RAY OPTICS

Synopsis :

REFLECTION :

1. **Light** is a form of energy which on striking the eye makes things visible (stimulates the sensation of vision).
2. A substance through which light can more or less pass is called **optical medium**.
3. A medium through which light can pass very easily is called **transparent medium**.
4. A medium through which light can partially pass, but through which things cannot be clearly seen is called **translucent medium**. Eg : ground glass, tracing paper, etc.
5. A medium through which light cannot pass is called **opaque medium**.
6. When light travelling through homogeneous transparent medium is incident on a surface which separates this medium from another, then a part of the light comes back into the first medium in a definite direction. This is called **reflection** of light. The surface from which reflection takes place is called a reflector. The amount of light reflected depends on (i) the angle of incidence and (ii) the nature of the two media.
7. **Laws of reflection :**
   i) The incident ray, the normal to the reflecting surface at the point of incidence and the reflected ray, all lie in one plane.
   ii) The angle of incidence is equal to the angle of reflection.
8. **Image formed by a plane mirror :** The image of a point source after reflection on a plane mirror
   i) lies on the normal drawn from the source to the mirror,
   ii) is as far behind the mirror as the source is in front of it,
   iii)is virtual in nature,
   iv)is of the same size as the object and
   v) is laterally inverted.
9. A plane mirror can form a real image if a convergent beam strikes the mirror. (object is virtual)
10. The angle between the incident ray and the plane mirror is known as angle of glancing.
11. The angle between the incident ray extended and the reflected ray is called the angle of deviation. If i is the angle of incidence, then the angle of deviation is (180°–2i). The angle of glancing and the angle of incidence are complementary i.e., their sum is 90°.
12. For a normal incidence, the angle of deviation is 180°.
13. For the same incident ray, if the plane mirror is rotated through θ, then the reflected ray rotates through 2θ. Sextant, optical lever and lamp and scale arrangement work on the above principle.
14. When an object is moving in front of a plane mirror with a velocity v, the image of the observer (as seen by him) travels to or opposite to the object with twice the velocity with which the observer moves to or opposite to the mirror. Any stationary observer in front of the mirror sees the image moving with a velocity v.
15. The minimum size of a plane mirror fixed on the wall of a room in which an observer at the center of the room can see the full image of the wall behind him is one third of the wall.
16. The minimum size of the mirror for seeing the full image of a person is half his size.
17. Two mirrors are inclined at an angle θ. If a ray of light is obliquely incident on the first mirror, the deviation after two reflections is $360°-2\theta$ i.e., the deviation of the ray due to successive reflections at the two mirrors does not depend on the angle of incidence but depends on the angle between the mirrors.

18. If two plane mirrors are kept at an angle θ and if an object is kept between them, then the number of images formed (n) is given by the formula, n=$\frac{360^o}{\theta}-1$ or n=$\frac{360^o}{\theta}$ which ever is odd.
19. **Spherical mirror :** If the reflecting surface of a mirror is spherical, then it is called a spherical mirror.
20. **Convex mirror :** When the reflecting surface of a spherical mirror is bulging, then it is called a convex mirror.
21. **Concave mirror :** When the reflecting surface of a spherical mirror is hollow, then it is called a concave mirror.
22. **Pole :** The center of reflecting surface of a spherical mirror is called the pole of the mirror (P).
23. **Centre of curvature :** The center of the sphere of which the spherical mirror is a part is called the center of curvature (C).
24. **Radius of curvature :** The radius of the sphere of which the spherical mirror is a part is called the radius of curvature of the mirror (r).
25. **Principal axis :** The line joining the center of curvature and pole of the mirror is known as the principal axis of the mirror.
26. **Principal focus :** When rays of light parallel to the principal axis strike a spherical mirror, they either focus at a point or appear to diverge from a point on the principal axis after reflection. This point is known as principal focus (F).
27. **Focal length :** The distance between the pole and the principal focus is called focal length (f).
28. The relation between the focal length (f) and the radius of curvature (r) of a spherical mirror is r=2f.
29. Types of images formed with a concave mirror :

Position of Object	Position of image	Nature
At infinity	At F	Point size; real; inverted
Beyond C	Between F & C	Diminished; real; inverted
At C	At C itself	Same size; real; inverted
Between F & C	Beyond C	Magnified; real; inverted
At F	At infinity	Real
Between P & F	Behind the mirror	Magnified; virtual; erect

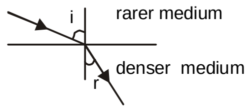
30. With a convex mirror, the image is always formed behind the mirror within its focal length. The image if diminished, virtual and erect.
31. The ratio of the size of the image to the size of the object is called linear magnification (m) and m=v/u.
32. **Mirror formulae :** $\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$ or $f=\frac{uv}{u+v}$

    v=f(1+m) and u=$f\left(1+\frac{1}{m}\right)$
33. In spherical mirrors of large aperture, the marginal and paraxial rays do not come to the same focus. This is known as **spherical aberration**.
34. A paraboloidal mirror has no spherical aberration. It is used in reflecting telescopes and in search lights.

35. The field of view of a convex mirror is more than that of a plane mirror. Hence convex mirror is used as a rear-view mirror.
36. Concave mirror is an ideal one for shaving purposes. Ophthalmoscope consists of a concave mirror. It is also used by dentists.

REFRACTION :

1. When a light ray travels from one medium to another, it suffers a change of direction at the surface of separation of the two media. This is known as **refraction**.
2. **Laws of refraction** :

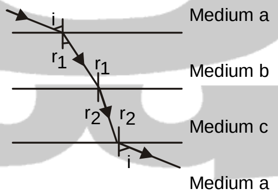


   i) The incident ray, the refracted ray and the normal at the point of incidence on the surface of separation of the two media, all lie in one plane.

   ii) For the same pair of media and for the same colour of light, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant. This is known as **Snell's law**. $\mu = \frac{\sin i}{\sin r}$

   If the first medium is vacuum, then it is called absolute refractive index.
3. When a ray is incident normally i = 0, r = 0 and hence there is no deviation.
4. When a ray of light travels from a rarer medium into a denser medium, its velocity decreases, wavelength decreases and its frequency remains unaltered.
5. Refractive index is dependent on the colour of light. It is minimum for red and maximum for violet.
6. Refractive index "μ" varies with wave length λ as

   $\mu = A + \frac{B}{\lambda^2}$. This relation is known as Cauchy's relation.
7. **Principle of reversibility of light** : If the path of a light ray, after going through a number of reflections and refractions is reversed, it always retraces its path in the opposite direction.
8. As the temperature of a medium increases, its refractive index decreases.

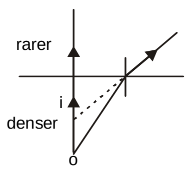


   $_a\mu_b = \frac{\mu_b}{\mu_a} = \frac{1}{_b\mu_a}$

   $_a\mu_b \cdot {_b\mu_c} \cdot {_c\mu_a} = 1$
9. When a ray is passing from one medium (μ_1) into another medium (μ_2), then

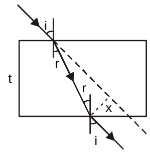
   μ_1 Sin i = μ_2 Sin r.
10. $\mu = \frac{V_o}{V}$ where V_o = velocity of light in vacuum and V = velocity of light in the medium.

    $_1\mu_2 = \frac{V_1}{V_2}$ where V_1 = velocity of light in medium 1 & V_2 = velocity of light in medium 2.
11. When light is traveling from rarer medium to denser medium it bends towards normal. When light is traveling from denser medium to rarer medium it bends away from normal.
12. When an object placed in a denser medium is seen through a rarer medium, it appears to be closer. Eg. a coin placed inside water. When an object in a rarer medium is seen from a denser medium, it appears to be shifted to a point farther away from the eye of the observer.



    $\mu = \frac{\text{Real depth}}{\text{Apparent depth}}$

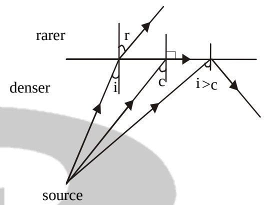
13. The apparent shift produced by a denser medium of thickness (t) is $t(1-\frac{1}{\mu})$.



The apparent shift due to multiple layers= $t_1(1-\frac{1}{\mu_1})+t_2(1-\frac{1}{\mu_2})+\ldots\ldots$

14. When a ray travels through a glass slab, it suffers displacement or lateral shift but is not deviated. Lateral shift (x) is given by $x = \frac{t\sin(i-r)}{\cos r}$.
15. When a light ray travels from a denser medium into a rarer medium, the angle of incidence for which the angle of refraction becomes 90° is known as **critical angle** (C) of the denser medium w.r.t. the rarer medium.
16. The critical angle for water ($\mu = 4/3$) is $48°35^{I}$ and for glass ($\mu = 3/2$) it is $41°49^{I}$.
17. The critical angle is proportional to the wavelength of the spectral line. It is maximum for red and minimum for violet. The critical angle is proportional to temperature.
18. The critical angle (C) depends on the two media. If the angle of incidence is greater than the critical angle, instead of refraction, reflection occurs. This is known as **total internal reflection**.

$${}_a\mu_b = \frac{1}{\sin C_b};\ \sin C_b = \frac{1}{{}_a\mu_b} = {}_b\mu_a$$



19. Mirages and looming are due to total internal reflection.
20. Diamond has maximum refractive index and hence the least critical angle. Hence a well cut diamond shines brilliantly due to total internal reflection.
21. A small air bubble in water shines due to total internal reflection.
22. A bob coated with lamp black, placed under water appears silvery white due to total internal reflection.
23. The conditions for total internal reflection are (i) light must travel from a denser medium to a rarer medium and (ii) the angle of incidence must be greater than the critical angle.
24. **Uses of total internal reflection:** i) It confines the light only to the denser medium and avoids refraction, ii) It permits lossless propagation known as nonradiative propagation i.e., there is no energy loss during transmission, iii) The phenomenon finds wide application in optical communication.
25. **Consequences of total internal reflection :**
    Due to total internal reflection
    a) An air bubble in water appears shining.
    b) A diamond glitters.
    c) Mirages are formed in places or deserts.
    d) The images are formed in cold countries during to looming.
    e) The upper surface of water contained in a glass beaker and held above the eye level appears silvery.
26. **Optical Fibre :**
    a) It is a thin fibre of diameter 2 micron made up of pure quartz or glass of high quality known as light guiding core.
    b) It is coated with a material of less refractive index called the cladding.
    c) The refractive index of the core is 1.7 and that of cladding is 1.5 to 1.6.
    d) The angle of incidence on one end of the fibre is called launching angle.
    e) The cladding is surrounded by a second co-axial layer which serves as a supporting structure.

f) The angle of incidence on the cladding is greater than critical angle of the core with respect to the cladding. Hence total internal reflection takes place several times at the cladding and finally emerges out.

g) To form the image of an object a bundle of fibres of 72 in number is used in general. It is called an optical pipe.

h) **Uses :**

i) The optical fibres are used in the filed of communication since they are thin, light weight, flexible and interference free.

ii) Different telephone signals by superposing on the optical beam can be transmitted simultaneously through fibres without any interference. The response time reduces since the velocity of transmission is high.

iii) The optical fibres are used for medical investigations. Optical fibres are used in laproscope, endoscope for visual examination of inaccessible regions in the human body.

iv) The optical fibres in the form of photometric sensors are used for measuring the blood flow in the heart.

v) The optical fibre sensors have been used to measure temperature and pressure.

vi) The optical fibres in the form refractometers are used to determine the refractive indices of liquids.

27. **Expression for glancing angle (or) launching angle :**

a) The maximum angle of incidence in air for which all the light is totally reflected at the core-cladding interface of an optical fibre is called glancing angle.

b) If μ_1 and μ_2 are the refractive indices of cladding and core respectively ($\mu_2 > \mu_1$) and θ is the glancing angle in air then $\sin\theta = \sqrt{\mu_2^2 - \mu_1^2}$.

c) The factor $\sqrt{\mu_2^2 - \mu_1^2}$ is called numerical aperture, denoted by NA.

$\therefore$ $NA = \sqrt{\mu_2^2 - \mu_1^2}$.

28. The apparent altitude of a star is more than the real altitude because of atmospheric refraction.

29. A person under water observes the setting or rising sun at an angle of 41°25^{I} i.e., (90°–C) with the horizontal.

30. The sun is seen before it actually rises above the horizon due to atmospheric refraction. If there were no atmosphere, then the length of the day on earth would decrease by four minutes.

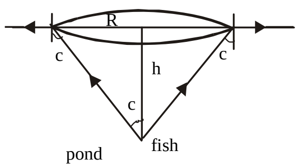
31. The rising sun appears to be bigger or oval in shape when it is at the horizon due to atmospheric refraction.

32. If light travels a distance x in a medium of refractive index μ, the equivalent path in vacuum it would cover in the same time is μx and it is called **optical path**.

33. For a fish or diver under water, the outside world appears to be within a cone of vertex angle 2C (= 98°).

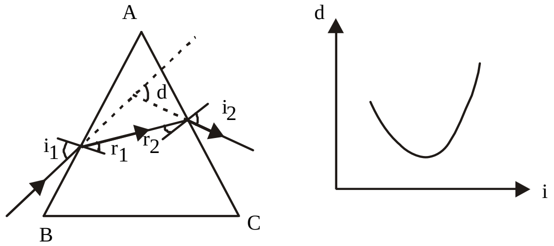
34. If h is the depth of the fish from the surface of water of refractive index μ, the radius of the circle R on the surface of water through which it can see the outside world is

R = htanC or $R = \frac{h}{\sqrt{\mu^2 - 1}}$.



35. **PRISM :**

a) A prism is a piece of gas or any other transparent material, bounded by two triangular and three rectangular surfaces.



b) When a light ray passes through a prism it bends towards the base of the prism.

c) The angle made by emergent ray with incident ray is called angle of deviation (d).

d) $d=i_1+i_2-A$, $A=r_1+r_2$ where i_1 – angle of incidence,
i_2 – angle of emergence, A – angle of prism,
r_1 – angle of refraction at first retracing face,
r_2 – angle of refraction at second refracting face.

e) As the angle of incidence increases, angle of deviation first decreases to a minimum value (D) and then increases.

f) If d=D, then $i_1=i_2=i$ and $r_1=r_2=r$

$$\Rightarrow D = 2i - A, \quad A = 2r$$

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

h) As refractive index (μ) of material of prism increases the angle of deviation increases.

i) As angle of prism (A) increases, the angle of deviation increases.

j) As wavelength of light increases, the angle of deviation decreases. Ex : The angle of deviation for red is minimum as it has maximum wavelength. The angle of deviation of violet is maximum as it has minimum wavelength.

k) If D=A, then $\mu = 2\cos\frac{A}{2}$

l) The prism whose angle is very small is called thin prism.

m) For a thin prism $D=(\mu-1)A$.

36. **Refraction through a prism :**

A → angle of the prism or refracting angle
D → angle of deviation
i_1, i_2 → are the angles of refraction

i) Angle of prism, $A=r_1+r_2$

ii) Angle of deviation $D=i_1+i_2-A$

iii) Refractive index of the prism, $\mu = \frac{\sin i_1}{\sin r_1} = \frac{\sin i_2}{\sin r_2}$

37. **Limiting angle of the prism :**

a) It is the angle of the prism for which a ray grazing on one of the face of the prism after refraction grazes out from the second face.

b) In this case $i_1=i_2=90°$, $r_1=r_2=C$
As $A=r_1+r_2$
$\therefore$ $A=2C$

c) $\mu = \frac{1}{\sin C} = \frac{1}{\sin(A/2)}$

d) Angle of deviation, $D=i_1+i_2-A=90+90-2C$. $\therefore D=180-2C$

38. Deviation in a small angled prism :

a) From snell's law
$\sin i_1=\mu \sin r_1$ and $\sin i_2=\mu \sin r_2$
For a small angled prism, i_1, i_2, r_1 and r_2 are small
$\therefore$ $i_1=\mu r_1$ and $i_2=\mu r_2$
$d=(i_1+i_2)-A=\mu (r_1+r_2)-A=\mu A-A$
$\therefore$ $d=(\mu-1)A$

b) As $\mu_V > \mu_R$. Therefore the deviation for violet colour is more than the deviation for red colour ($d_v>d_r$).

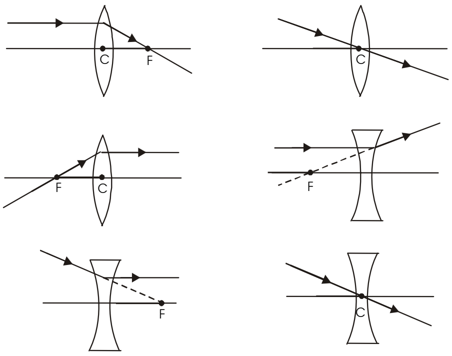
c) For a given colour of light the deviation increases as the angle of the prism increases.

d) For a given monochromatic light $\frac{d_1}{d_2}=\frac{A_1}{A_2}$.

e) In case of thin prism, the angle of minimum deviation, $d_m=(\mu-1)A$.

LENSES :

39. A transparent substance bounded by two surfaces of definite geometrical shape is called **lens**.
40. A lens may be considered to be made up of a number of small prisms put together.
41. **Principal axis** : The line joining the two centres of curvature of the spherical surfaces constituting a lens is called principal axis.
42. **Radius of curvature** : A double convex lens or a concave lens is bounded by two spherical surfaces which are parts of spheres. The centre of such a sphere is called the centre of curvature and the distance from this centre upto the spherical surface is called the radius of curvature.
43. **Optic centre** : When a ray of light incident on one surface of a lens meets the second surface of the lens after refraction and passes through a particular point on the principal axis inside the lens such that the emergent ray is parallel to the incident ray, then that point on the axis is called optic centre (C).
44. **Principal focus** : When a narrow beam of light parallel to the principal axis strikes a lens, the rays after refraction either focus at a point (in the case of convex lens) or appear to diverge from a fixed point on the principal axis (in the case of a concave lens) of the lens. This point is called principal focus (F).
45. **Focal length** : The distance between the optical centre and the principal focus is called focal length (f).



46. Types of images formed with a convex lens :

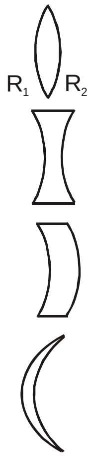
Position of object	Position of image	Nature of image	Application
At infinity	At F	Point size; real; inverted	Astronomical telescope
Beyond 2F	Between F and 2F	Diminished; real; inverted	Camera
At 2F	At 2F	Same size; real; inverted	Erecting lens of terrestrial telescope
Between F and 2F	Beyond 2F	Magnified; real; inverted	Projector
At F	At infinity	Real	
Within the focal length	On the same side	Magnified; virtual; erect	Simple microscope

47. With a concave lens, irrespective of the position of the object, the image is formed on the same side as the object within the focal length. It is always diminished, erect and virtual.
48. The shape of u-v graph in the case of a convex lens or concave mirror is a rectangular hyperbola.
49. The shape of $\frac{1}{u}-\frac{1}{v}$ graph in the case of a convex lens or concave mirror is a straight line.
50. **Lens formulae** :

$$\frac{1}{f}=\frac{1}{u}+\frac{1}{v}; \quad f=\frac{uv}{u+v}; \quad m=\frac{v}{u};$$

$$v=f(1+m); \quad u=f(1+\frac{1}{m})$$

51. The sets of points on the principal axis of a lens where the position of the object and the image can be interchanged are called **conjugate foci**.
52. The formula for the focal length by the conjugate foci method is $f=\frac{L^2-d^2}{4L}$ where L=distance between the object and the screen, d=distance between the two positions of the lens, d=v–u and L=v+u.
53. The minimum distance between the object and the real image in the case of a convex lens is 4f.
54. Newton's formula is $f_1f_2=x_1x_2$ where x_1 and x_2 are the distances of the object and the image from the first and second focal points of the lens.



Double Convex, $R_1 \rightarrow +ve$; $R_2 \rightarrow -ve$

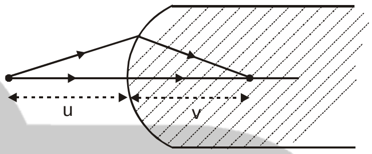
Double Concave, $R_1 \rightarrow -ve$; $R_2 \rightarrow +ve$

Convexo-concave, $R_1 \rightarrow -ve$; $R_2 \rightarrow -ve$

Concavo-convex, $R_1 \rightarrow +ve$; $R_2 \rightarrow +ve$

55. If I_1 is the size of the image in the first case and I_2 is the size of the image in the second case (of conjugate foci), then the size of the object= $\sqrt{I_1 I_2}$.

56. **Refraction at curved surfaces** :



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

where μ_1 = refractive index of the medium in which the object lies.
μ_2 = refractive index of the medium on the other side of curved surface
R = radius of curvature of curved surface

Sign convention :
R is positive, if object faces convex surface
R is negative, if object faces concave surface
v is positive, if image is real (forms on the other side of the lens)
v is negative, if image is virtual (form on the same side of the lens)
First principal focus is the object point for which image point lies at infinity.

$$u = f_1;\ v = \infty \text{ and } \frac{\mu_1}{f_1} = \frac{\mu_2 - \mu_1}{R}$$

Power of refracting surface is given by $\frac{1}{f_1} = \frac{\mu_2 - \mu_1}{\mu_1 R}$

Second principal focus is the image point for which object point lies at infinity.

$$u = \infty;\ v = f_2 \text{ and } \frac{\mu_2}{f_2} = \frac{\mu_2 - \mu_1}{R}$$

Power of refracting surface is given by $\frac{1}{f_2} = \frac{\mu_2 - \mu_1}{\mu_2 R}$

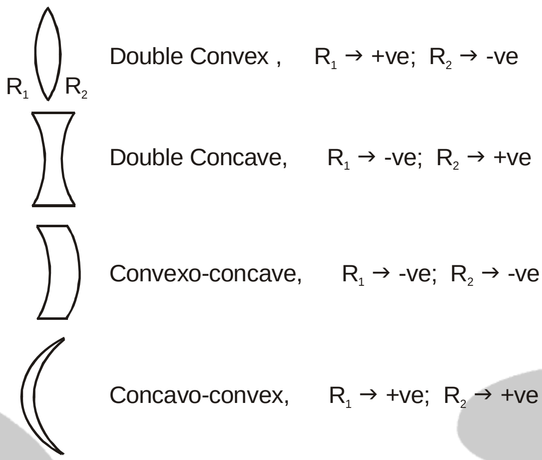
57. **Lens maker's formula** is

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{f}=\left(\frac{\mu_l-\mu_m}{\mu_m}\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

where μ_l = refractive index of the material of lens and μ_m = refractive index of the surrounding medium of the lens.

This formula is applicable for thin lens and for paraxial rays.



58. The focal length of a plane glass plate is infinity.
59. The reciprocal of focal length of a lens measured in metres is called its **focal power (P).**

$$P=\frac{1}{\text{f in metres}}\ \text{(or)}\ P=\frac{100}{\text{f in cm}}$$

60. The unit of focal power is **dioptre**.
61. One dioptre is the focal power of a lens of focal length one metre.
62. When two thin lenses of focal lengths f_1 and f_2 are kept in contact and f is the focal length of the combination, then $\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$ or $P = P_1 + P_2$.
63. When two thin lenses are separated by a distance d then
$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}-\frac{d}{f_1f_2}$ or $f=\frac{f_1f_2}{f_1+f_2-d}$ or
$P = P_1+P_2-P_1P_2d$. It acts as a glass slab if $f_1+f_2=d$.
64. If a double convex lens is vertically cut into two pieces, each piece will have a focal length equal to twice the original.
65. If a convex lens of focal length f is broken into two semicircular pieces, each piece will have a focal length f.
66. An air bubble in water behaves like a divergent lens (i.e., concave lens)
67. If a convex lens of focal length f made of glass (μ=1.5) is immersed in water (μ=4/3), its focal length becomes 4f. The focal power decreases by a factor 4.
68. If a glass lens is immersed in a liquid of the same refractive index, it disappears and does not act like a lens. i.e., the lens will have infinite focal length or zero focal power.
69. A convex lens immersed in a liquid of refractive index greater than the refractive index of the lens behaves like a concave lens.

70. If a planoconvex lens of radius of curvature R and of focal length f is silvered on the plane surface, it acts like a concave mirror of focal length $\frac{f}{2}$ or $\frac{R}{2(\mu-1)}$.
71. If a planoconcave lens of radius of curvature R and of focal length f is silvered on the plane surface, it acts like a convex mirror of focal length $\frac{f}{2}$ or $\frac{R}{2(\mu-1)}$.
72. If a planoconvex lens of radius of curvature R and of focal length f is silvered on the curved surface, it acts like a concave mirror of focal length $R/2\mu$.
73. **Aberrations :**
    a) The defects in the optical images is known as aberration.
    b) There are two types of aberrations.
       i) chromatic aberration
       ii) monochromatic aberration
74. **Chromatic aberration :**
    a) Formation of several images with different colours of an object that give white light is called chromatic aberration.
    b) If the image of a white object is multi coloured and blurred. This defect is called as chromatic aberration.
    c) It is due to the fact that the focal length varies with wavelength (coolour).
    d) Violet ray meet first and red rays at a farthest point from the lens (i.e., $f_R>f_v$)
    e) The longitudinal chromatic aberration=f_R-f_v (when object is at infinity)
    f) The distance x measures longitudinal chromatic aberration and the distance y measures the lateral chromatic aberration.
75. **Characteristics of chromatic aberration :**
    a) The longitudinal chromatic aberration is positive for convex lens and is negative for concave lens.
    b) The chromatic aberration depends on the colours of light (wavelength)
    c) The longitudinal chromatic aberration depends on the distance between the images of different colours of light and lateral chromatic aberration depends on the sizes of the images.
    d) When object is at infinity, longitudinal chromatic aberration is equal to the product of the mean focal length and the dispersive power (material) of the lens.
    e) When object is at finite distance, longitudinal chromatic aberration depends (i) dispersive power (material) of lens (ii) mean colour image distance and (iii) mean focal length.
76. **Elimination of chromatic aberration :**
    a) Achromatic doublet : The combination of lenses in contact with each other which minimizes the chromatic aberration is called an achromatic doublet.
       The combination of a convex lens made of crown and a plano-concave lens made of flint glass acts as achromatic doublet and minimizes the chromatic aberration.
       The combination of fluorite convex lens and a plano-concave lens made of flint glass is called apochromate and it removes completely the chromatic aberration.
    b) Achromatic combination of two lenses separated by a distance : Two thin lenses made of the same material separated by a distance equal to the mean of their focal lengths eliminates the chromatic aberration. i.e., $d=\frac{f_1+f_2}{2}$.

c) Chromatic aberration is eliminated by using a pair of thin lenses of focal lengths f_1 and f_2 separated by a distance d such that d=$\frac{\omega_1 f_2 + \omega_2 f_1}{\omega_1 + \omega_2}$ where $\omega = \frac{\mu_v - \mu_r}{\mu - 1} = \frac{d\mu}{\mu - 1}$ is called dispersive power.

If the two lenses are made of same material, then d=$\frac{f_1 + f_2}{2}$.

d) Chromatic aberration can be eliminated by an achromatic doublet. An achromatic doublet is the combination of a bi-convex lens (usually crown glass) and a plano-concave lens (usually flint glass) kept in contact.

e) The condition to be satisfied by an achromatic doublet is $\frac{\omega_1}{\omega_2} = \frac{-f_1}{f_2}$ or $\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0$ where ω_1 and ω_2 are the dispersive powers of the lens. Negative sign shows that one of the lens is concave.

77. **Spherical aberration :**

a) The inability of the lens to form a point image of an axial point object is called spherical aberration.

b) It is due to the fact that the marginal rays suffer greater deviation than the paraxial rays. Therefore the marginal rays are focuses nearer than paraxial rays. So the image formed by the marginal rays is nearer than the image formed by paraxial rays.

78. **Characteristics of spherical aberration :**

a) The spherical aberration produced by a concave lens is negative while that produced by a convex lens is positive.

b) The spherical aberration depends on the object distance from the optic center.

c) The spherical aberration depends on the refractive index of the lens medium and the shape.

d) The spherical aberration varies as the square of the distance of the object ray from the axis.

e) The spherical aberration is proportional the square of the total deviation produced by the lens.

79. **Elimination of spherical aberration :**

By using Stops :

a) The spherical aberration can be minimised by using stops. An annular disc made with opaque material acts as stop. When it is placed in the path of the emergent rays or the central portion of the lens is obscured by a stop allowing only the peripheral rays to form the image. It allows paraxial rays by stopping marginal rays. In this method, the intensity of image will decrease.

Bending of a lens :

b) If deviations produced in a light ray are equal at the two refracting surfaces of a lens then spherical aberration becomes minimum. Such a lens which produced equal deviations at the two surfaces is called a **crossed lens**.

The shape of the lens is modified to minimise the spherical aberration. This process is called bending the lens. A quantity known as **shape factor** of a lens is defined as S=$\frac{R_1 + R_2}{R_2 - R_1}$ where R1 and R2 are the radii of curvature of the lens. This factor measures the symmetry of the shape of the lens. The bending of a lens is to find that shape of the lens for which spherical aberration is minimum. To determine the proper shape of the lens of material of index of refraction 1.5, we have to choose the values of R_1 and R_2 in such a way that the ratio $\frac{R_1}{R_2} = \left(-\frac{1}{6}\right)$ or the **shape factor** S=5/7 so that the longitudinal spherical aberration is a minimum.

The general rule to minimise the spherical aberration in a plano-convex lens is that the convex side should face the incident or emergent beam which ever is more parallel to the axis.

A plano convex lens made of flint glass (μ=1.68) is a perfect crossed lens.

c) By a suitable combination of convex and concave lenses the spherical aberration can be minimised.

By using plano-convex lenses :

d) The spherical aberration can be minimised by using two plano-convex lenses of the same material placed at a distance equal to the difference of their focal lengths. i.e., $d=f_1-f_2$.

The convex surfaces of the lenses must be towards the incident rays.

Suitable combination of a concave and convex lenses :

e) Suitable combination of concave and convex lenses minimises spherical aberration, because a concave lens produces a negative spherical aberration and a convex lens a positive spherical aberration.

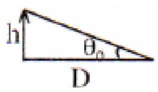
For every spherical refracting surface there will be a pair of points on the axis such that all the light rays diverging from a point converge at the other point. These points are called aplanatic points. Spherical aberration can be eliminated completely by placing the object at one of those points.

80. Optical Instruments:

1. The nearest point at which an object is seen clearly by the eye is called the "near point" of the eye.
2. The least distance upto which on object can be clearly seen by a naked eye is called the least distance of distant vision. That is D = 25 cm for normal eye.
3. The farthest point from an eye at which and object is distinctly seen is called far point, for a normal eye it is theoretically at infinity.
4. **Visual angle** :It is the angle subtended by an object at the eye.

   It is maximum when the object is at the least distance of distinct vision.

   It 'h' is the height of the object placed at the near point, the visual angle is $\theta_0 = \dfrac{h}{D}$

   (the angle is small) 

5. MICROSCOPES :

It is an optical instrument used to see very small objects. It's magnifying power is given by

$$m = \frac{Visual\ angle\ with\ instrument}{Visual\ angle\ when\ object\ is\ placed\ at\ least\ distance\ of\ distinct\ vision}$$

<u>A. Simple microscope:</u>

It is a single convex lens of lesser focal length.

It is also called magnifying glass or reading lens.

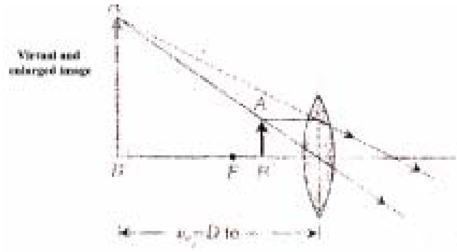
Magnification m = D/u.

Magnification when final image is formed at D and (i.e. m_D and).

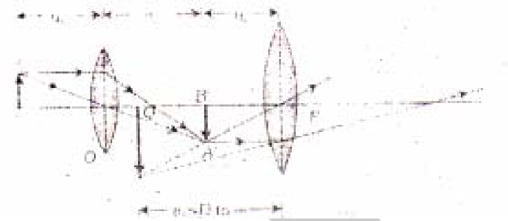
$m_D = \left(1 + \frac{D}{f}\right)_{max}$ and $m_\infty = \left(\frac{D}{f}\right)_{min}$

If lens is kept at a distance a from the eye then

$m_D = 1 + \frac{D-a}{f}$ and $m_\infty = \frac{D-a}{f}$



B. Compound microscope:



Consist of two converging lenses called objective and eye lens.

$f_{eye\ lens} > f_{objective}$ and $(diameter)_{eye\ lens} > (diameter)_{objective}$

Intermediate image is real and enlarged.

Final image is magnified, virtual and inverted.

u_0= Distance of object from objective (o).

υ_0 = Distance of the image A^1B^1 formed by objective from eye lens.

u_e= Distance of A^1B^1 from eye lens.

υ_e = Distance of final image from eye lens.

f_0 = Focal length of objective.

f_e = Focal length of eye lens.

Magnification $m = \frac{\upsilon_0}{u_0}\left(\frac{D}{u_e}\right)$ and the length of the tube is $L = \upsilon_0 + u_e$

Final image formed at D : Magnification $m = -\frac{\upsilon_0}{u_0}\left(1 + \frac{D}{f_e}\right)$ and length of the microscope tube (distance between two lenses) is . $L_D = \upsilon_0 + u_e$

Generally object is placed very near to the principal focus of the objective hence $\upsilon_0 \cong L_D$, the length of the tube.

Hence, we can write $m_D = \frac{-L}{f_0}\left(1 + \frac{D}{f_e}\right)$

Final image formed at ∞

$m_\infty = -\frac{\upsilon_0}{u_0}.\frac{D}{f_e} \approx \frac{LD}{f_0 f_e}$ and length of tube $L_\infty = \upsilon_0 + f_e$

For large magnification of the compound microscope, both f_0 and f_e should be small.

The magnifying power os the compoudn microscope may be expressed as $m = m_0 \times m_e$; where m_0 is the magnification of the objective and me is magnification os eye piece.

6. Astronomical Telescope

(Refracting Type)

By astronomical telescope heavenly bodies are seen.

1) $f_{objective} > f_{eyelens}$ and $d_{objective} > d_{eyelens}$ (d= diameter)

2) Intermediate image is real, inverted and small (diminshed).

3) Final image is virtual, inverted and diminshed.

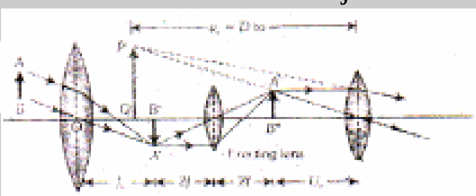
4) Magnification : $m = -\frac{f_0}{u_e}$ and length. $L = f_0 + u_e$

5) Magnification : $m_D = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$ and $m_\infty = -\frac{f_0}{f_e}$

(for normal adjustment)

7) Terrestrial Telescope :

It is used to see distance object on the earth.



1) It consists of three converging lens: objective, eye lens and erecting lens.

2) Final image is virtual, erect and diminished.

3) Magnification : $m = \frac{f_0}{u_e}$ and $m_D = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$

$m_\infty = \frac{f_0}{f_e}$ (for normal adjustment)

4) Length : $L = f_0 + 4f + f_e$

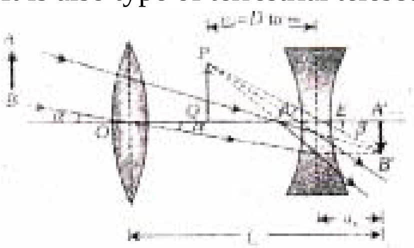
$L_D = f_0 + 4f + u_e$ and

$= f_0 + 4f + f_e$

(f = focal length of erecting lens)

8. Galilean Telescope:

It is also type of terrestrial telescope but of much smaller field of view.



1) Objective is a converging lens while eye lens is diverging lens.
2) Final image is virtual, erect and diminshed
3) Magnification : $m = \frac{f_0}{u_e}$

$$m_D = \frac{f_0}{f_e}\left(1 - \frac{f_e}{D}\right) \text{ and } m_\infty = \frac{f_0}{f_e}$$

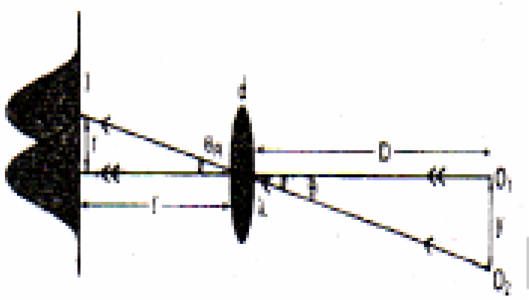
4) Length : L= $f_0 + u_e$

$L_D = f_0 - u_e$ and = $f_0 - f_e$

9. Resolving Limit and Resolving Power :

A. Telescope :

Smallest angular separations (d_θ) between two distant objects, whose images are separated in the telescope is called resolving limit.



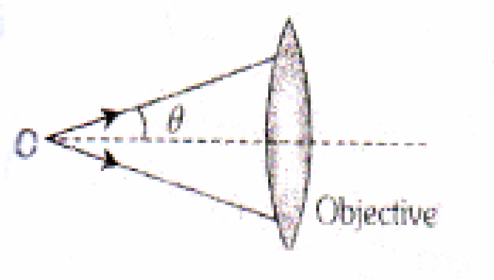
Resolving limit $d_\theta = \frac{1.22\lambda}{a}$ and resolving power

(RP) = $\frac{1}{d\theta} = \frac{a}{1.22\lambda} \Rightarrow R.P \propto \frac{1}{\lambda}$

where a = aperture of objective.

B. Microscope:

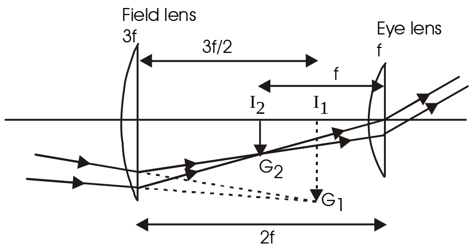
The resolving power of an optical instrument is defined as the reciprocal of smallest angular separation between two neightbouring objects whose images are just distinctly formed by the instrument. The smallest angular seperation is called the limite of resolution.



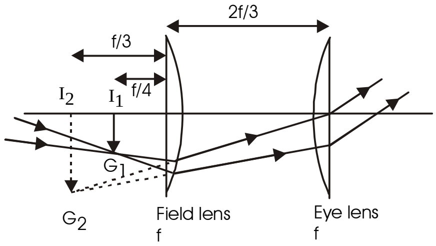
$$R.L = \frac{\lambda}{2\mu \sin\theta} \text{ and } R.P. \frac{2\mu \sin\theta}{\lambda} \Rightarrow R.P \propto \frac{1}{\lambda}$$

λ = Wavelength of light used to illuminate the object,
μ = Refractive index of the medium between object and objective
θ = Half angle of the cone of light from the point object, $\mu \sin\theta$ = Numerical aperture

81. **Eyepieces :**
   a) Eyepiece is an optical device used in optical instrument such as telescope and microscope to see the final image.
   b) Eyepiece is usually a combination of two lenses one is field lens and the other is eye lens.
   c) By using an eye piece the aberrations in the image can be eliminated and the field of view can be increased.
   d) There are several types of eye pieces like Ramsden's eyepiece, Huygen's eyepiece, Gauss eyepiece, Kellner eyepiece etc.
82. **Huygen's eyepiece :**



   a) It consists of two plano-convex lenses of focal length 3f and f separated by a distance of 2f.
   b) The focal length of the field lens is 3f and focal length of eye lens is f.
   c) Convex surfaces of both the lenses will be towards incident light.
   d) The effective focal length is F=3f/2.
   e) The distance of the equivalent lens from field lens is 3f.
   f) It is a negative eyepiece, since the image due to the objective is formed behind the field lens.
   g) It is not possible to provide cross wires in this eye piece. As the cross wires should be kept at the position of the image due to the objective.
   h) The virtual image formed by the objective is at a distance of 3f/2 from the field lens.
   i) The real image formed by the field lens is at a distance of 'f' from the field lens.
   j) This eye piece is free from chromatic and spherical aberrations.
   k) It is used in biological instruments in which the cross wires are not required.
83. **Ramsdens eyepiece :**
   a) It consists of two plano-convex lenses of same focal length 'f' separated by a distance 2f/3.



   b) Convex surfaces of the lenses face each other. So either lens can be used as field lens or eye lens.
   c) The effective focal length of the eyepiece is F=3f/4.
   d) The distance of the equivalent lens from field lens is f/2.
   e) It is a positive eyepiece because the image due to objective is formed infront of the field lens.
   f) The cross wires are fixed infront of the field lens at the same position where the image due to objective is formed.
   g) The distance of the cross wires before the field lens is f/4.

h) The distance of the cross wires from the eye lens is $\frac{2f}{3}+\frac{f}{4}=\frac{11f}{12}$.

i) The virtual image formed by the field lens is at a distance of f/3 from the field lens and at a distance of f from the eye lens.

j) It is not completely free from chromatic and spherical aberrations.

k) The eyepice is used in measuring instruments like traveling microscope and spectrometer.

84. **Comparision between Ramsden's and Huygen's eyepices :**

Huygen's eyepiece	Ramden's eyepiece
Focal plane of the eye-piece lie in between the two lenses.	Focal plane of the eye-piece lie in front of the two lenses at a distance of f/4 from the field lens.
Image formed by the objective act as virtual object for the eye-piece, hence this is called negative eye-piece.	Image formed by the objective act as a real object for the eye-piece, hence this is called positive eye piece.
Provision of cross wires is not possible.	Cross wires can be provided.
Eliminates spherical and chromatic aberrations completely.	Minimises the defects of spherical and chromatic aberrations.
Field of view is inferior.	Field of view is greater.
Cannot be used for measurement purposes.	Can be used for measurement purposes.

85. **Dispersion :**

a) The splitting of white light into constituent colours is called dispersion and the band of colours is called spectrum.

b) Dispersion of light was discovered by Newton.

c) As the wavelength is minimum for violet and hence R.I is maximum for violet.

d) As the wavelength is maximum for red and hence R.I is minimum for red.

e) A spectrum in which there is overlapping of colours is called impure spectrum.

f) A spectrum in which there is no overlapping of colours is called pure spectrum.

g) **Conditions to get a pure spectrum :**

i) The incident beam should be passed through a narrow slit.

ii) The incident beam is made parallel by using a convergent lens.

iii)The prism should be in minimum deviation position.

iv)The emergent beam is brought to focus on a screen by using a convergent lens.

86. **Angular dispersion :**

a) The difference in deviation between any two colours (generally violet and red) is called angular dispersion.

b) The angular dispersion $=d_V-d_R=(\mu_V-\mu_R)A$

[since for small angled prism, $d_V=(\mu_V-1)A$ and $d_R=(\mu_R-1)A$]

87. **Dispersive power :**

a) Dispersive power, $\omega=\frac{\text{angular dispersion}}{\text{mean deviation}}$

$\omega=\frac{d_V-d_R}{d}$ where $d=(\mu-1)A$ the mean deviation (i.e., for yellow colour)

$\therefore \omega=\frac{\mu_V-\mu_R}{\mu-1}$

Dispersive power is independent of the angle of prism. It depends only on refractive index and nature of material.

b) If μ_1 and μ_2 are the refractive indices of two colours and μ is the refractive index of the mean colour, then the dispersive power of the two colours is given by $\omega = \frac{\mu_2 - \mu_1}{\mu - 1}$. It is constant for those two colours and for the material of the prism. It is independent of the angle of the prism but angular dispersion depends on the angle of the prism.

c) If f_1 and f_2 are the focal lengths of a lens for clours 1 and 2 and f is the focal length of the mean colour, then dispersive power of the lens, $\omega = \frac{df}{f}$ where $f = \sqrt{f_1 f_2}$.

88. **Deviation without dispersion :**

a) Deviation with out dispersion means an achromatic combination of the prisms in which net or resultant dispersion is zero and deviation is produced.

b) For the two prisms made of different materials and of different refracting angles the net dispersion is zero if

$(d_V - d_R) + (d_V^1 - d_R^1) = 0 \Rightarrow \frac{A^1}{A} = -\frac{(\mu_V - \mu_R)}{(\mu_V^1 - \mu_R^1)}$ The negative sign indicates that the refracting angles of two prisms are in the opposite directions.

89. **Dispersion without deviation :**

A combination of two prisms in which the deviation produced for the mean ray (yellow colour) by the first prism is equal and opposite to that produced by the second prism. For the deviation to be zero $d+d^1=0 \Rightarrow (\mu-1)A + (\mu^1-1)A^1 = 0$

$$\Rightarrow \frac{A^1}{A} = -\frac{(\mu-1)}{(\mu^1-1)}$$

The negative sign indicates that refracting angles of the two prisms are in the opposite directions.

90. **Types of spectra :**

Spectra are two types

A) Emission spectra and B) Absorption spectra

A) Types of emission spectra :

Emission spectra is of three types.

a) continuous spectra, b) line spectra and c) band spectra

a) continuous spectra :

i) It is given by incandescent (red hooted) solids liquids).

ii) Continuous spectrum contains all wavelengths from violet tored.

iii) It is not the characteristic of atom or molecule but it is emitted by matter in bulk.

iv) It depends on the temperature of the source.

v) It is due to thermal excitation.

vi) Incandescent platinum wire (burning platinum wire), burning charcoal, filament of an electric bulb, kerosene lamp, candle flame, gases under great pressure produce continuous spectrum.

b) Line spectrum :

i) Hot gases or vapours in atomic state produce line spectrum.

ii) Line spectrum is also called ionic spectrum or atomic spectrum.

iii) It consists of bright lines of different colours against dark back ground.

iv) The intensity of one line is different from the other.
v) Line spectrum is a discontinuous one.
vi) Line spectrum is due to electronic transition from higher orbits to lower orbits.
vii) Line spectrum is the characteristic property of the atom producing light and it differs from one element to another.
viii) Sodium vapour lamp emits light of wavelength 5890 Å and 5896 Å causing two lines called D_1, D_2 lines in the spectrum.
ix) Tube light, mercury vapour lamp, hydrogen discharge tube, helium discharge tube, neon discharge tube produce line spectrum.

c) Band spectrum :

i) Hot gases in molecular state gives band spectrum.
ii) It is also called molecular spectrum.
iii) It consists of bright bands of different colour over dark back ground. Each band consists of closely packed lines.
iv) The spacing between two bands and the width of the band depends on the nature of the compound.
v) At very high temperature the band spectrum changes into line spectrum as the molecules split into atoms.
vi) This spectrum is due to transition of electrons combined with rotatory, translatory and vibratory effects of molecules.
vii) Blue light of Bunsen burner, N_2 gas, cynogen gas, nitric acid, lead fluoride, calcium chloride, calcium bromide and other compound of calcium, carbon produce band spectrum.

B) Absorption spectra :

i) It is due to absorption of radiation by the matter.
ii) Absorption is based on Kirchoff's law which states that a substance which emits particular wavelength of radiation when excited, also possess the property of absorbing the same wavelength from the incident radiation when unexited.
iii) Absorption spectrum consists of dark lines over a bright back ground.
iv) Absorption spectrum is the characteristic property of the absorbing material. That is one can identify what are the elements present in the absorbing material.
v) When the white light is passed through the gas in atomic state (say sodium vapour) line absorption spectrum is formed.
vi) When the white light is passed through the molecular gas (say iodine vapour) band absorption spectrum is formed.

91. **Solar spectrum :**

a) Solar spectrum is an absorption spectrum.
b) The dark lines present in a solar spectrum are called Fraunhoffer lines.
c) By studying Fraunhofferlines, helium was first discovered in the sun's atmosphere before it could be identified on earth.
d) Fraunhoffer lines are due to absorption of certain wavelength of light by the elements present in the chromosphere.
e) The study of Fraunhoffer lines indicates that the chromosphere contain gases of hydrogen, oxygen, sodium etc.
f) During total solar eclipse the solar spectrum contains bright lines. It is because the absorption spectrum changes to emission spectrum.

92. **Phosphorescence :**

a) Certain substances continue to emit light even after the incident light is cut off. This phenomenon is called phosphorescence.

Ex : cadmium sulphide, strontium sulphide.

93. **Fluorescence :**

a) The phenomenon of converting radiation of smaller wavelength into radiation of longer wavelength.

Ex : Petrol, zinc sulphide, uranium oxide, quinine sulphate, barium platino cyanide, calcium fluoride, paraffin oil.