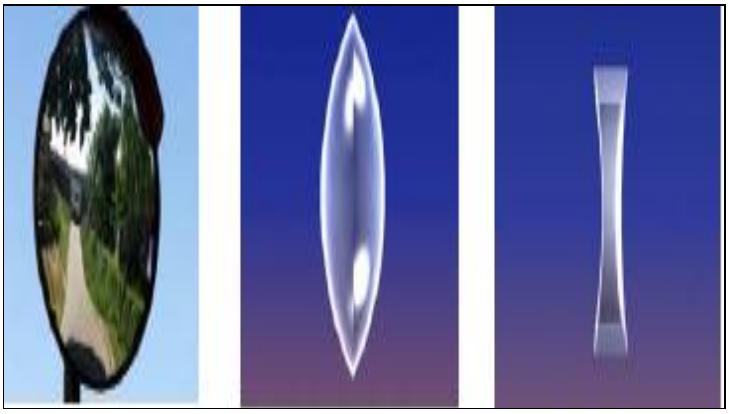
Kirkuk University
Science College
Physics Department

# Lectures of GEOMETRIC OPTICS
# Lecture – 8 –



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# Lecture 8: Refraction and Refraction index-Part 1



## 8-1 The Laws of Refraction

- In this Lecture we will use the ray model of light to explore one of the most important aspects of light propagation: **refraction.**
- When light wave strikes a smooth interface separating two transparent materials such as (air and glass) or(water and glass) , the wave is in general partly reflected and partly refracted into the second material , as shown in Fig.(**8-1**) , that showed the wave can be represented by bundles of rays forming beams of light **.**

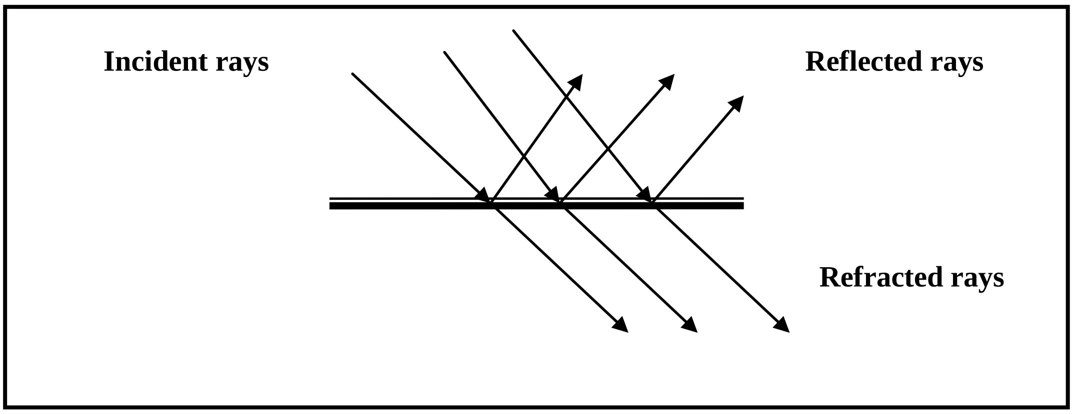


**Fig. (8-1): A plane wave is in part reflected and in part refracted at the boundary between two media**

- For simplicity we often draw only one ray in each beam, as shown in Fig. (**8-2**).

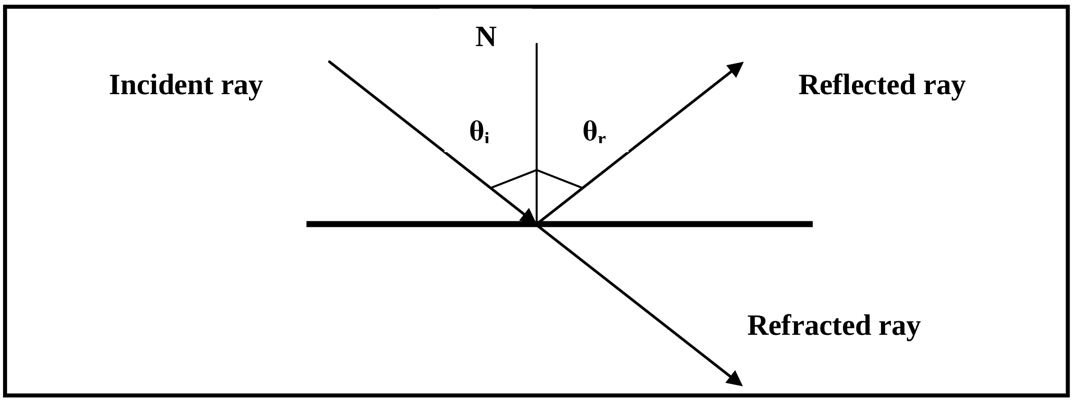


**Fig. (8-2): For simplicity, only one example for an incident ray, a reflected ray and a refracted ray is drawn**

- Experimental studies of the directions of the incident , reflected , and refraction rays at a smooth interface between two optical materials lead to the following **refraction laws :**

**1-** The incident, refracted rays and the normal to the surface all lie in the same plane**.**

**2-** The ratio of the sines of the angles ($\theta_i$) and ($\theta_{re}$) where both angles are measured from the normal to the surface is equal to the inverse ratio of the two indexes of refraction , as represent in Eq. (**8-1a**) and Eq.(**8-1b**) **:**

$$\frac{\sin\theta_i}{\sin\theta_{re}} = \frac{n_2}{n_1} \ldots(8-1a)$$

$$n_1.\sin\theta_i = n_2.\sin\theta_{re} \ldots(8-1b)$$

- This experimental result is called the **Snell's law**, after the Dutch scientist Willebrord Snell (**1591** – **1626**)**.**

## 8-2 Refraction index

- The index of refraction of an optical material (also called the refractive index), denoted by ($n$), plays a central role in geometric optics.
- It is ratio of the speed of light in vacuum ($c$) to the speed of light in the material ($v$) , as represented in Eq.(**8-2**) **:**

$$n = \frac{c}{v} \ldots (8-2)$$

- Light always travels more slowly in a material than in vacuum, so the value of ($n$) in anything other than a vacuum is always greater than unity **.**
- For vacuum, ($n$ **= 1**) **.**
- Since, ($n$) is a ratio of two speeds, it is pure number without units**.**

**CAUTION:**

- Keep in mind that the wave speed ($v$) is inversely proportional to the index of refraction ($n$)**.**
- The greater the index of refraction in a material, the slower the wave speeding that material**.**

 

- When a ray passes from one material (1) into another material (2) having a large index of refraction ($n_2 \succ n_1$) and hence a slower wave speed, hence the ray is bent toward the normal, as shown in Fig. (**8-3a**).
- When the second material has a smaller index of refraction than the first material ($n_2 \prec n_1$) and hence a faster wave speed, the ray is bent away from the normal, as shown in Fig. (**8-3b**).

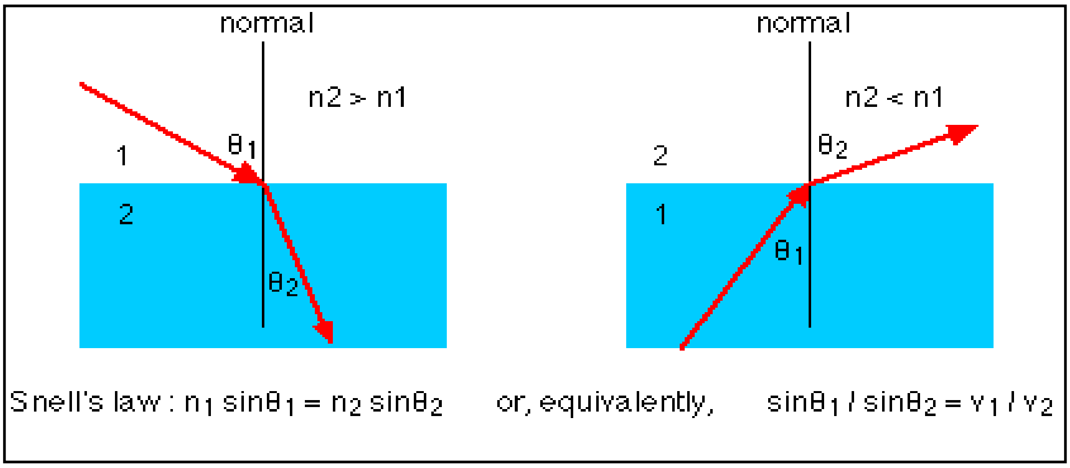


**Figure (8-3): Tow types of refraction**

**8-3 (a) :** $n_2 \succ n_1$ **8-3 (b) :** $n_2 \prec n_1$

**NOTES**:

- The index of refraction depends not only on the substance but also on the wavelength of light.
- The dependence on wave length is called dispersion.
- The index of refraction of a gas increase as its density increase.
- Most glasses used in optical instruments have indexes of refraction between about (**1.5**) and (**2**).
- A few substance have large indexes, one example is diamond, with (**2.417**).

**Example**: The refractive index of water with respect to air is ($\frac{n_{water}}{n_{air}} = 1.33$). The velocity of light in vacuum is ($3x10^8 m/s$). Calculate the velocity of light in water?

**Solution**:

refractive index of water with respect to air is = **1.33**

$$\text{Now, Absolute refractive index of water} = \frac{\text{Velocity of light in vacuum}}{\text{Velocity of light in water}}$$

$$\therefore \text{Velocity of light in water} = \frac{\text{Velocity of light in vacuum}}{\text{Absolute refractive index of water}}$$

$$\therefore \text{Velocity of light in water} = \frac{3 \times 10^8}{1.33}$$

$$\therefore \text{Velocity of light in water} = \boxed{2.25 \times 10^8 \text{ m/s}}$$

**Example:** If the incident ray of light makes an angle of ($60^\circ$) with normal when passing from water with index of refraction ($1.33$), to glass with index of refraction ($1.52$) **.**Find**:**

**1-** The angle of reflected ray**?**

**2-** The angle of refracted ray**?**

**Solution:**

**1-** To find the angle of reflected ray**:**

$$\theta_r = \theta_i$$

$$\boxed{\theta_r = 60^\circ}$$

**2-** To find the angle of refracted ray**:**

$$n_1 . \sin\theta_i = n_2 . \sin\theta_{re}$$

$$(1.33). \sin 60^\circ = (1.52). \sin\theta_{re}$$

$$\sin\theta_{re} = \frac{(1.33)}{(1.52)} \sin 60^\circ$$

$$\sin\theta_{re} = \frac{(1.33)}{(1.52)} .(0.86)$$

$$\sin\theta_{re} = 0.75$$

$$\boxed{\theta_{re} = 48.59^\circ}$$

## Exercises about Refraction and Refraction index-Part 1

**$Q_1$**: A ray of light enters from water to glass .Refractive index of glass with respect to water is $(1.12)$. Find absolute refractive index of water if absolute refractive index of glass is $(1.5)$?

**Answer:** $(n_{water} = 1.33)$

**$Q_2$**: Rays of light are entering from glass to glycerin .If the absolute refractive index of glass is $(1.5)$ and that of glycerin is $(1.47)$ then find the refractive index of glycerin with respect to glass.

**Answer:** $(n = 0.98)$

**$Q_3$**: A swimmer lights a torch under sea water .Light from the torch is incident on water surface in such a way that incident light makes an angle of $(37^\circ)$ with water surface. Find the angle of refraction if absolute refractive indices of water and air are $(1.33)$ and $(1.0)$ respectively.

**Answer:** $(\theta_{re} = 53^\circ)$

**$Q_4$**: Rays of light are entering from air to water. If the angle of incidence at the surface separating two mediums is $(70^\circ)$, find the angle of refraction of light in water. Absolute refractive index of water is $(1.33)$.

**Answer:** $(\theta_{re} = 44.95^\circ)$