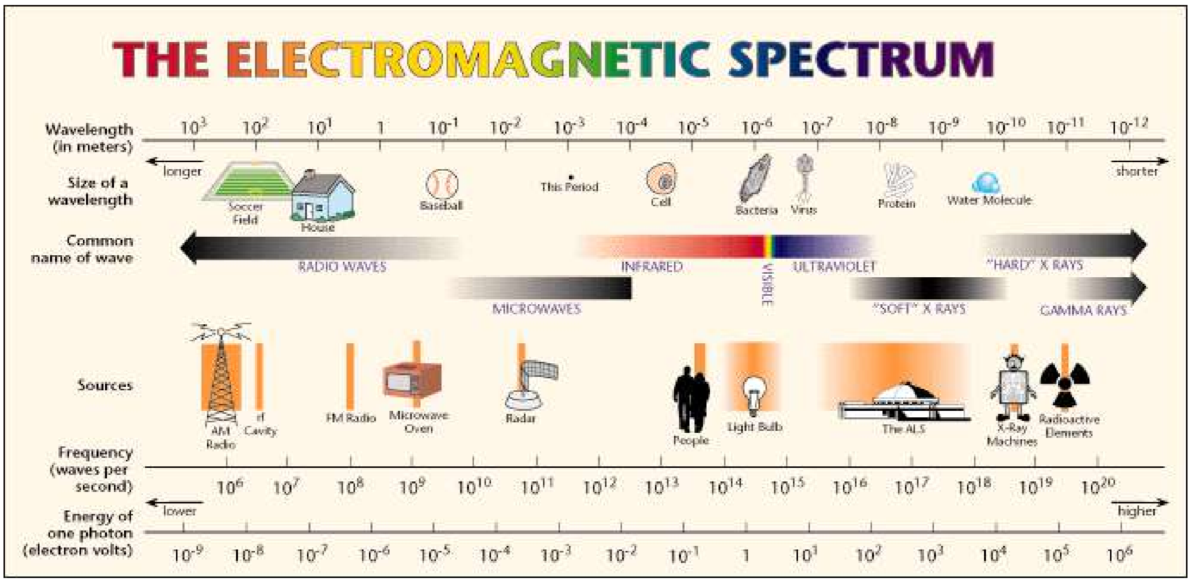
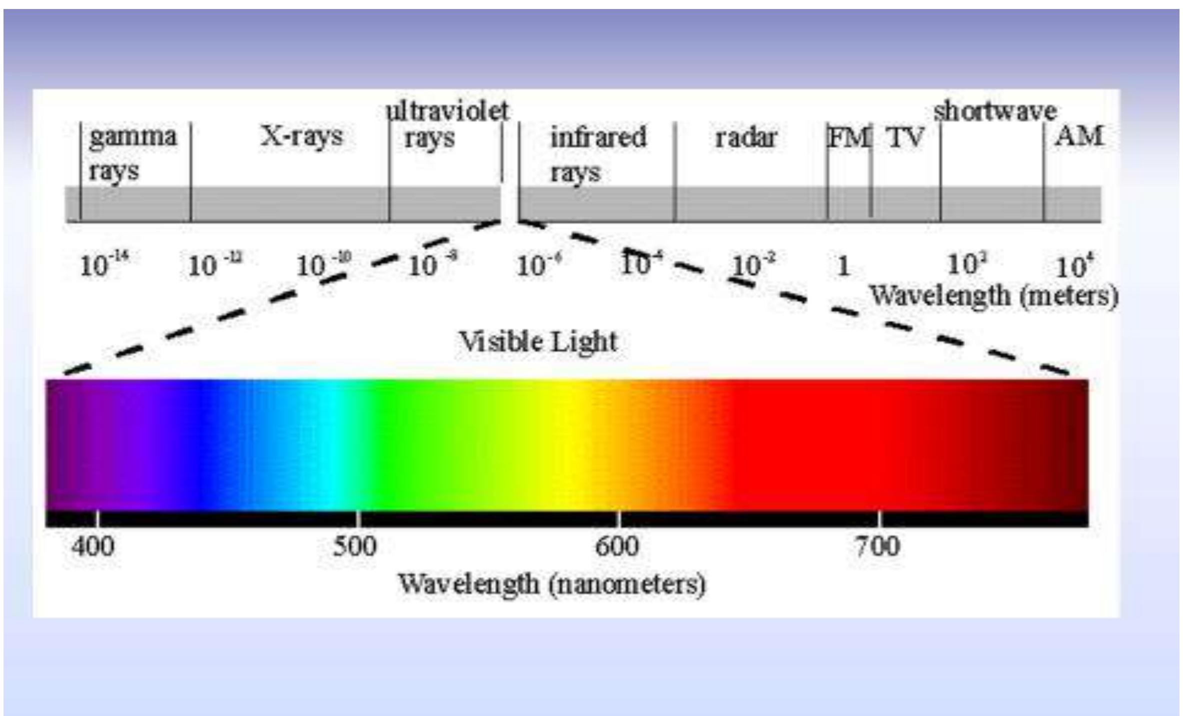
The Electromagnetic Spectrum

The electromagnetic spectrum encompasses a continuous range of frequencies or wave lengths of electromagnetic, ranging from long wave length, low energy radio waves to short wave length, high frequency, and high energy gamma rays.

The electromagnetic spectrum is traditionally divided into regions of radio waves, microwaves, infrared radiation, visible light, ultraviolet rays, x-rays and gamma rays.





	Region of the spectrum	Main interactions with matter & Use
1.	Radio	Collective oscillation of charge carriers in bulk material. Waves generally are utilized by antennas .They are used for transmission of data, via modulation. Television, mobile phones, wireless networking
2.	Microwave	Molecular rotation. As in a microwave oven, this effect is used to heat food.
3.	Infrared	Molecular vibration. Infrared waves are discernible to humans as thermal radiation (heat).
	Region of the spectrum	Main interactions with matter & Use
4.	Visible	Molecular electron excitation (including pigment molecules found in the human retina).
5.	Ultraviolet	Excitation of molecular and atomic valence electrons, Ultraviolet radiation is a common cause of sunburn even when visible light is obscured or blocked by clouds .
6.	X-rays	Excitation and ejection of core atomic electrons. X rays are a highly energetic region of electromagnetic radiation. The ability of x rays to penetrate skin and other substances

		renders them useful in both medical and industrial radiography.
7.	**Gamma rays**	**Excitation of atomic nuclei, including dissociation of nuclei Gamma rays are generated by nuclear reactions (e.g., radioactive decay, nuclear explosions, etc.).**

Velocity Of Light

The magnitude of the velocity of light in free space is one of the fundamental constants of nature, the velocity of light is so great (3*10ˆ8 m / sec).

The velocity of light is important because it is through that nothing can travel at a speed greater than speed of light in vacuum(c), speed of light decreases when it enters a denser medium.

The frequency of light is the number of waves that pass a point in space during any time interval usually on second. The frequency of a light is determined by the period of the oscillations.

We measure it in units of cycles (waves) per second or hertz. The frequency does not normally change as the way travels through different materials (media), but the speed of the wave depends on the medium.

The speed, frequency, and wave length of a wave are related by the formula

$$V = \lambda \times f$$

Where:

v is the velocity of light in medium(m/sec),

λ is the wavelength (m),

f is the frequency (HZ).

Because the frequency is fixed, a change in the waves speed produces a change in the wavelength.

The relation between Frequency & Energy

In 1900, Planck discovered that there was a direct relationship between a photon's frequency and its energy:

$$E = h\,f$$

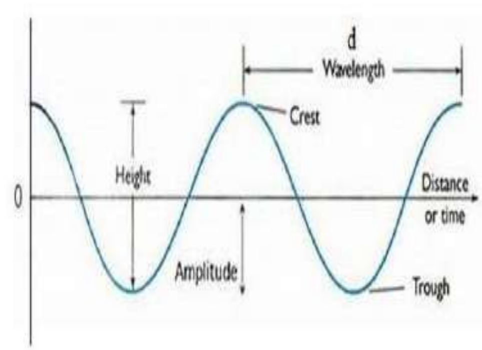
The higher the frequency of light, the higher its energy. We know from the problems above that higher frequencies mean shorter wavelengths. We can also say that:

$$E = h\,c/\lambda \text{ (lambda)}$$

High frequency light has short wavelengths and high energy. X-rays or gamma-rays are examples of this. Radio waves are examples of light with a long wavelength, low frequency, and low energy.

$C = 3\times10^{8}$ m/sec , $h = 6.63\times10^{-34}$ joul.sec

The Amplitude: **The measurement of the wave from the center, or equilibrium point to the highest point (the top of the peak), so amplitude tells you about the intensity of the light.**



The Frequency: **The frequency is defined as the number of wave cycles that pass a particular point per unit time, and is commonly measured in Hertz (cycles per second) .**

$$f = c/\lambda$$

The Wavelength Of Light

Defines the distance between adjacent points of the electromagnetic wave that are in equal phase.

Unites used to measure the wavelength

Its unit is meter. A nanometer (10^{-9})m and Angstrom (A◦)are the most common unit used for characterizing the wavelength of visible light where :

Nanometer) 1nm= (10^{-9} m= 10^{-7}cm= 10A,°

Angstrom (1 A°) = 10^{-10} m = 10^{-8} cm

Q/ Planck's constant is 4.136 x 10-15 eV sec. What is the frequency of light that has an energy of 12.5 keV? (Hint: 1 keV = 1000 eV)

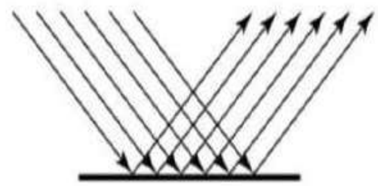
Q/ what is the frequency of the X-ray of wave length 3 A° .

The reflection

The reflection is rays that travel back in the direction from which the incident rays came. Reflections can be divided into two types:

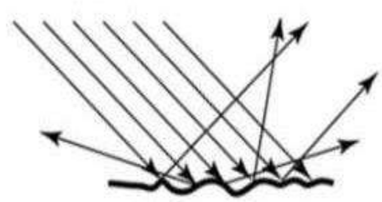
- **Undiffused (Regular, Specular) reflection**
- **Diffuse (irregular) reflection**

- Regular reflection which describes glossy surfaces such as mirrors, which reflect light in a simple, predictable way, this allows for production of reflected images, actual (real) or (virtual) location in space.



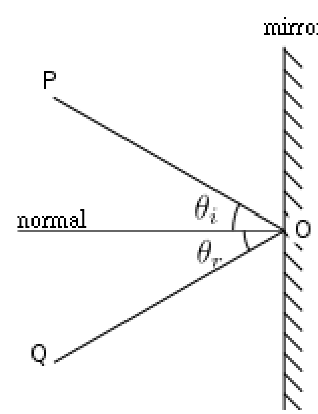
Specular reflection (smooth surfaces)

- Irregular reflection :This describes rough surfaces, such as paper or rock.



Diffuse reflection (rough surfaces)

- Angle of incident: The angle between the incident rays and the normal, a line perpendicular to the surface at the point where the ray hits.
- Angle of reflection: The angle between the reflected rays and the normal.



Law of Reflection

The two laws of reflection are:

- ✓ The incident and reflected rays lie in a single plane
- ✓ The angle between the reflected ray and the surface normal is the same as that between the incident ray and the normal.

Mirrors

The mirror is highly reflecting smooth surface

Types of mirrors :-

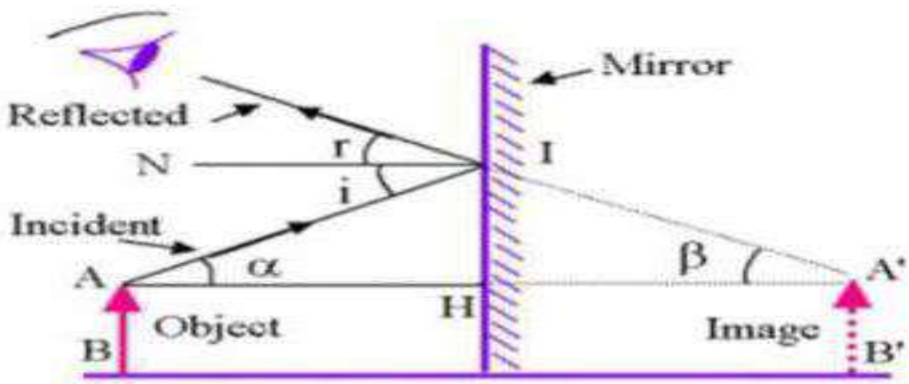
- plane mirror
- spherical mirror , can be divided into two types:
  - concave mirror
  - convex mirror

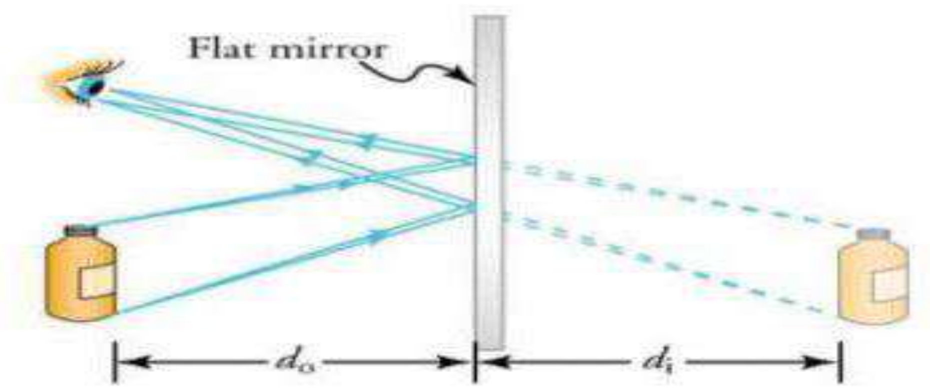
- plane mirror

Plane mirror is simply mirror with a flat surface, all of as use plane mirrors every day.

Properties of the image formed by plane mirror:

1. **Virtual**
2. **Upright**
3. **Left-Right reversed**
4. **The same distance from the mirror as the objects distance.**
5. **Same size as the object.**



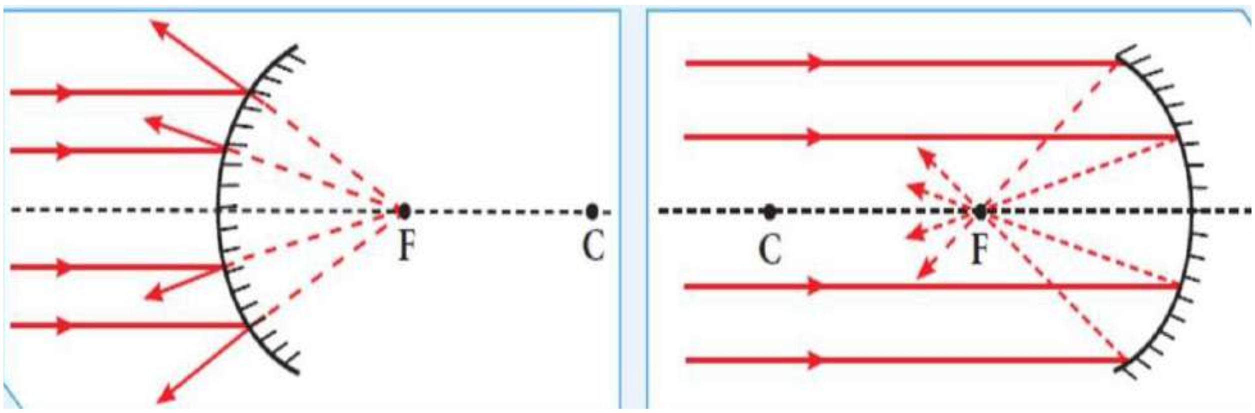


Spherical Mirrors

A **mirror** whose polished, reflecting surface is a part of a hollow sphere of glass or plastic is called a **spherical mirror**. In a **spherical mirror**, one of the two curved surfaces is coated with a thin layer of silver followed by a coating of red lead**.**

The types of **spherical mirror** are:

- **Convex mirror** **Concave mirror**

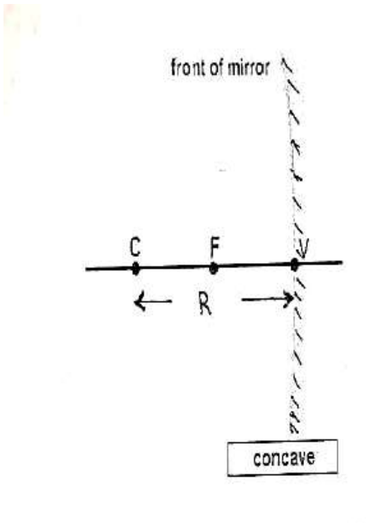


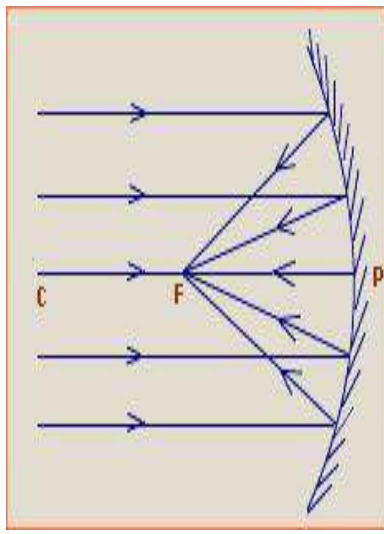
Definitions

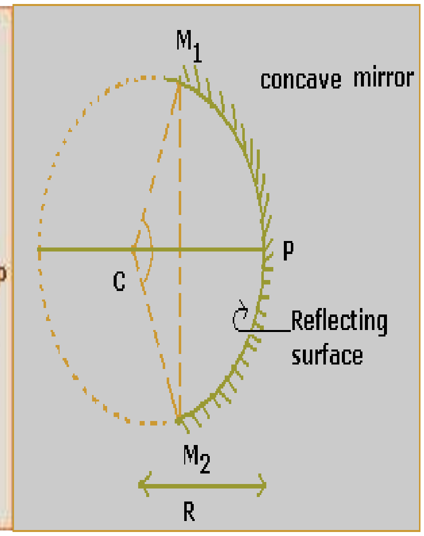
- **The focus (F):** F is a point on the principal axis of the mirror at which, rays incident on the mirror in a direction parallel to the axis actually meet or appear to diverge after reflection from the mirror. F is a real point in case of concave mirror and F is a virtual point in case of convex mirror.
- **Focal Length (f):** The distance of principal focus from the pole of the spherical mirror is called focal length (f) of the mirror
- **Radius of Curvature:** The distance of C from P is called radius of curvature of the mirror.

Concave Mirror

Concave mirror whose reflecting surface is towards the center of the sphere of which the mirror is a part



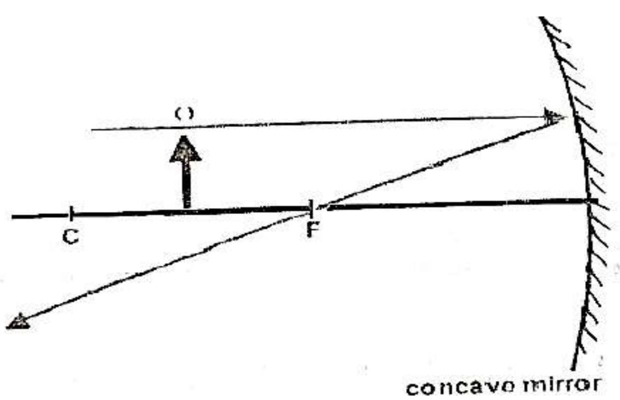




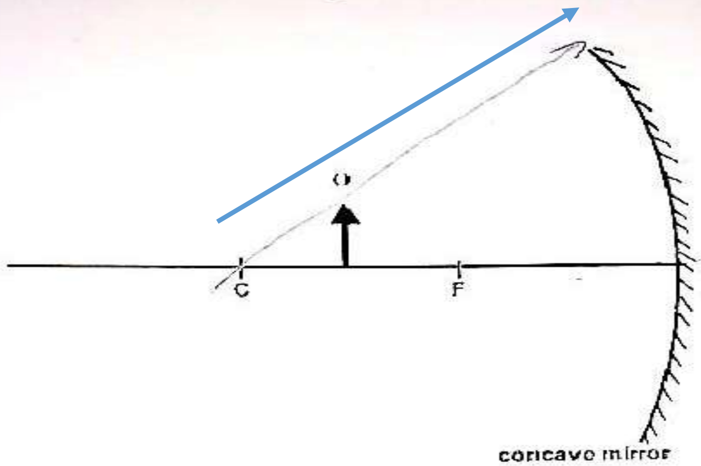
How the image formed in the concave mirror

There are three primary rays which are used to locate the images formed by converging mirror each rays starts from the top of the object

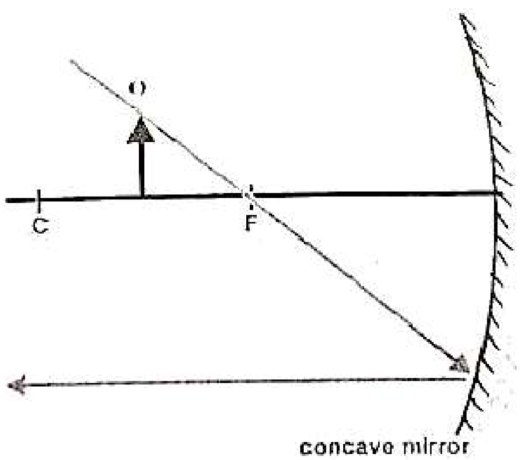
1. Ray (1) runs parallel to the axis until it reaches the mirror , then it reflected of the mirror and leaves along a path that passes through the mirror focus



2. Ray (2) runs straight the center of the mirror reflects of the mirror , and reflects through the center , never bending

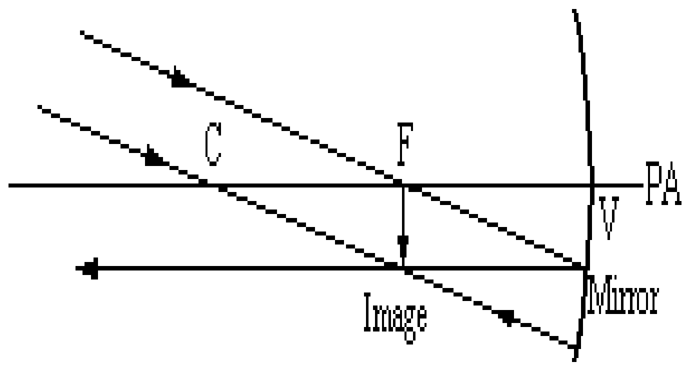


3. Ray (3) first passes through the focal point until it reaches the mirror then it reflects of the mirror and leaves parallel to the mirror axis .



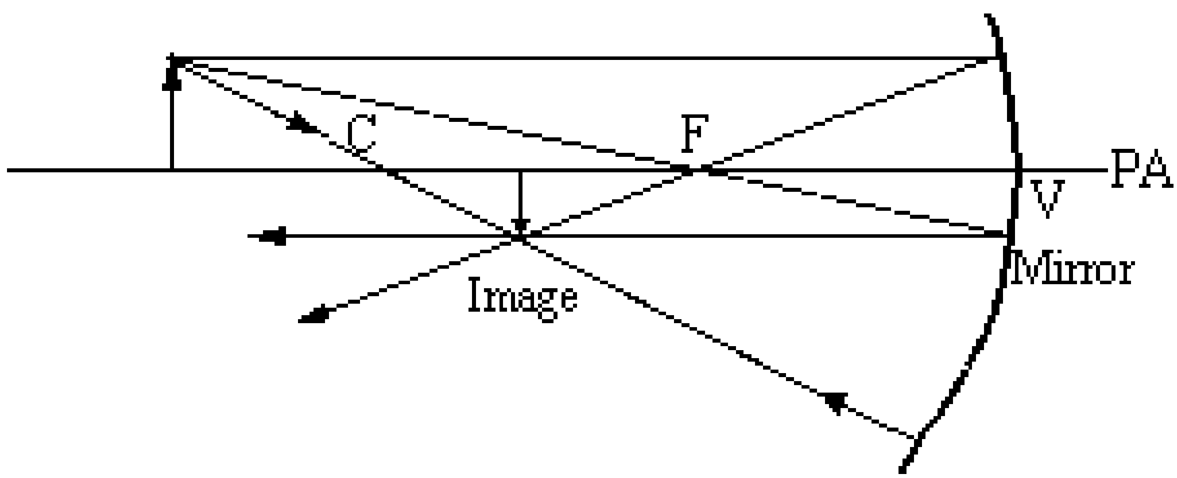
Special cases of image formation by concave mirror

1- Distant object



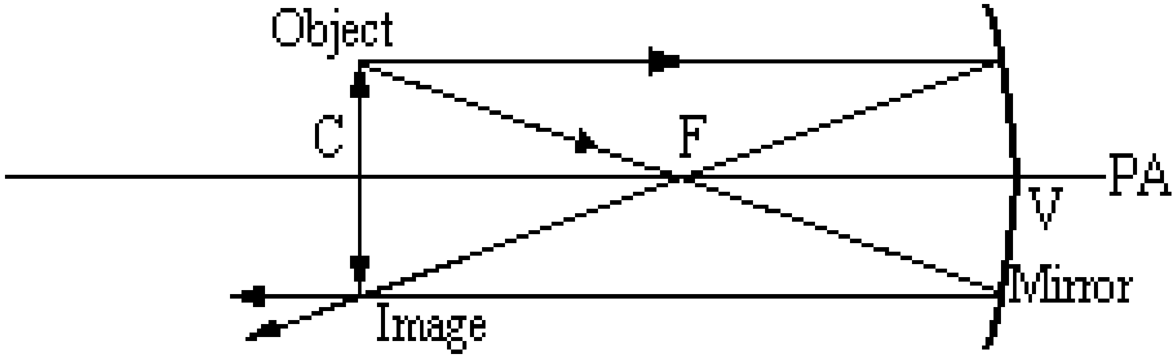
Characteristics of the Image: Inverted, Smaller than object, Real, At F.

2-Object beyond C



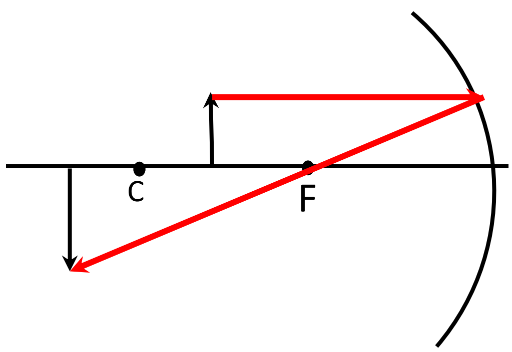
The image is Real, Inverted, and Smaller, Between C and F.

3-Object at C



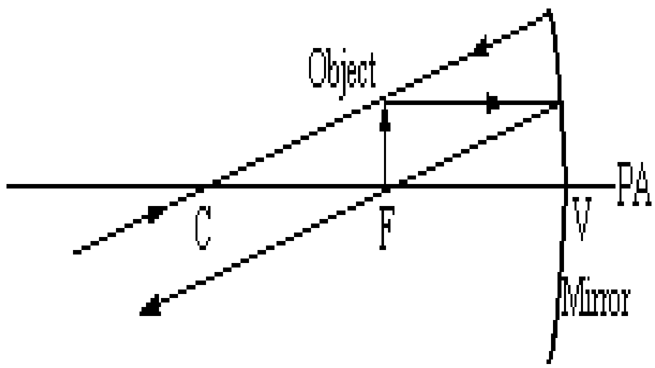
The image is Real, Inverted, Same size as object At C.

4-Object between C and F



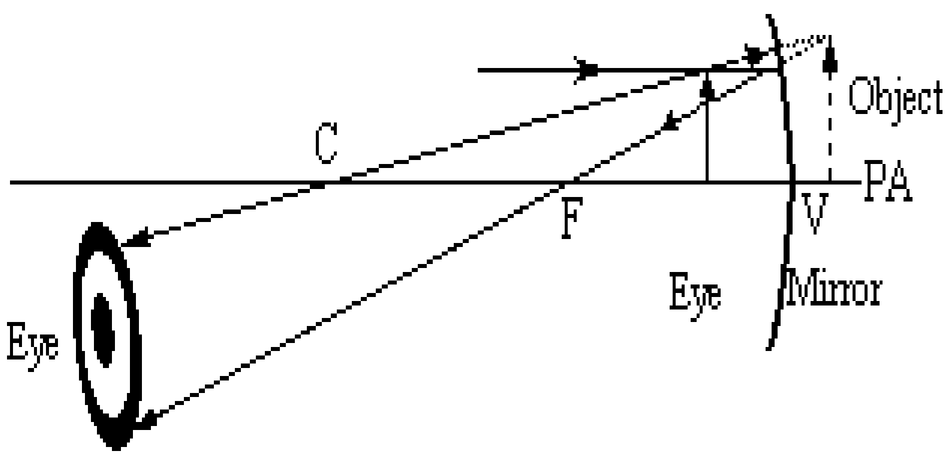
The image is Real, Inverted, and larger than object, beyond C.

5-Object at F



No image Reflected rays are parallel

6-Object between F and V



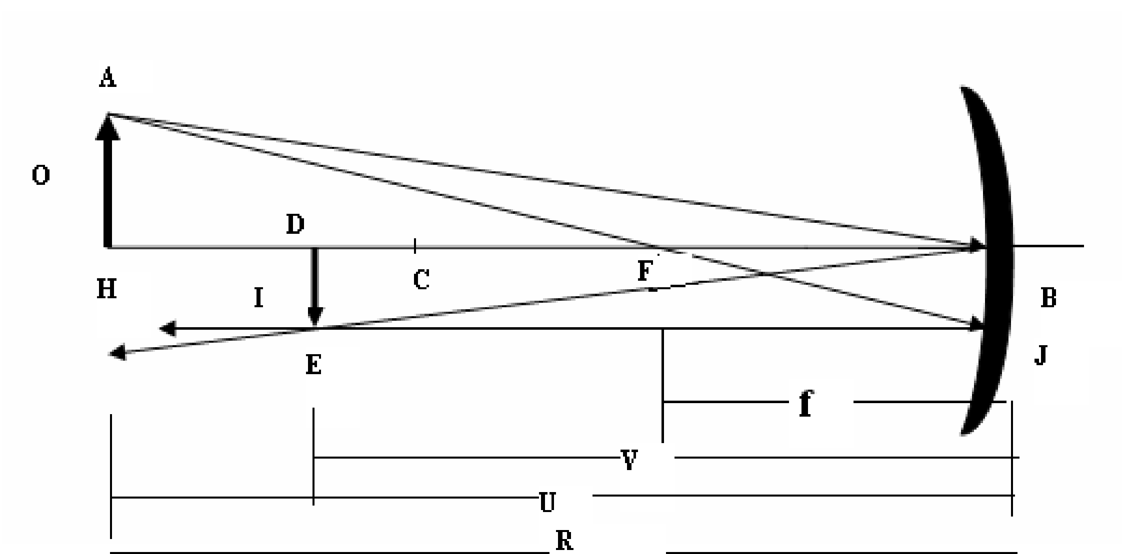
The image is: Larger than object, Erect, Virtual, Behind mirror.

Applications of concave mirror :

1- Ophthalmoscope.
2- Solar heating device.
3- Dentist.

The Equation of the Mirrors (Mirror formula):

Mirror formula is the relationship between object distance (u), image distance (v) and focal length.



The magnification of a mirror:

$$m = \frac{L'}{L} = \frac{V}{U}$$

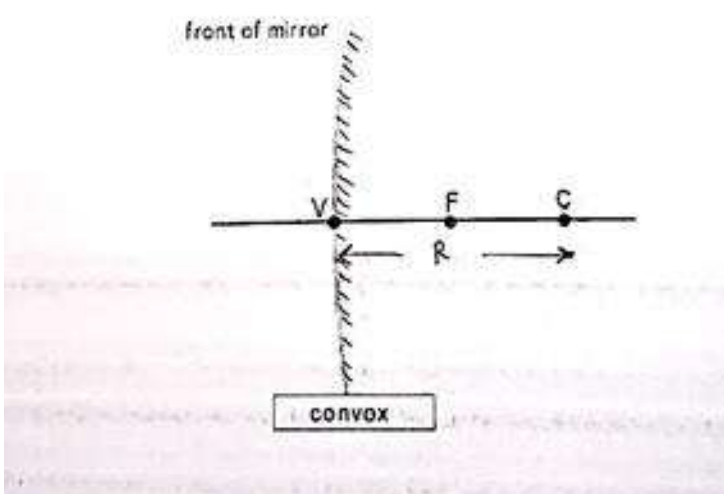
Where L' : is the length of the image.

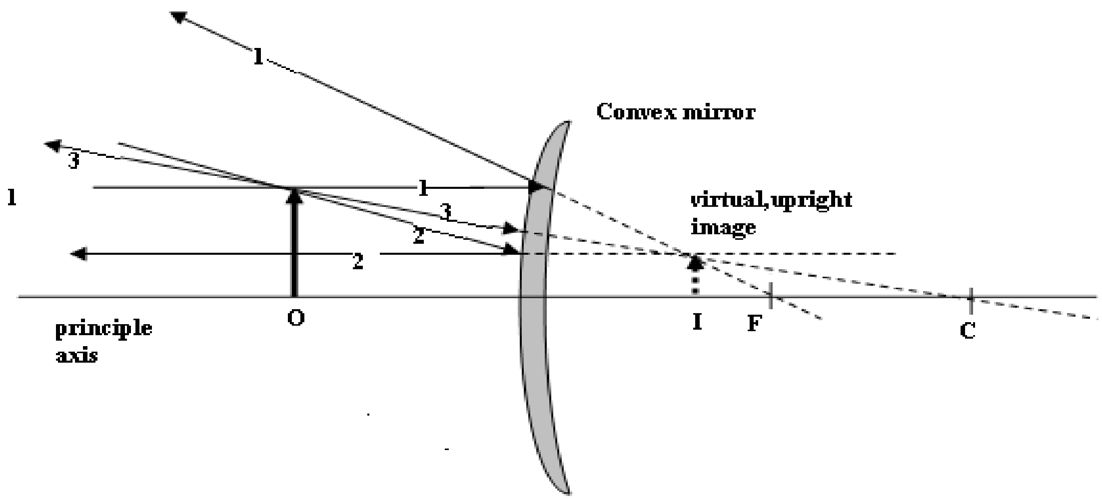
L: is the length of the object.

If the magnification is greater than 1, the image is enlarge. If the magnification is less than 1, the image is small.

Convex Mirror:

Convex mirror is one whose reflecting surface is away from the center of the sphere of which the mirror is a part





Convex mirror

Properties of image formed by convex mirror :

1. Convex mirror always form a virtual image.
2. All formed images are smaller than the object.
3. The focus and the center of curvature are both imaginary points.

Applications of convex mirror:

1. Rear view side (car).
2. Automated teller machines.
3. Reflecting telescopes.

Concave mirrors	**Convex mirrors**
1- was described as a portion of a sphere which had the outside of the sphere is silvered so reflecting surface is towards the center of the sphere of which the mirror is a part	**was described as a portion of a sphere which had the inside of the sphere is silvered so reflecting surface is outwards the center of the sphere of which the mirror is a part**
2-There are six cases by using the concave mirror	**There is one case by using the convex mirror**
3-Has positive focal length and positive focal point	**Has negative focal length and negative focal point**

Example: **An object with (2) cm length at a distance of (30) cm from a concave mirrors, its radius of curvature is (10) cm. Find the position and the length of the image.**

Since R=2f $\rightarrow$ f = R/2 $\rightarrow$ f =10/2 = 5 cm

By using the equation of the mirror equ. $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$$\frac{1}{5} = \frac{1}{30} + \frac{1}{V} \rightarrow \frac{1}{5} - \frac{1}{30} = \frac{1}{V} \qquad \rightarrow \text{ v = 6 cm}$$

The image is in the same side of the reflected surface and this mean it is real image.

To find the length of the image we use equation

$m = \frac{L'}{L} = \frac{V}{U}$ L'/2 =6/30 → L'=0.4

Refraction

Refraction: is the change in direction of a light due to a change in its speed.

This is most commonly observed when a light passes from one medium to another at an angle. Refraction of light is the most commonly observed phenomenon

The straw appears to be broken, du
refraction of light as it emerges into t

The Refractive Index

The index of refraction is defined as the speed of light in vacuum divided by the speed of light in the medium.

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

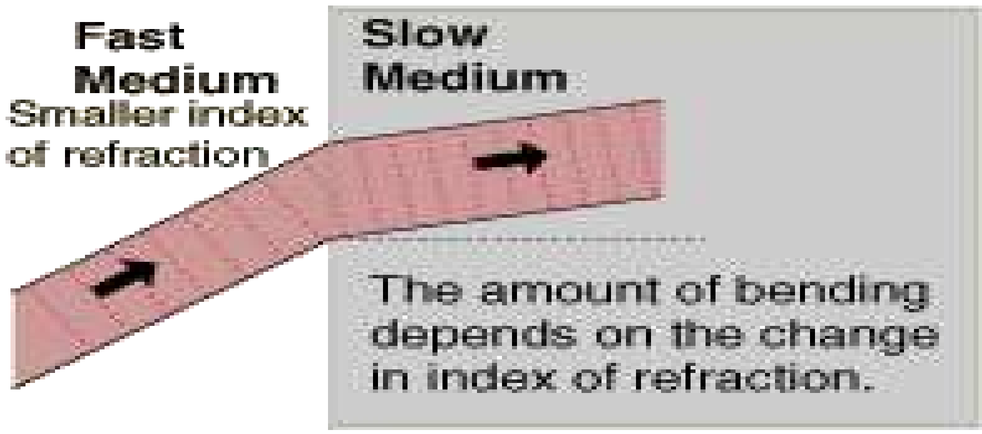
Where:

n is the refractive index,

c the speed of light in vacuum,

v the speed of light in the medium.

Fig. below shows that in fast medium (like the air) where the speed of the light is high, there is smaller index of refraction, while in slow medium (like the glass) where the speed of the light is less than in the first medium there is larger index of refraction.



The index of refraction of most common glasses used in optical instrument lies between (1.52-1.72)

The Relative Refractive Index

Let light travel from air to medium 1. If c and v1 are the velocities of light in these media, the refractive index of medium 1 with respect to air, or the absolute refractive index of medium 1 is given by:

$$n_1 = \frac{c}{v_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Similarly, when light travels from air to medium 2, we can write

$$n_2 = \frac{c}{v_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Dividing equation (ii) by equation (i) we get

$$\frac{n_1}{n_2} = \frac{\frac{c}{v_1}}{\frac{c}{v_2}} = \frac{v_2}{v_1} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$n_r = \frac{v_2}{v_1} = \frac{n_1}{n_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where nr is the relative refractive index.

Thus the relative refractive index between a pair of media is the ratio of their absolute refractive indices. While the absolute refractive index of any material medium is always greater than unity, its relative refractive index may be greater or lesser than unity.

It's the ratio between the velocities of the light in the second medium to the velocity of the light in the first medium, it is represented by the letter nr

In optics, refraction occurs when light waves travel from a medium with a given refractive index (n_1) to a medium with another (n_2) at an angle. At the boundary between the media, the light velocity is altered, usually causing a change in direction. Understanding of this concept led to the invention of lenses and the refracting telescope.

Note

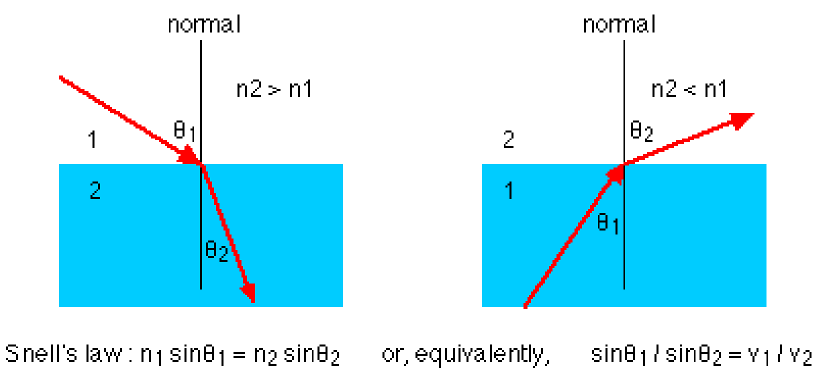
A ray traveling along the normal (perpendicular to the boundary) will change speed, but not direction. Refraction still occurs in this case

Laws of refraction:

1. The incident ray, the **refracted** ray and the normal to the **surface** at the point of incidence all lie in one plane**.**
2. For any two given pair of media, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant. Refraction is described by Snell's law, which states that the angle of incidence θ_1 is related to the angle of refraction θ_2 by

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

Where v_1 and v_2 are the light velocities in the respective media, and n_1 and n_2 the refractive indices



3- When light is Refracted at the interface between two media of different refractive indices, with $n_2 > n_1$, the light velocity is lower in the second medium ($v_2 < v_1$), the angle of refraction θ_2 is less than the angle of incidence θ_1; that is, the ray in the higher-index medium is closer to the normal. Conversely, light traveling across an interface from higher n to lower n will bend away from the normal

Example:

Light travels from air into an optical fiber with an index of refraction of 1.44. (a) In which direction does the light bend? (b) If the angle of incidence on the end of the fiber is 22°, what is the angle of refraction inside the fiber? (c) Sketch the path of light as it changes media.

Solution:

(a) Since the light is traveling from a rarer region (lower n) to a denser region (higher n), it will bend toward the normal.

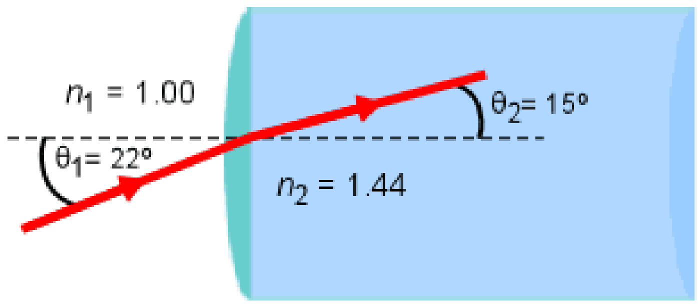
(b) We will identify air as medium 1 and the fiber as medium 2. Thus, n1 = 1.00, n2 = 1.44, and θ1 = 22˚. Snell's Law then becomes

$(1.00) \sin 22^\circ = 1.44 \sin \theta_2$.

$\sin \theta_2 = (1.00/1.44) \sin 22^\circ = 0.260$

$\theta_2 = \sin^{-1}(0.260) = 15^\circ$.

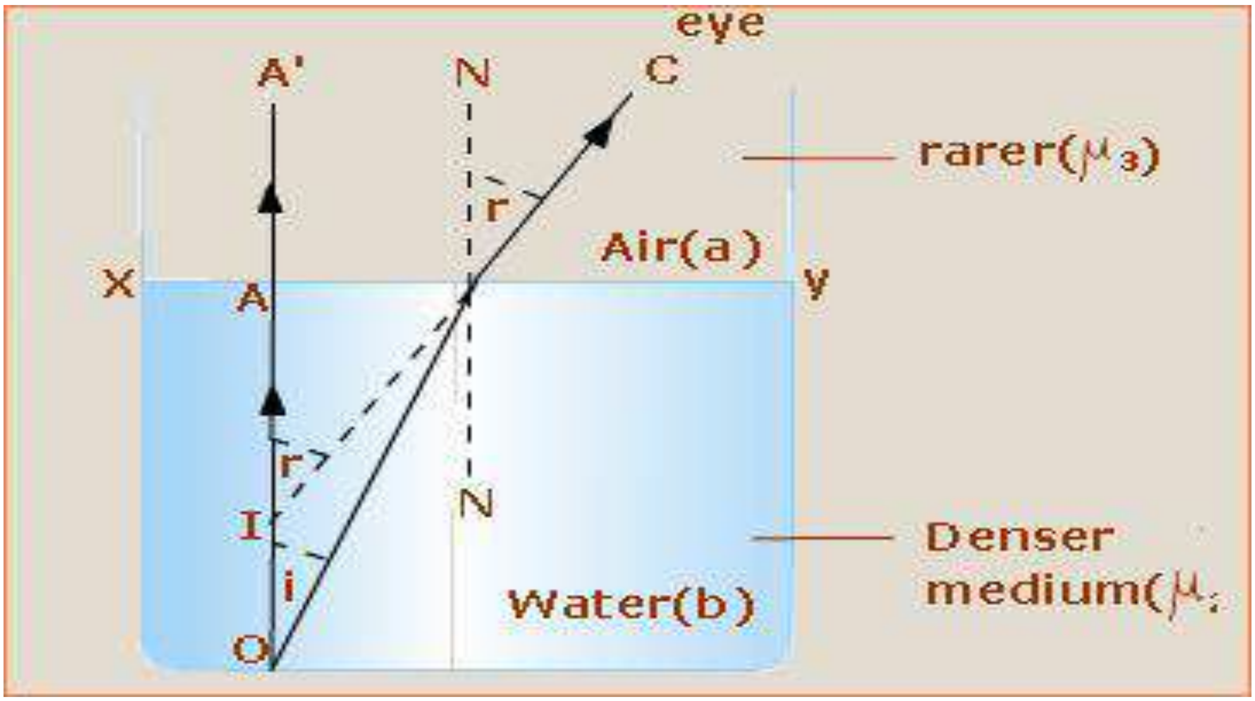
(c) The path of the light is shown in the figure below.



Real Depth and Apparent Depth

The real depth of an object is the actual distance of the object from the surface of the liquid

The apparent depth of an object is the vertical distance of the image of the object from the surface of the liquid

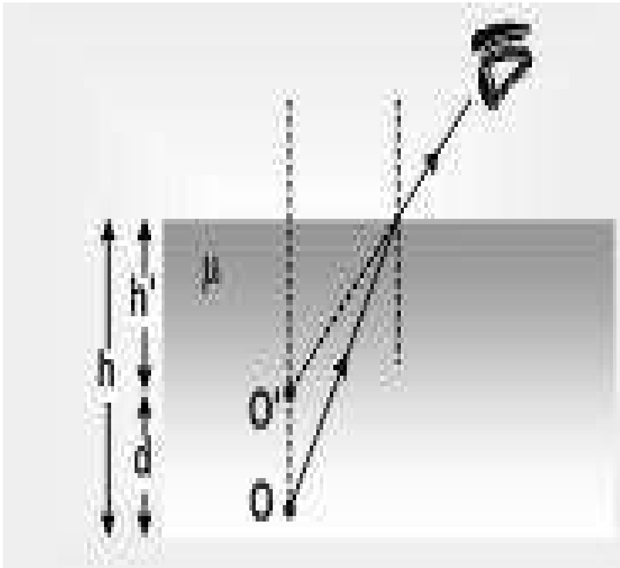


1

When object is in denser medium and observer is in rarer medium:

n = real depth / apparent depth

$= h / h^l$

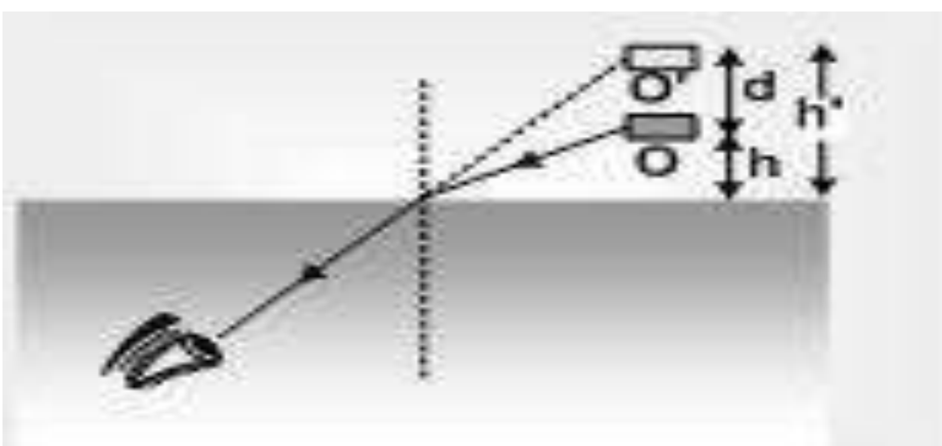


Real depth > apparent

2

When object is in rarer medium and observer is in denser medium

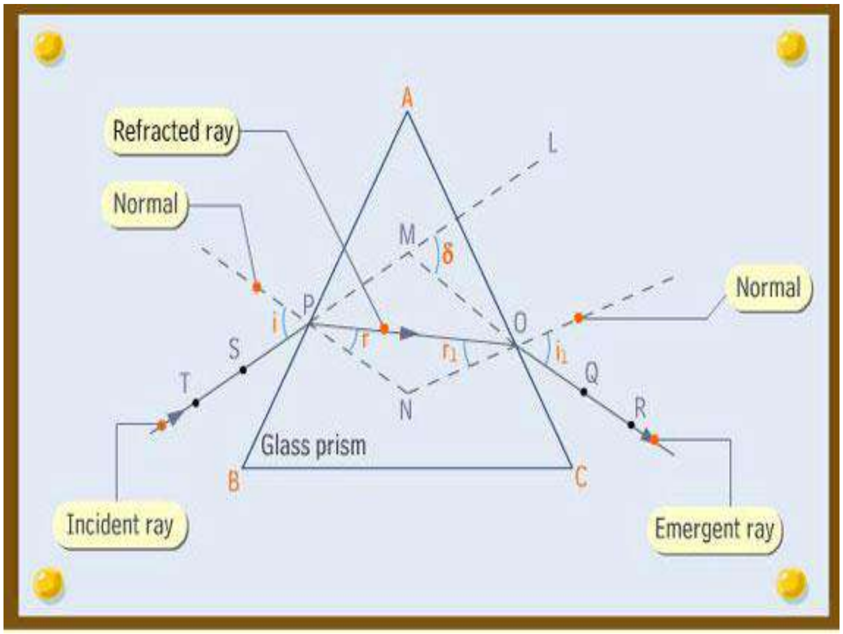
$n = h^l / h$



Real depth < apparent depth

Refraction by a prism

Consider a light ray incident at one face of a prism of refractive index (n) and angle of apex of the prism (A) and the medium of the other side is air, δ is the minimum deviation angle

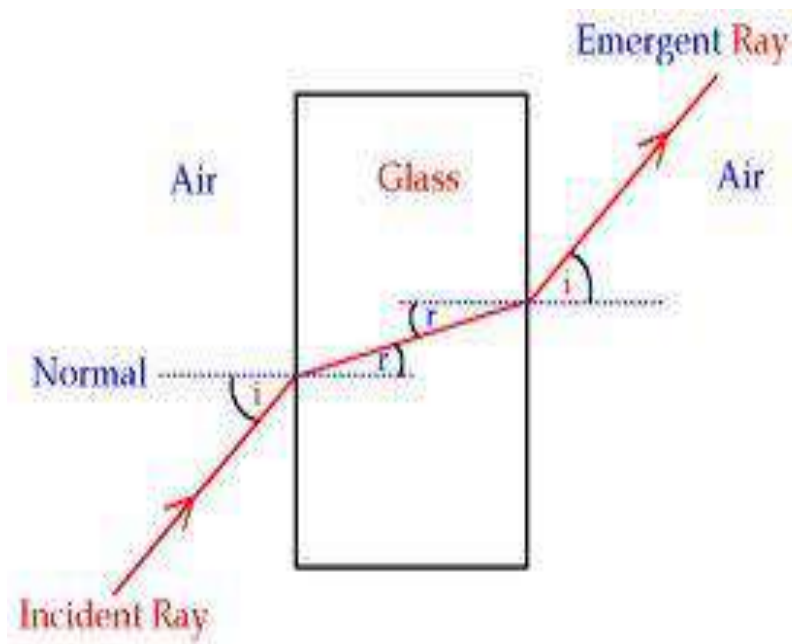


$$\boxed{n = \frac{\sin\frac{A+\delta}{2}}{\sin\frac{A}{2}}}$$

Refraction by plane parallel plate

Consider a plane parallel transparent plate (a plate which two surfaces are parallel to each other) of refractive index (n_1) Surrounding by a medium of refractive index (n) .

Suppose that a plane wave of light incident upon the plate by incident angle Θ_1 , the light refracted from the upper surface of the plate by refracted angle Θ_2 then it transmitted in to the lower surface and incident the lower boundary surface by incident angle Θ_3 and refracted by angle of refraction Θ_4 .



From Snell's law

$n_1 \sin \Theta_1 = n_2 \sin \Theta_2$

$n_2 \sin \Theta_3 = n_1 \sin \Theta_4$

But $\Theta_2 = \Theta_3$

$\Theta_1 = \Theta_4$

Penetrating angle = incident angle

Problems

1. A ray of light incident upon the boundary surface separating two transparent media of indices (1.6) and (1.4) by incident angle (30) the ray originated from denser media. Find angle of refraction?

2. A wave of light incident from air to glass by incident angle (30) then travels from the glass to the air find the refraction angle from the second boundary surface?

3. What is the apparent depth of an object whose real depth below the water surface is 5 m?

4. A light beam enters a piece of glass from the vacuum at (60) from the normal then bends to (45) from the normal inside the glass

   a- what is the index of refraction of the glass

   b- At what angle does the light exit the slab of glass?

5. Using the information given in the following diagram, calculate the optical index of refraction?