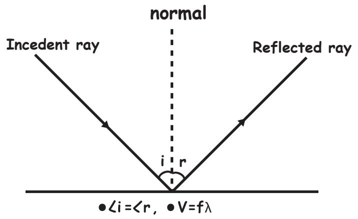
Ray Optics

- Reflection
  - Plane mirror
  - Spherical mirror
- Refraction
  - Plane surface
  - Spherical surface
  - Prism
  - TIR

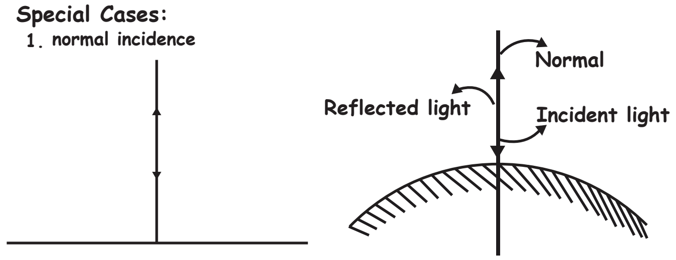
Laws of Reflection



- Angle of incidence=Angle of reflection
- After reflection velocity & frequency of light remains same, but intensity decreases
- phase change of π occurs if light is incident from rare to denser medium

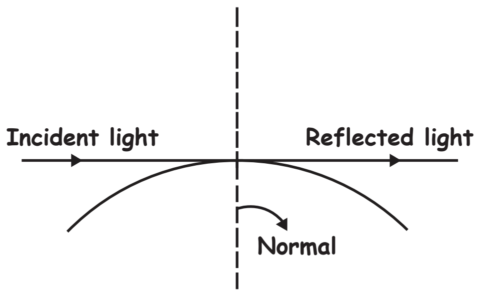
Special Cases:

1. normal incidence



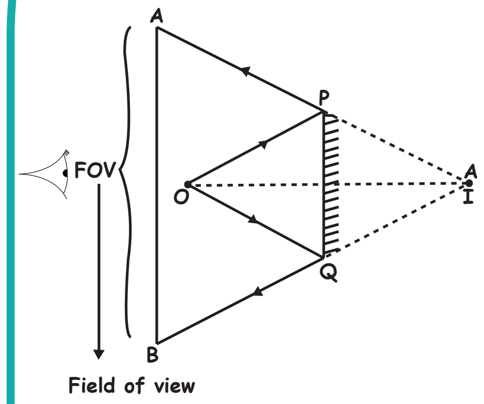
$\angle i=\angle r=0$

2. Grazing incedence:-



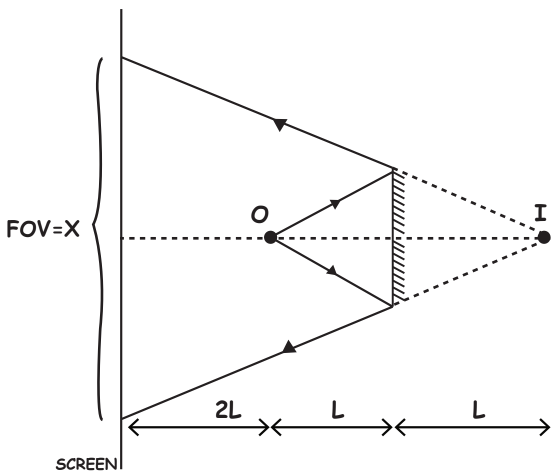
In case light strikes the reflecting surface tangentially $\angle i=\angle r=90^\circ$

Field of View



Field of view defines the area visible from the perspective of observer through mirror.

Finding Field of view



if the distance from observer to mirror is L, then field of view is x

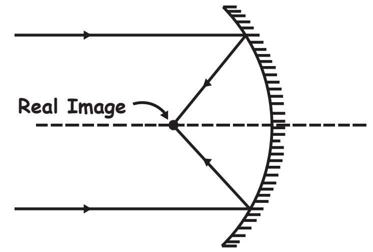
By similar Δs,

$$\frac{x}{4L}=\frac{2L}{L}$$

$$x=4\times 2L$$
$$=8L$$

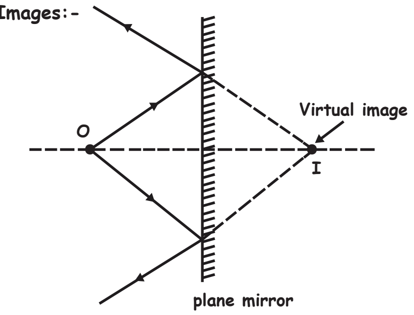
Images & Objects

Real Images:-



Reflected or refracted rays actually meet or converge at a point

Virtual Images:-



If rays do not meet at a point but appear to meet virtual image is formed

- Reflected Ray(Image):-

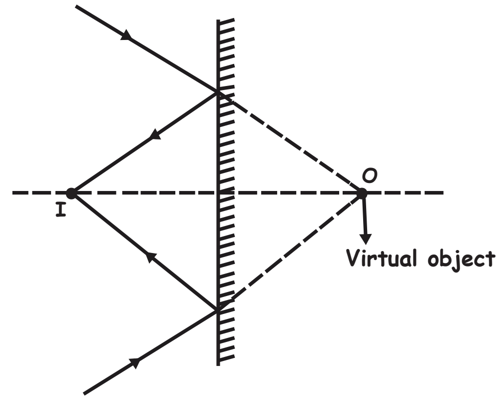
Diverging-Virtual Image

Converging-Real Image

- Incident Ray(Object):-

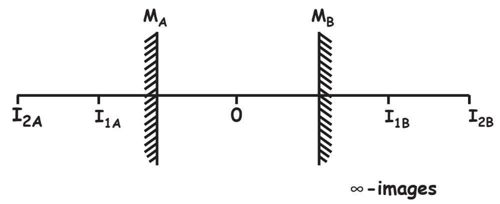
Diverging-Virtual object

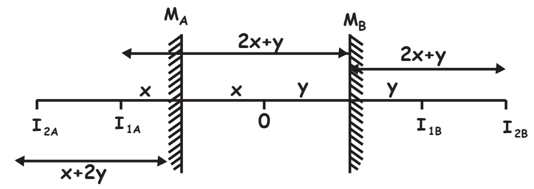
(see diagram)



Number of Images

If two plane mirrors were placed opposite to each other, there will be infinite number of images



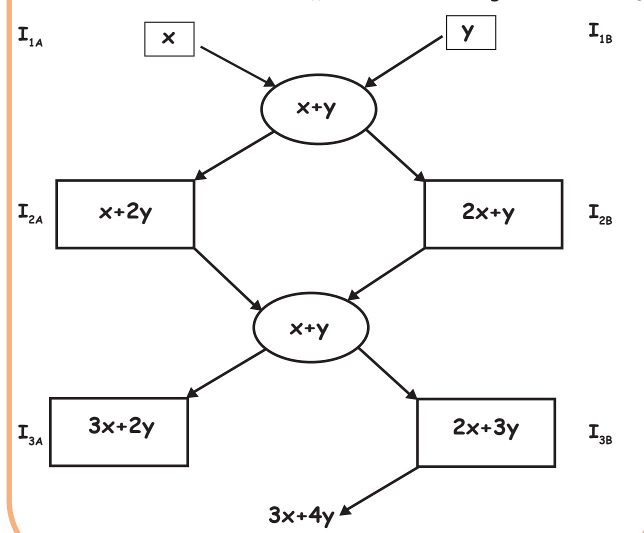


x,y is the distance of object from mirrors M_A&M_B

O is the object, $I_{1A}I_{2B}$ images

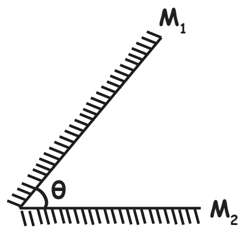
Shortcut to find the distance to images

Distance of images formed in M_A Distance of images formed in M_B



Number of Images for Inclined Mirror

Let the mirrors be at an angle θ



Method to find number of images

$\frac{360}{\theta}=n$

- n=even
  - No.of images=n-1
- n=odd
  - Object lying symmetrically between mirrors → No.of images=(n-1)
  - Object lying unsymmetrically between mirrors → No.of images=(n)

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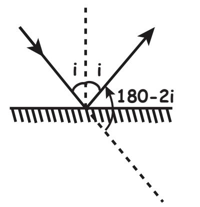
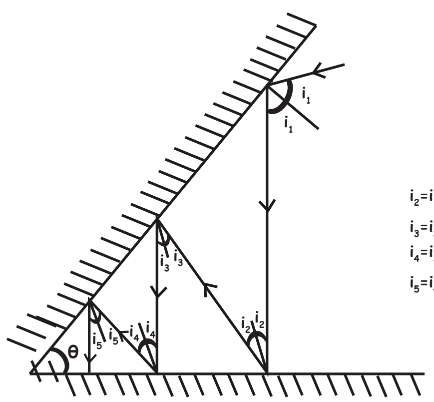
Deviation of Rays

Deviation in single mirror:

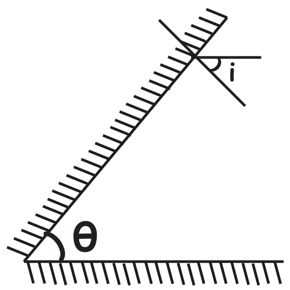


Deviation, $\delta = 180 - 2i$

Deviation for two mirrors inclined at an angle



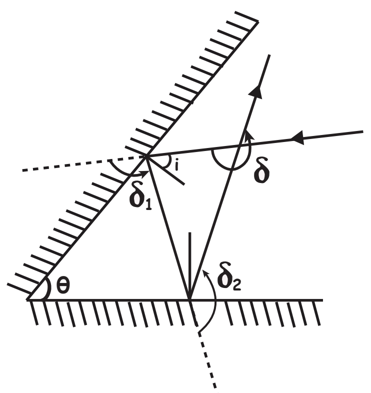
$i_2 = i_1 - \theta$
$i_3 = i_2 - \theta$
$i_4 = i_3 - \theta$
$i_5 = i_4 - \theta$



No.of reflections at which light becomes normal $= \frac{i}{\theta} + 1$

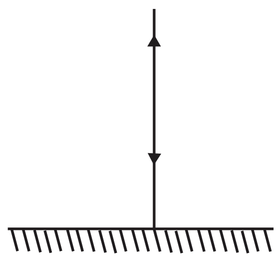
Total no.of reflections $= \frac{i}{\theta} + 1 + \frac{i}{\theta} = \frac{2i}{\theta} + 1$

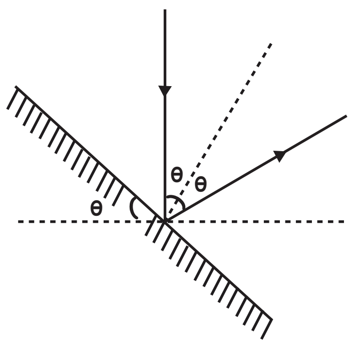
Deviation after two sucessive reflections



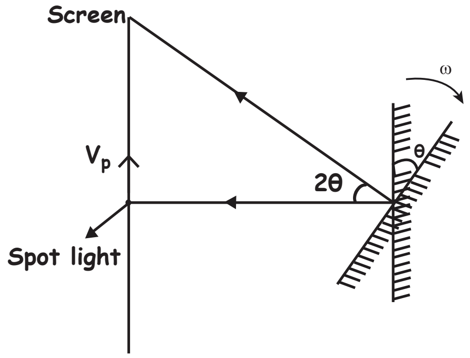
$\theta > i$
$\delta = \delta_1 + \delta_2$
$= 360 - 2\theta$

Effect of rotation of mirror

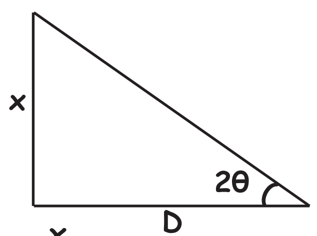




Angle of rotation $= \theta$



Deviation of reflected ray $= 2\theta$



$\tan 2\theta = \frac{x}{D}$

small angle
$\tan 2\theta \approx 2\theta = \frac{x}{D}$

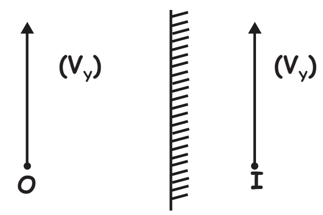
$\Rightarrow \theta = \frac{x}{2D}$

Differentiate, $\Rightarrow \omega = \frac{V_p}{2D}$

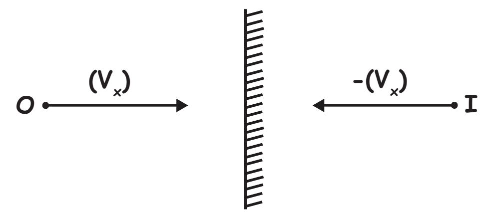
$\Rightarrow V_p = 2\omega D$

Relative motion in plane mirror

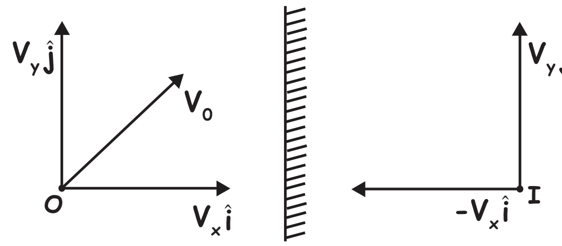
parallel direction



Perpendicular direction

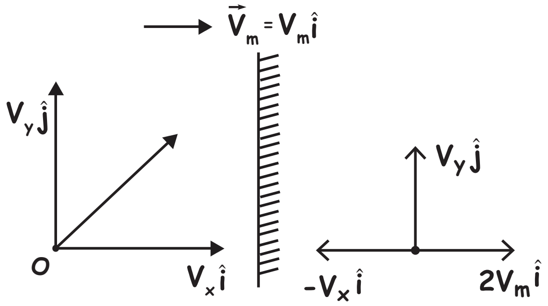


Both parallel and perpendicular:-

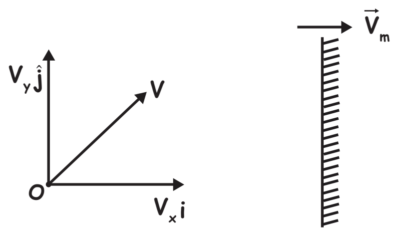


$\vec{V}_O = V_x\hat{i} + V_y\hat{j}$ $\quad \vec{V}_I = -V_x\hat{i} + V_y\hat{j}$

Both object and mirror are moving:-



Relative velocity of object with respect to mirror



$V_{O/m} = (V_x - V_m)\,\hat{i} + V_y\,\hat{j}$

Relative velocity of image with respect to mirror

$V_{I/m} = -(V_x - V_m)\,\hat{i} + V_y\,\hat{j}$

Velocity of image

$V_I = \vec{V}_{I/m} + \vec{V}_m \quad = (2V_m - V_x)\,\hat{i} + V_y\hat{j}$

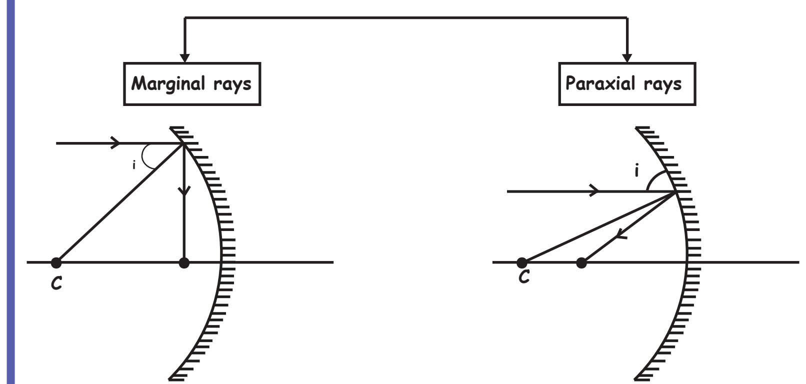
Relative velocity of image with respect to object

$V_{I/o} = \vec{V}_I + \vec{V}_o$

The relationship between angle of incidence and focal length

$f = R - \frac{R}{2\cos i}$ $\quad \Rightarrow f \approx \frac{R}{2}$ (Paraxial rays)

Spherical mirror



To avoid spherical aberration

1) Use small aperture mirror → Avoid marginal
→ Only paraxial

2) Blackening of central portion → Avoid paraxial
→ Only marginal

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Magnification and mirror formula

Sign convention and different terminology

1) Radius of curvature (R) :

Distance between pole and center of curvature

2) Focal length (f):

Image point on the principle axis for an object at ∞

Convex $\rightarrow$ +ve

Concave $\rightarrow$ -ve

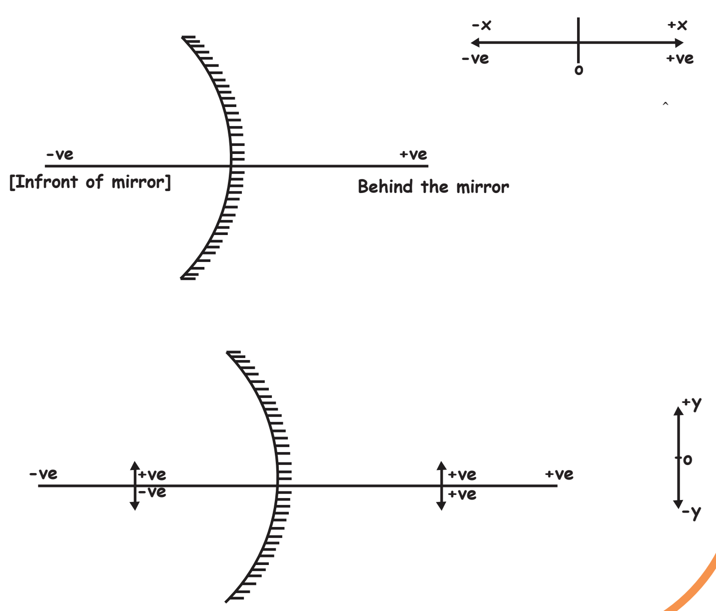
Plane mirror $\rightarrow \infty$

3) Aperture:

Effective diameter of portion of mirror reflecting the light.

Reflecting area α (aperture)^2

Sign convention

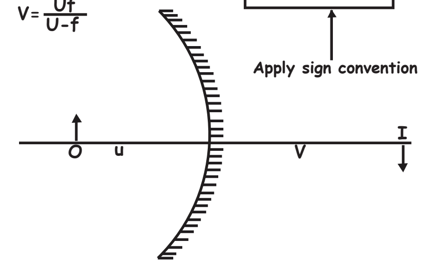


Mirror formulae

$v = \frac{uf}{u-f}$

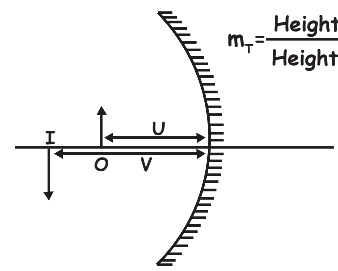
$\boxed{\frac{1}{u} + \frac{1}{v} = \frac{1}{f}}$

Apply sign convention



Transverse magnification

$m_T = \frac{\text{Height of the image}}{\text{Height of the object}} = \frac{h_i}{h_o}$



$\boxed{m_T = -\frac{v}{u}}$

$\boxed{m_T = \frac{f}{f-u}}$

$\boxed{m_T = \frac{f-v}{f}}$

m_T → $|m_T| > 1$ → magnified

m_T → $|m_T| = 1$ → same size

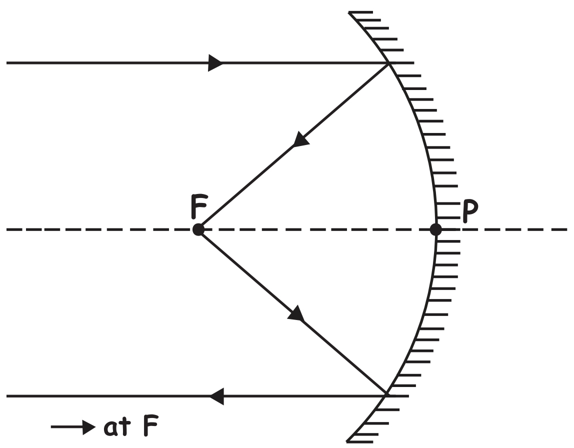
m_T → $|m_T| < 1$ → small

m_T → +ve ⟹ Erect

m_T → -ve ⟹ Inverted

- u, v => Same sign => virtual image
- u, v => Opposite sign => real image

Object at ∞



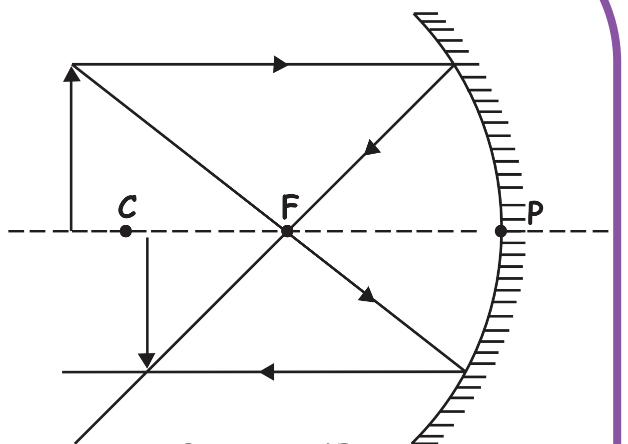
→ at F

→ Inverted

→ Extremely small

→ $m << -1$

Object beyond C



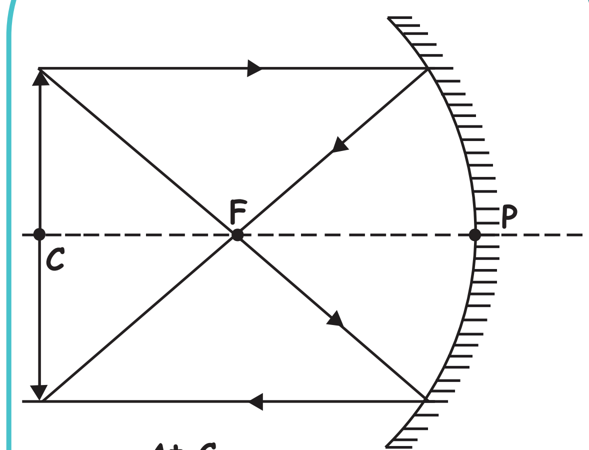
→ Between C&F

→ Inverted

→ small

→ $m < -1$

At C



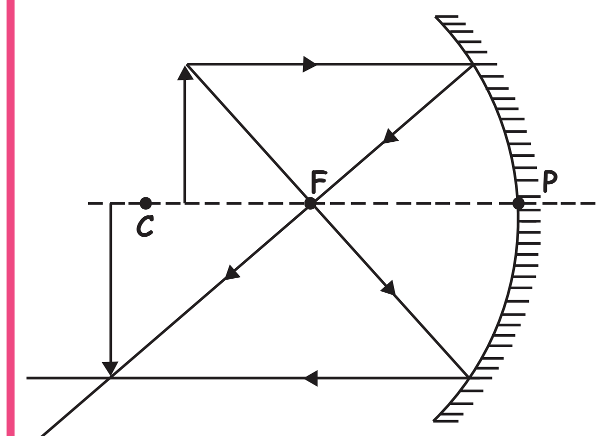
→ At C

→ Inverted

→ same size

→ $m = -1$

Between F and C



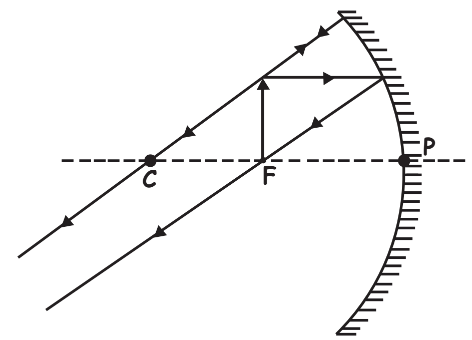
→ Beyond C

→ Inverted

→ $m > -1$

→ Large

At F



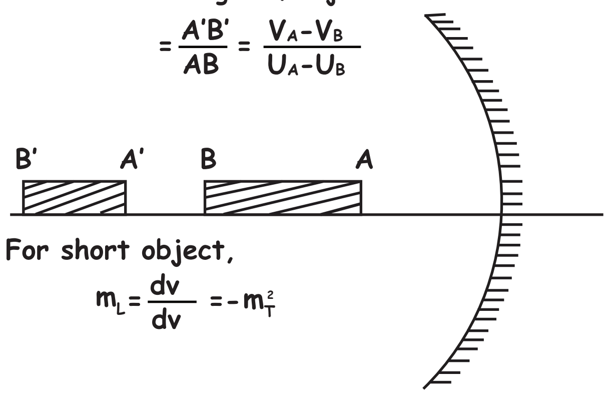
→ At ∞

→ Extremely large

→ $m >> -1$

longitudinal magnification

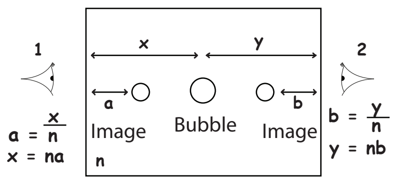
$$m_L = \frac{\text{length of image}}{\text{length of object}} = \frac{A'B'}{AB} = \frac{V_A - V_B}{U_A - U_B}$$



For short object,

$$m_L = \frac{dv}{dv} = -m_T^2$$

Air bubble in glass slab

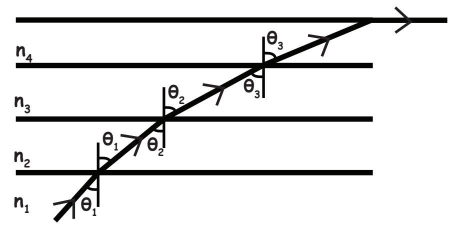


$a = \frac{x}{n}$, $x = na$

$b = \frac{y}{n}$, $y = nb$

Width of glass slab= x + y = na + nb

TIR in multiple medium



From snells law,
$n_1 \sin\theta_1 = n_2 \sin\theta_2 = n_3 \sin\theta_3 \ldots\ldots$

If $\sin\theta = 1$, means TIR Occured in a medium

For TIR to occur, $i > i_c$

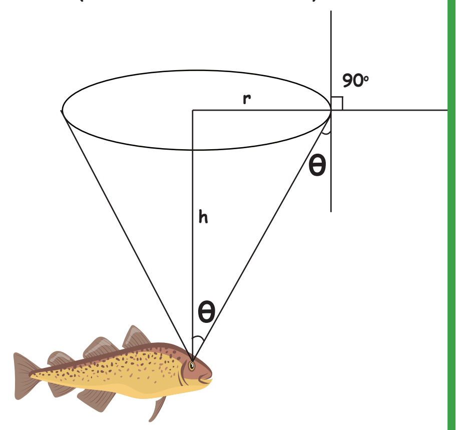
$\sin i > \sin i_c$

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

$\therefore \sin i > \frac{1}{\mu}$

$$\boxed{\mu > \frac{1}{\sin i}}$$

Area of visible region
(From Under Water)



$$\boxed{r = h \times \frac{1}{\sqrt{\left(\frac{n_d}{n_r}\right)^2 - 1}}}$$

If $n_d = n$ and $n_r =$ (air) then,

$$r = \frac{h}{\sqrt{n^2 - 1}}$$

If $n_r = 1$; Area $= \frac{\pi h^2}{n^2 - 1}$

Angle of cone

Total angle $= 2 \times i_c$
$= 2\theta$

Minimum Deviation

At minimum deviation:

1) $\angle i = \angle e$

2) $\angle r_1 = \angle r_2 = \angle r$

3) $\delta_{min} = D = i + e - (r_1 + r_2)$
$= i + e - A$
$D = 2i - A$

4) $2r = A$

5) Refractive index (n):-

$1 \times \sin i = n \times \sin r$

$n = \frac{\sin i}{\sin r}$

$$\boxed{n = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\frac{A}{2}}}$$

Note:-
If angle of prism = angle of minimum deviation i.e $\angle A = D$ then, $n = 2\cos(A/2)$

Relative motion in spherical mirror

Relative velocity of image with respect to spherical mirror

$(V_{I/m}) = -m^2(V_{O/m})$

Relative velocity of object with respect to spherical mirror

$V_{O/m} = \vec{V}_O - \vec{V}_m$

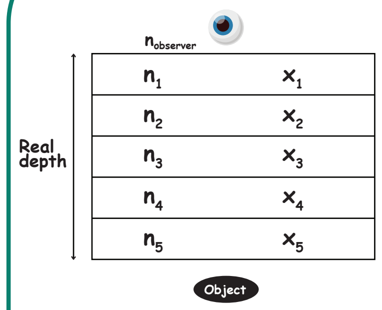
Velocity of image

$V_I = V_{I/m} + V_m$

Relative Velocity of image with respect to object

$V_{I/O} = V_{I/M} - V_{O/M}$

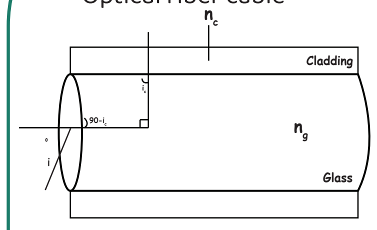
Multiple medium



Apparent height of object with respect to observer

$$\boxed{X = n_{observer} \sum \frac{x}{n}}$$

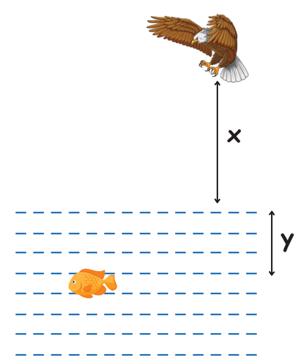
Applications of TIR
Optical fiber cable



$\sin i_c = \frac{n_c}{n_g}$, $\sin i_a = \sqrt{n_g^2 - n_c^2}$

$\cos i_c = \frac{\sqrt{n_g^2 - n_c^2}}{n_g}$

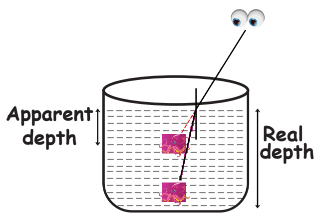
Bird fish problem



$$V_{Fish/Bird} = n_{Bird}\left[\frac{x}{n_{Bird}} + \frac{y}{n_{Fish}}\right]$$

$$X_{Bird/Fish} = n_{Fish}\left[\frac{x}{n_{Bird}} + \frac{y}{n_{Fish}}\right]$$

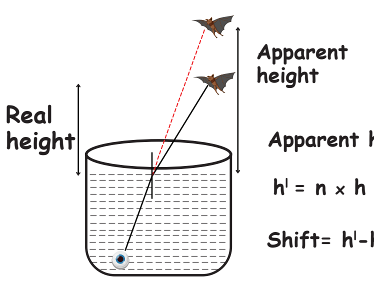
When object is in denser medium and observer in rarer medium



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

$h' = \frac{h}{n}$

Shift= $h - h' = h - \frac{h}{n} = h\left(1 - \frac{1}{n}\right)$



Apparent height= n × Real height

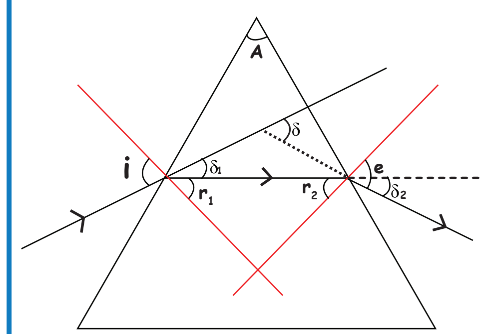
$h' = n \times h$

Shift= $h' - h' = nh - h = h(n-1)$

Object is in denser medium → Shift is towards the surface

Object is in rarer medium → Shift is away from the surface

Prism

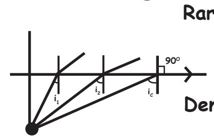


$r_1 + r_2 = A$

$$\delta = i + e - (r_1 + r_2)$$

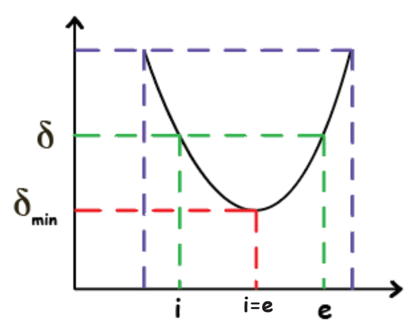
Total Internal Reflection

Critical angle



$$i_c = \sin^{-1}\left(\frac{n_r}{n_d}\right)$$

Deviation vs i graph



At δ_{min}, $i = \angle e$

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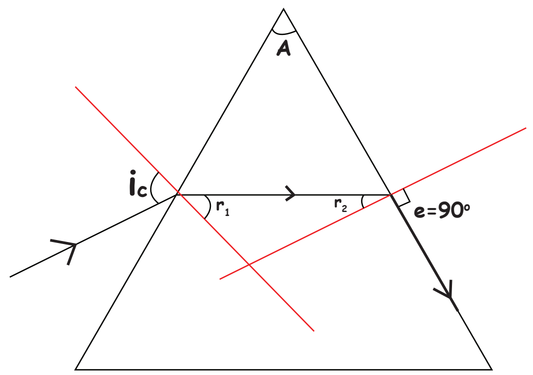
TIR in Prism



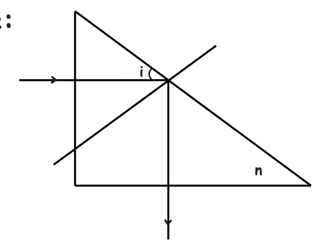
At second face,
$n \times \sin r_2 = 1 \times \sin 90$

$\sin r_2 = \frac{1}{n}$

$r_1 + r_2 = A$

$\sin i_c = n \times \sin r_1$

Note:



For TIR,
$i \geq i_c$

$n \geq \frac{1}{\sin i}$

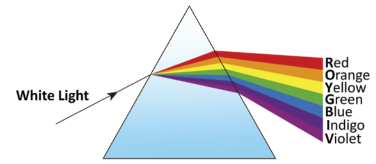
Thin Prism

$\sin \theta \approx \theta$

$$\boxed{n = \frac{\sin\left(\frac{A+D}{2}\right)}{\frac{A}{2}}}$$

$D = (n-1) \times A$

Dispersion in Prism



Cause:-

$n = A + \frac{B}{\lambda^2} \Rightarrow n \propto \frac{1}{\lambda}$

$D = (n-1)A \Rightarrow D \propto n$

Maximum deviation for violet

Minimum deviation for red

$D_{max} = (n_V - 1)A$

$D_{min} = (n_R - 1)A$

Mean ray → Yellow

$n_y = \frac{n_V + n_R}{2}$

Some natural phenomenon due to Sunlight

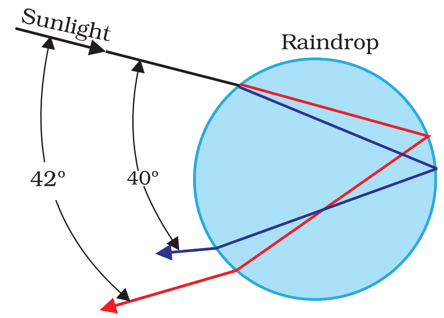
Rainbow

Combined effect of dispersion, refraction and reflection of sunlight by spherical water droplets of rain.

Condition for observing rainbow: Sun should be shining in one part and raining in opposite part of sky observer can see rainbow only when his back is towards the sun.

Formation of Rainbow:

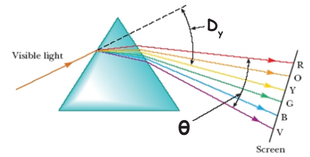
- Sunlight is refracted as it enters a raindrop Causing dispersion.
- Violet is bent most while red is bent least
- Light gets internally reflected if angle between refracted ray and normal to the drop surface is greater than critical angle (48")
- Light is refracted again when it comes out of the drop
- Violet light emerges at an angle of 40° related to incoming sunlight and red light emerges at 42"



Angular Dispersion (θ)

$\theta = (n_v - n_r) A$

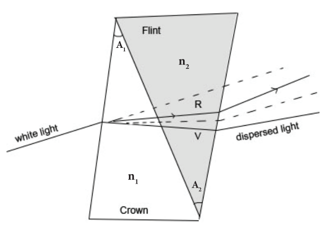
Deviation of mean ray



$D_y = \left[\frac{n_R + n_V}{2} - 1\right] A$

Dispersive power

$\omega = \frac{n_V - n_R}{n_y - 1}$; $n_y = \frac{n_V + n_R}{2}$



$(n_1 - 1) A_1 = (n_2 - 1) A_2$

Cauchy's Relation

$n = A + \frac{B}{\lambda^2}$

For VIBGYOR

$\lambda \rightarrow V < I < B < G < Y < O < R$

$n \rightarrow V > I > B > G > Y > O > R$

$\sin r_2 = \frac{1}{n} \Rightarrow i_c \propto \frac{1}{n}$

$i_c \rightarrow V < I < B < G < Y < O < R$

From V to R

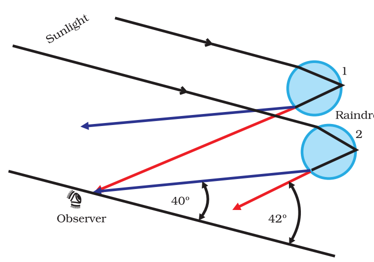
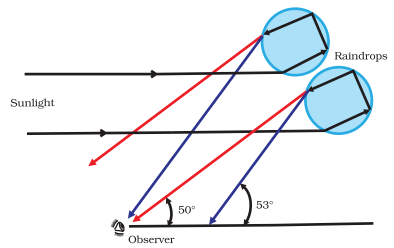
$\lambda \uparrow$

$n \downarrow$

$i_c \uparrow$

Value of i for which rays will retrace its path

$\sin i = \left(\frac{n_2}{n_1}\right) \sin A$

Primary Rainbow	Secondary Rainbow
	
One TIR Colours more clear Red colour on top and Violet On bottom 3 step process	Two TIRs Colours fainter Violet on top & red on bottom 4 step process

Scattering of Light

Amount of scattering inversely proportional to fourth power of wavelength. [Rayleigh scattering]

$\boxed{I \propto \frac{1}{\lambda^4}}$ Also, $I \propto f^4$

This is true only if particle size $a << \lambda$

If $a >> \lambda$ all wavelengths scattered equally

→ Bluish colour predominates in a clear sky :
Blue has shorter wave length than red and is Scattered strongly.
Also our eyes are more Sensitive to blue than violet

→ Clouds are white
Clouds which have droplets of water with $a >> \lambda$ are generally white.

→ Red colour of sun at Sunrise and sunset.
At Sunrise and Sunset, Sun's rays have to pass through larger distance.
Shorter wavelength are removed by Scattering. The least scattered light reaching our eyes looks reddish.