REFRACTION

Refraction is defined as the apparent change in the direction of a (light) wave when it travels from one medium to another.

During refraction, **frequency remains unchanged** but the **direction, velocity and wavelength all change**. Optical density increases from gases (air) to liquid (water) and to solids (glasses)

The following equation shows the optical densities relation of the following objects

$$Gas(air) < Liquid(Water) < Solid(Glass)$$

When light travels from a less dense medium to a denser medium, like from gas to liquid or liquid to solid or gas to solid, the light bends towards the normal. However, if the light travels from a denser medium to a less dense medium, it bends away from the normal.

The refraction of the light depends on the index of refraction of the media. Index of refraction or refractive index, n, of a medium is the ratio of the speed of light in a vacuum (c) to the speed of light in the medium (v)

$$n=\frac{c}{v}=\frac{f\lambda_a}{f\lambda_m}=\frac{\lambda_a}{\lambda_m}$$

LAWS OF REFRACTION

1. The incident ray, refracted ray and the normal all lie on a common point. The incident ray is the angle the ray makes with the normal.

2. The ratio of the sine of the incident ray to the sine of the refraction angle is equal to the ratio of the refractive indices of the materials at the interface and is constant for any given pair of media. This statement is known as **Snell's law**.

The angle that the incident ray makes with the normal is called the angle of incidence

Let the refractive index of medium A be n_A and let the refractive index of medium "B" be n_B

If the light is incident at medium A and is refracted at medium B, let the angle of incident (at medium A) be $\theta_A$and the angle of refraction be θ_B

From Snell's law,

$$\frac{\sin\theta_A}{\sin\theta_B}=\frac{n_B}{n_A}$$

$$n_A\sin\theta_A=n_B\sin\theta_B$$

Let n be a constant known as the refractive index (of the second medium with respect to the first) or the absolute refractive index

We have

$$n = \frac{n_B}{n_A}$$

Therefore,

$$n = \frac{\sin\theta_A}{\sin\theta_B}$$

The refractive index (n) of a medium can also be defined as the ratio of the velocity of light in air to the velocity in that medium

$$n = \frac{v_{air}}{v_{medium}}$$

But

$$v = f\lambda$$

$$n = \frac{(f\lambda)_{air}}{(f\lambda)_{medium}}$$

Since in refraction, frequency remains unchanged, that means it is constant

$$n = \frac{f(\lambda_{air})}{f(\lambda_{medium})}$$

Therefore,

$$n = \frac{\lambda_{air}}{\lambda_{medium}}$$

REFRACTIVE INDEX OF A LIQUID

When a metallic coin is in a beaker of water, the coin appears to be (displaced) above its normal level when viewed vertically from above (the beaker of water). Similarly, a swimming pool appears to be shallow when viewed from vertically above the pool. All these effects are due to the refraction of light in the water.

The distance between the top of the liquid (water) and the real position of object (in the liquid) is called the Real depth (R). The distance between the top of the liquid and the where it appears to be (i.e. its apparent position) is called the apparent depth (A). The distance between the real depth and the apparent depth is called the displacement (d).

The refractive index of the liquid is defined as the ratio of the real depth to the apparent depth

$$n=\frac{R}{A}$$

$$d=R-A$$

$$R=A+d$$

$$A=R-d$$

Since

$$n=\frac{R}{A}$$

$$n=\frac{R}{R-d}$$

$$R=n(R-d)$$

$$R=nR-nd$$

$$nd=nR-R$$

$$nd=R(n-1)$$

$$d=\frac{R(n-1)}{n}$$

CRITICAL ANGLE AND TOTAL INTERNAL REFLECTION

When a ray of light travels from a denser medium to a less dense medium, the ray bends away from the normal; as the angle of incidence increases, there is also an increase in the angle of refraction.

The largest angle of incidence that will give a maximum angle of refraction is called the critical angle.

The largest angle of refraction is 90 degrees

Critical angle can now be defined as the highest incident angle (which produces the highest angle of refraction) below which light rays can escape from an optically denser medium to a less dense medium.

If the angle of incidence becomes greater than the critical angle, there will be no more refraction but a strong reflection call Total Internal Reflection

CONDITIONS FOR TOTAL INTERNAL REFLECTION

1. Light must travel from an optically denser medium to a less dense medium
2. The incident angle must be greater than the critical angle.
3. The relationship between the critical angle (c) and the refractive index (n) is expressed as

$$\sin c = \frac{1}{n}$$

$$n = \frac{1}{\sin c}$$

MIRAGE

This happens when the ground is very hot and the air is cool. The hot ground warms a layer of air just above the ground and makes it optically less dense than the cool air above it. When light moves through the cold air into the layer of hot air it is refracted. A layer of very warm air near the ground refracts the light from the sky nearly into a U-shaped bend.

Mirage is caused by the total internal reflection of light at layers of air of different densities and the sky which looks like a pool of water when viewed from a distance is produced.