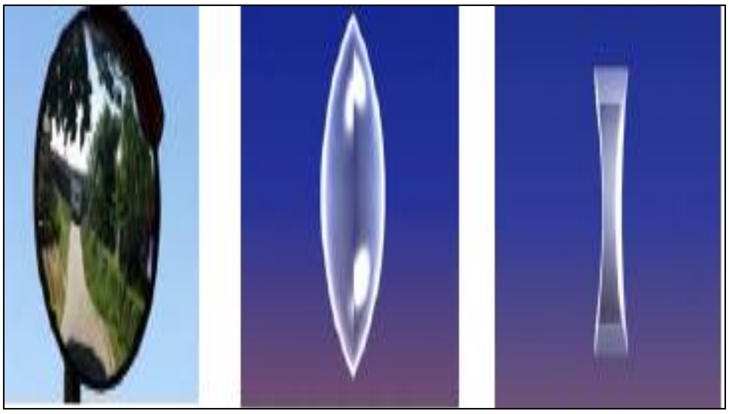
Kirkuk University
Science College
Physics Department

Lectures of GEOMETRIC OPTICS
Lecture – 9 –



Assistant professor Dr.Jawdet Hedayet Mohammed
Lecturer in Kirkuk University
Science College – Physics Department

Lecture 9: Refraction and Refraction index-Part 2

9 – 1 Index of Refraction and the wave Aspects of Light
9 – 2 Total internal reflection

9-1 Index of Refraction and the wave Aspects of Light

- We have discussed how the direction of a light ray changes when it passes from one material to another with a different index of refraction.
- It is also important to see what happens to the wave characteristics of the light when this happens.
- **First**, the frequency of the wave (f) does not change when passing from one material to another.
- **Second**, the wavelength of the wave (λ) is different in general in different materials.
- This is because in any material the relationship the wave speed (v) , length (λ), frequency (f) is given as Eq.(**9-1**) **:**

$$v = \lambda . f ...(9-1)$$

- Since the frequency (f) is the same in any material as in vacuum, and the wave speed in any material (v) is always less than the wave speed in vacuum (c), then the wave length (λ) is also correspondingly reduced.
- Thus the wavelength of light in material (λ) less than the wavelength of the same light in vacuum ($\lambda_\circ$).

- From the above discussion , we obtained Eq.(**9-2**) **:**

$$f = \frac{c}{\lambda_\circ} = \frac{v}{\lambda} ...(9-2)$$

- Combining Eq.(**9.2**) with Eq.(**8.2**) ($n = \frac{c}{v}$) we find that the length of light in a material is given as Eq.(**9-3**) **:**

$$\lambda = \frac{\lambda_\circ}{n} ...(9-3)$$

- When a wave passes from one material (a) into a second material (b) with larger index of refraction so that ($n_b \succ n_a$), the wave speed decrease**.**
- The wavelength in the second material ($\lambda_b = \frac{\lambda_\circ}{n_b}$) is then shorter than the wavelength in the first material ($\lambda_a = \frac{\lambda_\circ}{n_a}$)**.**
- If instead the second material (b) has a smaller index of refraction than the first material (a), so that ($n_b \prec n_a$), then the wave speed increase**.**
- Then the wavelength in the second material (λ_b) is longer than the wavelength in the first material (λ_a)**.**
- This make intuitive sense, the wavelength gets shorter if the wave speed decrease, and the wavelength gets longer if the speed increase**.**

Example: The wavelength of the red light from a helium – neon laser is ($633nm$) in air but ($474nm$) in the certain material**.** Calculate**:**

1- The index of refraction of the material**?**

2- The speed of the light in this substance**?**

3- The frequency of the light in this substance**?**

Solution:

1- To calculate the index of refraction of the material**:**

$$\lambda = \frac{\lambda_\circ}{n} \qquad \Rightarrow n = \frac{\lambda_\circ}{\lambda}$$

$$n = \frac{(633nm)}{(474nm)} \qquad \boxed{\Rightarrow n = 1.34}$$

2- To calculate the speed of the light in this substance**:**

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

$$v = \frac{(3x10^8\, m/s)}{(1.34)} \qquad \boxed{\Rightarrow v = 2.24x10^8\, m/s}$$

3- To calculate the frequency of the light in this substance**:**

$$v = \lambda . f \qquad \Rightarrow f = \frac{v}{\lambda}$$

$$f = \frac{(2.24x10^8\, m/s)}{(474x10^{-9}\, m)} \qquad \boxed{\Rightarrow f = 4.73x10^{14}\, Hz}$$

9-2 Total internal reflection

- We have described how light is partially reflected and partially transmitted at an interface between two materials with different indexes of refraction.
- Under certain circumstances, however, all of the light can be reflected back from the interface, with none of it being transmitted, even though the second material is transparent.
- Several rays are shown in Fig.(**9-1**) radiating from a point source in material (**1**) with index of refraction (n_1).
- The rays strike the surface of a second material (**2**) with index (n_2), where ($n_1 \succ n_2$) .
- For instance, materials (**1**) and (**2**) could be water and air, respectively.
- The angle of incidence for which the refracted ray emerges tangent to the surface is called the **critical angle**, denoted by (θ_c), as shown Fig. (**9-1**).
- The angle of incidence of a ray for which the angle of refraction is 90° is called **critical angle.**
- Beyond the critical angle, the ray cannot pass the upper material; it is trapped in the lower material and is completely reflected at the boundary surface.
- This situation called **total internal reflection**, as shown in Fig. (**9-1**), occurs only when a ray is incident on the interface with a second material whose index of refraction is smaller than that of the material in which the ray is traveling.

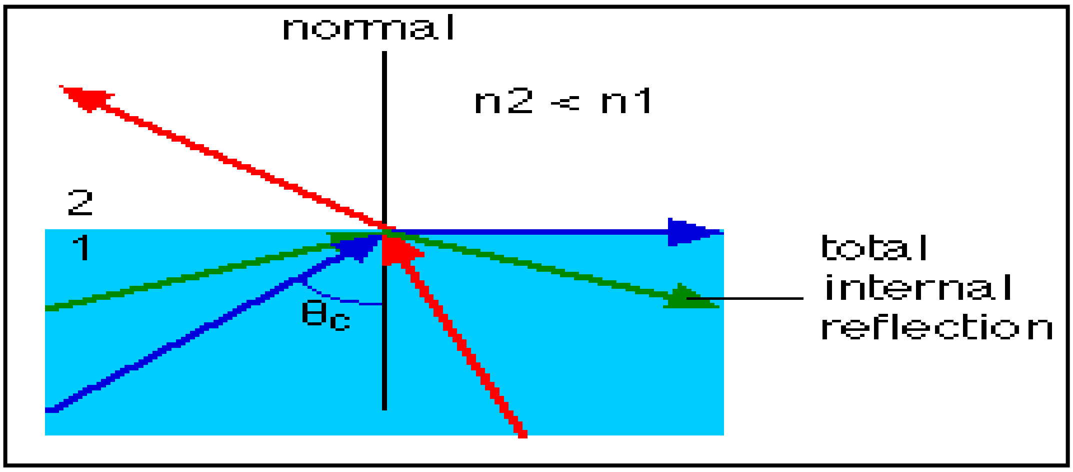


Figure (9-1) : Total internal reflection

- We can find the critical angle for two given materials by setting (θ_{re} **= 90**$^\circ$) , ($\sin\theta_{re}$ = 1) in Snell's law , we then have **:**

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

$$\Rightarrow n_1 \sin\theta_c = n_2(1) \; n_1 \sin\theta_c = n_2 \sin 90^\circ$$

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$\therefore \theta_c = \sin^{-1}\frac{n_2}{n_1} \ldots(9-4)$$

- Total internal reflection will occur if the angle of incidence (θ_i) is greater than the critical angle (θ_c)**.**

Example: Calculate the critical angle for the glass-air boundary, if absolute refractive indices of glass and air are (1.52) and (1.0) respectively**.**

Solution:

$$\because \theta_c = \sin^{-1}\frac{n_2}{n_1} \qquad \Rightarrow \theta_c = \sin^{-1}\frac{1}{1.52}$$

$$\therefore \theta_c = 41.1^\circ$$

Exercises about Refraction and Refraction index-Part 2

Q$_1$: Calculate the critical angle for the diamond-air boundary, if absolute refractive indices of diamond and air are (2.42) and (1.0) respectively**. Answer:** $(\theta_c = 24.39^\circ)$

Q$_2$: Determine the critical angle for the following boundaries**:**

a. glass $(n = 1.52)$ - air $(n = 1)$**. Answer:** $(\theta_c = 41.15^\circ)$
b. diamond $(n = 2.42)$ - glass $(n = 1.52)$**. Answer:** $(\theta_c = 38.90^\circ)$

Q$_3$: The critical angle for a certain liquid - air- surface is (44.7°)**.** What is the index of refraction of the liquid, if absolute refractive index of air is (1.0)**. Answer:** $(\theta_c = 1.42^\circ)$

Q$_4$: If the critical angle for internal reflection inside a certain transparent material is found to be (48°) , what is the index of refraction of the material**?** (Air is outside the material)**. Answer:** $(\theta_c = 1.35^\circ)$

Q$_5$: Light moving from certain material to air changes wavelength from $(452nm)$ to $(633nm)$**.** Calculate**:**

1- What is the index of refraction of the material**?**

Answer: $(n_{material} = 1.40)$

2- What is the speed of light in the material**?**

Answer: $(v_{material} = 2.14x10^8 m/s)$

3- What is the frequency of the light in the material**?**

Answer: $(f_{material} = 4.73x10^{14} Hz)$

4- What is the frequency of the light in air**?**

Answer: $(f_{air} = 4.73x10^{14} Hz)$