) Toward the normal
(C) Not at all
(D) About 49°

9. The index of refraction is based on the ratio of the speed of light in

(A) A vacuum to the speed of light in the transparent material
(B) Air to the speed of light in the transparent material
(C) Two transparent materials
(D) Water to the speed of light in the transparent material

10. The speed of light in a piece of glass is 1.5×10^8 m/s. What is the index of refraction of the glass?

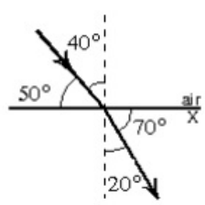
(A) 2.0
(B) 1.5
(C) 0.67
(D) 0.33

11. If the speed of light in a medium is 2.0×10^8 m/s, the index of refraction for the medium is

(A) 2.0
(B) 67
(C) 1.5
(D) 1.0

12. The diagram shows the passage of a ray of light from air into a substance X. What is the index of refraction of X?

(A) 0.53
(B) 0.88
(C) 1.9
(D) 2.2



13. If the angle of incidence of a light ray passing through a pyrex block is 40°, and the angle of refraction is 25.9°, what is the refractive index of pyrex?

(A) 0.68
(B) 0.85
(C) 1.17
(D) 1.47

14. When a light ray moves from air into glass, which has a higher index of refraction, its path is

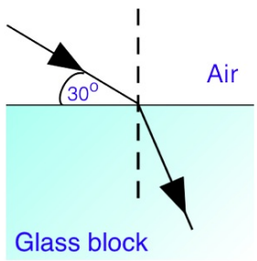
(A) Bent toward the normal
(B) Bent away from the normal
(C) Parallel to the normal
(D) Not bent

15. Snell's Law is also known as

(A) Second law of reflection
(B) Second law of refraction
(C) First law of reflection
(D) First law of refraction

16. A ray of light travels from air into a glass block as shown. It makes an angle of 30° degrees with the surface of the block. If the refractive index of the glass is 1.5, what is the angle of refraction?

(A) 1.30°
(B) 19.47°
(C) 35.26°
(D) 48.59°



17. When a light ray passes from zircon (n = 1.923) into fluorite (n = 1.434) at an angle of 60° , its path is

(A) Bent toward the normal .
(B) Bent away from the normal
(C) Parallel to the normal
(D) Not bent

18. When light is going from a more dense to a less dense medium, the critical angle is the angle of incidence for which the angle of refraction is

(A) 42°
(B) 48°
(C) 51°
(D) 90°

19. If a ray of light is incident upon an air surface at an angle greater then the critical angle, the ray will

(A) Partly refract and partly diffract
(B) Partly refract and partly reflect
(C) Reflect, only
(D) Refract, only

20. The critical angle for a beam of light passing from water into air is 49°. Which of the following statements is true for a beam of light with an incident angle less than the critical angle ?

(A) The beam will all be absorbed
(B) The beam will be totally reflected
(C) The beam will be partially reflected and partially transmitted
(D) The beam will be totally transmitted

21. What is the critical angle for light passing from mineral oil (n=1.47) into water (n=1.33)?

(A) 42.9°
(B) 90°
(C) 64.8°
(D) 25.2°

22. What is the critical angle for light passing from mineral oil (n= 1.47) to air (n=1)?

(A) 42.9^{O}
(B) 90^{o}
(C) 64.8^{o}
(D) 25.2^{o}

23. Total internal reflection occurs when

(A) Light passes from air into water
(B) Light refracts as it exits glass into air
(C) Light reflects off of a mirror
(D) Light passing through glass is reflected inside the glass

24. A mirage is produced because

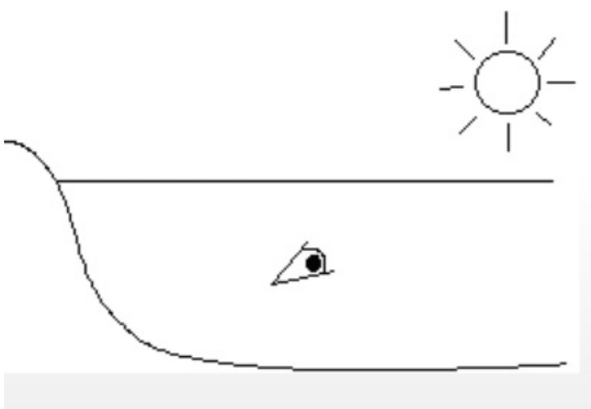
(A) Warm air has a higher index of refraction than cool air
(B) Water from oceans and lakes is highly reflective
(C) Images of water are reflected from the sky
(D) Light travels faster through air than through water

25. The shimmering that is observed over a hot surface is

(A) Heat
(B) Reflections from rising heat
(C) Changing refraction from the mixing of warm and cool air
(D) Mirage

26. How will the sun appear to a scuba diver looking upward through the water at the sun ?

(A) Higher than it actually is
(B) Lower than it actually is
(C) Smaller than it actually is
(D) Larger than it actually is



27. Which of the following is true for the dispersion of light when it passes through a prism?

(A) All colors in the light are treated the same
(B) Different colors have different indices of refraction
(C) The speed of light in a vacuum is a constant
(D) The prism contains many narrow, equally spaced slit

PART B: WRITTEN RESPONSE

1 . A ray of light passes from air into cubic zirconia at an angle of 46.9 to the normal. The angle of refraction is 19.4°. What is the index of refraction of cubic zirconia? Answer is 2.20

2 . A ray of light passes from air (n = 1.000) into ice (n = 1.314) at an angle of 23.7 to the normal. The refracted ray of light then passes from ice into glycerine (n = 1.477). What is the angle of refraction of the ray of light in glycerine? Answer is 15.8 º

3 . A ray of light passes from air into carbon disulfide (n = 1.628) at an angle of 55.6º to the normal. The refracted ray of light then passes from carbon disulfide into water (n = 1.333). What is the refracted angle in the water? .

4. Could the index of refraction for a material ever be less than 1.0? Explain.

5. Explain why the index of refraction for air (a gas) is smaller than the index of refraction for a solid like glass.

6. A light ray moves from water (n = 1.33) to a transparent plastic (polystyrene n = 1.59). Will the light ray bend toward or away from the normal?

7. A light ray moves from sapphire (n = 1.77) to air (n = 1.0001). Does the light ray bend toward or away from the normal?

8. Which light ray will be bent more, one moving from diamond (n = 2.42) to water (n = 1.33), or a ray moving from sapphire (n = 1.77) to air (n = 1.0001)?

9. Calculate the index of refraction for material X if the angle in air is 57° and the refracted angle is 35°

10. Calculate the index of refraction for material X if the angle in air is 34° and the refracted angle is 23°

11. Calculate the index of refraction for material X if the angle in air is 89° and the refracted angle is 55°

12. Light traveling through an optical fiber (n=1.44) reaches the end of the fiber and exits into air. (a) If the angle of incidence on the end of the fiber is 30°, what is the angle of refraction outside the fiber? (b) How would your answer be different if the angle of incidence were 50°?

13. Fused silica has a refractive index of 1.46. Calculate its critical angle. (43.2°) Find the subsequent paths of rays of light incident internally on the surface of fused silica at angles of incidence of:

a) 35°
b) 65°

14. Describe an application of total internal reflection used in the communications industry.

15. Calculate the speed of light in the following media:

a) Flint glass (n = 1.91)

b) Crown glass (n = 1.50)

c) Ethyl alcohol (n = 1.36)

16. Calculate the critical angles for the following refractive indices (assume it is in air).

a) 1.21

b) 1.76

c) 2.43

d) 1.84

17. Snell's Law compares the ratios of the sines of the angles of incidence and refraction. This ratio equals the index of refraction. If a material bends light more, does it slow light down more as well?

18. Determine the speed of light in block B. Assume the light enters from air.