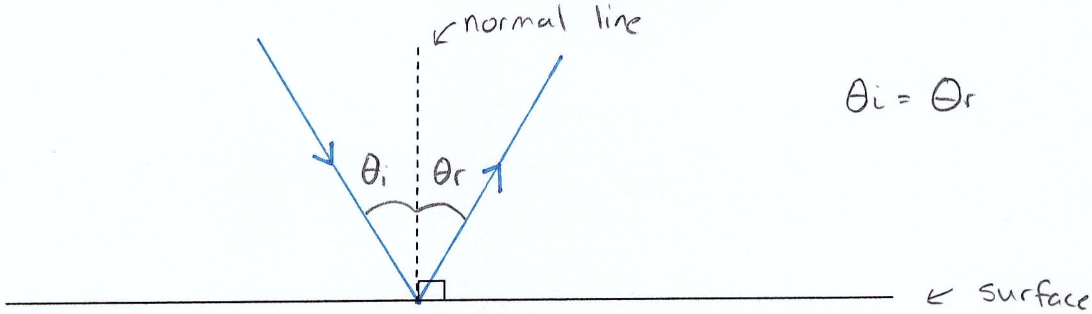
can support both the wave theory & particle theory

Reflection

- The **Law of Reflection** says, "the angle of incidence equals the angle of reflection."
  ↳ initial
  - These angles are always measured from the normal line so that we have a common reference
  - A line drawn 90° to the surface is the **normal line**



Refraction

- **Refraction** is when waves change the direction they are traveling when they go from one medium to another
  ↳ bend slightly
- * Refraction of EMR supports the wave theory of EMR
- The **Law of Refraction** (also known as **Snell's Law**) shows the relationship of how EMR bends as it moves from one medium to another and how the wavelength and speed changes as EMR travels from one medium to another
  - Remember the speed of EMR is constant in the same medium, but will change if the EMR changes media

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$$

only compare two variables at one time!

where
θ is the angle measured from the normal
n is the index of refraction for a specific medium
λ is wavelength of light (m)
v is speed of EMR (usually light) in m/s

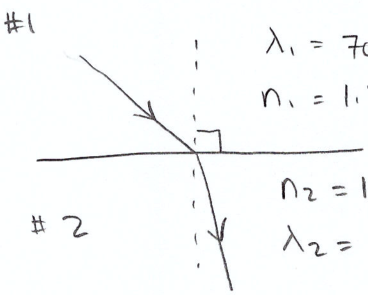
the 1 and 2 subscripts indicate different mediums

- * Notice there is no frequency in Snell's Law. This means that as an EMR wave travels from one medium to another *frequency does not change*

- The **index of refraction** (n) is a way of comparing the *optical density* of different materials
  - *Optical density* is a measurement of how easily light can travel through a medium
  - A low index of refraction (like air n_a = 1.00) is pretty easy to travel through ↗ EMR speeds up
  - A high index of refraction (like diamond n_d = 2.42) is difficult for light to travel through → EMR slows down
  - Index of refraction has no units and is based on a comparison to how light/EMR travels in a vacuum (n_v = 1.00)

EXAMPLES:

1. A beam of red light has a wavelength of 700nm and is travelling through water, which has an index of refraction of 1.33. The beam of light leaves the water and travels into a piece of flint glass with an index of refraction of 1.75.
   a. Determine the wavelength of the light when it is in the flint glass.
   b. Compare the frequency of the incident wave to the refracted wave.



$\lambda_1 = 700nm$

$n_1 = 1.33$

$n_2 = 1.75$

$\lambda_2 = ?$

a.) $\frac{n_2}{n_1} = \frac{\lambda_1}{\lambda_2} \rightarrow \lambda_2 = \frac{\lambda_1 n_1}{n_2}$

$$\lambda_2 = \frac{(700nm)(1.33)}{(1.75)} = 532nm$$

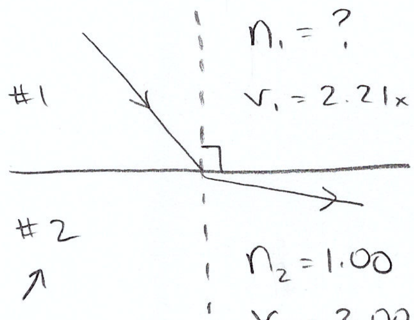
$$\boxed{\lambda_2 = 532nm}$$

b.) $f_1 = f_2$

2. A student is doing a lab and measures the speed of light to be 2.21×10^8 m/s as it travels through a certain substance. Use the table below to determine the identity of the substance.

<u>INDEX OF REFRACTION FOR DIFFERENT MEDIA</u>

Medium	Index of Refraction
Vacuum	1.00
Air	1.00
Water	1.33
Ethanol	1.36
Glycerin	1.47
Quartz	1.54
Diamond	2.42



$n_1 = ?$

$v_1 = 2.21 \times 10^8$ m/s

$n_2 = 1.00$

$v_2 = 3.00 \times 10^8$ m/s

needs to be air b/c we know "n" ∴ "v"

$$\frac{n_2}{n_1} = \frac{v_1}{v_2} \longrightarrow n_1 = \frac{n_2 v_2}{v_1}$$

$$n_1 = \frac{(1.00)(3.00 \times 10^8 \text{ m/s})}{2.21 \times 10^8 \text{ m/s}}$$

$n_1 = 1.357...$

∴ substance is <u>ethanol</u>

Let's go over #19 on page 210 of the work book together.

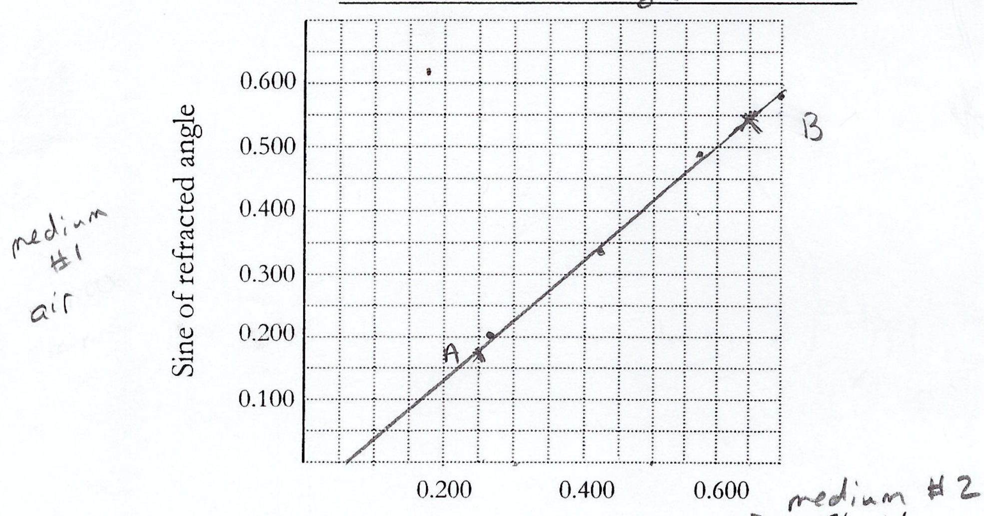
*****Now try pg. 204 #1, 3, 4, 6, 8-10, 13 (acceptable), pg. 204 #2 (do only first row) & pg. 209 #17, 18 (intermediate)*****

19. Aidan sets out to determine the speed of light in a viscous fluid by using the principles of refraction. Using a red pen laser he manipulates the angle of incidence and records the angle of refraction.

Incident angle (degrees)	Sine of incident angle	Refracted angle (degrees)	Sine of refracted angle
15.0	0.2588	12.0	0.2079
25.0	0.4226	20.0	0.3420
35.0	0.5736	28.0	0.4695
45.0	0.7071	36.0	0.5878

a. Determine the sine of the angles and place data in the chart.
b. Plot the sine of the angles.
c. Determine the slope of the line. [~0.864]
d. Use the slope to determine the speed of light in the viscous fluid. [~2.59 x 10^8 m/s]

Sine of Refracted Angle vs. Sine of Incident Angle.



on calculator

$y = ax + b$

$a = 0.8464$

$b = -0.01339$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$

$\sin\theta_2 = \frac{\sin\theta_1 v_2}{v_1}$

$y = m x + b$

$\sin\theta_2 = \left(\frac{v_2}{v_1}\right)\sin\theta_1 + 0$

$v_1 = 3.00 \times 10^8$ m/s

$v_2 = ?$

$\sin\theta_1 = x$

$\sin\theta_2 = y$

$\therefore$ slope $= \frac{v_2}{v_1}$

$v_2 = (\text{slope})\, v_1$

$v_2 = (0.8464)(3.0 \times 10^8 \text{ m/s})$

$v_2 = 2.54 \times 10^8$ m/s

- **Critical Angle:** the angle of the incident ray/wave that causes the refracted ray/wave to be 90° relative to the normal line (ie. the refracted wave will travel along the surface boundary)
  - * This means that the critical angle is the incident angle and the refracted angle will always be equal to 90°
  - * In order for the refracted wave to travel along the boundary surface, the wave must be traveling *from a high* index of refraction *into a lower* index of refraction

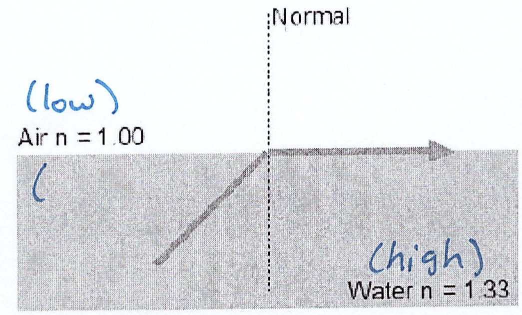


Illustration 3: The incident angle is so big that the refracted ray never truly leaves the water.

- * When the incident ray/wave is at an angle greater than the critical angle, **total internal reflection** occurs
  - Total internal reflection occurs when light gets refracted so much that it becomes trapped within the first medium
  - * Total internal reflection will also occur if the index of the medium increases from that of the critical angle situation
  - * Again, this can only occur when EMR/light goes from a *high* index of refraction to a *low* index of refraction
  - An application of total internal reflection is fiber optics

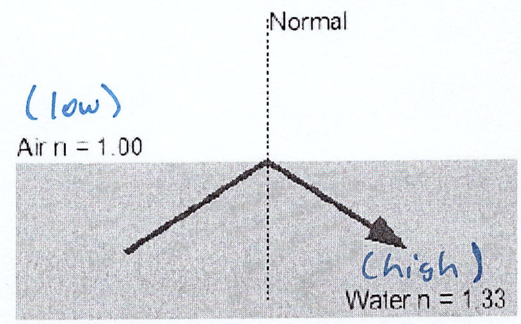
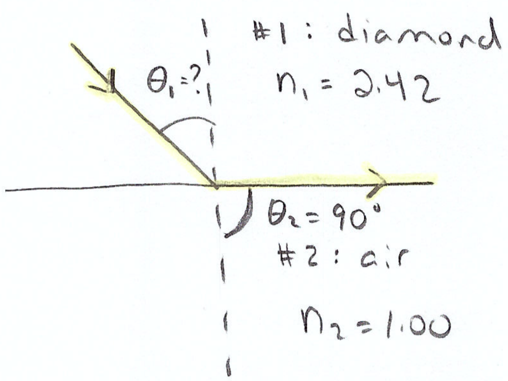


Illustration 4: The angle of incidence is so big that the ray reflects.

EXAMPLES:

1. Calculate the critical angle for the diamond-air boundary if diamond has an index of refraction of 2.42.

*needs to go from high to low!



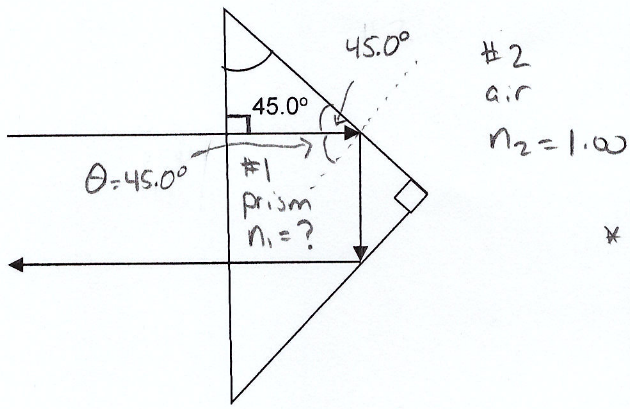
$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} \rightarrow \sin\theta_1 = \frac{n_2 \sin\theta_2}{n_1}$$

$$\sin\theta_1 = \frac{(1.00)\sin(90°)}{2.42} = 0.413223...$$

$$\therefore \theta_1 = \sin^{-1}(0.413223...) = 24.4074...°$$

$\boxed{\theta_1 = 24.4°}$ critical angle

Use the following diagram to answer the next question.



* total internal reflection occuring ∴ index of refraction of prism must be greater than critical angle conditions

2. Find the *minimum* index of refraction the prism needs to be in order for the light to follow the path as indicated in the diagram.

$n_1 = ?$

$n_2 = 1.00$

$\theta_1 = 45.0$

$\theta_2 = 90.0°$ for critical angle conditions

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} \rightarrow n_1 = \frac{n_2 \sin\theta_2}{\sin\theta_1}$$

$$n_1 = \frac{(1.00)\sin(90.0°)}{\sin(45.0°)} = 1.4142...$$

$$\boxed{n_1 = 1.41°}$$

↑ this is the minimum index of refraction; any value greater will result in total internal reflection!

***Now try pg. 211 # 20, 21, 23, 24, 27 (acceptable), pg. 212 # 25 & pg. 244 #7 (excellence)**