1.1. Refraction

- Definition – is defined as *the changing of direction of a light ray and its speed of propagation as it passes from one medium into another.*
- Laws of refraction state :
  - The incident ray, the refracted ray and the normal all lie in the same plane.
  - For two given media,

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = \text{constant}$$

Or

$$n_1 \sin i = n_2 \sin r$$

Snell's law

where

i : angle of incidence

r : angle of refraction

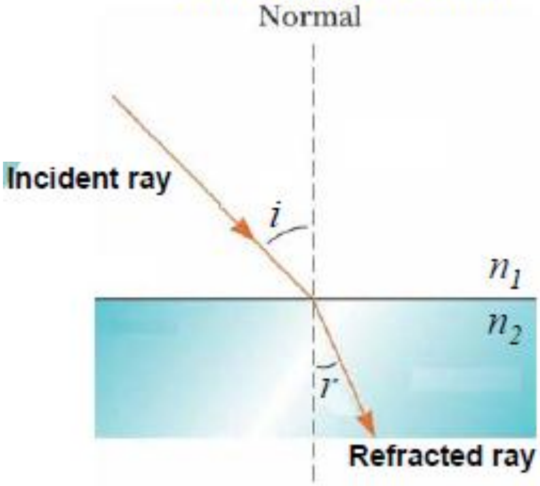
n_1 : refractive index of the medium 1 (Medium containing the incident ray)

n_2 : refractive index of the medium 2 (Medium containing the refracted ray)

- Examples for refraction of light ray travels from one medium to another medium can be shown in figures below.

(a) $n_1 < n_2$

(Medium 1 is less dense than medium 2)

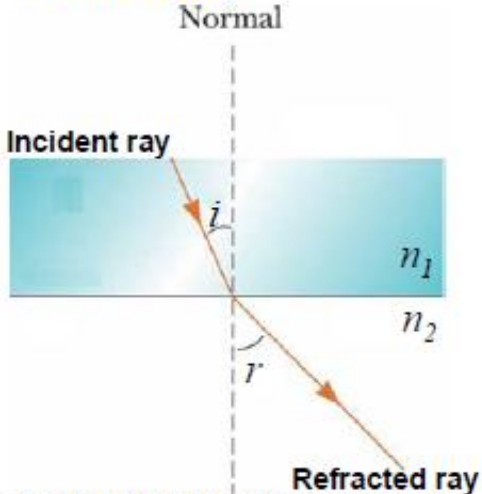


The light ray is bent toward the normal, thus

$$r < i$$

(b) $n_1 > n_2$

(Medium 1 is denser than medium 2)



The light ray is bent away from the normal, thus

$$r > i$$

- Refractive index (**index of refraction**)
  - Definition – is defined as *the constant ratio* $\frac{\sin i}{\sin r}$ *for the two given media.*
  - The value of refractive index depends on the type of medium and the colour of the light.
  - It is dimensionless and its value greater than 1.
  - Consider the light ray travels from medium 1 into medium 2, the refractive index can be denoted by

$$ {}_1n_2 = \frac{\text{velocity of light in medium 1}}{\text{velocity of light in medium 2}} = \frac{v_1}{v_2} $$

(Medium containing the incident ray) – subscript 1

(Medium containing the refracted ray) – subscript 2

  - Absolute refractive index, n (for the incident ray is travelling in **vacuum or air** and is then refracted into the **medium concerned**) is given by

$$ n = \frac{\text{velocity of light in vacuum}}{\text{velocity of light in medium}} = \frac{c}{v} $$

- The relationship between refractive index and the wavelength of light.
  - As light travels from one medium to another, its **wavelength, λ changes** but its **frequency, f remains constant**.
  - The wavelength changes because of **different material**. The frequency remains constant because the number of wave cycles arriving per unit time must equal the number leaving per unit time so that the boundary surface **cannot create or destroy waves**.
  - By considering a light travels from medium 1 (n_1) into medium 2 (n_2), the velocity of light in each medium is given by

$$ v_1 = f\lambda_1 \quad \text{and} \quad v_2 = f\lambda_2 $$

then

$$ \frac{v_1}{v_2} = \frac{f\lambda_1}{f\lambda_2} \quad \text{where} \quad v_1 = \frac{c}{n_1} \quad \text{and} \quad v_2 = \frac{c}{n_2} $$

$$ \frac{\left(\frac{c}{n_1}\right)}{\left(\frac{c}{n_2}\right)} = \frac{\lambda_1}{\lambda_2} \implies n_1\lambda_1 = n_2\lambda_2 $$

(Refractive index is inversely proportional to the wavelength)

- If medium 1 is vacuum or air, then n_1 = 1. Hence the refractive index for any medium, n can be expressed as

$$n = \frac{\lambda_0}{\lambda}$$

where

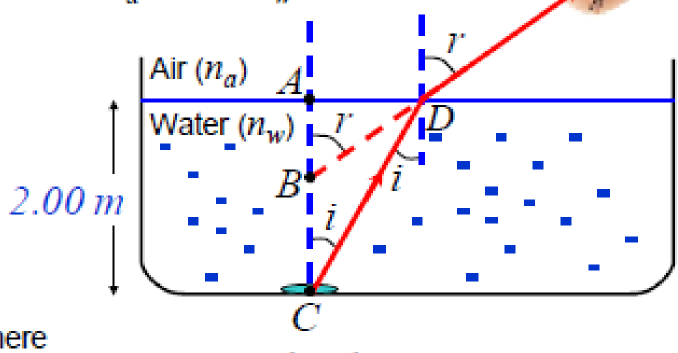
λ_0 : wavelength of light in vacuum

λ : wavelength of light in medium

- **Example 1 :**

A fifty cent coin is at the bottom of a swimming pool of depth 2.00 m. The refractive index of air and water are 1.00 and 1.33 respectively. What is the apparent depth of the coin?

<u>Solution</u>: $n_a=1.00,\ n_w=1.33$



where

AB : apparent depth

AC : actual depth = 2.00 m

From the diagram,

$\triangle$ABD ⟹ $\tan r = \dfrac{AD}{AB}$

$\triangle$ACD ⟹ $\tan i = \dfrac{AD}{AC}$

By considering only small angles of r and i , hence

$\tan r \approx \sin r$ and $\tan i \approx \sin i$

then

$$\frac{\tan i}{\tan r} = \frac{\sin i}{\sin r} = \frac{\left(\frac{AD}{AC}\right)}{\left(\frac{AD}{AB}\right)} = \frac{AB}{AC}$$

From the Snell's law,

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = \frac{n_a}{n_w}$$

$$\frac{AB}{AC} = \frac{n_a}{n_w}$$

$$AB = 1.50\ m$$

Note : (Important)

Other equation for absolute refractive index in term of depth is given by

$$n = \frac{\text{real depth}}{\text{apparent depth}}$$

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