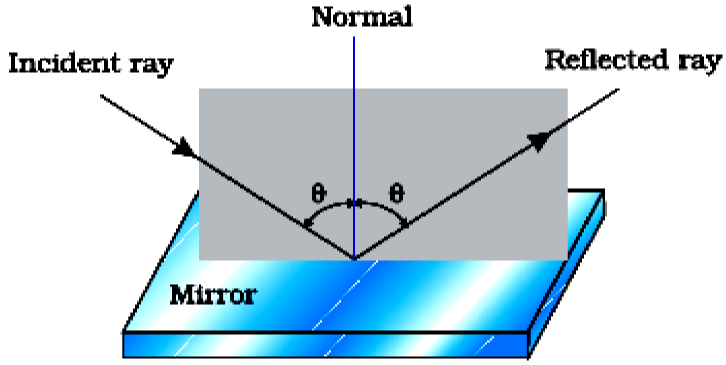
NCERT-XII / Unit- 09 – Ray Optics

REFLECTION OF LIGHT



The laws of reflection are…………..

(i) The incident ray, reflected ray and the normal to the reflecting surface at the point of incidence lie in the same plane

(ii) The angle of reflection (i.e., the angle between reflected ray and the normal to the reflecting surface or the mirror) equals the angle of incidence (angle between incident ray and the normal).

Relation between focal length and radius of curvature of a mirror & Mirror formula

$$f = \frac{R}{2} \qquad \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \qquad m = \frac{I}{O} = \frac{-v}{u} = \frac{f-v}{f} = \frac{f}{f-u}$$

According to the new sign convention,

(i) All distances are measured from the pole of the mirror or the optical centre of the lens.

(ii)The distances measured in the same direction as the incident light are taken as positive and those measured in the direction opposite to the direction of incident light are taken as negative.

(iii) The heights measured upwards with respect to x-axis and normal to the principal axis (x-axis) of the mirror/lens are taken as positive and measured downwards are taken as negative .

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Refraction -

When a ray of light enters from one transparent medium into another, there is a change in speed and direction of the ray in the second medium. This phenomenon is called refraction.

Laws of Refraction :

(i) The incident ray, the refracted ray and the normal to the surface separating the two media, all lie in the same plane.

(ii) Snell's Law : For two media, the ratio of sine of angle of incidence to the sine of the angle of refraction is constant for a beam of particular wavelength,

$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} = {}_2\mu^1$ where μ_1 and μ_2 are absolute refractive indices of 1 and 2media respectively and ${}_2\mu^1$ is a refractive index of second (2) medium with respect to first (1) medium.

$${}_m\mu^v = \frac{\text{velocity of light in vacuum}}{\text{velocity of light in given medium}}$$

Also, the frequency of light remains unchanged when passing from one medium to the other , but velocity and wavelength changes

$${}_2\mu^1 = \frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

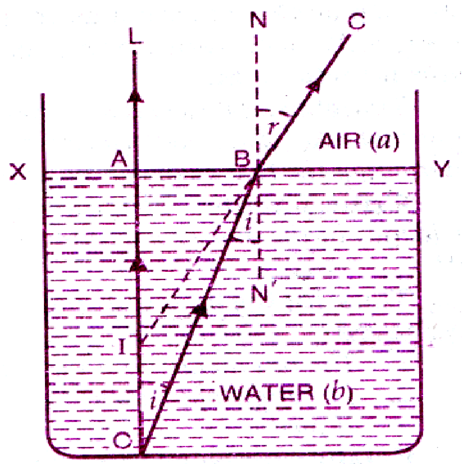
Principle of reversibility ${}_2\mu^1 = \frac{1}{{}_1\mu^2}$

Refraction through Compound Plate:

$${}^a\mu_b \times {}^b\mu_c \times {}^c\mu_a = 1$$

$${}^a\mu_b \times {}^b\mu_c = \frac{1}{{}^c\mu_a} = {}^c\mu_a$$

Real and Apparent Depth



Whenever an object is placed in optically denser medium, like object **O** placed at the bottom of the container, the ray of light starting from object moves from denser to rarer medium and bends away from normal. Thus a virtual image of the object is formed at I. Then, distance **OA** is called **real depth** and **IA** is called **apparent depth** of object.

Now,

$$\sin i = \frac{AB}{OB} \quad and \quad \sin r = \frac{AB}{IB}$$

Using Snell's law,

$$\frac{\sin i}{\sin r} = \frac{\mu_1}{\mu_2} \Rightarrow \frac{IB}{OB} = \frac{\mu_1}{\mu_2}$$

If rarer medium is air, then $\mu_1 = 1$, $\mu_2 = \mu$

$$\frac{OB}{IB} = \mu$$

If angles are small then OB≈OA and IB≈IA

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

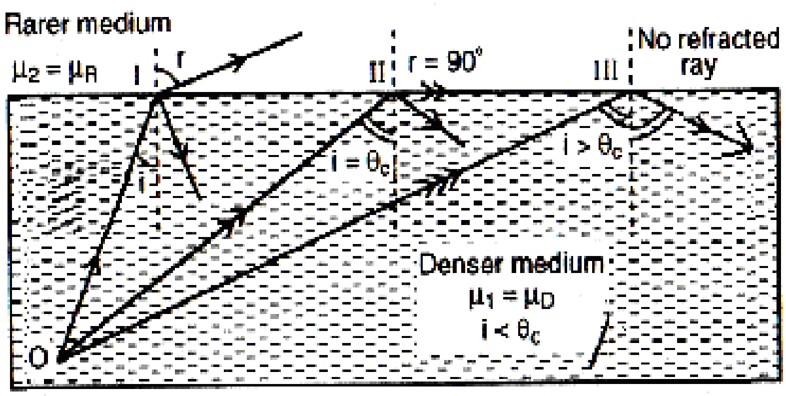
The shift in the position which takes place after refraction from the surface is , x= OA – IA

$$x = OA - \frac{OA}{\mu}$$, or $$x = h - \frac{h}{\mu} = h\left(1 - \frac{1}{\mu}\right)$$

here 'h' denotes the real depth of the object

Total Internal Reflection:

This phenomenon is observed when a ray of light moves from denser to rarer medium. When the angle of incidence in such a case is greater than the critical angle then light would be reflected back into the same medium & phenomenon is called **total internal reflection**.



As the rays move from denser to rarer medium they bends away from the normal. If we go on increasing the angle of incidence angle of refraction also goes on increasing (according to Snell's law). At one particular angle of incidence, angle of refraction becomes 90º. The angle of incidence for which the angle of refraction is 90º is called ***critical angle*.**

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If angle of incidence is increased further the ray gets totally reflected back into the same medium instead of refraction.

At critical angle, i_c, **r = 90**.

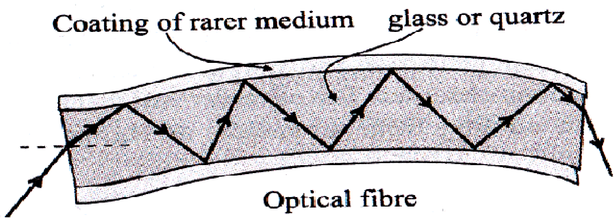
$$\frac{\sin i_c}{\sin 90} = {}^2\mu_1 \quad \text{or ,} \quad {}^1\mu_2 = \frac{1}{\sin i_c}$$

Applications of Total Internal Reflection:

1. Mirage Formation: It is an optical illusion which takes place in hot countries. The layers of earth in contact with the earth are hooter and rarer whereas the upper layers are colder and denser. When the ray of light moves downwards after reflection from object like tree it is moving from denser to rarer medium. The agle of incidence goes on increasing with refraction are each layer of atmosphere. For one particular layer the angle of incidence is greater than critical angle and the ray of light suffers total internal reflection back in the upward direction. Thus a virtual and inverted image of the object is formed on the ground. These virtual images produces the impression of reflection from water due to atmospheric disturbance.

2.Diamond: Diamonds are known for their spectacular brilliance. Their brilliance is mainly due to the total internal reflection of light inside them. The critical angle for diamond-air interface (about 24.4°) is very small, therefore once light enters a diamond, it is very likely to undergo total internal reflection inside it.Diamonds found in nature rarely exhibit the brilliance for which they are known. It is the technical skill of a diamond cutter which makes diamonds to sparkle so brilliantly. By cutting the diamond suitably, multiple total internal reflections can be made to occur.

3. Optical Fibres :



Optical fibres consists of several thousand of very long fibres of the diameter of 10^{-4} cm, with refractive index 1.7. The fibres are located with a thin layer of material of lower refractive index. Light entering from one side undergoes about 10^{12} thousand reflections per meter and comes out from other end. Optical fibres can be put to number of application ;

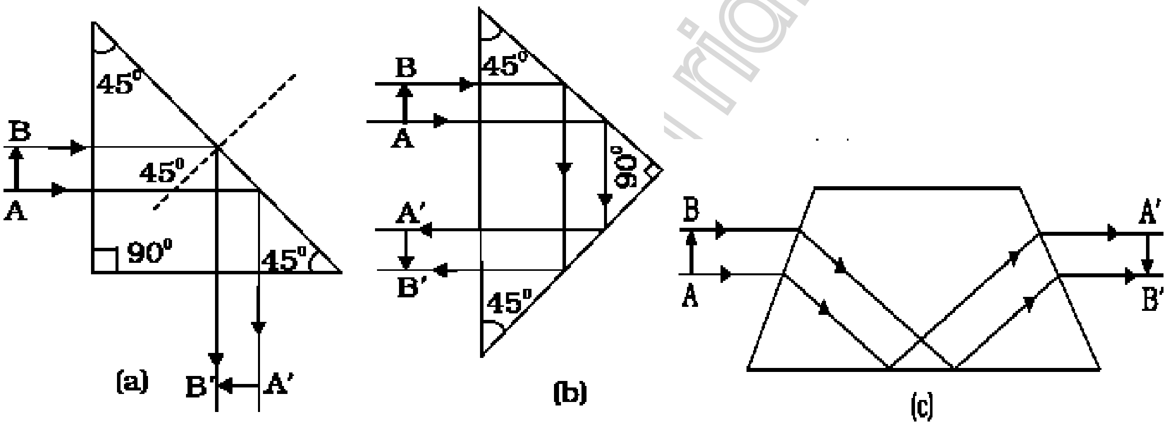
(i) They can be used to transmit high intensity laser light insider the body.

(ii) They can be used in the field of communication in sending video signals from one place to another.

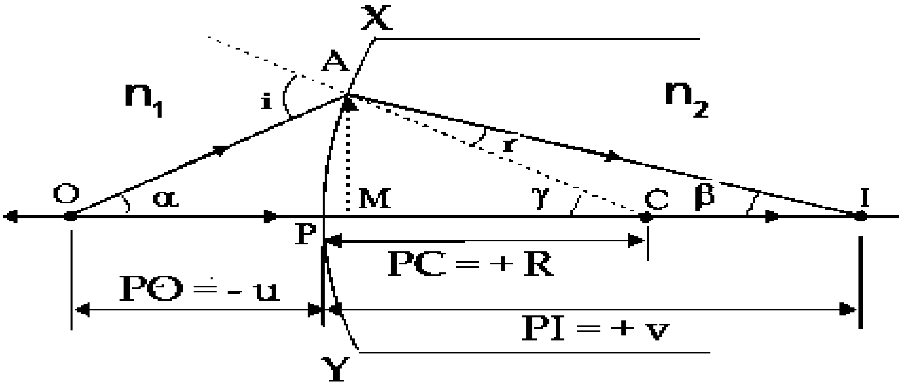
(iii) They are used to see images of body parts not clearly visible in X- Rays.

4. Prism:

Prisms designed to bend light by 90º or by 180º make use of total internal reflection . Such a prism is also used to invert images without changing their size



Refraction formula at a spherical surface with the object in rarer medium



Let be an object O placed in a rarer medium of refractive index n_1 , on the principal axis of a spherical surface XY, of refractive index $\mathbf{n_2}$ centre of curvature C, forms the real image **I** , in the denser medium .

Let AM be perpendicular on the principal axis and

$\alpha = \angle AOM$,$\beta = \angle AIM$, $\gamma = \angle ACM$

From Δ ACO , **$i = \alpha + \gamma = \tan\alpha + \tan\gamma$**

=> $i = \frac{MN}{OM} + \frac{MN}{MC}$ …….. 1 [as α & γ **are small**]

From Δ **ACI**, **$\gamma = \beta + r$ => $r = \tan\gamma + \tan\beta$**

i.e., $r = \frac{MN}{MC} - \frac{MN}{MI}$ …….2 [as β & γ **are small**]

Now, by Snell's law, **$n_1 \sin i = n_2 \sin r$**

or for small angles , **$n_1 i = n_2 r$** => $\left(\frac{n_1}{OM} + \frac{n_1}{MC}\right) = \left(\frac{n_2}{MC} - \frac{n_2}{MI}\right)$

Since A & P are very much close to each other

$\left(\frac{n_1}{PM} + \frac{n_1}{PC}\right) = \left(\frac{n_2}{PC} - \frac{n_2}{PI}\right)$ => $-\frac{n_1}{u} + \frac{n_2}{v} = \frac{n_2 - n_1}{R}$ ………….4

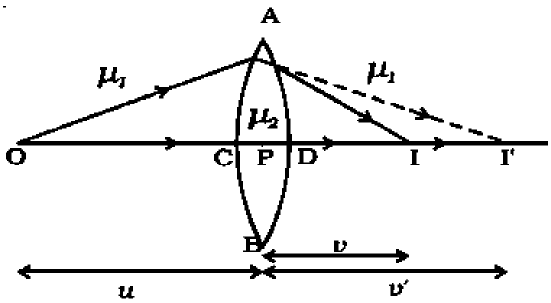
Equation (4) gives us the Refraction formula at a spherical surface with the object in rarer medium_age distance and It holds for any curved spherical surface.

Refraction formula at a spherical surface with the object in denser medium

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

Lens maker's formula

Let us consider a lens made up of a medium of refractive index μ_2 placed in a medium of refractive index μ_1, with R_1 and R_2 *as* the radii of curvature of two spherical surfaces *ACB* & *ADB* respectively ,P as optical centre.



Let O be a point object on the principal axis of the surface ACB, of which real image is formed at I' by it in the denser medium .

The refraction formula for the surface ACB is

$$-\frac{n_1}{u}+\frac{n_2}{v'}=\frac{n_2-n_1}{R_1} \quad \text{...........1}$$

The image at I' is behaving like a virtual object for the surface ADB , thereby forming the final image at **I** .

The refraction formula for the surface ADB is

$$-\frac{n_2}{v'}+\frac{n_1}{v}=\frac{n_1-n_2}{R_2} \quad \text{.........2}$$

Adding equations (2) and (1)

$$-\frac{n_1}{u}+\frac{n_1}{v}=(n_2-n_1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$

Dividing the above equation by $\mathbf{n_1}$

$$-\frac{1}{u}+\frac{1}{v}=\left(\frac{n_2}{n_1}-1\right)\left[\frac{1}{R_1}-\frac{1}{R_2}\right] \text{.....3}$$

If the object is at infinity, the image is formed at the focus of the lens.i.e. u = $\propto$, $v = f$. Then the eq (3) becomes.

$$\frac{1}{f} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \quad ....4$$

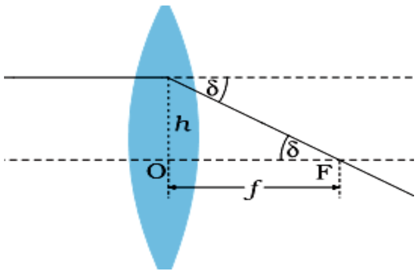
If the refractive index of the lens is n and it is placed in air. $\mu_2 = \mu$ and $\mu_1 = 1$. So the equation (5) becomes

$$\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \quad ....5$$

This is called the lens maker's formula.

Power of a lens

The power P of a lens is defined as the tangent of the angle by which it converges or diverges a beam of light falling at unit distant from the optical center



$$\tan\delta = \frac{h}{f};\ \text{if } h = 1 \quad \tan\delta = \frac{1}{f} \quad \text{or} \quad \delta = \frac{1}{f}$$

for small value of δ. Thus, P = 1/f

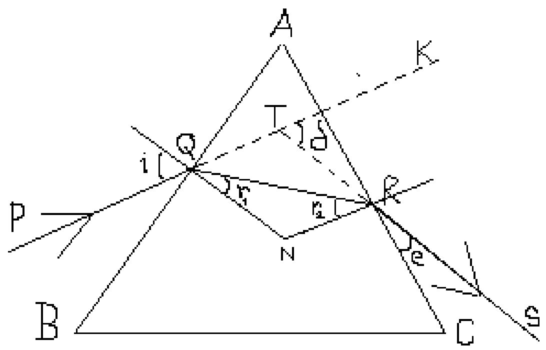
The SI unit for power of a lens is dioptre (D) 1D = $1m^{-1}$

The power of a lens of focal length of 1 metre is one dioptre. Power of a lens is positive for a converging lens and negative for a diverging lens.

Dispersion through prism

Q.1:- What is angle of dispersion ? find an expression for it

Ans : - The angle by which a ray of light is deviated from its original path while passing through a prism suffering refraction at its refracting surfaces is known as angle of deviation



Let a ray of light be incident along PQ at angle of incidence (i) on refracting surface AB of a prism. Let it be refracted angle QR angle of refraction (r_1) and again be incident is the other refracting surface AC at an angle (r_2), which immerges along RS at an angle of emergence (e)

If we proceed the emergent Ray RS in the backward direction then it will meet the original direction of light PQK at T making an angle

STK= δ is known as angle of deviation.

From ΔQRT , $\angle$STK = $\angle$TQR + $\angle$TRQ

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

=> δ = (i – e) – ($r_1 + r_2$) ------ (i)

From the quadrilateral AQNR

$\angle A + \angle Q + \angle N + \angle R = 360^0$.

=> $\angle A + 90 + \angle N + 90 = 360^0$

=> $\angle A + \angle N = 360 - 180$

=> $\angle A + \angle N = 180$ ------ (ii)

From ΔQNR , $r_1 + r_2 + N = 180^0$ ----------- (iii)

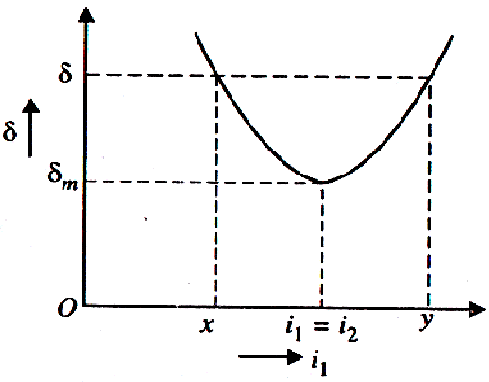
From (iii) & (ii) $A + N = r_1 + r_2 + N$ => $A = r_1 + r_2$ -------- (iv)

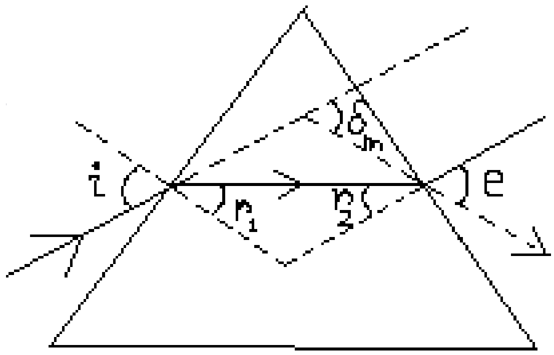
Putting in equation (i) $\delta = (i + e) - A$ …..(v)

Q. What is angle of minimum deviation. Find out an expression for refractive index in terms of minimum elevation of prism formula.

Ans:- If we draw the graph between angle of incidence and angle of deviation then it is found that with angle of incidence, angle of deviation decreases first , becomes minimum; then again increases with the further increase in angle of incidence as shown in i – δ graph.

The minimum value of angle of deviation for a ray of high passing through a prism is known as angle of minimum elevation





Condition of minimum deviation : -

1) The ray through the prism should be parallel to the base of the prism.

2) $\angle i = \angle e$ ($\angle$of incidence = $\angle$of emergence)

3) $\angle r_1 = \angle r_2$

The angle of elevation, from the expression

$\delta = i + e - A$ … (i) Where A is angle of prism.

$A = r_1 + r_2$ ------------------ (ii)

For minimum deviation, i.e. when $\delta = \delta_m$

i = e and $r_1 = r_2$.

=> $\delta_m = i + i - A$

=>2i = δ_m + A => $i = \frac{\delta_m + A}{2}$ ………….. (iii)

(ii) => A = r + r => $r = \frac{A}{2}$----(iv)

The refractive index of the material of the prism is given as

$$\mu = \frac{\sin i}{\sin r} \Rightarrow \mu = \frac{\sin(\frac{\delta m + A}{2})}{\sin r/2}$$

Q. Find the condition for no emergent of light through the prism

Ans. For the ray of light not to emerge through a prism

$\mathbf{r_2 \geq i_c \Rightarrow A - r_1 \geq i_c \Rightarrow A \geq r_1 + i_c}$

From $\frac{\sin i}{\sin r} = \mu$

$$\Rightarrow \sin r_1 = \frac{\sin i}{\mu}$$

$$\Rightarrow r_1 = \sin^{-1}\left(\frac{\sin i}{\mu}\right)$$

$$\text{So, } A \geq \sin^{-1}\left(\frac{\sin i}{\mu}\right) + i_c \text{ .....(ii)}$$

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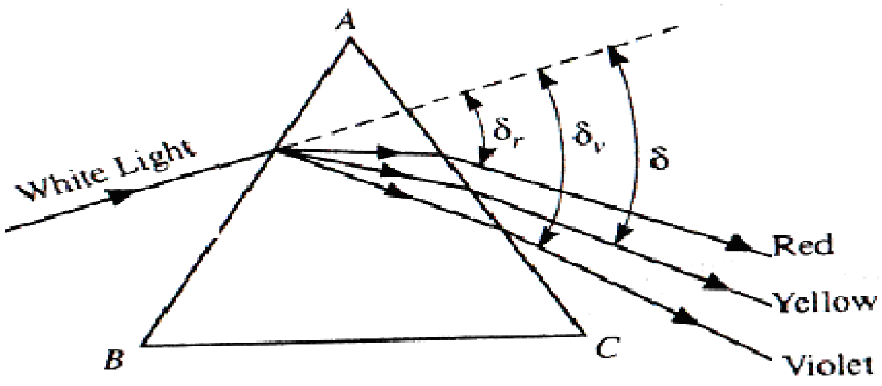
Dispersion:



The phenomenon by virtue of a ray of light while passing through a prism spilts up into its constituent wavelengths , is known as **dispersion.**

Q: Exlain why

(i) violet deviates the most and red the least in the spectrum

(ii) the deviation suffered by different clours of the spectrun is different for different colours

Ans: (i) By Cauchy's relation

$\mu = a + b/\lambda^2 + c/\lambda^2 + \ldots\ldots$ **(1)** a,b,c are constants

Deviation produced by prism of small angle,

$\delta = (\mu - 1)A$ ……………...(2) A is ∠ of prism

From (1) => $\mu \ \alpha \ 1/\lambda^2$

From (2) => $\delta \ \alpha \ \mu$ …….(4)

From (3) and (4) => $\delta \ \alpha \ 1/\lambda^2$ **,** Since wavelength of red is more than that of violet , so deviation produced by violet is more than that produced by red

(ii) By Cauchy's relation

$\mu = a + b/\lambda^2 + c/\lambda^2 + \ldots\ldots$ **(1)** a,b,c are constants

Deviation produced by prism of small angle,

$\delta = (\mu - 1)A$ ….(2) A is ∠of prism

From (1) => $\mu \ \alpha \ 1/\lambda$ ...(3)

From (2) => $\delta \ \alpha \ \mu$ …….(4)

From (3) , it is seen that for different colours of white light, there will be different values of μ

From (4) , it is seen that for different values of μ . there will be different values of δ .

So different colours deviated by different angles of deviations .

Angular dispersion

The difference of deviations produced by the two extreme colours of the sectrum is called **angular dispersion**. It is denoted by $\delta_v - \delta_r$.

$\delta_v - \delta_r = (\mu_v - 1)A - (\mu_r - 1)A = (\mu_v - \mu_r)A$ ……….(1)

If deviation suffered by mean light

is δ, $\delta = (\mu - 1) A$ …(2)

(1) and (2) => $$\frac{\delta_v - \delta_r}{\delta} = \frac{(\mu_v - \mu_r)}{(\mu - 1)} = \omega$$

where ω is called the **dispersive power of prism**.

Dispersive power of a prism is defined as the ratio of angular dispersion to mean deviation produced by prism.

As $\mu_v > \mu_r$, therefore, dispersive power is always positive.

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Scattering :- When a beam of light is incident on particles of very small size, smaller than the order of wavelength of light, light proceeds in all possible directions. The phenomenon is called scattering.

According to Rayleigh's law " The intensity of scattered light, having wavelength λ, varies inversely as fourth power of its wavelength."

$$I \propto \frac{1}{\lambda^4}$$

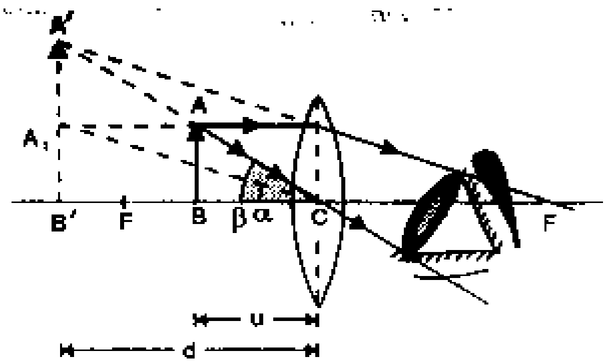
As $\lambda_r = 2\lambda_b$, therefore, scattering of blue colour will be 16 times more than that of light.

Blue color of Sky : Being shorter wavelength, scattered blue light dominates and hence sky appears blue.

Simple Microscope:

Object is placed between convex lens and principal focus an erect, virtual and magnified image is formed on the same side of the object.

In the figure AB is the object . A convex lens is producing a virtual, erect and magnified image A' B' at least distance of distinct vision.



Magnifying Power :

It is the ratio of angle subtended by the image at the eye to the angle subtended by the object at the eye when both are placed at least distance of distinct vision.

$$\textit{Magnifying Power} = \frac{\beta}{\alpha} = \frac{\tan\beta}{\tan\alpha} = \frac{\frac{AB}{CB}}{\frac{A_1B'}{CB'}} = \frac{CB'}{CB} = \frac{D}{u} \quad ...(1)$$

Since the virtual image is formed at least distance of distinct vision, therefore, **V = –D**. Using Lens Formula,

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

Multiplying both sides by D, we get,

$$-1 + \frac{D}{u} = \frac{D}{f} \Rightarrow \frac{D}{u} = 1 + \frac{D}{f} \quad \text{—(2)}$$

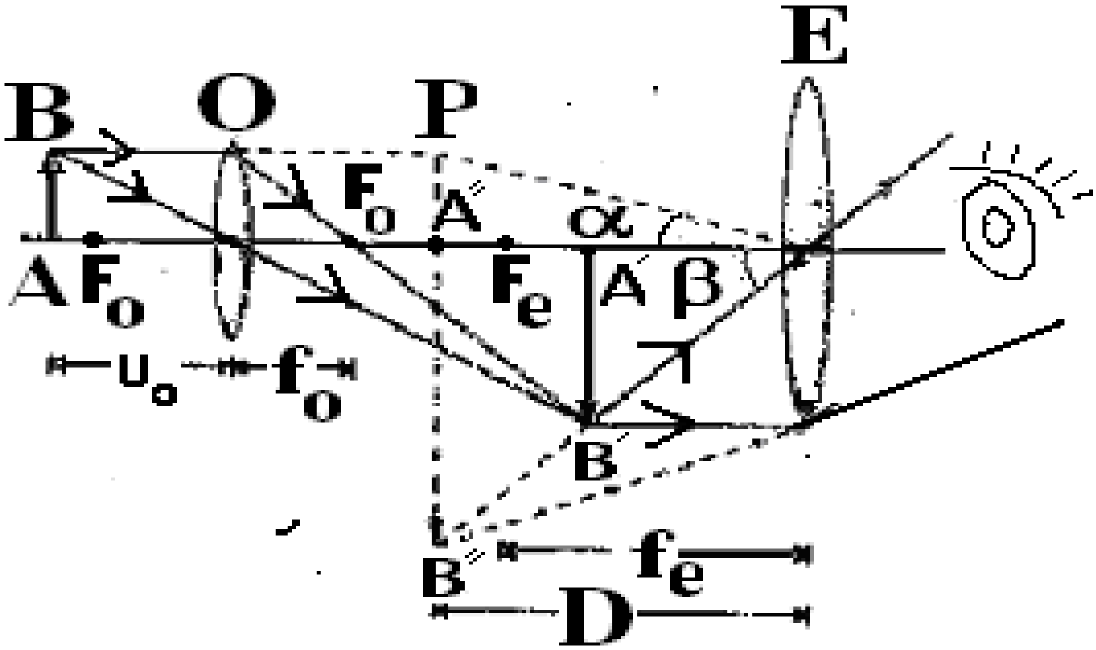
From (1) and (2),

$$M = 1 + \frac{D}{f}$$

Compound Microscope:

It is used where larger magnification is required. The convex lens O of short focal length and short aperture and eye piece of short focal and large aperature is required.

Let AB be an extended object situated on the principal axis at distance greater than focal length of the objective. As refraction takes place through the objective O, a real inverted and magnified image A'B' is formed. The position of eye piece so adjusted that **A'B'** falls within its focal length and so the final image **A''B''** is formed at least distance of distinct vision. Thus, final image **A"B"** is formed in highly magnified but is inverted with respect to the object AB. The course of rays forming the final image.



Magnifying Power:

The magnifying power is defined as the angle subtended by the final image at the eye to the angle subtended by object when both are placed at least distance of distinct vision from eye.

$$M = \frac{\beta}{\alpha} \cong \frac{\tan\beta}{\tan\alpha}$$

$$M = \frac{A''B'''}{A'B'} \times \frac{A'B'}{AB} = M_O \times M_C$$

For objective lens, $M_O = \frac{-v}{u}$

Again since the lens **E**, acts like simple microscope, its magnification M_C is given by,

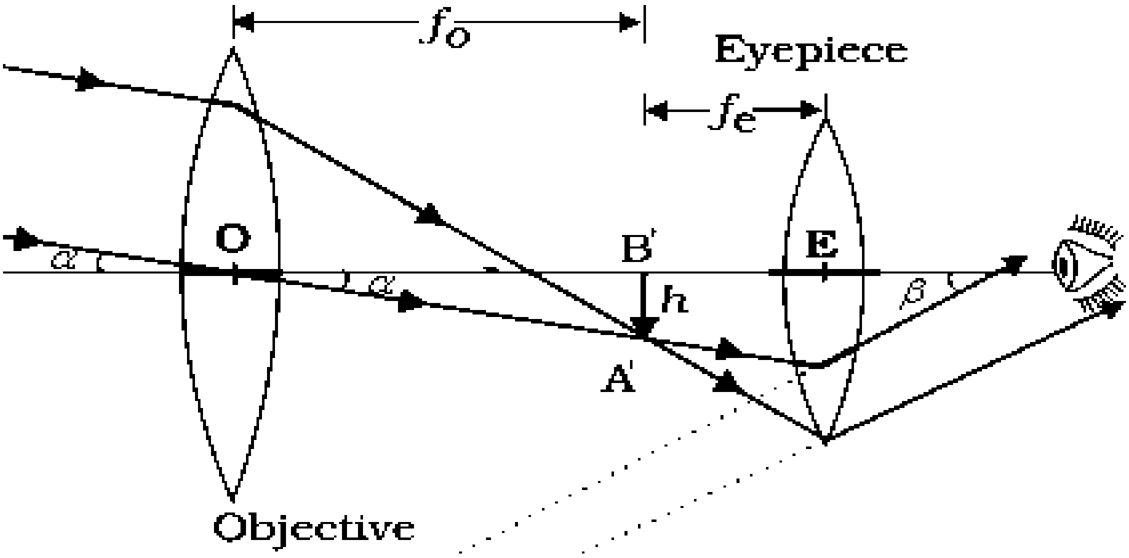
$$M_C = 1 + \frac{D}{f_e}$$

Thus, magnification of compound microscope should be,

$$M = \frac{v}{u}\left(1+\frac{D}{f_e}\right)$$

Astronomical Telescope:

Device used to see very far off heavenly bodies. The objective lens has large focal length and large aperture. The eye piece has small focal length and small aperture. A parallel beam of light coming from distance object forms a real, inverted and diminished image at a distance $\mathbf{f_0}$ from O. The image then acts as an object for eye piece, and final image is formed after refraction through eye piece.



Normal Adjustment:

If the final image is formed at infinity after refraction through the eye piece. The magnifying power of telescope is defined as the ratio of angle b subtended by the image to the angle subtended by the object at the eye when both are placed at infinity.

$$M = \frac{\beta}{\alpha} \cong \frac{\tan\beta}{\tan\alpha}$$

$$M = \frac{A'B'}{C_2B'} \times \frac{C_1B'}{A'B'} = \frac{C_1B'}{C_2B'}$$

$$C_1B' = f_0 \ (\text{focal length of objective})$$

$$C_2B' = f_e \ (\text{focal length of eye piece})$$

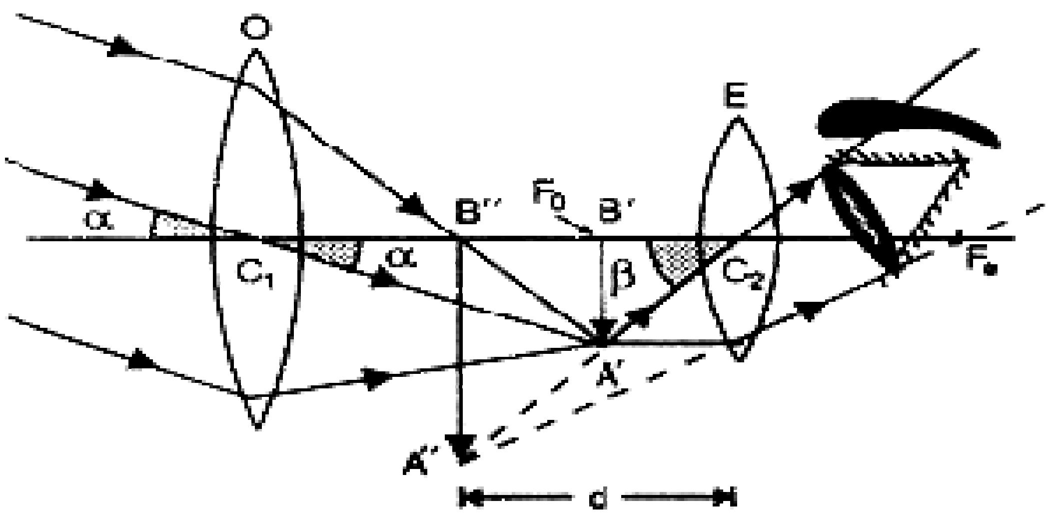
$$M = \frac{f_0}{f_e}$$

The distance between the two lenses is **($f_0 + f_e$)**.

When image is at least distance of distinct vision:

The objective lens forms the real inverted and diminished image **A'B'** at **f_n**.

If **A'B'** forms the real image within the focal length **f_e** of the eye piece, a final virtual but magnified image **A"B"** is observed. The position of eye piece is so adjusted that final image is formed at least distance of distinct vision D from the eye



Magnifying Power:

It is the ratio of angle subtended at the eye by the final image formed at least distance of distinct vision to the angle subtended by the unaided eye by the object at infinity.

$$M = \frac{\beta}{\alpha} \cong \frac{\tan\beta}{\tan\alpha} = \frac{A'B'}{C_2B'} \times \frac{C_1B'}{A'B'}$$

$$= \frac{C_1B'}{C_2B'} = \frac{f_0}{-u_e}$$

Using Lens formula,

$$\frac{1}{f_e} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{-1}{u} = \frac{1}{f_e} + \frac{1}{D}$$

$$u = \frac{-f_e D}{f_e + D}$$

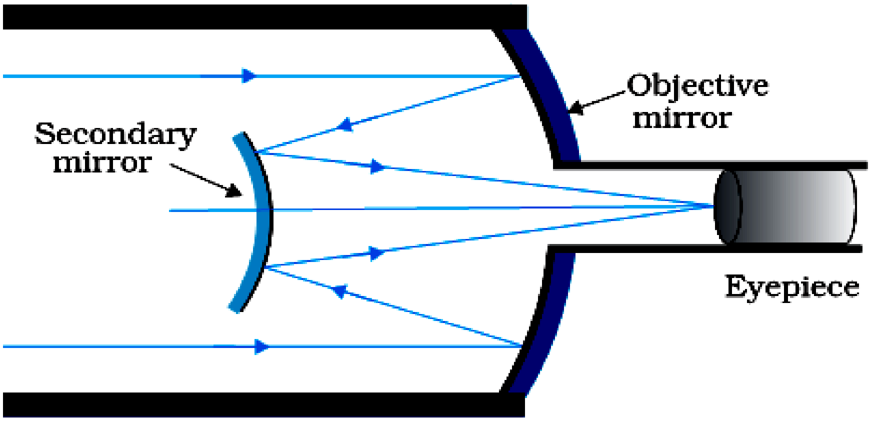
$$M = \frac{f_0}{f_e}\left[\frac{f_e + D}{D}\right]$$

Reflecting telescopes have several advantages over refracting telescopes (1) There is no chromatic aberration in a mirror.

(2) If a parabolic reflecting surface is chosen, spherical aberration is also removed.

(3) Mechanical support is much less of a problem since a mirror weighs much less than a lens of equivalent optical quality, and can be supported over its entire back surface, not just over its rim.

Reflecting telescopes



Since in a reflecting telescope ,the objective mirror focuses light inside the telescope tube , so an eyepiece is used to observe the light inside of it . A paraboloidal concave mirror of aperture , equal to 200 inches (nearly 6·6 metres) is used . It is known as objective .

To focus the incident light , another secondary convex mirror is used , which now passes the light through a hole in the objective primary mirror to the eyepiece . This is known as a Cassegrain telescope, named after its inventor.

It has the advantages of a large focal length in a short telescope. The largest telescope in India is in Kavalur, Tamil Nadu. It is a 2.34 m diameter reflecting telescope (Cassegrain). It was ground, polished, set up, and is being used by the Indian Institute of Astrophysics, Bangalore.

The largest reflecting telescopes in the world are the pair of Keck telescopes in Hawaii,USA, with a reflector of 10 metre in diameter.

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