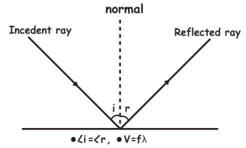
RAY OPTICS

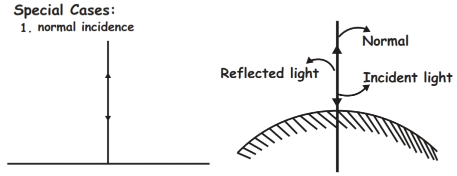
Ray Optics
- Reflection
  - Plane mirror
  - Spherical mirror
- Refraction
  - Plane surface
  - Spherical surface
  - Prism
  - TIR

Laws of Reflection



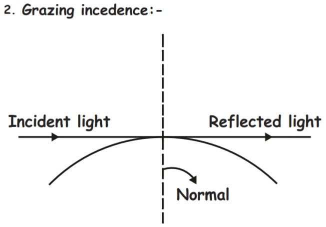
- Angle of incidence=Angle of reflection
- After reflection velocity & frequency of light remains same, but intensity decreases
- phase change of π occurs if light is incident from rare to denser medium

Special Cases:
1. normal incidence



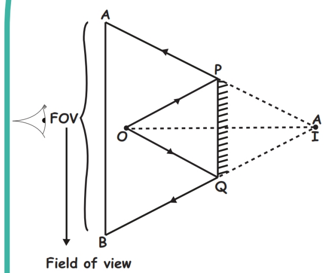
<i=<r=0

2. Grazing incedence:-



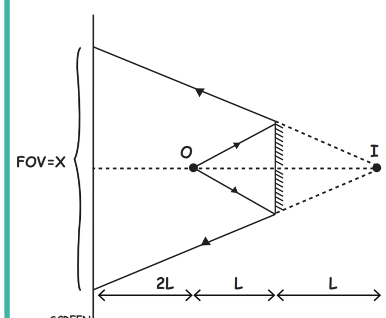
In case light strikes the reflecting surface tangentially $\angle i = \angle r = 90^\circ$

Field of View



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

Finding Field of view

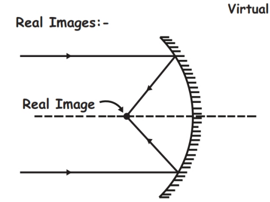


if the distance from observer to mirror is L, then field of view is x
By similar Δ s,

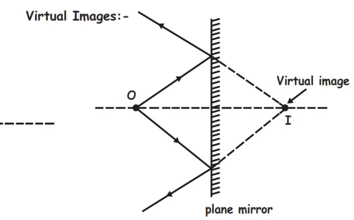
$$\frac{x}{4L} = \frac{2L}{L}$$

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

Images & Objects



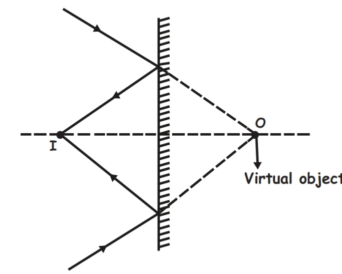
Reflected or refracted rays actually meet or converge at a point



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

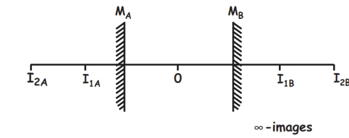
- Reflected Ray(Image):-
  Diverging-Virtual Image
  Converging-Real Image

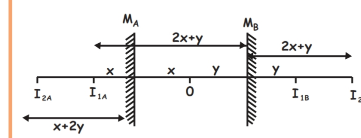
- Incident Ray(Object):-
  Diverging-Virtual object
  (see diagram)



Number of Images

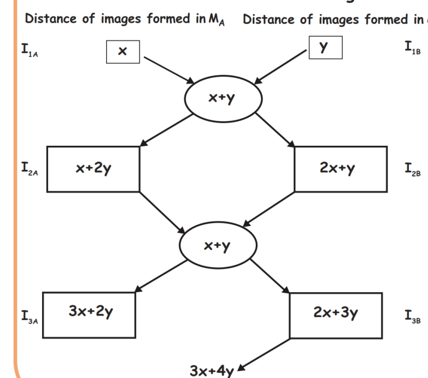
If two plane mirrors were placed opposite to each other, there will be infinite number of images





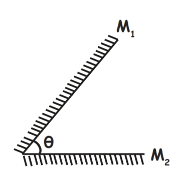
x,y is the distance of object from mirrors M_A & M_B
O is the object, I_{1A}, I_{2B} images

Shortcut to find the distance to images



Number of Images For Inclined Mirror

Let the mirrors be at an angle θ

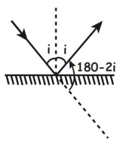


Method to find number of images

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

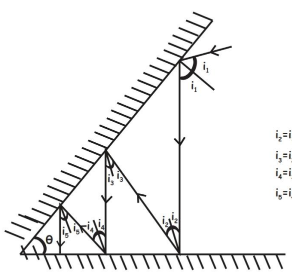
Deviation of Rays

Deviation in single mirror:

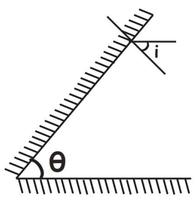


Deviation, $\delta = 180 - 2i$

Deviation for two mirrors inclined at an angle



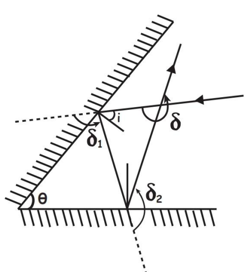
$i_2 = i_1 - \theta$
$i_3 = i_2 - \theta$
$i_4 = i_3 - \theta$
$i_5 = i_4 - \theta$



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

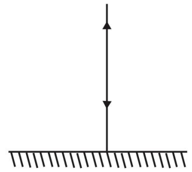
Total no.of reflections= $\frac{i}{\theta} + 1 + \frac{i}{\theta} = \frac{2i}{\theta} + 1$

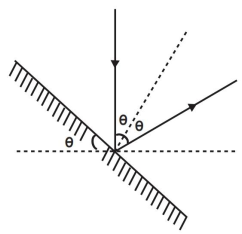
Deviation after two sucessive reflections



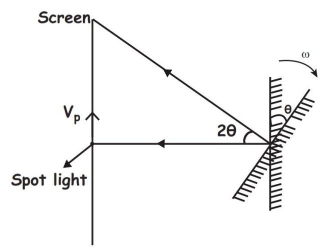
$\theta > i$
$\delta = \delta_1 + \delta_2$
$= 360 - 2\theta$

Effect of rotation of mirror

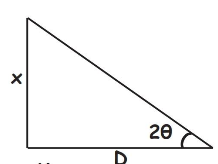




Angle of rotation=θ



Deviation of reflected ray=2θ



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

small angle

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

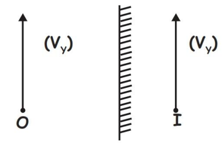
$\Rightarrow \theta = \frac{x}{2D}$

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

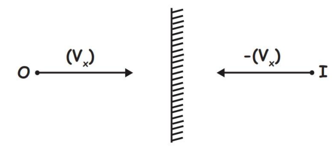
$\Rightarrow V_p = 2\omega D$

Relative motion in plane mirror

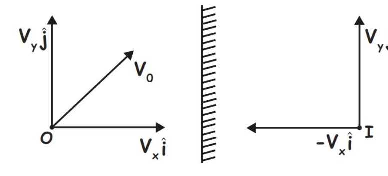
parallel direction



Perpendicular direction

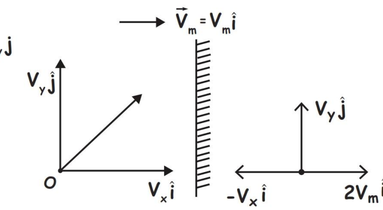


Both parallel and perpendicular:-

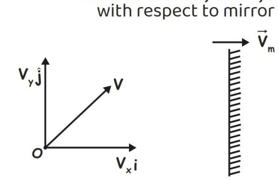


$\vec{V}_O = V_x\hat{i} + V_y\hat{j}$ $\qquad$ $\vec{V}_I = -V_x\hat{i} + V_y\hat{j}$

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

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

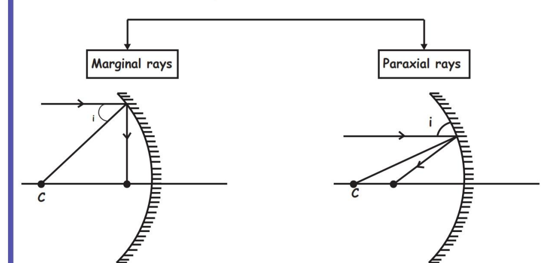
Relative velocity of image with respect to object

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

The relationship between angle of incidence and focal length

$f = R - \frac{R}{2\cos i}$ $\qquad \Rightarrow f \approx \frac{R}{2}$ (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

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

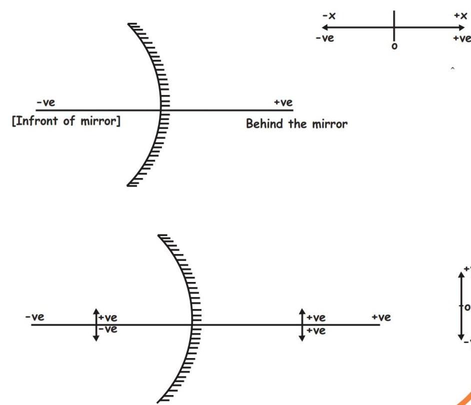
Plane mirror $\rightarrow \infty$

3) Aperture:

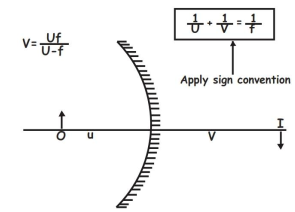
Effective diameter of portion of mirror reflecting the light.

Reflecting area α (aperture)^2

Sign convention

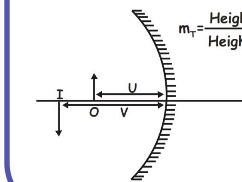


Mirror formulae



Transverse magnification

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



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

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

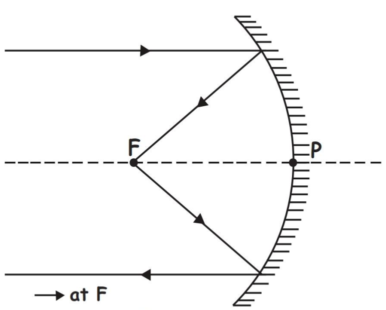
$m_T = \frac{f-V}{f}$

m_T:
- $|m_T| > 1 \rightarrow$ magnified
- $|m_T| = 1 \rightarrow$ same size
- $|m_T| < 1 \rightarrow$ small

m_T:
- (+ve) ⇒ Erect
- (-ve) ⇒ Inverted

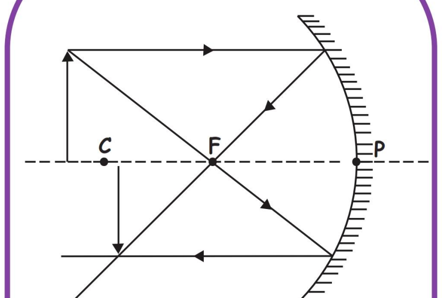
- u, v ⇒ Same sign ⇒ virtual image
- u, v ⇒ Opposite sign ⇒ real image

Object at ∞



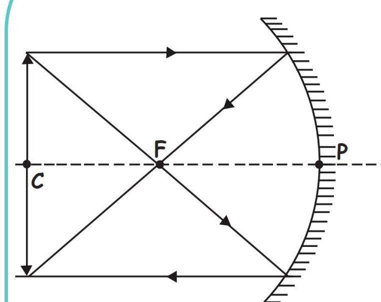
- → at F
- → Inverted
- → Extremely small
- → $m << -1$

Object beyond C



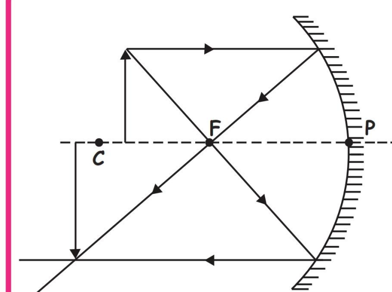
- → Between C&F
- → Inverted
- → small
- → $m < -1$

At C



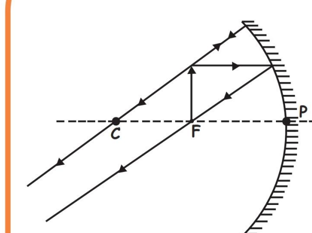
- → At C
- → Inverted
- → same size
- → $m = -1$

Between F and C



- → Beyond C
- → Inverted
- → $m > -1$
- → Large

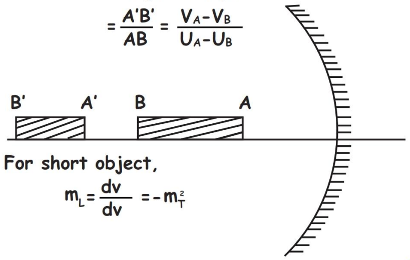
At F



- → 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,

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

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

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

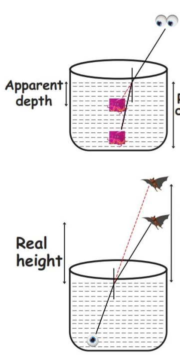
Velocity of image

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

Relative Velocity of image with respect to object

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

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 x Real height

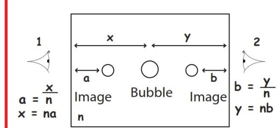
$h' = n \times h$

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

Air bubble in glass slab

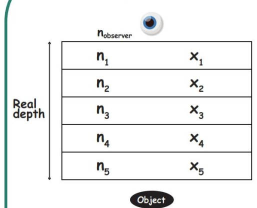


$\frac{x}{a} = n$, $x = na$

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

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

Multiple medium

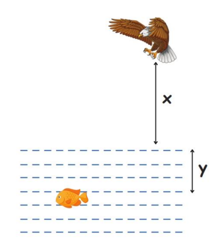


n_1	x_1
n_2	x_2
n_3	x_3
n_4	x_4
n_5	x_5

Apparent height of object with respect to observer

$$X = n_{observer} \Sigma \frac{x}{n}$$

Bird fish problem

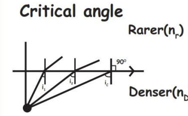


$$V_{Fish/Bird} = n_{Bird}\left[\frac{x}{n_{Bird}} + \frac{y}{n_{Fish}}\right]$$

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

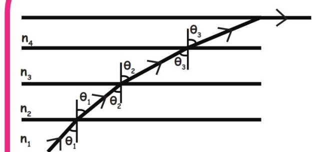
Total Internal Reflection

Critical angle



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

TIR in multiple medium



From snells law,

$n_1\sin\theta_1 = n_2\sin\theta_2 = n_3\sin\theta_3$......

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

For TIR to occur, $i > i_c$

$\sin i > \sin i_c$

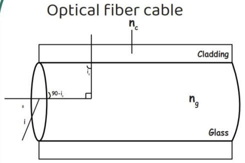
But, $\sin i_c = \frac{1}{\mu}$

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

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

Applications of TIR

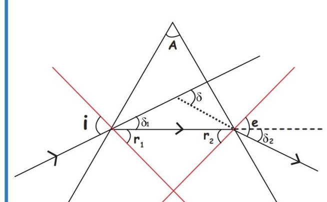
Optical Fiber cable



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

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

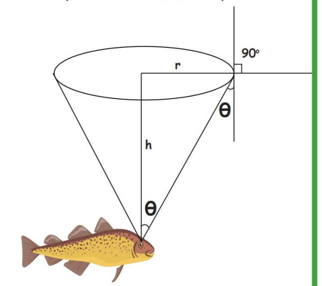
Prism



$r_1 + r_2 = A$

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

Area of visible region
(From Under Water)



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

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

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

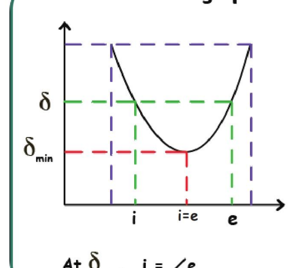
If $n_r = 1$; Area $= \frac{\pi h^2}{n^2 - 1}$

Angle of cone

Total angle $= 2 \times i_c$

$= 2\theta$

Deviation vs i graph



At δ_{min}, $\angle i = \angle e$

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):-

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

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

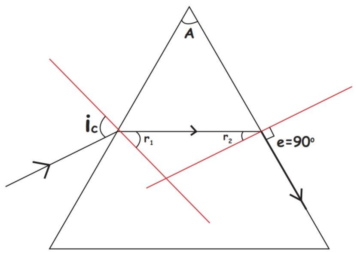
$$n = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\frac{A}{2}}$$

Note:-

If angle of prism = angle of minimum deviation

i.e $\angle A = D$ then, $n = 2\cos(A/2)$

TIR in Prism



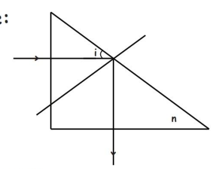
At second face,
$n \times \sin r_2 = 1 \times \sin 90$

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

$r_1 + r_2 = A$

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

Note:



For TIR,
$i \geq i_c$
$n \geq \frac{1}{\sin i}$

Thin Prism

$\sin \theta \approx \theta$

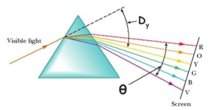
$$n = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\frac{A}{2}}$$

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

Angular Dispersion (θ)

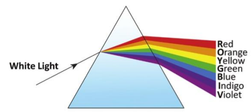
$\theta = (n_v - n_r) A$

Deviation of mean ray



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

Dispersion in Prism

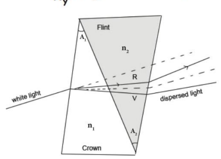


Cause:-
$n = A + \frac{B}{\lambda^2} \Rightarrow n \propto \frac{1}{\lambda}$
$D = (n-1)A \Rightarrow D \propto n$

Maximum deviation for violet
Minimum deviation for red
$D_{max} = (n_V - 1) A$
$D_{min} = (n_R - 1) A$
Mean ray ⟶ Yellow
$n_y = \frac{n_V + n_R}{2}$

Dispersive power

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



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

Some natural phenomenon due to Sunlight

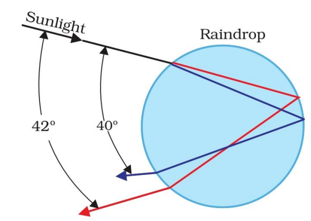
Rainbow

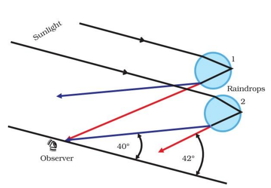
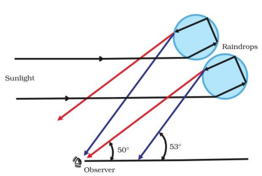
Combined effect of dispersion, refraction
and reflection of sunlight by spherical water droplets of rain.

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"



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

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

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

Scattering of Light

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

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

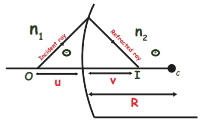
This is true only if particle size $a << \lambda$
If $a >> \lambda$ all wavelengths scattered equally

→ 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.

REFRACTION AT CURVED SURFACES



u= -ve
V= +ve
R= +ve

$\frac{n_2}{v} - \frac{n_1}{-u} = \frac{n_2 - n_1}{R}$

all lengths on the side of incident ray are taken as -ve
all lengths on the side of reflected ray are taken as +ve

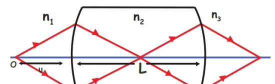
$\frac{\text{I-O=S Medium}}{\text{I.Distance}} - \frac{\text{Medium}}{\text{O.Distance}} = \frac{\text{Change in medium}}{\text{Radius of curvature}}$

Transverse Magnification $T.M = m = \frac{\frac{v}{n_2}}{\frac{u}{n_1}} = \frac{v \times n_1}{u \times n_2}$

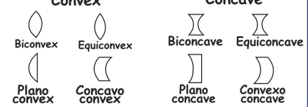
LENSES

<u>Types</u>

Thick lens - Two surfaces are at some distance apart.
Thin lens - Two surfaces are close

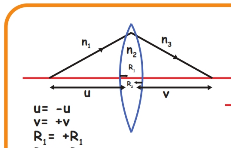


Thin Lens



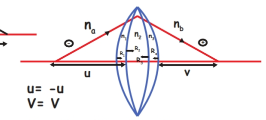
Convex mirror, Convex lens } f=+ve
Concave mirror, Concave lens } f=-ve

IOS METHOD



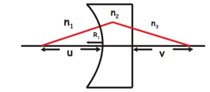
u= -u
v= +v
$R_1 = +R_1$
$R_2 = -R_2$
I-O=S

$\frac{n_3}{v} - \frac{n_1}{-u} = \frac{n_2 - n_1}{R_1} + \frac{n_3 - n_2}{-R_2}$



u= -u
V= V
$R = +R_1, +R_2, -R_3, -R_4$

$\frac{n_b}{v} - \frac{n_a}{-u} = \frac{n_1 - n_a}{R_1} + \frac{n_2 - n_1}{R_2} + \frac{n_3 - n_2}{-R_3} + \frac{n_b - n_3}{-R_4}$

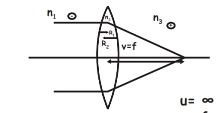


u= -ve
V= V
$R_1 = -ve = -R_1$
$R_2 = \infty$

I-O=S

$\frac{n_3}{v} - \frac{n_1}{-u} = \frac{n_2 - n_1}{-R_1}$

IOS METHOD FOR FOCAL LENGTH

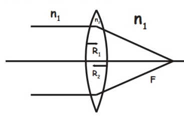


$\frac{n_3}{f} = \frac{n_2 - n_1}{R_1} + \frac{n_3 - n_2}{-R_2}$

u= ∞
v= f
$R = +R_1, -R_2$

LENS MAKERS FORMULA

To find focal length if refractive index is same on both sides of lens.

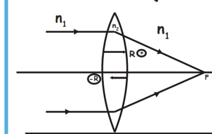


I-O=S $\frac{n_1}{F} - 0 = \frac{n_2 - n_1}{R_1} + \frac{n_1 - n_2}{R_2}$

$\frac{1}{F} = \left[\frac{n_2}{n_1} - 1\right]\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

$\frac{1}{F} = \left[{}_1n_2 - 1\right]\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

EQUICONVEX LENS



$F = \frac{R}{2[{}_1n_2 - 1]}$

If Prism is placed in air

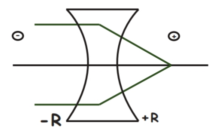
$F = \frac{R}{2\left[\frac{n_g}{n_a} - 1\right]} = \frac{R}{2[n_g - 1]}$

In water,

$F = \frac{R}{2\left[\frac{n_g}{n_w} - 1\right]}$

⇒ F↑ than air

FOCAL LENGTH OF EQUICONCAVE LENS IN AIR



$f = \frac{-R}{2[{}_1n_2 - 1]}$

PLANO CONVEX LENS

F of planoconvex lens = 2 x f of equiconvex lens

$f = \frac{R}{{}_1n_2 - 1}$

PLANO CONCAVE LENS

Equiconvex = f ⟶ Equi Concave = - f

⇓ ⇓

Plano Convex = 2f   Plano Concave = -2 f

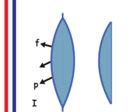
$f = -\frac{R}{{}_1n_2 - 1}$

POWER

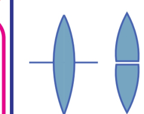
$Power = \frac{1}{F \text{ in metre}}$ [Power= 1 dioptre = $1m^{-1}$]

In centimetre, $P = \frac{100}{f \text{ in cm}}$

CUTTING OF LENS

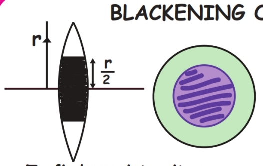


	Before cutting	After cutting
Focal Length	f	2f
Power	P	P/2
Area	A	A
Intensity	I	I



	Before cutting	After cutting
Focal Length	f	f
Power	P	P
Area	A	A/2
Intensity	I	I/2

BLACKENING OF LENS



Intensity ∝ Area of transmission of light
$I \propto A_T$

Blackening of lens ⇒ A_T↓ ⇒ I↓

<u>To find new intensity :</u>

i) Find total A_T (Area of lens before blackening)
ii) Find new $A_T = (A_{total} - A_{opaque})$
iii) I ∝ original A_T (Total A_T)

$I' \propto$ new A_T

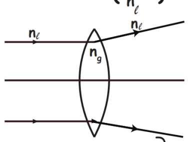
Taking ratio of these two equations we can find I'

<u>Comparison of focal length in air & Liquid</u>

1) If $n_{air} < n_{liquid} < n_{glass}$
- Nature of lens remains same
- Focal length increases

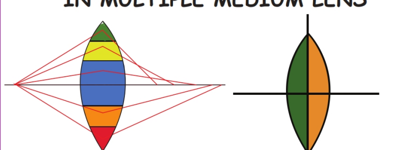
2) Same refractive index $[n_l = n_{glass}]$
- Lens become invisible

3) $n_l > n_g$ $f = \frac{R}{2\left(\frac{n_g}{n_l} - 1\right)}$ =negative



Convex become concave
Concave become convex } Nature of lens changes

NUMBER OF IMAGES FORMED IN MULTIPLE MEDIUM LENS



Number of medium =Number of images

Number of images = 1

LENS FORMULA

To find v when f and u are given

$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ $\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{u + f}{uf}$ $v = \frac{uf}{u + f}$

MAGNIFICATION

To find size of image

$m = \frac{[I]}{[O]} = \frac{v}{u}$

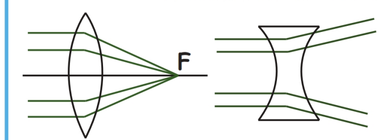
$m = \frac{f}{f+u}$

$m = \frac{f-v}{f}$

m_T — $|m_T| = 1$ ⇒ Same size; $|m_T| < 1$ ⇒ Small; $|m_T| > 1$ ⇒ magnified

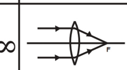
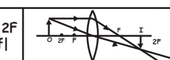
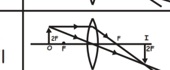
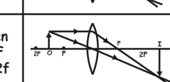
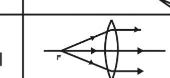
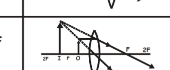
m_T — +ve ⇒ Virtual image, Erect; -ve ⇒ Real image, Inverted

IMAGE FORMATION BY CONVEX AND CONCAVE LENSES

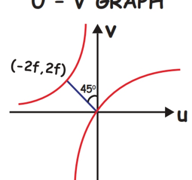


<u>Convex lens</u>
- Converging lens
- Similar to concave mirror

<u>Concave lens</u>
- Diverging lens
- Similar to convex mirror

Sl NO	Position of the object	Ray Diagram	Position of image	Nature of Image
1	At |u|=∞		At F	Real, inverted, diminished
2	Beyond 2F |u|> 2|f|		Between F and 2F	Real, inverted, diminished
3	At 2F |u|=2|f|		At 2F	Real, inverted, same size
4	Between F & 2F f<|u|<2f		Beyond 2F	Real, inverted, enlarged
5	At F |u|=|f|		At ∞	Cannot be defined
6	within F |u|<|f|		On the side of object	Virtual, erect, enlarged

U - V GRAPH

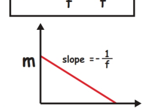


MAGNIFICATION VS V GRAPH

<u>Concave lens</u>

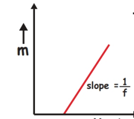
$m = \frac{f-v}{f}$

$m = 1 - \frac{v}{f} = -\frac{v}{f} + 1$

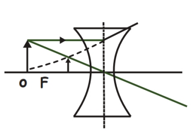


<u>Convex lens</u>

$m = \frac{v}{f} + 1$

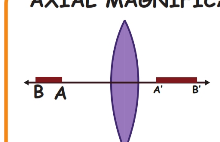


<u>Concave lens</u>



-Real object
-Virtual image
-Formed between F and Pole

AXIAL MAGNIFICATION



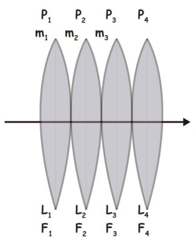
$m_L = \frac{\text{length of image}}{\text{length of object}} = \frac{A'B'}{AB} = \frac{V_A - V_B}{U_A - U_B}$

For short object

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

COMBINATION OF LENSES

Lenses are combined such that there is no gap between them



Power

$P_{comb} = P_1 + P_2 + P_3 + \ldots$

Focal length

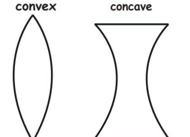
$\frac{1}{f_{comb}} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + \ldots$

Magnification,

$m_T = m_1 \times m_2 \times m_3 \ldots$

Note :

P_{Comb} determines whether the combination act as converging lens or diverging lens.



$P = xD$ $\quad P = -yD$

System acts as converging lens if total power > 0

$P_T > 0$

$\Rightarrow P_{convex} > P_{concave}$

$\Rightarrow f_{concave} > f_{convex}$

System acts as diverging lens if total power < 0

$P_T < 0$

$\Rightarrow P_{concave} > P_{convex}$

$\Rightarrow f_{convex} > f_{concave}$

System acts as plane lens /glass if $P_{comb} = 0$

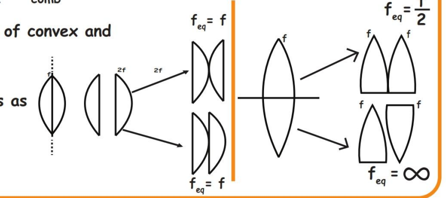
$P_{concave} = P_{convex}$ $=0$

$f_{concave} = f_{convex} = f_{comb} = \infty$

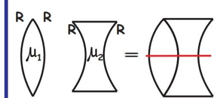
For a combination of convex and concave lenses

if $P_{convex} > P_{concave}$

→ combination acts as convex lens



F_{EQ} USING LENS MAKERS FORMULA



$f_{eq} = \frac{R}{2[\mu_1 - \mu_2]}$

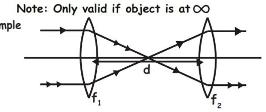
LENSES COMBINED SUCH THAT THERE IS A GAP BETWEEN THEM

Power : $P_{comb} = P_1 + P_2 - dP_1P_2$

$\frac{1}{f_{comb}} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$

Note: Only valid if object is at ∞

Example



If $P_{comb} = 0$

$\frac{1}{f_{comb}} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2} = 0$

$d = f_1 + f_2$

NATURE OF MIRROR IS DETERMINED BY FOCAL LENGTH

To find focal length, split the silvered lens into a lens and a mirror and apply IOS

$u = \infty$

$v = f_m$

$R_1 = +R$

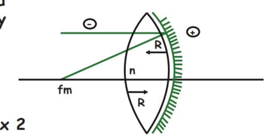
$R_2 = -R$

$I - O = S$

$\frac{-1}{f_m} = \frac{n-1}{R} \times 2 + \left[\frac{0+n}{+R}\right] \times 2$

[Ray passes through the surface 2 times thus multiplied by 2]

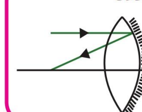
$f_m = \frac{-R}{4n-2} = \frac{-R}{2(2n-1)}$



When equiconvex lens is silvered (mirrored) its focal length become negative (concave mirror) with magnitude

$f_m = \frac{-R}{2(2n-1)}$

SILVERING OF LENS



Lens → Mirror

$m_T = \frac{v}{u} = \frac{[I]}{[o]} = \frac{f}{f-u} = \frac{f-v}{f}$

OPTICAL INSTRUMENTS

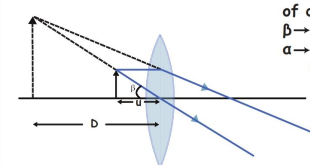
Simple Microscope

Only one lens [convex lens]

Image is formed at least distance of distinct vision (D)

β→ angle subtended by image at eye.

α→ angle subtended by object at eye when placed at distance D.



Case I :

Eye under relaxed state or normal vision

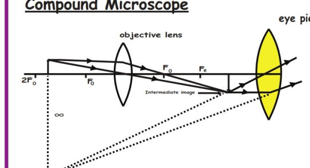
Final image at infinity

Object at f→ $u = u_{max}$ $\quad m_{min} = \frac{D}{u_{max}} = \frac{D}{f}$

Case 2 : Eye under strain

Final image at D $\quad u = u_{min}$ $\quad m_{max} = \frac{D}{u_{min}} = 1 + \frac{D}{f}$

Compound Microscope



- Has 2 lenses
- Length of microscope = Distance between lenses.
- Magnification $m = m_o \times m_e$

[m_e - same as simple microscope]

To get magnified image, object placed between F_o & $2F_o$ of objective lens. This image is called intermediate image.

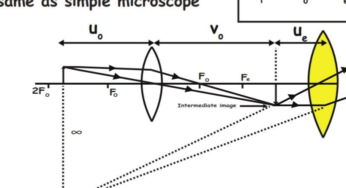
Intermediate image→ real, inverted , magnified.

Intermediate image is formed within or at the focus of eyepiece.

Total magnification $m_T = -m_o \times m_e$

m_e same as simple microscope

$m_T = -m_o \times m_e = -\left[\frac{V_o}{u_o} \times \frac{D}{u_e}\right]$



SILVERING OF PLANO-CONVEX LENS

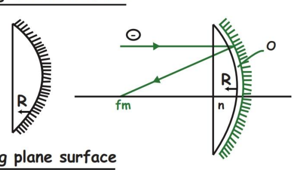
2 possibilities

i) silvering curved surface

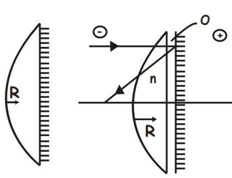
ii) Silvering plane surface

Silvering curved surface

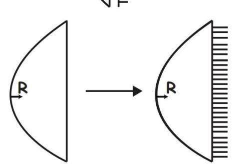
$f_m = \frac{-R}{2n}$



Silvering plane surface



$f_m = \frac{-R}{2(2n-1)}$



Before silvering

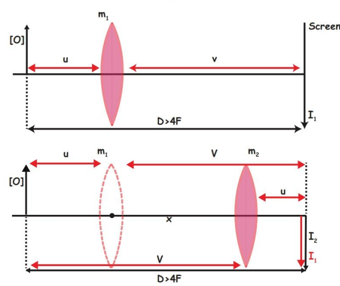
$f = \frac{R}{(n-1)}$

After silvering

$f_m = \frac{-R}{2(n-1)} = \frac{f}{2}$

LENS DISPLACEMENT METHOD

Distance between object & image > 4F



In lens Displacement method

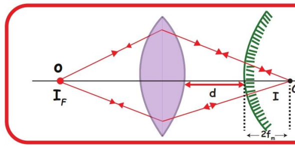
1) $D \geq 4F$

2) $F = \frac{D^2 - x^2}{4D}$ $\quad$ x→distance between 2 position of lens

3) $F = \frac{x}{m_1 - m_2}$ $\quad$ F= Focal length of lens

4) $m_1 m_2 = 1$

$[O] = \sqrt{I_1 I_2}$



If one is converging & other is diverging $d = v - 2f_m$

LENS MIRROR COMBINATION

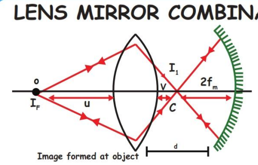


Image formed at object

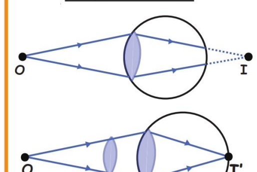
If both lens and mirror are converging. $d = v + 2f_m$

HUMAN EYE

Least distance of distinct vision is 25 cm

Defects of vision and their correction

i) Hypermetropia



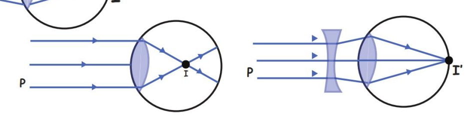
- Long sightedness -Cannot see nearby objects
- Eye focuses incoming light from nearby objects at a point behind retina.
- Correction : Convex lens

F = +ve , Power P= +ve

Focal length = Dd/(D-d)

D→Least distance of distinct vision.

ii) Myopia



- Short sightedness -Cannot see faraway objects
- Light from a distant object arriving at the eye lens may get converged at a point in front of the retina.
- Correction : Concave lens

F = -ve , P = - ve, $F = -d$, $P = \frac{1}{F}$

iii) Astigmatism

eye cannot focus in horizontal and vertical planes simultaneously

- Correction : Cylindrical lens

iv) Presbyopia

eye suffers both myopia and hypermetropia

- Correction : Bifocal lens

Case I :

Eye in relaxed state or final image at ∞, $u_e = f_e$

$m_T = m_{min} = -\left[\frac{V_o}{u_o}\ \frac{D}{f_e}\right]$ Also $L = L_{max} = V_o + u_{max} = V_o + f_e$

Case 2 : Strained eye

$u = u_{min}$

$L = L_{min} = L_D = V_o + U_e = V_o + u_{min} = V_o + \frac{Df_e}{D+f_e}$

$m_D = m_{max} = \frac{-v_o}{u_o}\left[1 + \frac{D}{f_e}\right]$ $\quad \frac{m_{max}}{m_{min}} = \frac{D+f_e}{D}$

$m_D = \left[\frac{L}{f_O}\right]\left[1 + \frac{D}{f_e}\right]$

$m_\infty = \left[\frac{L}{f_O}\ \frac{D}{f_e}\right]$

Note :

$L_\infty = V_O + U_{max}$ $\quad L_\infty = V_O + f_e$

$L_\infty = \frac{U_o f_o}{U_o - f_o} + f_e$ $\quad L_D = V_O + U_{min}$

$L_D = V_O + \frac{Df_e}{D+f_e}$ and $L_D = \frac{U f_O}{U_O - f_o} + \frac{Df_e}{D+f_e}$

For microscope, eyepiece larger than objective

$f_e \uparrow \Rightarrow m \uparrow \quad f_e \downarrow \Rightarrow m \downarrow$

For telescope, eyepiece smaller than objective to increase magnification.

<u>Telescope</u>

Magnification $m = \frac{f_o}{u_e}$ $\quad u = u_{max} \Rightarrow m = m_{min}$; $\quad u = u_{min} \Rightarrow m = m_{max}$

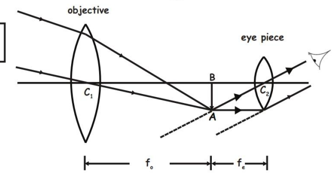
Length of telescope $L = f_0 + u_e$

Normal adjustment /Relaxed eye/final image at ∞

$m_{min} = \frac{f_O}{f_e}$

Length $= L_\infty = f_0 + u_e = f_0 + f_e$

$L_\infty = f_O + f_e$



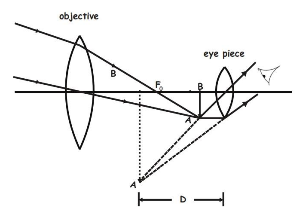
Eye under strain/Final image at least distance of distinct vision.

$u = u_{min} = \frac{Df_e}{D+f_e}$

$m_{max} = \frac{f_o}{f_e}\left[1 + \frac{f_e}{D}\right]$

$L_D = f_o + u_e$

$L_D = f_o + \frac{Df_e}{D+f_e}$



Length of Telescope

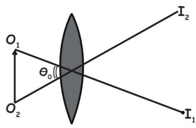
u_e can have values : f_e or $\frac{Df_e}{D+f_e}$

v_o can have values : f_o only

$L_D = v_o + u_e$

RESOLVING POWER

Resolving power$= \frac{1}{\text{Resolving limit}}$



X=Limit of resolution

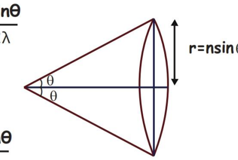
= Resolving limit

MICROSCOPE

Resolving Limit$= \frac{1.22\lambda}{a} = \frac{1.22\lambda}{2n\sin\theta}$, where a = diameter of lens

R.P$= \frac{a}{1.22\lambda} = \frac{2n\sin\theta}{1.22\lambda}$

R.P $\alpha\ \frac{1}{\lambda}$



TELESCOPE

R.P$= \frac{a}{1.22\lambda} = \frac{2n\sin\theta}{1.22\lambda}$