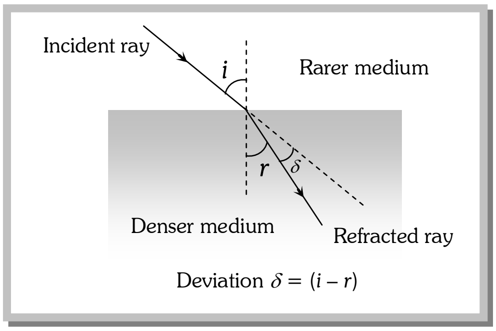
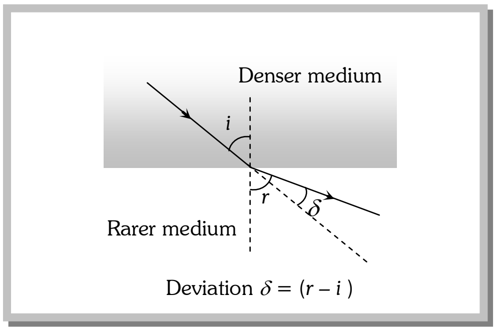
The bending of the ray of light passing from one medium to the other medium is called refraction.





Snell's law

The ratio of sine of the angle of incidence to the angle of refraction (r) is a constant called refractive index

i.e. $\frac{\sin i}{\sin r} = \mu$ (a constant). For two media, Snell's law can be written as ${}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{\sin i}{\sin r}$

$\Rightarrow \mu_1 \times \sin i = \mu_2 \times \sin r$ *i.e.* $\mu \sin\theta =$ constant

Also in vector form : $\hat{\boldsymbol{i}} \times \hat{\boldsymbol{n}} = \boldsymbol{\mu}(\hat{\boldsymbol{r}} \times \hat{\boldsymbol{n}})$

Refractive Index.

Refractive index of a medium is that characteristic which decides speed of light in it. It is a scalar, unit less and dimensionless quantity.

(1) **Types :** It is of following two types

Absolute refractive index	Relative refractive index
(i) When light travels from air to any transparent medium then R.I. of medium *w.r.t.* air is called it's absolute R.I. *i.e.* ${}_{\text{air}}\mu_{\text{medium}} = \frac{c}{v}$	(i) When light travels from medium (1) to medium (2) then R.I. of medium (2) *w.r.t.* medium (1) is called it's relative R.I. *i.e.* ${}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{v_1}{v_2}$ (where v_1 and v_2 are the speed of light in medium 1 and 2 respectively).
(ii) Some absolute R.I. ${}_a\mu_{\text{glass}} = \frac{3}{2} = 1.5$, ${}_a\mu_{water} = \frac{4}{3} = 1.33$ ${}_a\mu_{\text{diamond}} = 2.4$, ${}_a\mu_{Cs_2} = 1.62$ ${}_a\mu_{\text{crown}} = 1.52$, $\mu_{\text{vacuum}} = 1$, $\mu_{\text{air}} = 1.0003 \approx 1$	(ii) Some relative R.I. (a) When light enters from water to glass : ${}_w\mu_g = \frac{\mu_g}{\mu_w} = \frac{3/2}{4/3} = \frac{9}{8}$ (b) When light enters from glass to diamond : ${}_g\mu_D = \frac{\mu_D}{\mu_g} = \frac{2.4}{1.5} = \frac{8}{5}$

Note : $\cong$Cauchy's equation : $\mu = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \ldots\ldots$ $(\lambda_{\text{Red}} > \lambda_{\text{violet}}$ so $\mu_{\text{Red}} < \mu_{\text{violet}})$

$\cong$ If a light ray travels from medium (1) to medium (2), then ${}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$ → $\mu \propto \frac{1}{\lambda}$, $\mu \propto \frac{1}{v}$, $v \propto \lambda$

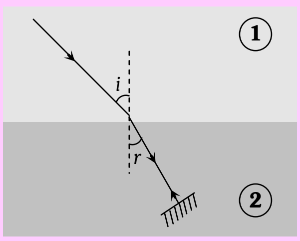
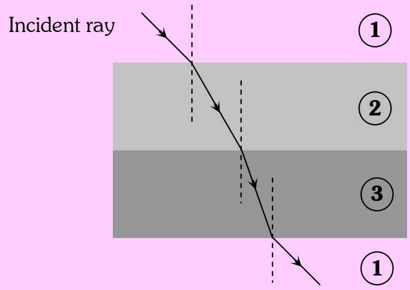
(2) **Dependence of Refractive index**

(i) Nature of the media of incidence and refraction.

(ii) Colour of light or wavelength of light.

(iii) Temperature of the media : Refractive index decreases with the increase in temperature.

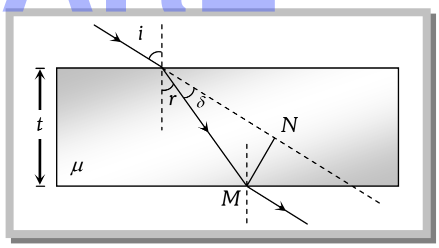
(3) **Principle of reversibility of light and refraction through several media :**

Principle of reversibility	**Refraction through several media**
 $_1\mu_2 = \frac{1}{_2\mu_1}$	 $_1\mu_2 \times {_2\mu_3} \times {_3\mu_1} = 1$

Refraction Through a Glass Slab and Optical Path

(1) **Lateral shift**

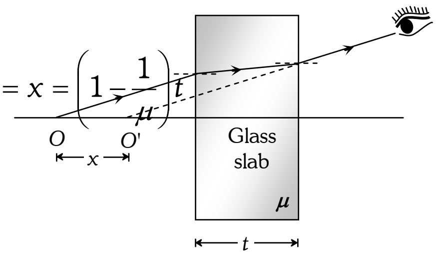
The refracting surfaces of a glass slab are parallel to each other. When a light ray passes through a glass slab it is refracted twice at the two parallel faces and finally emerges out parallel to it's incident direction *i.e.* the ray undergoes no deviation $\delta = 0$. The angle of emergence (e) is equal to the angle of incidence (i)



The Lateral shift of the ray is the perpendicular distance between the incident and the emergent ray, and it is given by $\boldsymbol{MN = t \sec r \sin(i - r)}$

Normal shift

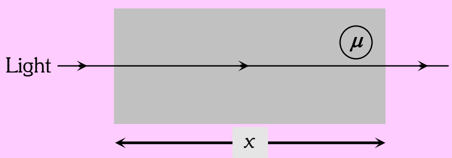
$OO' = x = \left(1 - \frac{1}{\mu}\right)t$

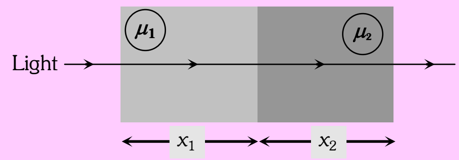


Or the object appears to be shifted towards the slab by the distance x

(2) **Optical path :**

It is defined as distance travelled by light in vacuum in the same time in which it travels a given path length in a medium.

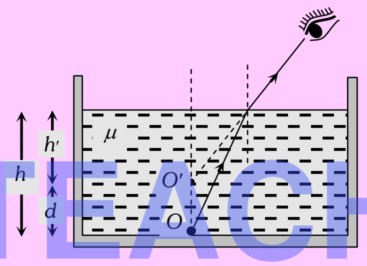
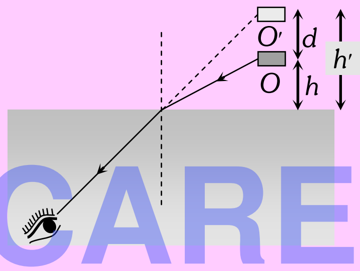
	Time taken by light ray to pass through the medium $= \frac{\mu x}{c}$; where x = geometrical path and μx = optical path

	For two medium in contact optical path $= \mu_1 x_1 + \mu_2 x_2$

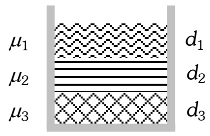
Note : ≅ Since for all media $\mu > 1$, so optical path length (μx) is always greater than the geometrical path length (x).

Real and Apparent Depth.

If object and observer are situated in different medium then due to refraction, object appears to be displaced from it's real position. There are two possible conditions.

(1) When object is in denser medium and observer is in rarer medium 	(1) Object is in rarer medium and observer is in denser medium. 
(2) $\mu = \dfrac{\text{Real depth}}{\text{Apparent depth}} = \dfrac{h}{h'}$ Real depth >Apparent depth that's why *a* coin at the bottom of bucket (full of water) appears to be raised)	(2) $\mu = \dfrac{h'}{h}$ Real depth < Apparent depth that's why high flying aeroplane appears to be higher than it's actual height.
(3) Shift $d = h - h' = \left(1 - \dfrac{1}{\mu}\right)h$	(3) $d = (\mu - 1)h$
(4) For water $\mu = \dfrac{4}{3} \Rightarrow d = \dfrac{h}{4}$ For glass $\mu = \dfrac{3}{2} \Rightarrow d = \dfrac{h}{3}$	(4) Shift for water $d_w = \dfrac{h}{3}$ Shift for glass $d_g = \dfrac{h}{2}$

Note : ≅If a beaker contains various immisible liquids as shown then



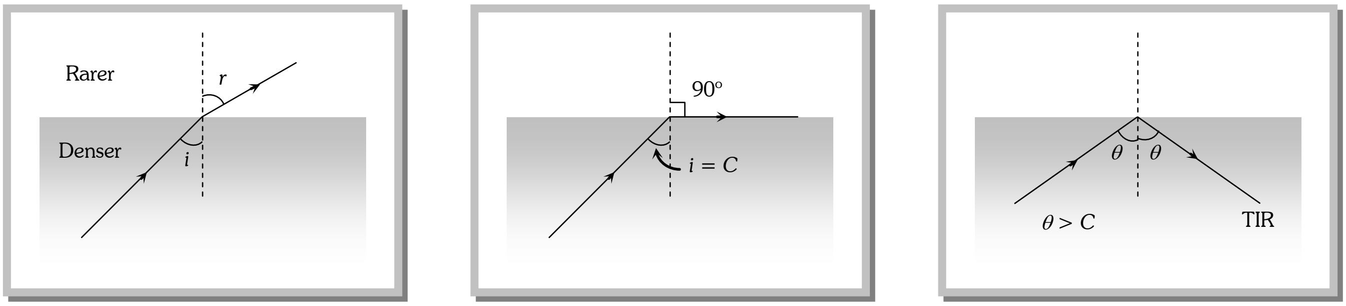
$$\text{Apparent depth of bottom} = \frac{d_1}{\mu_1} + \frac{d_2}{\mu_2} + \frac{d_3}{\mu_3} + \ldots.$$

$$\mu_{\text{combination}} = \frac{d_{AC}}{d_{App.}} = \frac{d_1 + d_2 + \ldots..}{\dfrac{d_1}{\mu_1} + \dfrac{d_2}{\mu_2} + \ldots.}$$ (In case of two liquids if $d_1 = d_2$ than $\mu = \dfrac{2\mu_1\mu_2}{\mu_1 + \mu_2}$)

Total Internal Reflection.

When a ray of light goes from denser to rarer medium it bends away from the normal and as the angle of incidence in denser medium increases, the angle of refraction in rarer medium also increases and at a certain angle, angle of refraction becomes 90°, this angle of incidence is called critical angle (C).

When Angle of incidence exceeds the critical angle than light ray comes back in to the same medium after reflection from interface. This phenomenon is called Total internal reflection (TIR).

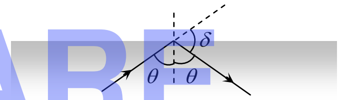


Important formula $\boldsymbol{\mu = \dfrac{1}{\sin C} = \operatorname{cosec} C}$; where $\mu \to {}_{\text{Rarer}}\mu_{\text{Denser}}$

Note : ≅When a light ray travels from denser to rarer medium, then deviation of the ray is

$\delta = \pi - 2\theta \Rightarrow \delta \to$ max. when $\theta \to$ min. $= C$

i.e. $\delta_{\max} = (\pi - 2C)$; $C \to$ critical angle



(1) Dependence of critical angle

(i) Colour of light (or wavelength of light) : Critical angle depends upon wavelength as $\lambda \propto \dfrac{1}{\mu} \propto \sin C$

(a) $\lambda_R > \lambda_V \Rightarrow C_R > C_V$

(b) Sin $C = \dfrac{1}{{}_R\mu_D} = \dfrac{\mu_R}{\mu_D} = \dfrac{\lambda_D}{\lambda_R} = \dfrac{v_D}{v_R}$ (for two media)

(c) For TIR from boundary of two media $i > \sin^{-1}\dfrac{\mu_R}{\mu_D}$

(ii) Nature of the pair of media : Greater the refractive index lesser will be the critical angle.

(a) For (glass- air) pair $\to C_{\text{glass}} = 42^o$

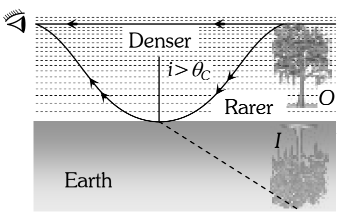
(b) For (water-air) pair $\to C_{\text{water}} = 49^o$

(c) For (diamond-air) pair $\to C_{\text{diamond}} = 24^o$

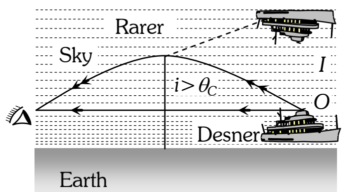
(iii) Temperature : With temperature rise refractive index of the material decreases therefore critical angle increases.

(2) Examples of total internal reflection (TIR)

(i)



Mirage : An optical illusion in deserts

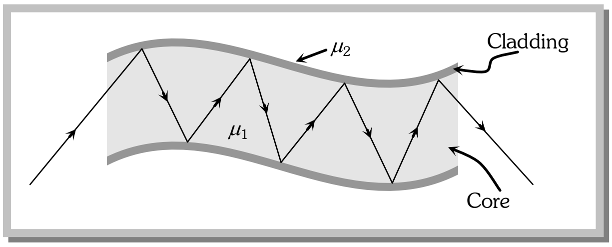


Looming : An optical illusion in cold countries

(ii) **Brilliance of diamond :** Due to repeated internal reflections diamond sparkles.

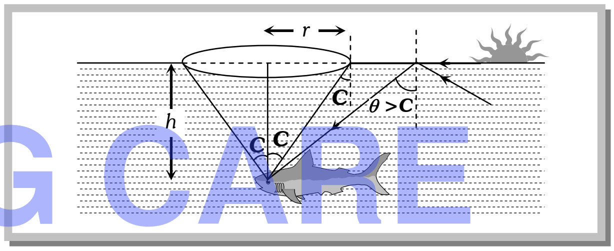
(iii) **Optical fibre :** Optical fibres consist of many long high quality composite glass/quartz fibres. Each fibre consists of a core and cladding. The refractive index of the material of the core (μ_1) is higher than that of the cladding (μ_2).

When the light is incident on one end of the fibre at a small angle, the light passes inside, undergoes repeated total internal reflections along the fibre and finally comes out. The angle of incidence is always larger than the critical angle of the core material with respect to its cladding. Even if the fibre is bent, the light can easily travel through along the fibre



A bundle of optical fibres can be used as a 'light pipe' in medical and optical examination. It can also be used for optical signal transmission. Optical fibres have also been used for transmitting and receiving electrical signals which are converted to light by suitable transducers.

(iv) **Field of vision of fish (or swimmer) :** A fish (diver) inside the water can see the whole world through a cone with.



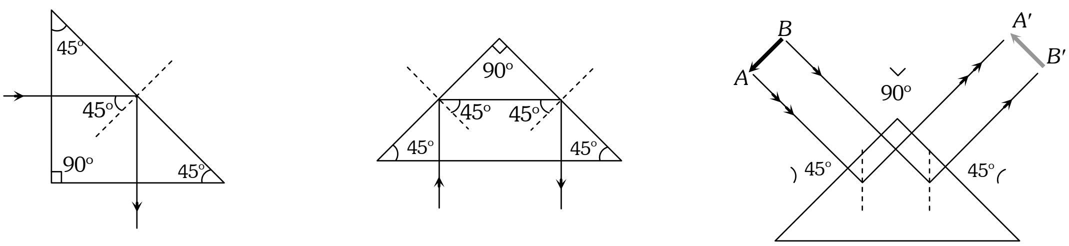
(a) Apex angle $= 2C = 98^o$

(b) Radius of base $r = h\tan C = \dfrac{h}{\sqrt{\mu^2-1}}$

(c) Area of base $A = \dfrac{\pi h^2}{(\mu^2-1)}$

Note : $\cong$ For water $\mu = \dfrac{4}{3}$ so $r = \dfrac{3h}{\sqrt{7}}$ and $A = \dfrac{9\pi h^2}{7}$.

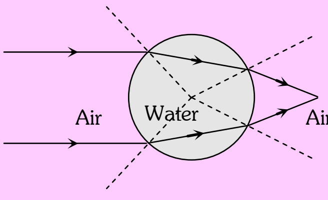
(v) **Porro prism :** A right angled isosceles prism, which is used in periscopes or binoculars. It is used to deviate light rays through 90^o and 180^o and also to erect the image.



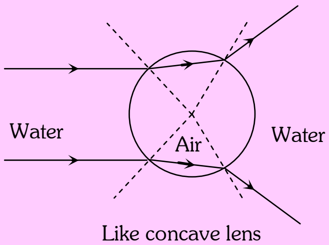
Concepts

- *In case of refraction of light frequency (and hence colour) and phase do not change (while wavelength and velocity will change).*
- *In the refraction intensity of incident light decreases at it goes from one medium to another medium.*
- *A transparent solid is invisible in a liquid of same refractive index (Because of No refraction).*
- *When a glass slab is kept over various coloured letters and seen from the top, the violet colour letters appears closer (Because $\lambda_v < \lambda_R$ so $\mu_V > \mu_R$ and from $\mu = \dfrac{\lambda}{\lambda'}$ if μ increases then h' decreases i.e. Letter appears to be closer)*

- *Water drop in air and air bubble in water behaves as a lens.*



Like convex lens



Like concave lens

Example

Example: 1 A beam of monochromatic blue light of wavelength 4200 Å in air travels in water $(\mu = 4/3)$. Its wavelength in water will be **[MNR 1991]**

(a) 2800 Å (b) 5600 Å (c) 3150 Å (d) 4000 Å

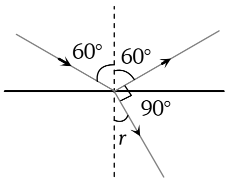
Solution: (c) $\mu \propto \frac{1}{\lambda} \Rightarrow \frac{\mu_1}{\mu_2} = \frac{\lambda_2}{\lambda_1} \Rightarrow \frac{1}{4/3} = \frac{\lambda_2}{4200} \Rightarrow \lambda_2 = 3150\,Å$

Example: 2 On a glass plate a light wave is incident at an angle of 60°. If the reflected and the refracted waves are mutually perpendicular, the refractive index of material is **[MP PMT 1994; Haryana CEE 1996]**

(a) $\frac{\sqrt{3}}{2}$ (b) $\sqrt{3}$ (c) $\frac{3}{2}$ (d) $\frac{1}{\sqrt{3}}$

Solution: (b) From figure $r = 30^o$

$\therefore \quad \mu = \frac{\sin i}{\sin r} = \frac{\sin 60^o}{\sin 30^o} = \sqrt{3}$



Example: 3 Velocity of light in glass whose refractive index with respect to air is 1.5 is $2 \times 10^8\, m/s$ and in certain liquid the velocity of light found to be $2.50 \times 10^8\, m/s$. The refractive index of the liquid with respect to air is **[CPMT 1978; MP PET/PMT 1988]**

(a) 0.64 (b) 0.80 (c) 1.20 (d) 1.44

Solution: (c) $\mu \propto \frac{1}{v} \Rightarrow \frac{\mu_{li}}{\mu_g} = \frac{v_g}{v_l} \Rightarrow \frac{\mu_l}{1.5} = \frac{2 \times 10^8}{2.5 \times 10^8} \Rightarrow \mu_l = 1.2$

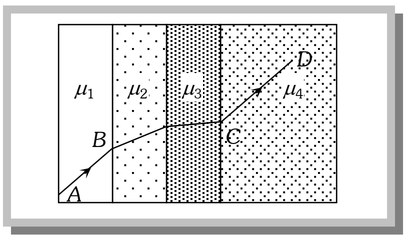
Example: 4 A ray of light passes through four transparent media with refractive indices $\mu_1 . \mu_2, \mu_3$, and μ_4 as shown in the figure. The surfaces of all media are parallel. If the emergent ray *CD* is parallel to the incident ray *AB*, we must have **[IIT-JEE (Screening) 2001]**

(a) $\mu_1 = \mu_2$

(b) $\mu_2 = \mu_3$

(c) $\mu_3 = \mu_4$

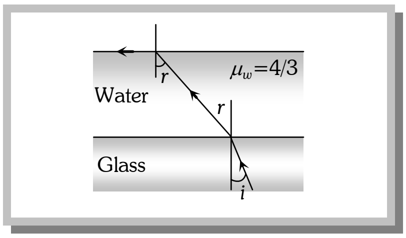
(d) $\mu_4 = \mu_1$



Solution: (d) For successive refraction through difference media $\mu \sin\theta =$ constant.

Here as θ is same in the two extreme media. Hence $\mu_1 = \mu_4$

***Example:* 5** A ray of light is incident at the glass–water interface at an angle *i*, it emerges finally parallel to the surface of water, then the value of μ_g would be **[IIT-JEE (Screening) 2003]**



(a) (4/3) sin *i*

(b) 1/ sin *i*

(c) 4/ 3

(d) 1

Solution: (b) For glass water interface ${}_g\mu_\omega = \dfrac{\sin i}{\sin r}$ ......(i) and For water-air interface ${}_\omega\mu_a = \dfrac{\sin r}{\sin 90}$ .....(ii)

$\therefore \quad {}_g\mu_\omega \times {}_\omega\mu_a = \sin i \qquad \Rightarrow \quad \mu_g = \dfrac{1}{\sin i}$

***Example:* 6** The ratio of thickness of plates of two transparent mediums *A* and *B* is 6 : 4. If light takes equal time in passing through them, then refractive index of *B* with respect to *A* will be **[UPSEAT 1999]**

(a) 1.4 (b) 1.5 (c) 1.75 (d) 1.33

Solution: (b) By using $t = \dfrac{\mu x}{c}$

$\Rightarrow \dfrac{\mu_B}{\mu_A} = \dfrac{x_A}{x_B} = \dfrac{6}{4} \Rightarrow {}_A\mu_B = \dfrac{3}{2} = 1.5$

***Example:* 7** A ray of light passes from vacuum into a medium of refractive index μ, the angle of incidence is found to be twice the angle of refraction. Then the angle of incidence is

(a) $\cos^{-1}(\mu/2)$ (b) $2\cos^{-1}(\mu/2)$ (c) $2\sin^{-1}(\mu)$ (d) $2\sin^{-1}(\mu/2)$

Solution: (b) By using $\mu = \dfrac{\sin i}{\sin r} \Rightarrow \mu = \dfrac{\sin 2r}{\sin r} = \dfrac{2\sin r\cos r}{\sin r}$ $(\sin 2\theta = 2\sin\theta\cos\theta)$

$\Rightarrow r = \cos^{-1}\left(\dfrac{\mu}{2}\right)$. So, $i = 2r = 2\cos^{-1}\left(\dfrac{\mu}{2}\right)$.

***Example:* 8** A ray of light falls on the surface of a spherical glass paper weight making an angle α with the normal and is refracted in the medium at an angle β. The angle of deviation of the emergent ray from the direction of the incident ray is **[NCERT 1982]**

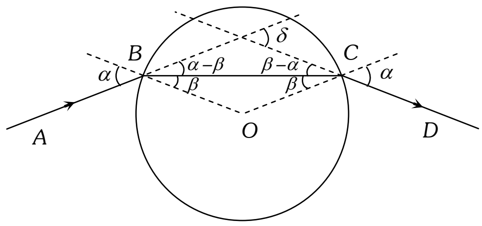
(a) $(\alpha-\beta)$ (b) $2(\alpha-\beta)$ (c) $(\alpha-\beta)/2$ (d) $(\alpha+\beta)$

Solution: (b) From figure it is clear that ΔOBC is an isosceles triangle,

Hence $\angle OCB = \beta$ and emergent angle is α

Also sum of two in terior angles = exterior angle

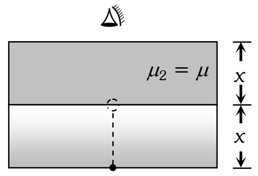
$\therefore \quad \delta = (\alpha-\beta)+(\alpha-\beta) = 2(\alpha-\beta)$



***Example:* 9** A rectangular slab of refractive index μ is placed over another slab of refractive index 3, both slabs being identical in dimensions. If a coin is placed below the lower slab, for what value of μ will the coin appear to be placed at the interface between the slabs when viewed from the top

(a) 1.8 (b) 2 (c) 1.5 (d) 2.5

Solution: (c) Apparent depth of coin as seen from top $= \frac{x}{\mu_1} + \frac{x}{\mu_2} = x$



$\Rightarrow \frac{1}{\mu_1} + \frac{1}{\mu_2} = 1 \quad \Rightarrow \frac{1}{3} + \frac{1}{\mu} = 1 \quad \Rightarrow \mu = 1.5$

***Example*: 10** A coin is kept at bottom of an empty beaker. A travelling microscope is focussed on the coin from top, now water is poured in beaker up to a height of 10 *cm*. By what distance and in which direction should the microscope be moved to bring the coin again in focus

(a) 10 *cm* up ward (b) 10 *cm* down ward (c) 2.5 *cm* up wards (d) 2.5 *cm* down wards

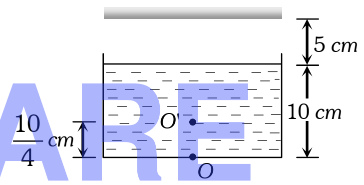
Solution: (c) When water is poured in the beaker. Coin appears to shift by a distance $d = \frac{h}{4} = \frac{10}{4} = 2.5cm$

Hence to bring the coil again in focus, the microscope should be moved by 2.5 *cm* in upward direction.

***Example*: 11** Consider the situation shown in figure. Water $\left(\mu_w = \frac{4}{3}\right)$ is filled in a breaker upto a height of 10 *cm*. A plane mirror fixed at a height of 5 *cm* from the surface of water. Distance of image from the mirror after reflection from it of an object *O* at the bottom of the beaker is

(a) 15 *cm* (b) 12.5 *cm* (c) 7.5 *cm* (d) 10 *cm*

Solution: (b) From figure it is clear that object appears to be raised by $\frac{10}{4} cm (2.5 cm)$



Hence distance between mirror and $O' = 5 + 7.5 = 12.5 cm$

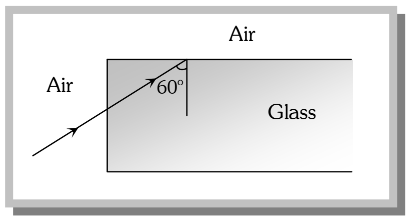
So final image will be formed at 12.5 *cm* behind the plane mirror.

***Example*: 12** The wavelength of light in two liquids 'x' and 'y' is 3500 Å and 7000 Å, then the critical angle of *x* relative to *y* will be

(a) 60° (b) 45° (c) 30° (d) 15°

Solution: (c) $\sin C = \frac{\mu_2}{\mu_1} = \frac{\lambda_1}{\lambda_2} = \frac{3500}{7000} = \frac{1}{2} \Rightarrow C = 30^\circ$

***Example*: 13** A light ray from air is incident (as shown in figure) at one end of a glass fiber (refractive index μ = 1.5) making an incidence angle of 60° on the lateral surface, so that it undergoes a total internal reflection. How much time would it take to traverse the straight fiber of length 1 *km* **[Orissa JEE 2002]**



(a) 3.33 μ *sec*

(b) 6.67 μ *sec*

(c) 5.77 μ *sec*

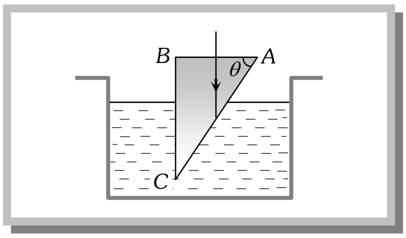
(d) 3.85 μ *sec*

Solution: (d) When total internal reflection just takes place from lateral surface then *i* = *C* *i.e.* *C* = 60°

From $\mu = \frac{1}{\sin C} \Rightarrow \mu = \frac{1}{\sin 60} = \frac{2}{\sqrt{3}}$

Hence time taken by light traverse some distance in medium $t = \frac{\mu x}{C} \Rightarrow t = \frac{\frac{2}{\sqrt{3}} \times (1 \times 10^3)}{3 \times 10^8} = 3.85 \mu\, sec.$

***Example*: 14** A glass prism of refractive index 1.5 is immersed in water $(\mu = 4/3)$. A light beam incident normally on the face *AB* is totally reflected to reach the face *BC* if **[CPMT 1981; IIT-JEE 1981]**



(a) $\sin\theta > 8/9$

(b) $2/3 < \sin\theta < 8/9$

(c) $\sin\theta \le 2/3$

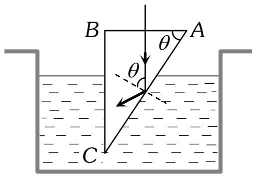
(d) $\cos\theta \ge 8/9$

Solution: (a) From figure it is clear that

Total internal reflection takes place at AC, only if $\theta > C$

$\Rightarrow \sin\theta > \sin C \qquad \Rightarrow \sin\theta > \dfrac{1}{{}_{\omega}\mu_g}$

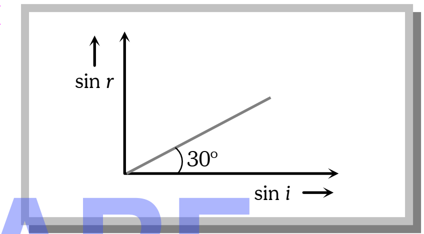
$\Rightarrow \sin\theta > \dfrac{1}{9/8} \qquad \Rightarrow \sin\theta > \dfrac{8}{9}$



Example: 15 When light is incident on a medium at angle i and refracted into a second medium at an angle r, the graph of sin i *vs* sin r is as shown in the graph. From this, one can conclude that

(a) Velocity of light in the second medium is 1.73 times the velocity of light in the I medium

(b) Velocity of light in the I medium is 1.73 times the velocity in the II medium



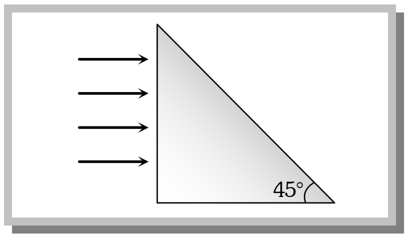
(c) The critical angle for the two media is given by $\sin\, i_c = \dfrac{1}{\sqrt{3}}$

(d) $\sin\, i_c = \dfrac{1}{2}$

Solution: (b, c) From graph $\tan 30^o = \dfrac{\sin r}{\sin i} = \dfrac{1}{{}_1\mu_2} \Rightarrow {}_1\mu_2 = \sqrt{3} \Rightarrow \dfrac{\mu_2}{\mu_1} = \dfrac{v_1}{v_2} = 1.73 \Rightarrow v_1 = 1.75\, v_2$

Also from $\mu = \dfrac{1}{\sin C} \Rightarrow \sin C = \dfrac{1}{{}_{Rarer}\mu_{Denser}} \Rightarrow \sin C = \dfrac{1}{{}_1\mu_2} = \dfrac{1}{\sqrt{3}}$.

Example: 16 A beam of light consisting of red, green and blue colours is incident on a right angled prism. The refractive indices of the material of the prism for the above red, green and blue wavelength are 1.39, 1.44 and 1.47 respectively. The prism will **[IIT-JEE 1989]**



(a) Separate part of red colour from the green and the blue colours

(b) Separate part of the blue colour from the red and green colours

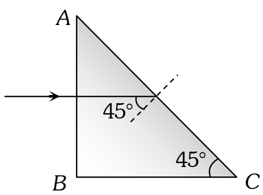
(c) Separate all the colours from one another

(d) Not separate even partially any colour from the other two colours

Solution: (a) At face AB, $i = 0$ so $r = 0$, *i.e.*, no refraction will take place. So light will be incident on face AC at an angle of incidence of 45°. The face AC will not transmit the light for which $i > \theta_C$, *i.e.*, $\sin i > \sin\theta_C$

or $\sin 45^o > (1/\mu)$ *i.e.*, $\mu > \sqrt{2}\ (= 1.41)$

Now as $\mu_R < \mu$ while μ_G and $\mu_B > \mu$, so red will be transmitted through the face AC while green and blue will be reflected. So the prism will separate red colour from green and blue.



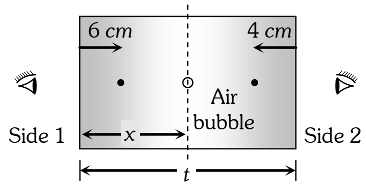
Example: 17 An air bubble in a glass slab $(\mu = 1.5)$ is 6 *cm* deep when viewed from one face and 4 *cm* deep when viewed from the opposite face. The thickness of the glass plate is

(a) 10 *cm* (b) 6.67 *cm* (c) 15 *cm* (d) None of these

Solution: (c) Let thickness of slab be t and distance of air bubble from one side is x

When viewed from side (1) : $1.5 = \frac{x}{6} \Rightarrow x = 9cm$

When viewed from side (2) : $1.5 = \frac{(t-x)}{4} \Rightarrow 1.5 = \frac{(t-9)}{4} \Rightarrow t = 15cm$



Tricky example: 1

One face of a rectangular glass plate 6 *cm* thick is silvered. An object held 8 *cm* in front of the first face, forms an image 12 *cm* behind the silvered face. The refractive index of the glass is **[CPMT 1999]**

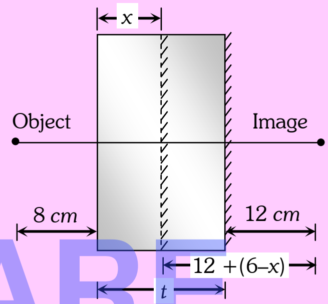
(a) 0.4 (b) 0.8 (c) 1.2 (d) 1.6

Solution : (c) From figure thickness of glass plate t = 6 *cm*.

Let x be the apparent position of the silvered surface.

According to property of plane mirror

$x + 8 = 12 + 6 - x \quad \Rightarrow \quad x = 5$ *cm*



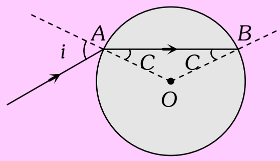
Also $\mu = \frac{t}{x} \quad \Rightarrow \quad \mu = \frac{6}{5} = 1.2$

Tricky example: 2

A ray of light is incident on a glass sphere of refractive index 3/2. What should be the angle of incidence so that the ray which enters the sphere doesn't come out of the sphere

(a) $\tan^{-1}\left(\frac{2}{3}\right)$ (b) $\sin^{-1}\left(\frac{2}{3}\right)$ (c) 90^o (d) $\cos^{-1}\left(\frac{1}{3}\right)$

Solution : (c) Ray doesn't come out from the sphere means TIR takes place.



Hence from figure $\angle ABO = \angle OAB = C$

$\therefore \quad \mu = \frac{1}{\sin C} \Rightarrow \sin C = \frac{1}{\mu} = \frac{2}{3}$

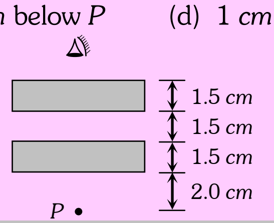
Applying Snell's Law at A $\quad \frac{\sin i}{\sin C} = \frac{3}{2} \Rightarrow \sin i = \frac{3}{2}\sin C = \frac{3}{2} \times \frac{2}{3} = 1 \quad \Rightarrow \quad i = 90^o$

Tricky example: 3

The image of point P when viewed from top of the slabs will be

(a) 2.0 *cm* above P (b) 1.5 *cm* above P (c) 2.0 *cm* below P (d) 1 *cm* above P

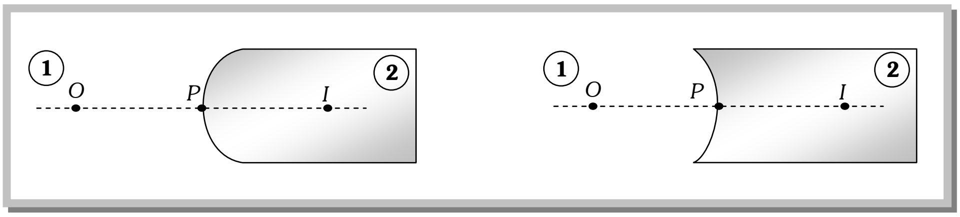
Solution: (d) The two slabs will shift the image a distance



$$d = 2\left(1 - \frac{1}{\mu}\right)t = 2\left(1 - \frac{1}{1.5}\right)(1.5) = 1cm$$

Therefore, final image will be 1 *cm* above point *P*.

Refraction From Curved Surface.



μ_1 = Refractive index of the medium from which light rays are coming (from object).

μ_2 = Refractive index of the medium in which light rays are entering.

u = Distance of object, v = Distance of image, R = Radius of curvature

Refraction formula : $\frac{\mu_2 - \mu_1}{R} = \frac{\mu_2}{v} - \frac{\mu_1}{u}$ (use sign convention while solving the problem)

Note : ≅ Real image forms on the side of a refracting surface that is opposite to the object, and virtual image forms on the same side as the object.

≅ Lateral (Transverse) magnification $m = \frac{I}{O} = \frac{\mu_1 v}{\mu_2 u}$.

Specific Example

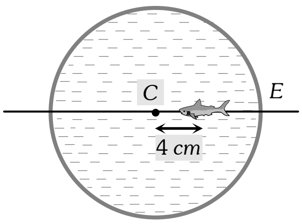
In a thin spherical fish bowl of radius 10 *cm* filled with water of refractive index 4/3 there is a small fish at a distance of 4 *cm* from the centre *C* as shown in figure. Where will the image of fish appears, if seen from *E*

(a) 5.2 *cm* (b) 7.2 *cm* (c) 4.2 *cm* (d) 3.2 *cm*

Solution : (a) By using $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$

where $\mu_1 = \frac{4}{3}$, $\mu_2 = 1$, $u = -6\,cm$, $v = ?$

On putting values $v = -5.2\,cm$

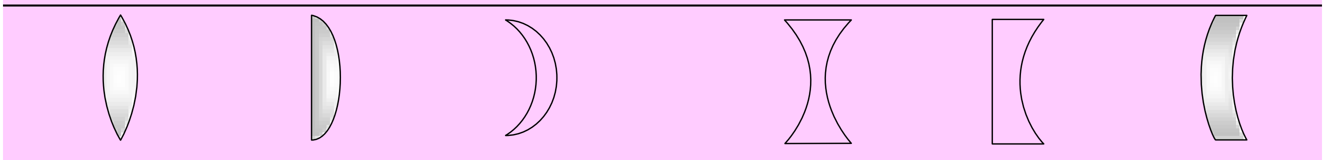


Lens.

Lens is a transparent medium bounded by two refracting surfaces, such that at least one surface is spherical.

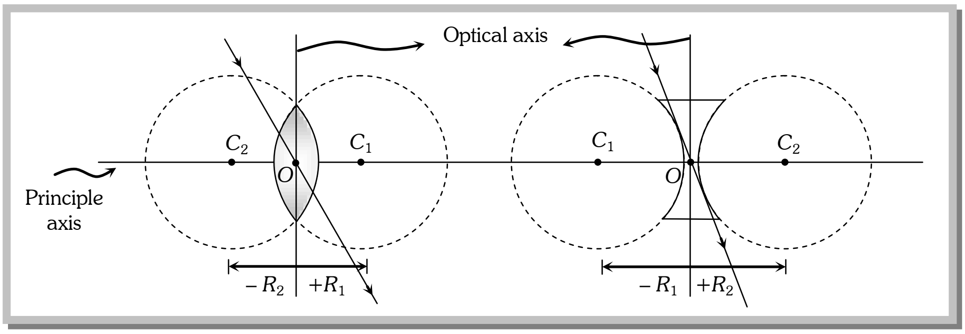
(1) Type of lenses

Convex lens (Converges the light rays)	Concave lens (Diverges the light rays)



Double convex	Plano convex	Concavo convex	Double concave	Plane concave	Convexo concave
Thick at middle			Thin at middle		
It forms real and virtual images both			It forms only virtual images		

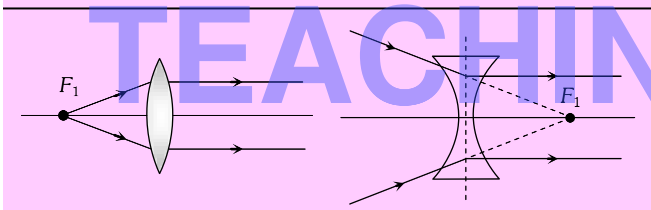
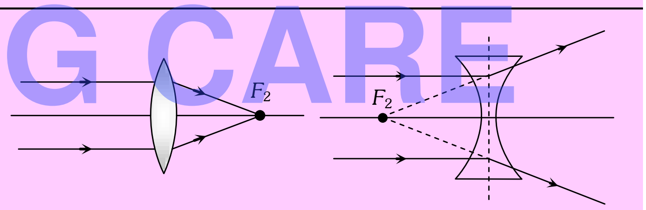
(2) **Some definitions**



C_1, C_2 – Centre of curvature,
R_1, R_2 – Radii of curvature

(i) **Optical centre (*O*) :** A point for a given lens through which light ray passes undeviated (Light ray passes undeviated through optical centre).

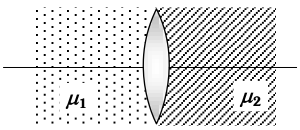
(ii) **Principle focus**

First principle focus	Second principle focus
	

Note : ≅Second principle focus is the principle focus of the lens.

≅ When medium on two sides of lens is same then $|F_1| = |F_2|$.

≅ If medium on two sides of lens are not same then the ratio of two focal lengths $\frac{f_1}{f_2} = \frac{\mu_1}{\mu_2}$



(iii) **Focal length (*f*) :** Distance of second principle focus from optical centre is called focal length

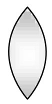
$f_{convex} \to$ positive, $f_{concave} \to$ negative, $f_{plane} \to \infty$

(iv) **Aperture :** Effective diameter of light transmitting area is called aperture. Intensity of image $\propto$ (Aperture)^2

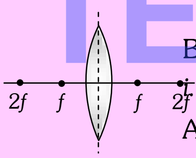
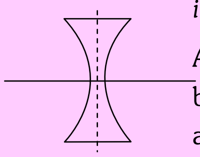
(v) **Power of lens (*P*) :** Means the ability of a lens to converge the light rays. Unit of power is Diopter (*D*).

$$P = \frac{1}{f(m)} = \frac{100}{f(cm)};\ P_{convex} \to \text{positive},\ P_{concave} \to \text{negative},\ P_{plane} \to \text{zero}.$$

Note : ≅ Thick lens $P\uparrow f\downarrow R\downarrow$ Thin lens $P\downarrow f\uparrow R\uparrow$




(3) **Image formation by lens**

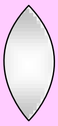
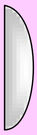
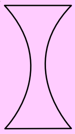
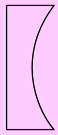
Lens	**Location of the object**	**Location of the image**	**Nature of image**		
			Magnification	**Real / virtual**	**Erect / inverted**
Convex	At infinity i.e. $u = \infty$	At focus i.e. $v = f$	$m < 1$ diminished	Real	Inverted
	Away from $2f$ i.e. $(u > 2f)$	Between f and $2f$ i.e. $f < v < 2f$	$m < 1$ diminished	Real	Inverted
	At $2f$ or $(u = 2f)$	At $2f$ i.e. $(v = 2f)$	$m = 1$ same size	Real	Inverted
	Between f and $2f$ i.e. $f < u < 2f$	Away from $2f$ i.e. $(v > 2f)$	$m > 1$ magnified	Real	Inverted
	At focus i.e. $u = f$	At infinity i.e. $v = \infty$	$m = \infty$ magnified	Real	Inverted
	Between optical centre and focus, $u < f$	At a distance greater than that of object $v > u$	$m > 1$ magnified	Virtual	Erect
Concave	At infinity i.e. $u = \infty$	At focus i.e. $v = f$	$m < 1$ diminished	Virtual	Erect
	Anywhere between infinity and optical centre	Between optical centre and focus	$m < 1$ diminished	Virtual	Erect

Note : ≅Minimum distance between an object and it's real image formed by a convex lens is $4f$.

≅ Maximum image distance for concave lens is it's focal length.

(4) **Lens maker's formula**

The relation between f, μ, R_1 and R_2 is known as lens maker's formula and it is $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Equiconvex lens	Plano convex lens	Equi concave lens	Plano concave lens
$R_1 = R$ and $R_2 = -R$ $f = \dfrac{R}{2(\mu - 1)}$ for $\mu = 1.5$, $f = R$ 	$R_1 = \infty$, $R_2 = -R$ $f = \dfrac{R}{(\mu - 1)}$ for $\mu = 1.5$, $f = 2R$ 	$R_1 = -R$, $R_2 = +R$ $f = -\dfrac{R}{2(\mu - 1)}$ for $\mu = 1.5$ $f = -R$ 	$R_1 = \infty$, $R_2 = R$ $f = \dfrac{R}{2(\mu - 1)}$ for $\mu = 1.5$, $f = -2R$ 

(5) **Lens in a liquid**

Focal length of a lens in a liquid (f_l) can be determined by the following formula

$$\frac{f_l}{f_a} = \frac{({}_a\mu_g - 1)}{({}_l\mu_g - 1)}$$ (Lens is supposed to be made of glass).

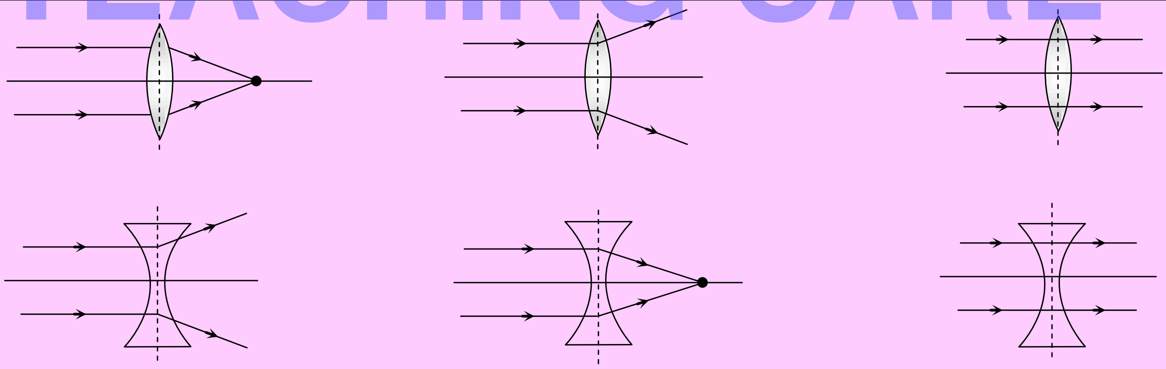
Note : ≅Focal length of a glass lens $(\mu = 1.5)$ is f in air then inside the water it's focal length is $4f$.

≅ In liquids focal length of lens increases (↑) and it's power decreases (↓).

(6) **Opposite behaviour of a lens**

In general refractive index of lens $(\mu_L) >$ refractive index of medium surrounding it (μ_M).

$\mu_L > \mu_M$	$\mu_L < \mu_M$	$\mu_L = \mu_M$



(7) **Lens formula and magnification of lens**

(i) Lens formula : $\dfrac{1}{f} = \dfrac{1}{v} - \dfrac{1}{u}$; (use sign convention)

(ii) Magnification : The ratio of the size of the image to the size of object is called magnification.

(a) Transverse magnification : $m = \dfrac{I}{O} = \dfrac{v}{u} = \dfrac{f}{f+u} = \dfrac{f-v}{f}$ (use sign convention while solving the problem)

(b) Longitudinal magnification : $m = \dfrac{I}{O} = \dfrac{v_2 - v_1}{u_2 - u_1}$. For very small object $m = \dfrac{dv}{du} = \left(\dfrac{v}{u}\right)^2 = \left(\dfrac{f}{f+u}\right)^2 = \left(\dfrac{f-v}{f}\right)^2$

(c) Areal magnification : $m_s = \dfrac{A_i}{A_o} = m^2 = \left(\dfrac{f}{f+u}\right)^2$, $(A_i =$ Area of image, $A_o =$ Area of object)

(8) Relation between object and image speed

If an object move with constant speed (V_o) towards a convex lens from infinity to focus, the image will move slower in the beginning and then faster. Also $V_i = \left(\dfrac{f}{f+u}\right)^2 . V_o$

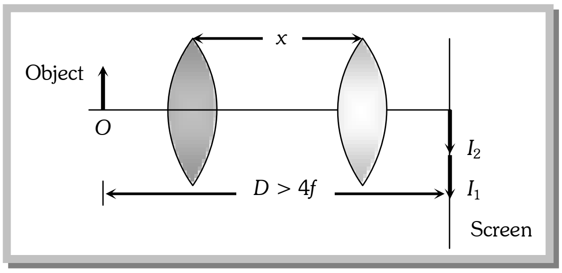
(9) Focal length of convex lens by displacement method

(i) For two different positions of lens two images $(I_1$ and $I_2)$ of an object is formed at the same location.

(ii) Focal length of the lens $f = \dfrac{D^2 - x^2}{4D} = \dfrac{x}{m_1 - m_2}$

where $m_1 = \dfrac{I_1}{O}$ and $m_2 = \dfrac{I_2}{O}$

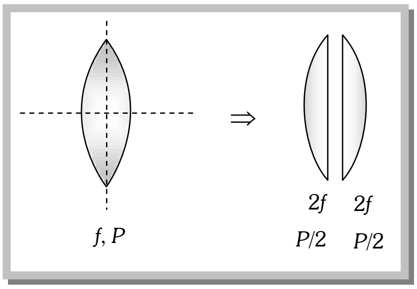
(iii) Size of object $O = \sqrt{I_1 . I_2}$

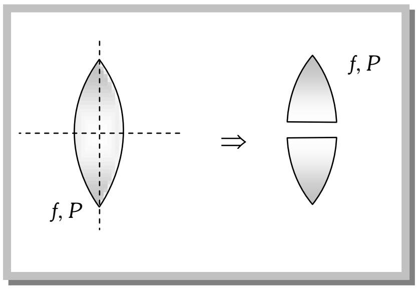


(10) Cutting of lens

(i) A symmetric lens is cut along optical axis in two equal parts. Intensity of image formed by each part will be same as that of complete lens.

(ii) A symmetric lens is cut along principle axis in two equal parts. Intensity of image formed by each part will be less compared as that of complete lens.(aperture of each part is $\dfrac{1}{\sqrt{2}}$ times that of complete lens)





(11) Combination of lens

(i) For a system of lenses, the net power, net focal length and magnification given as follows :

$$P = P_1 + P_2 + P_3 ...., \qquad \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + ..., \qquad m = m_1 \times m_2 \times m_3 \times ....$$

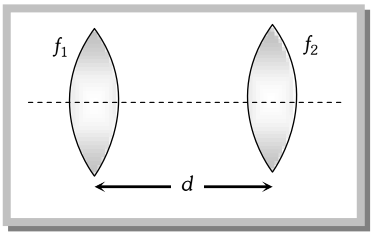
(ii) In case when two thin lens are in contact : Combination will behave as a lens, which have more power or lesser focal length.

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow F = \frac{f_1 f_2}{f_1 + f_2} \quad \text{and} \quad P = P_1 + P_2$$

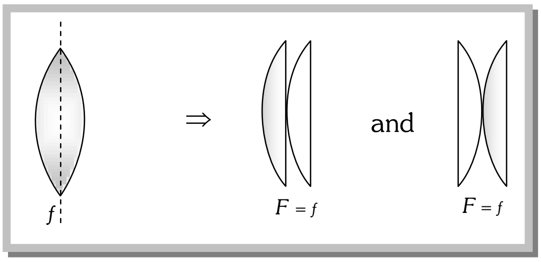
(iii) If two lens of equal focal length but of opposite nature are in contact then combination will behave as a plane glass plate and $F_{\text{combination}} = \infty$

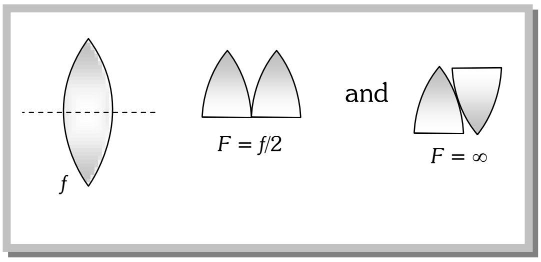
(iv) When two lenses are placed co-axially at a distance d from each other then equivalent focal length (F).

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}-\frac{d}{f_1 f_2} \quad \text{and} \quad P=P_1+P_2-dP_1P_2$$



(v) Combination of parts of a lens :





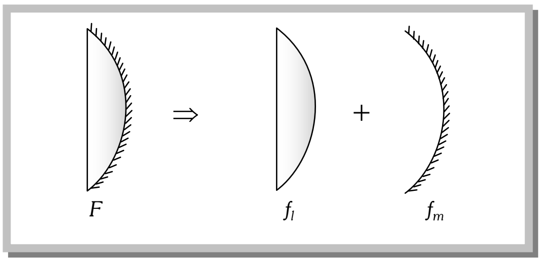
(12) **Silvering of lens**

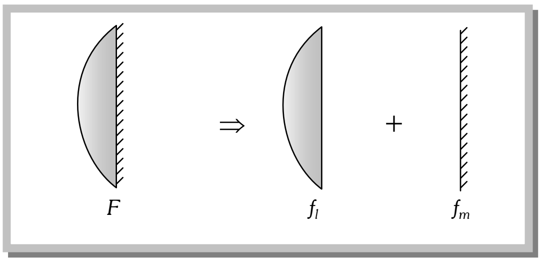
On silvering the surface of the lens it behaves as a mirror. The focal length of the silvered lens is $\frac{1}{F}=\frac{2}{f_l}+\frac{1}{f_m}$

where f_l = focal length of lens from which refraction takes place (twice)

f_m = focal length of mirror from which reflection takes place.

(i) Plano convex is silvered

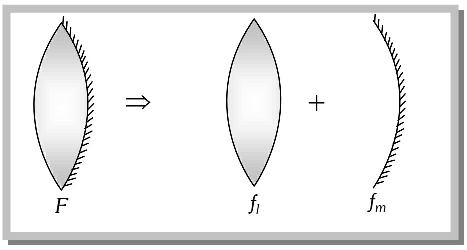




$f_m=\frac{R}{2},\ f_l=\frac{R}{(\mu-1)}$ so $F=\frac{R}{2\mu}$

$f_m=\infty,\ f_l=\frac{R}{(\mu-1)}$ so $F=\frac{R}{2(\mu-1)}$

(ii) Double convex lens is silvered



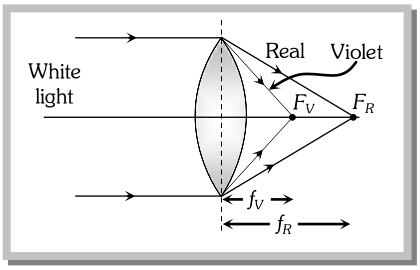
Since $f_l=\frac{R}{2(\mu-1)},\ f_m=\frac{R}{2}$

So $F=\frac{R}{2(2\mu-1)}$

Note : ≅ Similar results can be obtained for concave lenses.

(13) **Defects in lens**

(i) **Chromatic aberration :** Image of a white object is coloured and blurred because μ (hence f) of lens is different for different colours. This defect is called chromatic aberration.



$\mu_V > \mu_R$ so $f_R > f_V$

Mathematically chromatic aberration $= \boldsymbol{f_R - f_V} = \boldsymbol{\Delta f_y}$

$\omega =$ Dispersion power of lens.

$f_y =$ Focal length for mean colour $= \sqrt{f_R f_V}$

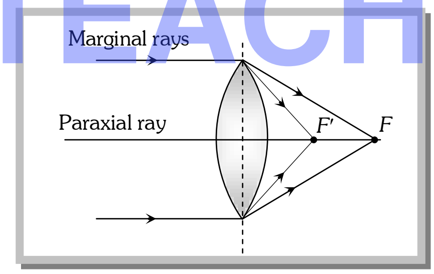
Removal : To remove this defect *i.e.* for Achromatism we use two or more lenses in contact in place of single lens.

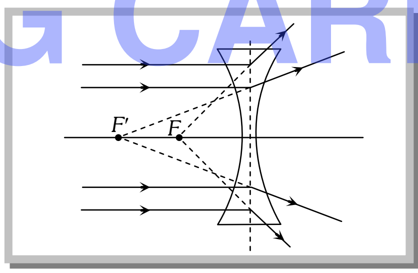
Mathematically condition of Achromatism is : $\dfrac{\omega_1}{f_1} + \dfrac{\omega_2}{f_2} = 0$ or $\omega_1 f_2 = -\omega_2 f_1$

Note : ≅ Component lenses of an achromatic doublet cemented by canada blasam because it is transparent and has a refractive index almost equal to the refractive of the glass.

(ii) **Spherical aberration :** Inability of a lens to form the point image of a point object on the axis is called Spherical aberration.

In this defect all the rays passing through a lens are not focussed at a single point and the image of a point object on the axis is blurred.





Removal : A simple method to reduce spherical aberration is to use a stop before and infront of the lens. (but this method reduces the intensity of the image as most of the light is cut off). Also by using plano-convex lens, using two lenses separated by distance $d = F - F'$, using crossed lens.

Note : ≅ Marginal rays : The rays farthest from the principal axis.

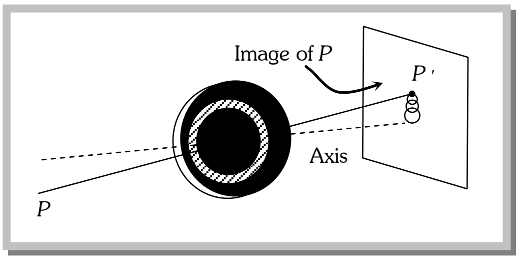
Paraxial rays : The rays close to the principal axis.

≅ Spherical aberration can be reduced by either stopping paraxial rays or marginal rays, which can be done by using a circular annular mask over the lens.

≅ Parabolic mirrors are free from spherical aberration.

(iii) **Coma :** When the point object is placed away from the principle axis and the image is received on a screen perpendicular to the axis, the shape of the image is like a comet. This defect is called Coma.

It refers to spreading of a point object in a plane $\perp$ to principle axis.

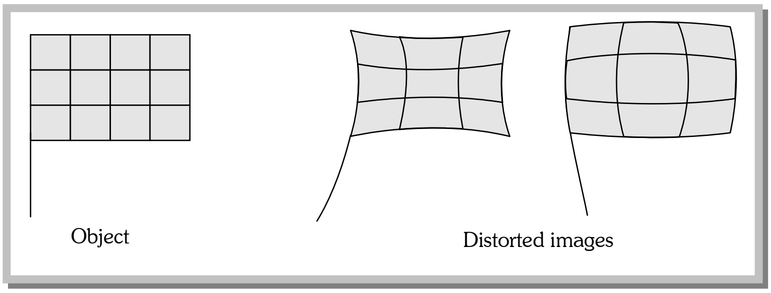


Removal : It can be reduced by properly designing radii of curvature of the lens surfaces. It can also be reduced by appropriate stops placed at appropriate distances from the lens.

(iv) **Curvature :** For a point object placed off the axis, the image is spread both along and perpendicular to the principal axis. The best image is, in general, obtained not on a plane but on a curved surface. This defect is known as Curvature.

Removal : Astigmatism or the curvature may be reduced by using proper stops placed at proper locations along the axis.

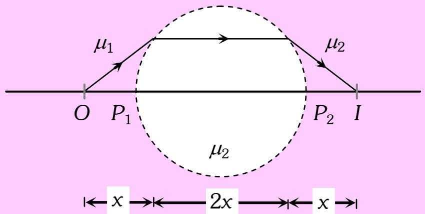
(v) **Distortion :** When extended objects are imaged, different portions of the object are in general at different distances from the axis. The magnification is not the same for all portions of the extended object. As a result a line object is not imaged into a line but into a curve.



(vi) **Astigmatism :** The spreading of image (of a point object placed away from the principal axis) along the principal axis is called Astigmatism.

Concepts

- *If a sphere of radius R made of material of refractive index μ_2 is placed in a medium of refractive index μ_1, Then if the object is placed at a distance $\left(\frac{\mu_1}{\mu_2 - \mu_1}\right)R$ from the pole, the real image formed is equidistant from the sphere.*



- *The lens doublets used in telescope are achromatic for blue and red colours, while these used in camera are achromatic for violet and green colours. The reason for this is that our eye is most sensitive between blue and red colours, while the photographic plates are most sensitive between violet and green colours.*

- ***Position of optical centre***

  Equiconvex and equiconcave $\longrightarrow$ *Exactly at centre of lens*

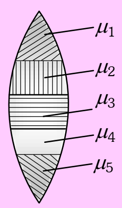
  Convexo-concave and concavo-convex $\longrightarrow$ *Outside the glass position*

  Plano convex and plano concave $\longrightarrow$ *On the pole of curved surface*

- ***Composite lens :*** *If a lens is made of several materials then*

  Number of images formed = Number of materials used

  Here no. of images = 5



Example

Example: 18 A thin lens focal length f_1 and its aperture has diameter d. It forms an image of intensity I. Now the central part of the aperture upto diameter $d/2$ is blocked by an opaque paper. The focal length and image intensity will change to **[CPMT 1989; MP PET 1997; KCET 1998]**

(a) $\frac{f}{2}$ and $\frac{I}{2}$ (b) f and $\frac{I}{4}$ (c) $\frac{3f}{4}$ and $\frac{I}{2}$ (d) f and $\frac{3I}{4}$

Example

Solution: (d) Centre part of the aperture up to diameter $\frac{d}{2}$ is blocked *i.e.* $\frac{1}{4}th$ area is blocked $\left(A = \frac{\pi d^2}{4}\right)$. Hence remaining area $A' = \frac{3}{4}A$. Also, we know that intensity $\propto$ Area $\Rightarrow \frac{I'}{I} = \frac{A'}{A} = \frac{3}{4} \Rightarrow I' = \frac{3}{4}I$.

Focal length doesn't depend upon aperture.

Example: 19 The power of a thin convex lens $({}_a\mu_g = 1.5)$ is + 5.0 D. When it is placed in a liquid of refractive index ${}_a\mu_l$, then it behaves as a concave lens of local length 100 cm. The refractive index of the liquid ${}_a\mu_l$ will be

(a) 5 / 3 (b) 4 / 3 (c) $\sqrt{3}$ (d) 5 / 4

Solution: (a) By using $\frac{f_l}{f_a} = \frac{{}_a\mu_g - 1}{{}_l\mu_g - 1}$; where ${}_l\mu_g = \frac{\mu_g}{\mu_l} = \frac{1.5}{\mu_l}$ and $f_a = \frac{1}{P} = \frac{1}{5}m = 20\,cm$

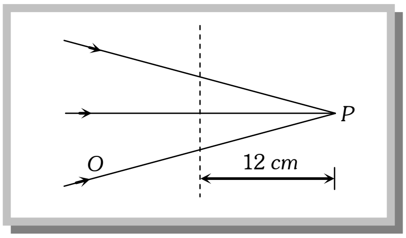
$\Rightarrow \frac{-100}{20} = \frac{1.5 - 1}{\frac{1.5}{\mu_l} - 1} \Rightarrow \mu_l = 5/3$

Example: 20 A double convex lens made of a material of refractive index 1.5 and having a focal length of 10 cm is immersed in liquid of refractive index 3.0. The lens will behave as **[NCERT 1973]**

(a) Diverging lens of focal length 10 cm
(b) Diverging lens of focal length 10 / 3 cm
(c) Converging lens of focal length 10 / 3 cm
(d) Converging lens of focal length 30 cm

Solution: (a) By using $\frac{f_l}{f_a} = \frac{{}_a\mu_g - 1}{{}_l\mu_g - 1} \Rightarrow \frac{f_l}{+10} = \frac{1.5 - 1}{\frac{1.5}{3} - 1} \Rightarrow f_l = -10\,cm$ (*i.e.* diverging lens)

Example: 21 Figure given below shows a beam of light converging at point P. When a concave lens of focal length 16 cm is introduced in the path of the beam at a place O shown by dotted line such that OP becomes the axis of the lens, the beam converges at a distance x from the lens. The value x will be equal to **[AMU (Med.) 2002]**

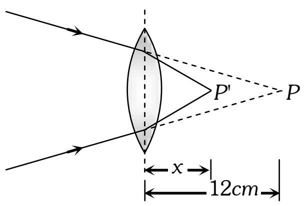


(a) 12 cm
(b) 24 cm
(c) 36 cm
(d) 48 cm

Solution: (d) From the figure shown it is clear that

For lens : u = 12 cm and $v = x$ = ?

By using $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$



$\Rightarrow \frac{1}{+16} = \frac{1}{x} - \frac{1}{+12} \Rightarrow x = 48\ cm.$

Example: 22 A convex lens of focal length 40 *cm* is an contact with a concave lens of focal length 25 *cm*. The power of combination is **[IIT-JEE 1982; AFMC 1997; CBSE PMT 2000]**

(a) – 1.5 *D* (b) – 6.5 *D* (c) + 6.5 *D* (d) + 6.67 *D*

Solution: (a) By using $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow \frac{1}{F} = \frac{1}{+40} + \frac{1}{-25}$

$\Rightarrow F = -\frac{200}{3} cm$, hence $P = \frac{100}{f(cm)} = \frac{100}{-200/3} = -1.5\ D$

Example: 23 A combination of two thin lenses with focal lengths f_1 and f_2 respectively forms an image of distant object at distance 60 *cm* when lenses are in contact. The position of this image shifts by 30 *cm* towards the combination when two lenses are separated by 10 *cm*. The corresponding values of f_1 and f_2 are **[AIIMS 1995]**

(a) 30 *cm*, – 60 *cm* (b) 20 *cm*, – 30 *cm* (c) 15 *cm*, – 20 *cm* (d) 12 *cm*, – 15 *cm*

Solution: (b) Initially $F = 60\ cm$ (Focal length of combination)

Hence by using $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow \frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{60} \Rightarrow \frac{f_1 f_2}{f_1 + f_2}$ ......(i)

Finally by using $\frac{1}{F'} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$ where $F' = 30\ cm$ and $d = 10\ cm$ $\Rightarrow \frac{1}{30} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{10}{f_1 f_2}$ ......(ii)

From equations (i) and (ii) $f_1 f_2 = -600.$

From equation (i) $f_1 + f_2 = -10$ .....(iii)

Also, difference of focal lengths can written as $f_1 - f_2 = \sqrt{(f_1 + f_2)^2 - 4 f_1 f_2} \Rightarrow f_1 - f_2 = 50$ .....(iv)

From (iii) × (iv) $f_1 = 20$ and $f_2 = -30$

Example: 24 A thin double convex lens has radii of curvature each of magnitude 40 *cm* and is made of glass with refractive index 1.65. Its focal length is nearly **[MP PMT 1997]**

(a) 20 *cm* (b) 31 *cm* (c) 35 *cm* (d) 50 *cm*

Solution: (b) By using $f = \frac{R}{2(\mu - 1)} \Rightarrow f = \frac{40}{2(1.65 - 1)} = 30.7\ cm \approx 31\ cm.$

Example: 25 A spherical surface of radius of curvature *R* separates air (refractive index 1.0) from glass (refractive index 1.5). The centre of curvature is in the glass. A point object *P* placed in air is found to have a real image *Q* in the glass. The line *PQ* cuts the surface at a point *O* and $PO = OQ$. The distance *PO* is equal to

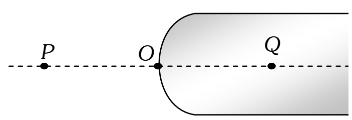
[MP PMT 1994; Haryana CEE 1996]

(a) 5 *R* (b) 3 *R* (c) 2 *R* (d) 1.5 *R*

Solution: (a) By using $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$

Where $\mu_1 = 1, \quad \mu_2 = 1.5, \quad u = -OP, \quad v = OQ$

Hence $\frac{1.5}{OQ} - \frac{1}{-OP} = \frac{1.5 - 1}{(+R)} \Rightarrow \frac{1.5}{OP} + \frac{1}{OP} = \frac{0.5}{R}$



$\Rightarrow \quad OP = 5\,R$

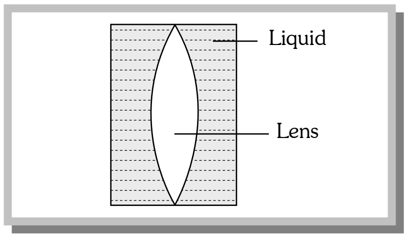
Example: 26 The distance between an object and the screen is 100 *cm*. A lens produces an image on the screen when placed at either of the positions 40 *cm* apart. The power of the lens is **[SCRA 1994]**

(a) 3 *D* (b) 5 *D* (c) 7 *D* (d) 9 *D*

Solution: (b) By using $f = \dfrac{D^2 - x^2}{4D} \Rightarrow f = \dfrac{100^2 - 40^2}{4 \times 100} = 21\,cm$

Hence power $P = \dfrac{100}{F(cm)} = \dfrac{100}{21} \approx +5D$

Example: 27 Shown in figure here is a convergent lens placed inside a cell filled with a liquid. The lens has focal length +20 *cm* when in air and its material has refractive index 1.50. If the liquid has refractive index 1.60, the focal length of the system is **[NSEP 1994; DPMT 2000]**



(a) + 80 *cm*

(b) – 80 *cm*

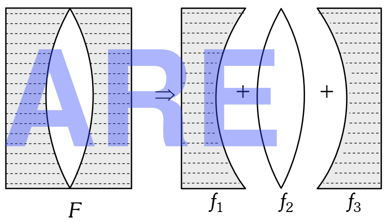
(c) – 24 *cm*

(d) – 100 *cm*

Solution: (d) Here $\dfrac{1}{f_1} = (1.6 - 1)\left(\dfrac{1}{\infty} - \dfrac{1}{20}\right) = \dfrac{-3}{100}$ ....(i)

$\dfrac{1}{f_2} = (1.5 - 1)\left(\dfrac{1}{20} - \dfrac{1}{-20}\right) = \dfrac{1}{20}$ ....(ii)

$\dfrac{1}{f_3} = (1.6 - 1)\left(\dfrac{1}{-20} - \dfrac{1}{\infty}\right) = \dfrac{-3}{100}$ ....(iii)



By using $\dfrac{1}{F} = \dfrac{1}{f_1} + \dfrac{1}{f_2} + \dfrac{1}{f_3} \Rightarrow \dfrac{1}{F} = \dfrac{-3}{100} + \dfrac{1}{20} - \dfrac{3}{100} \Rightarrow F = -100\,cm$

Example: 28 A concave lens of focal length 20 *cm* placed in contact with a plane mirror acts as a **[SCRA 1998]**

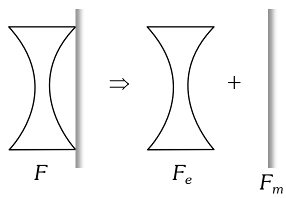
(a) Convex mirror of focal length 10 *cm* (b) Concave mirror of focal length 40 *cm*

(c) Concave mirror of focal length 60 *cm* (d) Concave mirror of focal length 10 *cm*

Solution: (a) By using $\dfrac{1}{F} = \dfrac{2}{f_l} + \dfrac{1}{f_m}$

Since $f_m = \infty \Rightarrow F = \dfrac{f_l}{2} = \dfrac{20}{2} = 10\,cm$

(After silvering concave lens behave as convex mirror)



Example: 29 A candle placed 25 *cm* from a lens, forms an image on a screen placed 75 *cm* on the other end of the lens. The focal length and type of the lens should be **[KCET (Med.) 2000]**

(a) + 18.75 *cm* and convex lens (b) – 18.75 *cm* and concave lens

(c) + 20.25 *cm* and convex lens (d) – 20.25 *cm* and concave lens

Solution: (a) In concave lens, image is always formed on the same side of the object. Hence the given lens is a convex lens for which $u = -25\,cm$, $v = 75\,cm$.

By using $\dfrac{1}{f} = \dfrac{1}{v} - \dfrac{1}{u} \Rightarrow \dfrac{1}{f} = \dfrac{1}{(+75)} - \dfrac{1}{(-25)} \Rightarrow f = +18.75\,cm.$

Example: 30 A convex lens forms a real image of an object for its two different positions on a screen. If height of the image in both the cases be 8 *cm* and 2 *cm*, then height of the object is **[KCET (Engg./Med.) 2000, 2001]**

(a) 16 *cm* (b) 8 *cm* (c) 4 *cm* (d) 2 *cm*

Solution: (c) By using $O = \sqrt{I_1 I_2}$ $\Rightarrow O = \sqrt{8 \times 2} = 4\,cm$

Example: 31 A convex lens produces a real image *m* times the size of the object. What will be the distance of the object from the lens **[JIPMER 2002]**

(a) $\left(\frac{m+1}{m}\right)f$ (b) $(m-1)f$ (c) $\left(\frac{m-1}{m}\right)f$ (d) $\frac{m+1}{f}$

Solution: (a) By using $m = \frac{f}{f+u}$ here $-m = \frac{(+f)}{(+f)+u} \Rightarrow -\frac{1}{m} = \frac{f+u}{f} = 1 + \frac{u}{f} \Rightarrow u = -\left(\frac{m+1}{m}\right).f$

Example: 32 An air bubble in a glass sphere having 4 *cm* diameter appears 1 *cm* from surface nearest to eye when looked along diameter. If ${}_a\mu_g = 1.5$, the distance of bubble from refracting surface is **[CPMT 2002]**

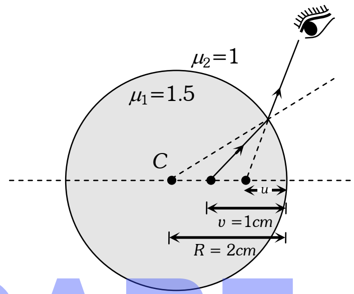
(a) 1.2 *cm* (b) 3.2 *cm* (c) 2.8 *cm* (d) 1.6 *cm*

Solution: (a) By using

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

where $u = ?$, $v = -1\,cm$, $\mu_1 = 1.5$, $\mu_2 = 1$, $R = -2\,cm$.

$$\frac{1}{-1} - \frac{1.5}{u} = \frac{1-1.5}{(-2)} \Rightarrow u = -\frac{6}{5} = -1.2\,cm.$$

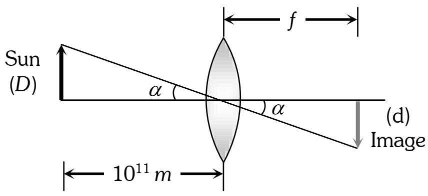


Example: 33 The sun's diameter is $1.4 \times 10^9\,m$ and its distance from the earth is $10^{11}\,m$. The diameter of its image, formed by a convex lens of focal length 2*m* will be **[MP PET 2000]**

(a) 0.7 *cm* (b) 1.4 *cm* (c) 2.8 *cm* (d) Zero (*i.e.* point image)

Solution: (c) From figure

$$\frac{D}{d} = \frac{10^{11}}{2} \Rightarrow d = \frac{2 \times 1.4 \times 10^9}{10^{11}} = 2.8\,cm.$$



Example: 34 Two point light sources are 24 *cm* apart. Where should a convex lens of focal length 9 *cm* be put in between them from one source so that the images of both the sources are formed at the same place

(a) 6 *cm* (b) 9 *cm* (c) 12 *cm* (d) 15 *cm*

Solution: (a) The given condition will be satisfied only if one source (S_1) placed on one side such that $u < f$ (*i.e.* it lies under the focus). The other source (S_2) is placed on the other side of the lens such that $u > f$ (*i.e.* it lies beyond the focus).

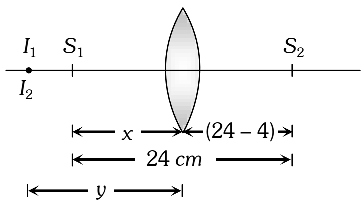
If S_1 is the object for lens then $\frac{1}{f} = \frac{1}{-y} - \frac{1}{-x} \Rightarrow \frac{1}{y} = \frac{1}{x} - \frac{1}{f}$ ....(i)

If S_2 is the object for lens then $\frac{1}{f} = \frac{1}{+y} - \frac{1}{-(24-x)} \Rightarrow \frac{1}{y} = \frac{1}{f} - \frac{1}{(24-x)}$ ....(ii)

From equation (i) and (ii)

$$\frac{1}{x} - \frac{1}{f} = \frac{1}{f} - \frac{1}{(24-x)} \Rightarrow \frac{1}{x} + \frac{1}{(24-x)} = \frac{2}{f} = \frac{2}{9} \Rightarrow x^2 - 24x + 108 = 0$$

On solving the equation $x = 18\,cm$, $6\,cm$

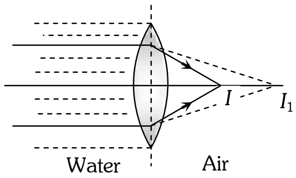


Example: 35 There is an equiconvex glass lens with radius of each face as R and ${}_a\mu_g = 3/2$ and ${}_a\mu_w = 4/3$. If there is water in object space and air in image space, then the focal length is

(a) $2R$ (b) R (c) $3R/2$ (d) R^2

Solution: (c) Consider the refraction of the first surface *i.e.* refraction from rarer medium to denser medium

$$\frac{\mu_2-\mu_1}{R}=\frac{\mu_1}{-u}+\frac{\mu_2}{v_1} \Rightarrow \frac{\left(\frac{3}{2}\right)-\left(\frac{4}{3}\right)}{R}=\frac{\frac{4}{3}}{\infty}+\frac{\frac{3}{2}}{v_1} \Rightarrow v_1 = 9R$$



Now consider the refraction at the second surface of the lens *i.e.* refraction from denser medium to rarer medium

$$\frac{1-\frac{3}{2}}{-R}=-\frac{\frac{3}{2}}{9R}+\frac{1}{v_2} \Rightarrow v_2=\left(\frac{3}{2}\right)R$$

The image will be formed at a distance do $\frac{3}{2}R$. This is equal to the focal length of the lens.

Tricky example: 4

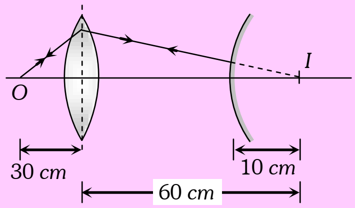
A luminous object is placed at a distance of 30 *cm* from the convex lens of focal length 20 *cm*. On the other side of the lens. At what distance from the lens a convex mirror of radius of curvature 10 *cm* be placed in order to have an upright image of the object coincident with it

[CBSE PMT 1998; JIPMER 2001, 2002]

(a) 12 *cm* (b) 30 *cm* (c) 50 *cm* (d) 60 *cm*

Solution : (c) For lens $u = 30\ cm$, $f = 20\,cm$, hence by using $\frac{1}{f}=\frac{1}{v}-\frac{1}{u} \Rightarrow \frac{1}{+20}=\frac{1}{v}-\frac{1}{-30} \Rightarrow v = 60\ cm$

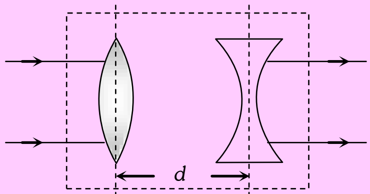
The final image will coincide the object, if light ray falls normally on convex mirror as shown. From figure it is seen clear that reparation between lens and mirror is 60 – 10 = 50 *cm*.



Tricky example: 5

A convex lens of local length 30 *cm* and a concave lens of 10 *cm* focal length are placed so as to have the same axis. If a parallel beam of light falling on convex lens leaves concave lens as a parallel beam, then the distance between two lenses will be

(a) 40 *cm* (b) 30 *cm* (c) 20 *cm* (d) 10 *cm*



Solution : (c) According to figure the combination behaves as plane glass plate (*i.e.*, $F = \infty$)

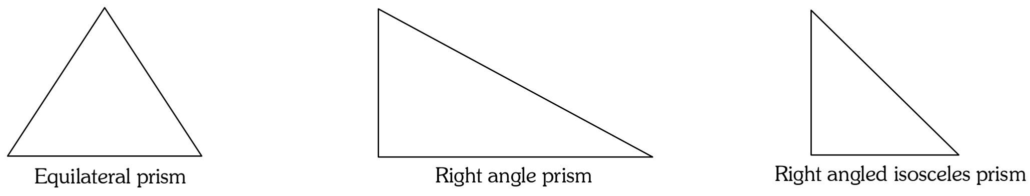
Hence by using $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$

$$\Rightarrow \frac{1}{\infty} = \frac{1}{+30} + \frac{1}{-10} - \frac{d}{(30)(-10)} \Rightarrow d = 20\ cm$$

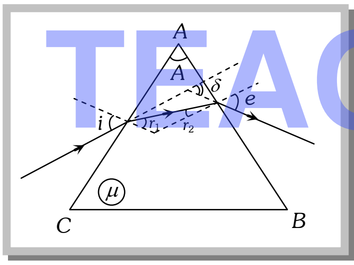
Prism

Prism is a transparent medium bounded by refracting surfaces, such that the incident surface (on which light ray is incidenting) and emergent surface (from which light rays emerges) are plane and non parallel.

Commonly used prism :



(1) Refraction through a prism



$A = r_1 + r_2$ and $i + e = A + \delta$

For surface AC $\mu = \frac{\sin i}{\sin r_1}$;

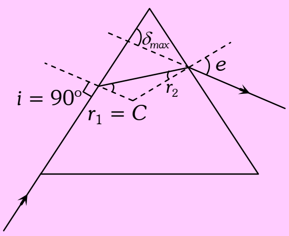
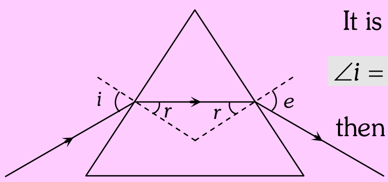
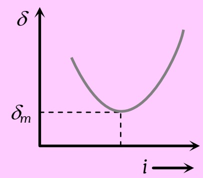
For surface AB $\mu = \frac{\sin r_2}{\sin e}$

i – Angle of incidence, e – Angle of emergence,
A – Angle of prism or refracting angle of prism,
r_1 and r_2 – Angle of refraction,
δ – Angle of deviation

(2) Deviation through a prism

For thin prism $\delta = (\mu - 1)A$. Also deviation is different for different colour light e.g. $\mu_R < \mu_V$ so $\delta_R < \delta_V$.

$$\mu_{\text{Flint}} > \mu_{\text{Crown}} \text{ so } \delta_F > \delta_C$$

Maximum deviation	Minimum deviation
 In this condition of maximum deviation $\angle i = 90^o$, $r_1 = C$, $r_2 = A - C$ and from Snell's law on emergent surface $e = \sin^{-1}\left[\frac{\sin(A-C)}{\sin C}\right]$	 It is observed if $\angle i = \angle e$ and $\angle r_1 = \angle r_2 = r$ then : (i) Refracted ray inside the prism is parallel to the base of the prism 

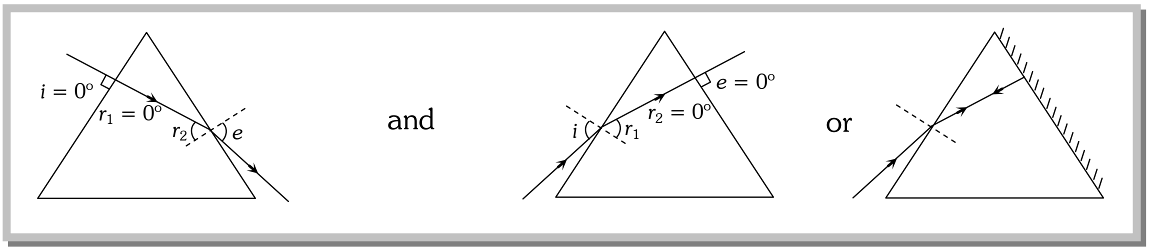
(ii) $r = \dfrac{A}{2}$ and $i = \dfrac{A+\delta_m}{2}$

(iii) $\mu = \dfrac{\sin i}{\sin A/2}$ or $\mu = \dfrac{\sin\dfrac{A+\delta_m}{2}}{\sin A/2}$

Note : ≅ If $\delta_m = A$ then $\mu = 2\cos A/2$

(3) Normal incidence on a prism

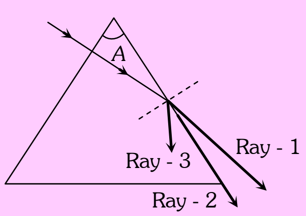
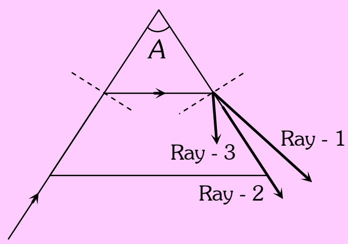
If light ray incident normally on any surface of prism as shown



In any of the above case use $\mu = \dfrac{\sin i}{\sin A}$ and $\delta = i - A$

(4) Grazing emergence and TIR through a prism

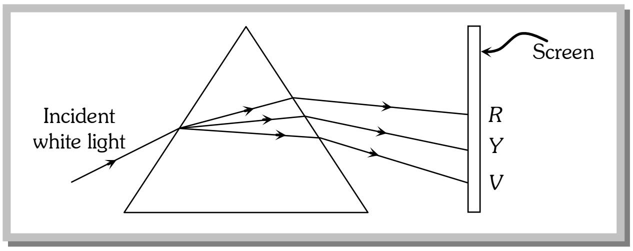
When a light ray falls on one surface of prism, it is not necessary that it will exit out from the prism. It may or may not be exit out as shown below

Normal incidence	Grazing incidence
 Ray –1 : General emergence $A < C$ and $\mu < \text{cosec } A$ Ray – 2: Grazing emergence $A = C$ and $\mu = \text{cosec } A$ Ray – 3: TIR $A > C$ and $\mu > \text{cosec } A$ A = angle of prism and C = Critical angle for the material of the prism	 Ray –1 : General emergence $A < 2C$ and $\mu < \text{cosec } (A/2)$ Ray – 2: Grazing emergence $A = 2C$ and $\mu = \text{cosec } (A/2)$ Ray – 3: TIR $A > 2C$ and $\mu > \text{cosec } (A/2)$

Note : ≅ For the condition of grazing emergence. Minimum angle of incidence $\boldsymbol{i_{min} = \sin^{-1}\left[\sqrt{\mu^2 - 1}\,\sin A - \cos A\right]}$.

(5) Dispersion through a prism

The splitting of white light into it's constituent colours is called dispersion of light.



(i) Angular dispersion (θ) : Angular separation between extreme colours *i.e.* $\theta = \delta_V - \delta_R = (\mu_V - \mu_R)A$. It depends upon μ and A.

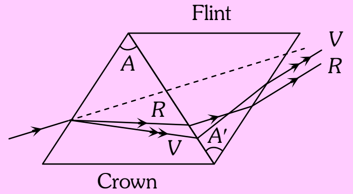
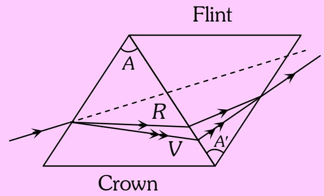
(ii) Dispersive power (ω) : $\omega = \dfrac{\theta}{\delta_y} = \dfrac{\mu_V - \mu_R}{\mu_y - 1}$ where $\left\{\mu_y = \dfrac{\mu_V + \mu_R}{2}\right\}$

$\Rightarrow$ It depends only upon the material of the prism *i.e.* μ and it doesn't depends upon angle of prism A

Note : $\cong$ Remember $\omega_{\text{Flint}} > \omega_{\text{Crown}}$.

(6) **Combination of prisms**

Two prisms (made of crown and flint material) are combined to get either dispersion only or deviation only.

Dispersion without deviation (chromatic combination)	Deviation without dispersion (Achromatic combination)
	
(i) $\dfrac{A'}{A} = -\dfrac{(\mu_y - 1)}{(\mu'_y - 1)}$	(i) $\dfrac{A'}{A} = -\dfrac{(\mu_V - \mu_R)}{(\mu'_V - \mu'_R)}$
(ii) $\theta_{net} = \theta\left(1 - \dfrac{\omega'}{\omega}\right) = (\omega\delta - \omega'\delta')$	(ii) $\delta_{net} = \delta\left(1 - \dfrac{\omega}{\omega'}\right)$

Scattering of Light

Molecules of a medium after absorbing incoming light radiations, emits them in all direction. This phenomenon is called Scattering.

(1) **According to scientist Rayleigh :** Intensity of scattered light $\propto \dfrac{1}{\lambda^4}$

(2) **Some phenomenon based on scattering :** (i) Sky looks blue due to scattering.

(ii) At the time of sunrise or sunset it looks reddish. (iii) Danger signals are made from red.

(3) **Elastic scattering :** When the wavelength of radiation remains unchanged, the scattering is called elastic.

(4) **Inelastic scattering (Raman's effect) :** Under specific condition, light can also suffer inelastic scattering from molecules in which it's wavelength changes.

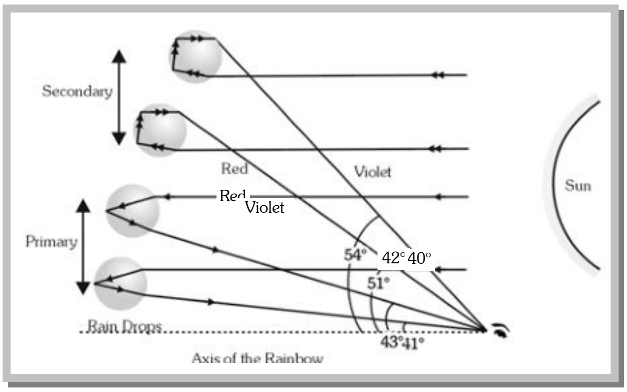
Rainbow

Rainbow is formed due to the dispersion of light suffering refraction and TIR in the droplets present in the atmosphere.

(1) **Primary rainbow :** (i) Two refraction and one TIR. (ii) Innermost arc is violet and outermost is red. (iii) Subtends an angle of 42^o at the eye of the observer. (iv) More bright

(2) **Secondary rainbow :** (i) Two refraction and two TIR. (ii) Innermost arc is red and outermost is violet.

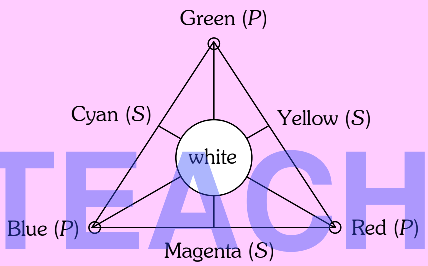
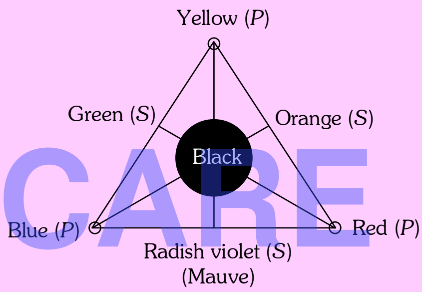
(iii) It subtends an angle of 52.5^o at the eye. (iv) Comparatively less bright.



Colours

Colour is defined as the sensation received by the eye (rod cells of the eye) due to light coming from an object.

(1) **Types of colours**

Spectral colours	Colours of pigment and dyes
	
(i) Complementary colours :	(i) Complementary colours :
Green and magenta	yellow and mauve
Blue and yellow	Red and green
Red and cyan	Blue and orange
(ii) Combination :	(ii) Combination :
Green + red + blue = White	Yellow + red + blue = Black
Blue + yellow = White	Blue + orange = Black
Red + cyan = White	Red + green = Black
Green + magenta = White	Yellow + mauve = Black

(2) **Colours of object :** The perception of a colour by eye depends on the nature of object and the light incident on it.

Colours of opaque object	Colours of transparent object
(i) Due to selective reflection.	(i) Due to selective transmission.
(ii) A rose appears red in white light because it reflects red colour and absorbs all remaining colours.	(ii) A red glass appears red because it absorbs all colours, except red which it transmits.
(iii) When yellow light falls on a bunch of flowers, then yellow and white flowers looks yellow. Other flowers	(iii) When we look on objects through a green glass or green filter then green and white objects will appear

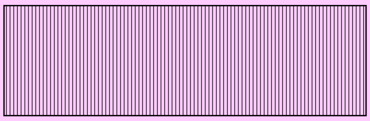
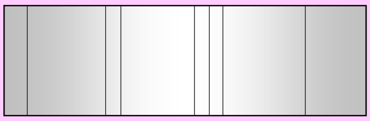
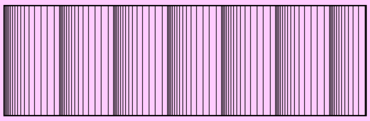
looks black.	green while other black.

Note : ≅A hot object will emit light of that colour only which it has observed when it was heated.

Spectrum.

The ordered arrangements of radiations according to wavelengths or frequencies is called Spectrum. Spectrum can be divided in two parts (I) Emission spectrum and (II) Absorption spectrum.

(1) **Emission spectrum :** When light emitted by a self luminous object is dispersed by a prism to get the spectrum, the spectrum is called emission spectra.

Continuous emission spectrum	Line emission spectrum	Band emission spectrum
(i) It consists of continuously varying wavelengths in a definite wavelength range.	(i) It consist of distinct bright lines.	(iii) It consist of district bright bands.
(ii) It is produced by solids, liquids and highly compressed gases heated to high temperature.	(ii) It is produced by an excited source in atomic state.	(ii) It is produced by an excited source in molecular state.
(iii) *e.g.* Light from the sun, filament of incandescent bulb, candle flame *etc*.	(iii) *e.g.* Spectrum of excited helium, mercury vapours, sodium vapours or atomic hydrogen.	(iii) *e.g.* Spectra of molecular H_2, CO, NH_3 etc.
		

(2) **Absorption spectrum :** When white light passes through a semi-transparent solid, or liquid or gas, it's spectrum contains certain dark lines or bands, such spectrum is called absorption spectrum (of the substance through which light is passed).

(i) Substances in atomic state produces line absorption spectra. Polyatomic substances such as H_2, CO_2 and $KMnO_4$ produces band absorption spectrum.

(ii) Absorption spectra of sodium vapour have two (yellow lines) wavelengths $D_1 (5890\,Å)$ and $D_2 (5896\,Å)$

Note : ≅ If a substance emits spectral lines at high temperature then it absorbs the same lines at low temperature. This is Kirchoff's law.

(3) **Fraunhoffer's lines :** The central part (photosphere) of the sun is very hot and emits all possible wavelengths of the visible light. However, the outer part (chromosphere) consists of vapours of different elements. When the light emitted from the photosphere passes through the chromosphere, certain wavelengths are absorbed. Hence, in the spectrum of sunlight a large number of dark lines are seen called Fraunhoffer lines.

(i) The prominent lines in the yellow part of the visible spectrum were labelled as *D*-lines, those in blue part as *F*-lines and in red part as *C*-line.

(ii) From the study of Fraunhoffer's lines the presence of various elements in the sun's atmosphere can be identified *e.g.* abundance of hydrogen and helium.

(4) **Spectrometer :** A spectrometer is used for obtaining pure spectrum of a source in laboratory and calculation of μ of material of prism and μ of a transparent liquid.

It consists of three parts : Collimator which provides a parallel beam of light; Prism Table for holding the prism and Telescope for observing the spectrum and making measurements on it.

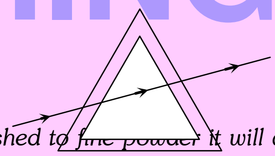
The telescope is first set for parallel rays and then collimator is set for parallel rays. When prism is set in minimum deviation position, the spectrum seen is pure spectrum. Angle of prism (A) and angle of minimum deviation (δ_m) are measured and μ of material of prism is calculated using prism formula. For μ of a transparent liquid, we take a hollow prism with thin glass sides. Fill it with the liquid and measure (δ_m) and A of liquid prism. μ of liquid is calculated using prism formula.

(5) **Direct vision spectroscope :** It is an instrument used to observe pure spectrum. It produces dispersion without deviation with the help of n crown prisms and $(n-1)$ flint prisms alternately arranged in a tabular structure.

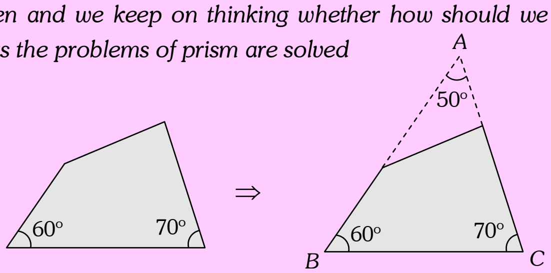
For no deviation $n(\mu-1)A = (n-1)\,(\mu'-1)A'$.

Concepts

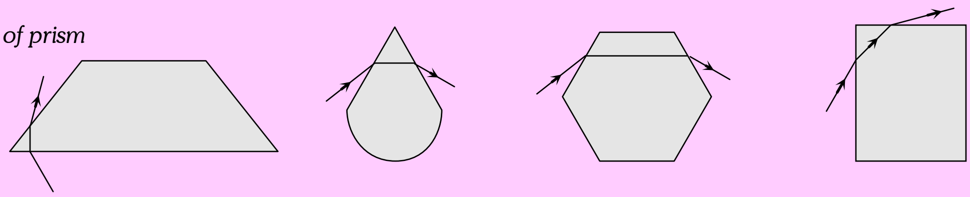
- *When a ray of white light passes through a glass prism red light is deviated less than blue light.*
- *For a hollow prism* $A \neq 0$ *but* $\delta = 0$



- *If an opaque coloured object or crystal is crushed to fine powder it will appear white (in sun light) as it will lose it's property of selective reflection.*
- *Our eye is most sensitive to that part at the spectrum which lies between the F line (sky green) one the C-line (red) of hydrogen equal to the refractive index for the D line (yellow) of sodium. Hence for the dispersive power, the following formula is internationally accepted* $\omega = \dfrac{\mu_F - \mu_C}{\mu_D - 1}$
- *Sometimes a part of prism is given and we keep on thinking whether how should we proceed ? To solve such problems first complete the prism then solve as the problems of prism are solved*



- *Some other types of prism*



Example

***Example*: 36** When light rays are incident on a prism at an angle of 45°, the minimum deviation is obtained. If refractive index of the material of prism is $\sqrt{2}$, then the angle of prism will be **[MP PMT 1986]**

(a) 30° (b) 40° (c) 50° (d) 60°

Solution: (d) $\mu = \dfrac{\sin i}{\sin \dfrac{A}{2}} \Rightarrow \sqrt{2} = \dfrac{\sin 45}{\sin \dfrac{A}{2}} \Rightarrow \sin \dfrac{A}{2} = \dfrac{\frac{1}{\sqrt{2}}}{\sqrt{2}} = \dfrac{1}{2} \Rightarrow \dfrac{A}{2} = 30^o \Rightarrow A = 60^o$

***Example*: 37** Angle of minimum deviation for a prism of refractive index 1.5 is equal to the angle of prism. The angle of prism is $(\cos 41^o = 0.75)$ **[MP PET/PMT 1988]**

(a) 62° (b) 41° (c) 82° (d) 31°

Solution: (c) Given $\delta_m = A$, then by using $\mu = \dfrac{\sin \dfrac{A+\delta_m}{2}}{\sin \dfrac{A}{2}} \Rightarrow \mu = \dfrac{\sin \dfrac{A+A}{2}}{\sin \dfrac{A}{2}} = \dfrac{\sin A}{\sin \dfrac{A}{2}} = 2\cos \dfrac{A}{2}$ $\left\{\sin A = 2 \sin \dfrac{A}{2} \cos \dfrac{A}{2}\right\}$

$\Rightarrow 1.5 = 2\cos \dfrac{A}{2} \Rightarrow 0.75 = \cos \dfrac{A}{2} \Rightarrow 41^o = \dfrac{A}{2} \Rightarrow A = 82^o$.

***Example*: 38** Angle of glass prism is 60° and refractive index of the material of the prism is 1.414, then what will be the angle of incidence, so that ray should pass symmetrically through prism

(a) 38° 61' (b) 35° 35' (c) 45° (d) 53° 8'

Solution: (c) incident ray and emergent ray are symmetrical in the cure, when prism is in minimum deviation position.

Hence in this condition $\mu = \dfrac{\sin i}{\sin \dfrac{A}{2}} \Rightarrow \sin i = \mu \sin\left(\dfrac{A}{2}\right) \Rightarrow \sin i = 1.414 \times \sin 30^o = \dfrac{1}{\sqrt{2}} \Rightarrow i = 45^o$

***Example*: 39** A prism $(\mu = 1.5)$ has the refracting angle of 30°. The deviation of a monochromatic ray incident normally on its one surface will be $(\sin 48^o 36' = 0.75)$ **[MP PMT/PET 1988]**

(a) 18° 36' (b) 20° 30' (c) 18° (d) 22° 1'

Solution: (a) By using $\mu = \dfrac{\sin i}{\sin A} \Rightarrow 1.5 = \dfrac{\sin i}{\sin 30} \Rightarrow \sin i = 0.75 \Rightarrow i = 48^o 36'$

Also from $\delta = i - A \Rightarrow \delta = 48^o 36' - 30^o = 18^o 36'$

***Example*: 40** Angle of a prism is 30° and its refractive index is $\sqrt{2}$ and one of the surface is silvered. At what angle of incidence, a ray should be incident on one surface so that after reflection from the silvered surface, it retraces its path **[MP PMT 1991; UPSEAT 2001]**

(a) 30° (b) 60° (c) 45° (d) $\sin^{-1}\sqrt{1.5}$

Solution: (c) This is the case when light ray is falling normally an second surface.

Hence by using $\mu = \dfrac{\sin i}{\sin A} \Rightarrow \sqrt{2} = \dfrac{\sin i}{\sin 30^o} \Rightarrow \sin i = \sqrt{2} \times \dfrac{1}{2} \Rightarrow i = 45^o$

***Example*: 41** The refracting angle of prism is A and refractive index of material of prism is $\cot\frac{A}{2}$. The angle of minimum deviation is **[CPMT 1992]**

(a) $180^o - 3A$ (b) $180^o + 2A$ (c) $90^o - A$ (d) $180^o - 2A$

Solution: (d) By using $\mu = \frac{\sin\frac{A+\delta_m}{2}}{\sin\frac{A}{2}} \Rightarrow \cot\frac{A}{2} = \frac{\sin\frac{A+\delta_m}{2}}{\sin\frac{A}{2}} \Rightarrow \frac{\cos\frac{A}{2}}{\sin\frac{A}{2}} = \frac{\sin\frac{A+\delta_m}{2}}{\sin\frac{A}{2}}$

$\Rightarrow \sin\left(90 - \frac{A}{2}\right) = \sin\left(\frac{A+\delta_m}{2}\right) \Rightarrow 90 - \frac{A}{2} = \frac{A+\delta_m}{2} \Rightarrow \delta_m = 180 - 2A$

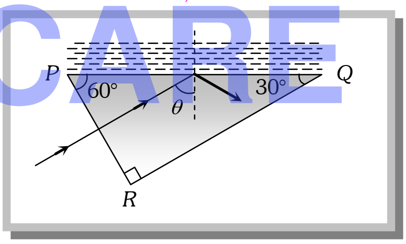
***Example*: 42** A ray of light passes through an equilateral glass prism in such a manner that the angle of incidence is equal to the angle of emergence and each of these angles is equal to 3/4 of the angle of the prism. The angle of deviation is **[MNR 1988; MP PMT 1999; Roorkee 2000; UPSEAT 2000]**

(a) 45° (b) 39° (c) 20° (d) 30°

Solution: (d) Given that $A = 60^o$ and $i = e = \frac{3}{4}A = \frac{3}{4}\times 60 = 45^o$

By using $i + e = A + \delta \Rightarrow 45 + 45 = 60 + \delta \Rightarrow \delta = 30^o$

***Example*: 43** *PQR* is a right angled prism with other angles as 60° and 30°. Refractive index of prism is 1.5. *PQ* has a thin layer of liquid. Light falls normally on the face *PR*. For total internal reflection, maximum refractive index of liquid is



(a) 1.4

(b) 1.3

(c) 1.2

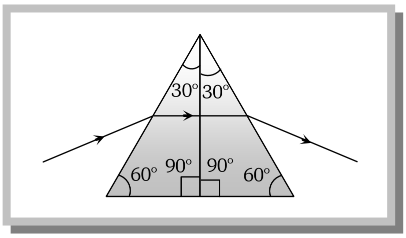
(d) 1.6

Solution: (c) For *TIR* at *PQ* $\theta < C$

From geometry of figure $\theta = 60$ *i.e.* $60 > C \Rightarrow \sin 60 > \sin C$

$\Rightarrow \frac{\sqrt{3}}{2} > \frac{\mu_{Liquid}}{\mu_{\text{Prism}}} \Rightarrow \mu_{Liquid} < \frac{\sqrt{3}}{2}\times\mu_{\text{Prism}} \Rightarrow \mu_{Liquid} < \frac{\sqrt{3}}{2}\times 1.5 \Rightarrow \mu_{Liquid} < 1.3$.

***Example*: 44** Two identical prisms 1 and 2, each will angles of 30°, 60° and 90° are placed in contact as shown in figure. A ray of light passed through the combination in the position of minimum deviation and suffers a deviation of 30°. If the prism 2 is removed, then the angle of deviation of the same ray is **[PMT (Andhra) 1995]**



(a) Equal to 15°

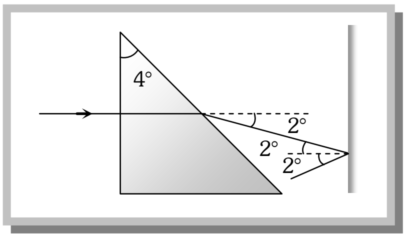
(b) Smaller than 30°

(c) More than 15°

(d) Equal to 30°

Solution: (a) $\delta = (\mu - 1)A$ as A is halved, so δ is also halves

***Example*: 45** A prism having an apex angle 4° and refraction index 1.5 is located in front of a vertical plane mirror as shown in figure. Through what total angle is the ray deviated after reflection from the mirror



(a) 176°

(b) 4°

(c) 178°

(d) 2°

Solution: (c) $\delta_{\text{Prism}} = (\mu - 1)A = (1.5 - 1)4^o = 2^o$

$\therefore \delta_{Total} = \delta_{\text{Prism}} + \delta_{Mirror} = (\mu - 1)A + (180 - 2i) = 2^o + (180 - 2 \times 2) = 178^o$

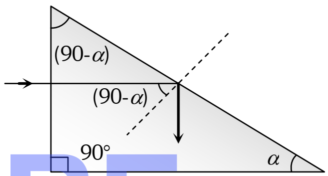
Example: 46 A ray of light is incident to the hypotenuse of a right-angled prism after travelling parallel to the base inside the prism. If μ is the refractive index of the material of the prism, the maximum value of the base angle for which light is totally reflected from the hypotenuse is **[EAMCET 2003]**

(a) $\sin^{-1}\left(\frac{1}{\mu}\right)$ (b) $\tan^{-1}\left(\frac{1}{\mu}\right)$ (c) $\sin^{-1}\left(\frac{\mu - 1}{\mu}\right)$ (d) $\cos^{-1}\left(\frac{1}{\mu}\right)$

Solution: (d) If $\alpha =$ maximum value of vase angle for which light is totally reflected from hypotenuse.

$(90 - \alpha) = C =$ minimum value of angle of incidence an hypotenuse for *TIR*

$\sin(90 - \alpha) = \sin C = \frac{1}{\mu} \Rightarrow \alpha = \cos^{-1}\left(\frac{1}{\mu}\right)$



Example: 47 If the refractive indices of crown glass for red, yellow and violet colours are 1.5140, 1.5170 and 1.5318 respectively and for flint glass these are 1.6434, 1.6499 and 1.6852 respectively, then the dispersive powers for crown and flint glass are respectively **[MP PET/PMT 1988]**

(a) 0.034 and 0.064 (b) 0.064 and 0.034 (c) 1.00 and 0.064 (d) 0.034 and 1.0

Solution: (a) $\omega_{\text{Crown}} = \frac{\mu_v - \mu_r}{\mu_y - 1} = \frac{1.5318 - 1.5140}{(1.5170 - 1)} = 0.034$ and $\omega_{\text{Flint}} = \frac{\mu_v' - \mu_r'}{\mu_y' - 1} = \frac{1.6852 - 1.6434}{1.6499 - 1} = 0.064$

Example: 48 Flint glass prism is joined by a crown glass prism to produce dispersion without deviation. The refractive indices of these for mean rays are 1.602 and 1.500 respectively. Angle of prism of flint prism is 10°, then the angle of prism for crown prism will be **[DPMT 2001]**

(a) $12^o 2.4'$ (b) $12^o 4'$ (c) 1.24^o (d) 12°

Solution: (a) For dispersion without deviation $\frac{A_C}{A_F} = \frac{(\mu_F - 1)}{(\mu_C - 1)} \Rightarrow \frac{A}{10} = \frac{(1.602 - 1)}{(1.500 - 1)} \Rightarrow A = 12.04^o = 12^o 2.4'$

Tricky example: 6

An achromatic prism is made by crown glass prism $(A_C = 19^o)$ and flint glass prism $(A_F = 6^o)$. If ${}^C\mu_v = 1.5$ and ${}^F\mu_v = 1.66$, then resultant deviation for red coloured ray will be

(a) 1.04° (b) 5° (c) 0.96° (d) 13.5°

Solution : (d) For achromatic combination $w_C = -w_F \Rightarrow [(\mu_v - \mu_r)A]_C = -[(\mu_v - \mu_r)A]_F$

$\Rightarrow [\mu_r A]_C + [\mu_r A]_F = [\mu_v A]_C + [\mu_v A]_F = 1.5 \times 19 + 6 \times 1.66 = 38.5$

Resultant deviation $\delta = [(\mu_r - 1)A]_C + [(\mu_r - 1)A]_F$

$= [\mu_r A]_C + [\mu_r A]_F - (A_C + A_F) = 38.5 - (19 + 6) = 13.5^o$

Tricky example: 7

The light is incident at an angle of 60° on a prism of which the refracting angle of prism is 30°. The refractive index of material of prism will be

(a) $\sqrt{2}$ (b) $2\sqrt{3}$ (c) 2 (d) $\sqrt{3}$

Solution : (d) By using $i + e = A + \delta \Rightarrow 60 + e = 30 + 30 \Rightarrow e = 0$.

Hence ray will emerge out normally so by using the formula $\mu = \frac{\sin i}{\sin A} = \frac{\sin 60}{\sin 30} = \sqrt{3}$