Reflection and Refraction of Light

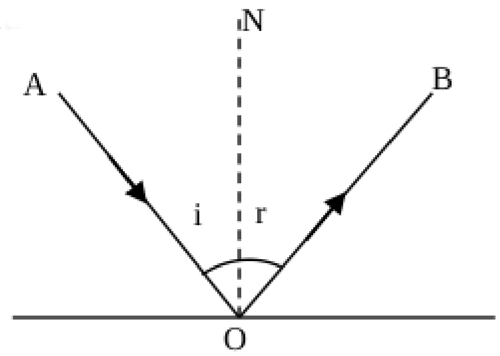
Reflection of Light

Phenomenon of coming back of the light in the same medium when light falls on a surface is known as reflection of light.

Laws of reflection:

When light reflect from a surface then it follow certain laws.

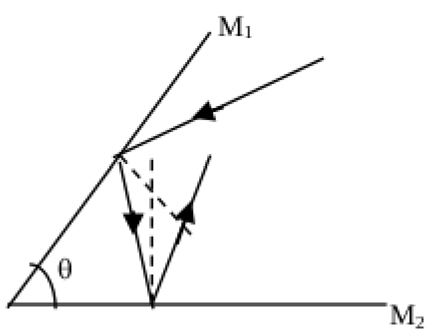
- The incident ray, the reflected ray and the normal meet at the point of incidence lie in the same plane.
- The angle of incidence is equal to the angle of reflection.



Reflection from plane mirror

- ### Image formed by Plane mirror:
    - The image is always erect, virtual and laterally inverted.
    - The image is always of same size as that of bject and object and image are at the same distance from the mirror i.e. magnification is one.
    - If the mirror is rotated by an angle θ the reflected ray is rotated through an angle 2θ.
    - If the object moves towards the plane mirror at speed v, the image moves towards the plane mirror at the same speed v. So the object and image will approach with 2v.
    - If the mirror is moved towards (or away) the object with speed v, the image will move towards (or away) the object with a speed 2v.
    - The minimum size of the mirror required to see full size of one self is equal to half the height of the observer.
    - The minimum size of the mirror required to observe the full image of an object behind the observer who is middle of object and mirror, is one third the height of object.
    - There is no change in the velocity, wavelength and frequency of light due to reflection.
    - Reflection from a plane mirror causes a phase change of π.
    - The radius of curvature and focal length of a plane mirror are infinite. This means, its power is zero.

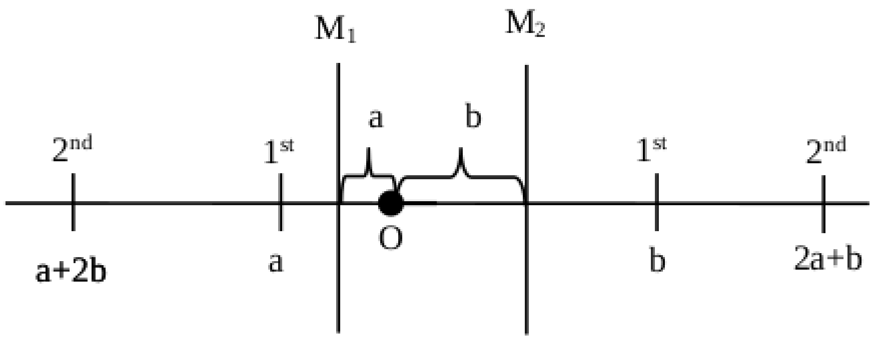
- ### Deviation due to two inclined plane mirrors:
    - Total deviation produced from two inclined plane mirror after two successive reflection, $\delta = 360^o - 2\theta$



- The no. of images (n) formed by two plane mirrors inclined at an angle of an object between them can be found as:

- If $\frac{360^o}{\theta} = \text{even integer}$ then $n = \frac{360^o}{\theta} - 1$
- If $\frac{360^o}{\theta} = \text{odd integer}$ then the no. of images is decided as:
  - If the object is kept symmetrically then,
    $n = \frac{360^o}{\theta} - 1$
  - If the object is kept asymmetrically, then
    $n = \frac{360^o}{\theta}$
- If $\frac{360^o}{\theta}$ is a fraction, the numbers of images wil be equal to its integral part.

- **Two plane parallel mirrors:**



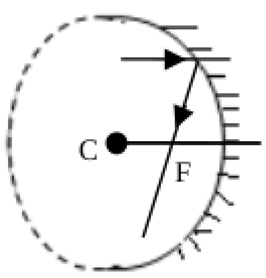
  - No. of images of an object between two plane and parallel mirror $= \infty$
  - Distance between n th images on two parallel mirror $= 2n(a+b)$

- **Multiple images in a thick mirror:**

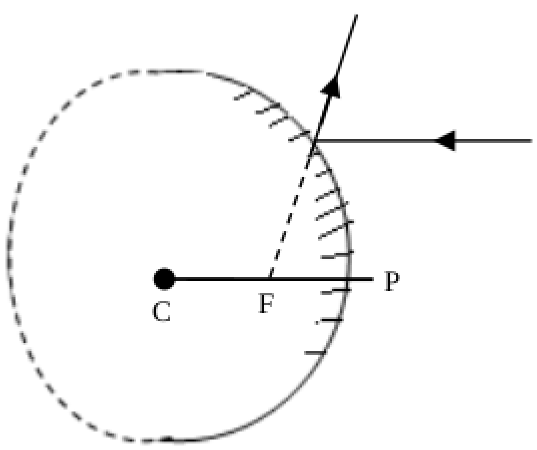
  When an object is kept in front of a thick plane mirror then several images are seen when viewed obliquely. The second image is the brightest.

Reflection at spherical mirror

Spherical mirror is a part of a reflecting surface which forms the part of a sphere. A spherical mirror may be concave or convex.



concave mirror



convex mirror

- **Sign Convention:**
  - All the distances are measured from the pole.
  - Real distance is taken as positive and virtual distance is taken as negative.
  - For concave mirror focal length and radius of curvature are positive and for convex mirror they are negative.

- **Formula related to mirrors:**
  - Focal length (f) and the radius of curvature (R) are related as, $f = R/2$
  - For all spherical mirror,
    $$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$
    where,
    u = object distance
    v = image distance
    f = focal length
  - Magnification:
    - Transverse or linear magnification is defined as,
      $$m = \frac{\text{size of image(I)}}{\text{size of object(O)}} = v/u$$
    - Areal magnification,
      $$m_A = \frac{\text{area of image}}{\text{area of object}} = m^2$$
    - Longitudinal magnification,
      $$m_L = \frac{I}{O} = \frac{dv}{du} \quad \text{(for small object)}$$
    - If the object distance (x) and the real image distance (y) are taken from focus then focal length (f) is given as:
      $f = \sqrt{xy}$ [Newton's formula]
    - Relation between speed of the object and image is obtained by differentiating:
      $$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$
      and we obtain the relation:
      $$dv/dt = -v^2/u^2 \frac{du}{dt}$$

- **Image formed by Concave mirror:**

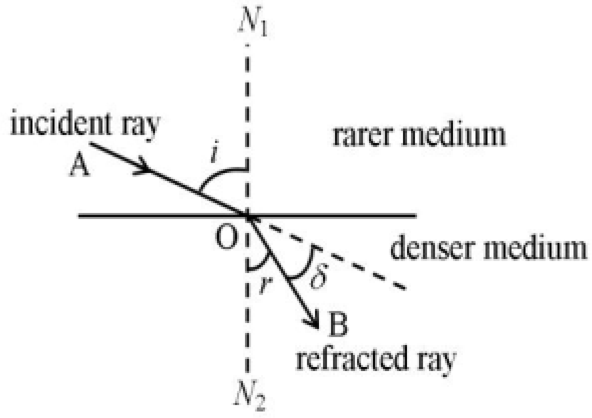
SN	Position of Object	Position of Image	Magnification	Nature of Image
1	At inifinity	At focus	$m \to 0$	Real, inverted
2	Between centre of curvature and infinity	Between focus and centre of curvature	$m < 1$	Real, inverted
3	At centre of curvature	At centre of curvature	$m = 1$	Real, inverted
4	Between centre of curvature and focus	Beyond centre of curvature	$m > 1$	Real, inverted
5	At focus	At infinity	$m \to \infty$	Real, inverted
6	Between pole and focus	Behind the mirror	$m > 1$	Virtual, erect

- **Image formed by Convex mirror:**

SN	Position of Object	Position of Image	Magnification	Nature of Image
1	At inifinity	At focus	$m \to 0$	Virtual, erect
2	At any point in front of mirror	Between pole and focus	$m < 1$	Virtual, erect

Refraction of Light

When a ray of light travels from one medium into another medium, it bends from its original path at the surface of separation of two media due to change in the speed of light. This is called refraction of light.



$\angle AON_1 = i$ (angle of incident)

$\angle BON_2 = r$ (angle of refraction)

Deviation, $\delta = (i - r)$ for $i > r$
$\delta = r - i$ for $r > i$

- **Laws of refraction:**
  - The incident ray, normal and the refracted ray all lie in the same plane.
  - The ratio of sine of angle of incidence to sine of angle of refraction is constant is called refraction index.

    i.e, $\frac{\sin i}{\sin r} = {}_a\mu_b$

    This is called Snell's law.
    ${}_a\mu_b$ is called the refractive index of medium 'b' w.r.t. 'a'.

- **Absolute refractive index:**

  It is the ratio of speed of light in vacuum (c) to that in a given medium (v) i.e $\mu = \frac{c}{v}$

  As, $c = f \times \lambda_a$ and $v = f \times \lambda_{med}$
  $\therefore \mu = \lambda_a / \lambda_{med}$

  - It is a scalar quantity without any unit and dimension.
  - Absolute refractive index depends on the wavelength of light.

    $$\mu = A + \frac{B}{\lambda^2} + \ldots\ldots\ldots\ldots \quad \text{(Cauchy's formula)}$$

  - Absolute refractive index depends on the temperature of the medium. As temperature increases, refractive index decreases.

- **Relative refractive index:**

  The relative refractive index of two media is equal to the ratio of their absolute refractive indices.

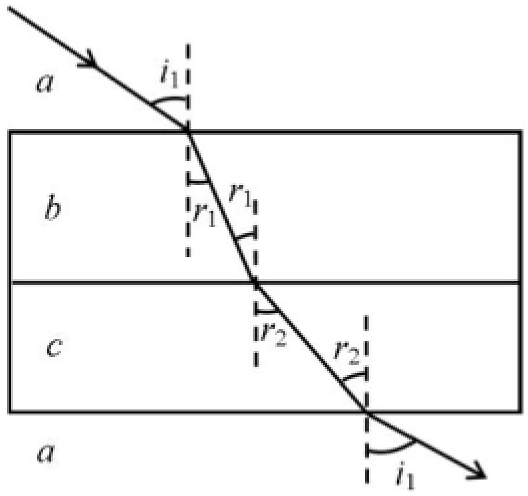
  i.e, ${}_a\mu_b = \frac{\mu_b}{\mu_b} = \frac{v_a}{v_b} = \frac{\lambda_a}{\lambda_b}$

- **Condition for no refraction:**
  - When light falls normally on a boundary of two medium. i.e. $\angle i = 0^o$
  - When the refractive indices of two media are equal i.e. $\mu_a = \mu_b$

Refraction through a number of media

As shown in the figure; a ray of light passes through different medium. The incident ray and the emergent ray lie in the same medium.

Using Snell's law at the interface,



$$_a\mu_b = \frac{\sin i_1}{\sin r_1} \ldots\ldots\ldots \text{(i)}$$

$$_b\mu_c = \frac{\sin r_1}{\sin r_2} \ldots\ldots\ldots \text{(ii)}$$

$$_c\mu_a = \frac{\sin r_2}{\sin \mathrm{i}_1} \ldots\ldots\ldots \ \text{(iii)}$$

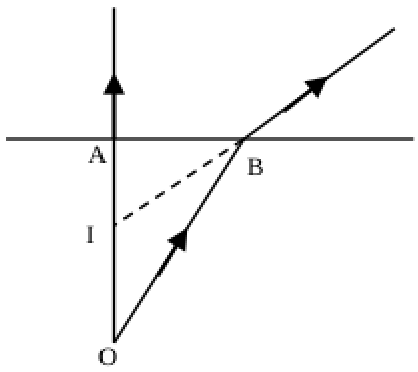
Multiplying (i),(ii) and (iii)

$$_a\mu_b \times {_b\mu_c} \times {_c\mu_a} = 1$$

Real and Apparent Depths

When the object and the observer are in different medium then due to the refraction of light, the object appears to be shifted from its actual position.

- **Observer in the rarer medium:**



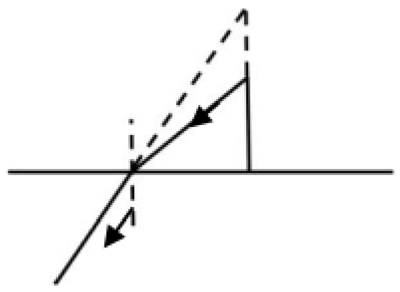
AO → Real depth
IA → Apparent depth
OI → Normal shift

$$_r\mu_d = \frac{\text{Real depth(R.D.)}}{\text{Apparent depth(A.D.)}}$$
$$\text{Normal shift} = R.D. - A.D.$$
$$\text{Normal shift} = R.D.\left(1 - \frac{1}{_r\mu_d}\right)$$

When there are different medium of R.I. $\mu_1, \mu_2, \ldots\ldots \mu_n$ one over the other and the observer observes an object at the bottom, then the apparent depth of the object is:

$$d_A = \frac{d_1}{\mu_1} + \frac{d_2}{\mu_2} + \cdots + \frac{d_n}{\mu_n}$$
where, $d_1, d_2, \ldots, d_m$ are the thickness of the medium taken.

- **Observer in the denser medium:**



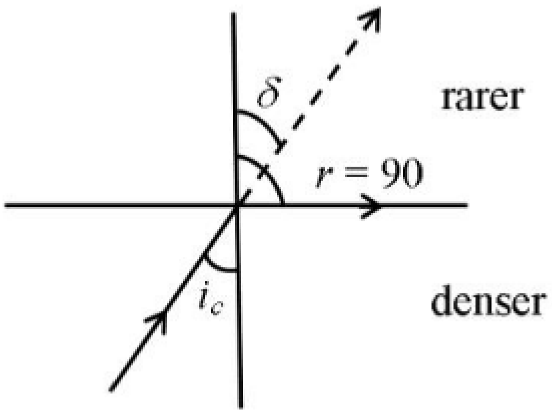
$$
\begin{aligned}
{}_r\mu_d &= \frac{A.D}{R.D} \\
\text{Normal shift} &= A.D. - R.D. \\
&= R.D.\left({}_r\mu_d - 1\right)
\end{aligned}
$$

Illustration of refraction:

- Twinkling of stars.
- Oval shape of sun in the morning and evening.
- Visibility of two images of an object.

Critical angle and total internal reflection

Angle of incidence in the denser medium for which the angle of refraction in the rarer medium is 90^o is called critical angle (i_c).



Applying Snell's law,

$$\frac{\sin i_c}{\sin 90^o} = {}_d\mu_r$$

$$\text{Or, } \sin i_c = \frac{\mu_r}{\mu_d}$$

For free space $\mu_r = 1$

Let $\mu_d = \mu$

Then,

$$\sin i_c = \frac{1}{\mu}$$

Critical angle depends on the colour of light and also on temperature.
If the angle of incidence is greater than the critical angle in the denser medium, then the light is totally reflected back into the denser medium according to laws of reflection. This is called total internal reflection.

Condition for total internal reflection:

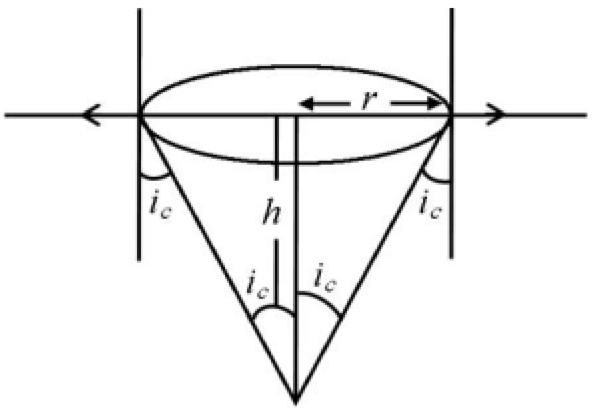
- Incidence ray must be in the denser medium.
- Angle of incidence in denser medium must be greater than critical angle.

Examples of total internal reflection:

- Glittering of diamond
- Mirage
- Looming
- Shining of air bubble in water
- Working of optical fibre

Field of vision from inside water:

An observer at a depth of ‘h’ inside water observes the outside world in a circle which is the base of a cone and vertex is the eye of observer.



Vertex angle = $2i_c$

If 'r' is the radius of the circle then,

$$r = h \tan i_c = \frac{h}{\sqrt{\mu^2 - 1}}$$

Area of field of vision is:

$$A = \pi r^2 = \frac{\pi h^2}{\mu^2 - 1}$$

Bird in air observe fish in water

When a bird is at height x from surface of pond in air observer a fish at a depth ‘y’ in water of refractive index μ then distance of 'y' fish seen by bird $= x + \frac{y}{\mu}$.

Distance of bird seen by fish $= y + \mu x$

When a glass slap is placed on word having different colour of different letter then letters appeared raised at different distance.

Here, Apparent depth $\propto \frac{1}{\mu}$ & $\mu \propto \frac{1}{\lambda}$

where, $\lambda_r > \lambda_v$. So, $\mu_r < \mu_v$

Hence red coloured letter will be raised least where as violet coloured letter will be raised maximum.