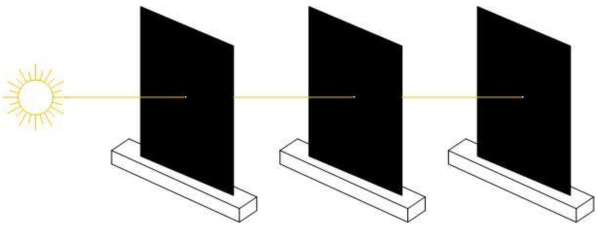
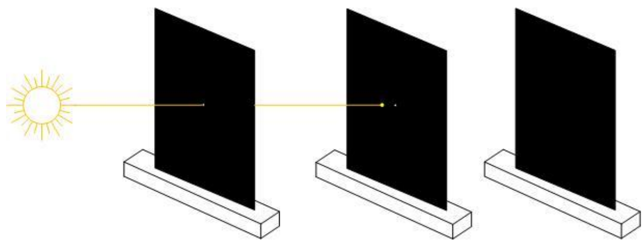
Chapter-VI: Waves and Motion : Part –III- Optics

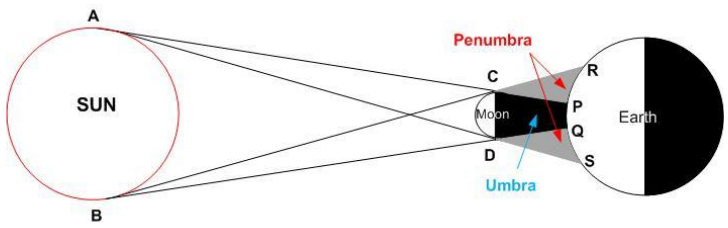
Light Waves : Initial experience of human being with light comes from observation with eyes, the organ which provides vision. Inability to see, unless a person is blind or sleeping, is perceived as absence of light. This vision has grown into discrimination of an object with its shadow and image. Shadow is the shape created by an object by intercepting light in its passage, while image is creation of a replica of an object. This formation of shadow created inquisitiveness on nature of light propagation. ***Newton,*** one of the greatest exponent of science, in 1704 in his book Opticks, *mistakenly considered light to be made up of tiny particles called* ***Corpuscules*** *and analysed its reflection and refraction with his basic laws of motion known as* ***Corpuscular Theory***. Despite, Huygens' Waves Theory, which was propounded in 1678, the Newton Theory, in the form of ***Ray Optics***, maintained its influence over community and continued unquestioned until 1801, when ***Thomas Young*** demonstrated interference of light which contradicts Newton's theory of light. This effect dominance of Newton was against the basic philosophy of scientific exploration and advancement. This land mark experiment changed the course of discovery of nature of light leading ***Electromagnetic Theory (EMT) of Light*** propounded by **Maxwell** in 1860, which has not yet contradicted any of the experimental observations in general and in particular contents of this manual. Nevertheless, inquisitive students are welcome for knowing more about EMT through *Contact Us*.

Simplest experiment that light travels in a straight line is using three non-transparent black screen, Two of them towards the light source, in this case a candle, have a pin-hole. When the middle screen is aligned to the light incident on the screen from candle, the light passes through it and creates a bright spot on third complete black screen. But, when alignment of the middle screen is slightly disturbed, the light instead of passing through the pin-hole in it creates a bright spot on the screen, indicating interception of light by it. In the process, the bright spot earlier appearing on third screen disappears, confirming the interception of rectilinear propagation of light ray by middle screen.



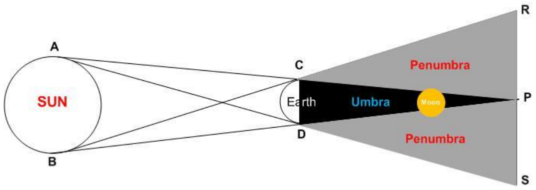


Another celestial phenomenon, more prominently observed and cited in mythology and pre-recoded history, is **Solar and Lunar Eclipse** and goes well with the Newton's Theory of light. ***Solar Eclipse*** (सूर्य ग्रहण) occurs when *view of Sun is obstructed by Moon as shown* in the figure. This can happen only during No-moon Nights (अमावस्या). Degree and duration of eclipse depends on relative orbital Motion of moon w.r.t Earth in context of **Spherical Geometry**. This happen iff motion of Moon's shadow is intercepted by Earth's Surface. This shadow has Two parts. One is ***Umbra***, *complete shadow of Moon* which is in shape of conical frustum such that cross-section of Moon, designated by CD, intercepting Sun Light form is base of frustum, while surface of earth intercepting the conical shadow, identified by PQ, is the top of frustum and is identified with points CDQP. The other is ***Penumbra***, *partial-shadow* of Moon Earth designated by CPR and DQS. Eventually, shape of the Penumbra is again conical frustum surface of the Earth, identified by RPQS, as its base and surface of Moon, identified by CD, as its top. In this conical volume of

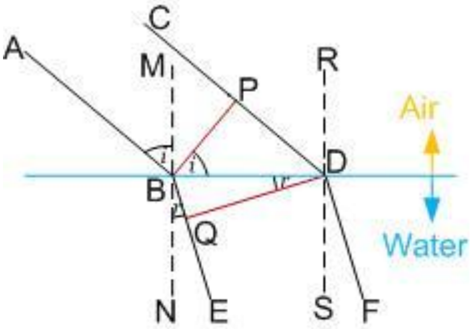


penumbra, shadow is uniformly graded all around from edge CPQS to CRSD leading complete darkness to brightness. The formation of the shadow, its occurrence and visibility, is only during Day of No-Moon.

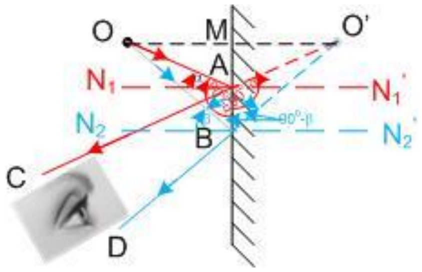
Lunar Eclipse (चंद्र ग्रहण) occurs during Full Moon Nights (पूर्णिमा) when shadow of Earth is intercepted by the surface of Moon as shown in the figure. This occurs when Moon passes through shadow of the Earth. Like Solar Eclipse, degree and duration of eclipse depends on same parameter, but with a difference of only relative position of Earth and Moon. In this also darkness of Penumbra gradually diminishes all around from CDP to CDSR. The formation of the shadow, its occurrence and visibility, is only during Nights of Full-Moon.



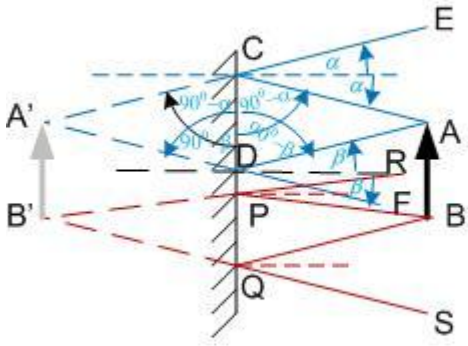
Since, wave nature of light is proved beyond doubt, reflection and refraction phenomenon of light is being elaborated in the same perspective. Accordingly, explanation of Reflection of Light goes in line with Reflection of Sound elaborated earlier. Refraction of light is explained with Huygens Wave Theory. This requires correlating the concept with the velocity of light is different for each transparent medium and so is the velocity of wave front. Taking a parallel beam of light AB-CD travelling in air at a velocity v_a intercepts surface of transparent water at BD. In water velocity of light is v_w. This change of velocity would be applicable to rays BE and DF forming edge of the beam such that wavefront, characteristically, remains perpendicular to the direction of propagation. This requires that time (t) taken by ray CP to travel a distance PD, in air, must be equal to time taken by ray AB to travel a distance BQ, in water. In ΔBPD, $BD = PD \sin i$; likewise in ΔBPD, $BD = BQ \sin r$. Further, $PD = v_a t$ and $BQ = v_w t$. Using these equalities, $= v_a t \sin i = v_w t \sin r$. It leads to $\frac{\sin i}{\sin r} = \frac{v_w}{v_a}$, and this ratio is characteristic to two mediums through which light is travelling and is called ***Refractive Index*** of the Two mediums designated as $_a\mu_w$. Since, at this point light wave travels reversibly, it leads to $_a\mu_w = \frac{1}{_w\mu_a} = \frac{\sin i}{\sin r}$. These, observations are experimentally verifiable and have been summarized into ***Laws of Refraction of Light*** as – **a)** Incident Light, Refracted Light and Normal to the surface at the point of incidence are in the same plane, **b)** Ratio of sine of angle of incidence ($\sin i$) and angle of refraction ($\sin r$) is directionally constant for the two medium and is called Refractive Index, **c)** Refractive Index from air to water is $_a\mu_w = \frac{v_w}{v_a}$, and **d)** Directional Refractive Index is reciprocal to each other i.e. $_a\mu_w = \frac{1}{_w\mu_a}$. This Reflection and Refraction phenomenon are most easily and widely observed and have found many applications in real life. Elaboration of these experiences and applications are in conformance with basics of Geometry and hence it is called ***Geometrical Optics***.



Reflection From a Plain Mirror: This is the beginning of Geometrical Optics at which concept of image is introduced. A point object O is placed in front of mirror is emitting light in all directions. Reflection of Two divergent rays OA and OB incident on the mirror are considered. As per *Laws of Reflection* these rays after reflection further diverge along AC and BD, respectively. These reflected rays to the observer appear to be coming from O', and this is called image of O. In this ray geometry, Δ OAB and Δ O'AB, side AB is common and are congruent by ASA theorem. Accordingly, perpendicular distance of object O in front of mirror shall be equal to O'M, the distance of image behind the mirror.

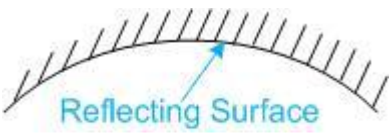


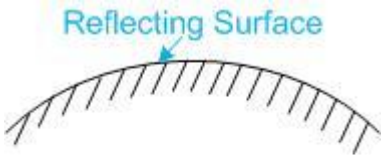
Every physical object can be considered to be comprising of points and for simplicity Trays emanating from top and bottom points of the Object AB, are considered for image formation, Formation of image of a point requires the reflected rays to converge, while in this case reflected rays CE and DF are diverging. These divergent-reflected rays when projected backwards, shown by dotted lines appear to be emerging from A', making it an apparent image of A. Likewise, image of bottom B of the object is B'. Geometrically Δ ADC and Δ A'DC with a common side CD are congruent by ASA theorem. Accordingly, A' is behind the mirror is placed symmetrically placed w.r. t. A. Likewise, image B' is mirror image of bottom B. This is true for every point of Object AB of the object in its mirror image A'B'. The image A'B' apparently radiating light is called **Virtual Image**, which characteristically can be experienced but not taken on a screen. This leads to two types of images **Real Image**, *which are formed by convergence of light and hence can be taken on a screen*. While ***Virtual Image*** is the one which *is experienced by apparent emergence of light but cannot be taken on screen*.



This elaboration of formation of image by plain mirror, can be extended to determine *minimum height and width of mirror to be half of the actual height and width of object*; it requires application of simple geometrical symmetry. Nevertheless, inquisitive reader can reach us for proof of this statement through *Contact Us*.

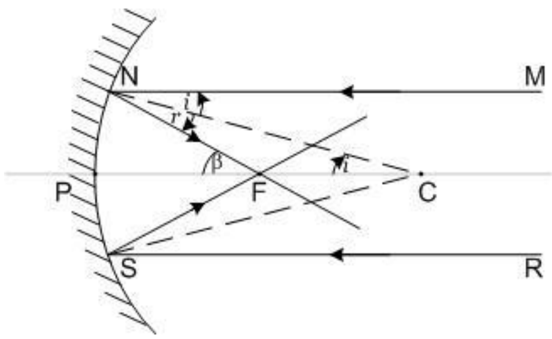
Reflection from Spherical Mirrors: Spherical mirrors have geometrical symmetry across its diameter and accordingly cross-section of mirrors are shown to classify ***Convex Mirror*** whose *outer surface is a reflecting surface*, while ***Concave mirrors*** have *inner surface is reflecting*.



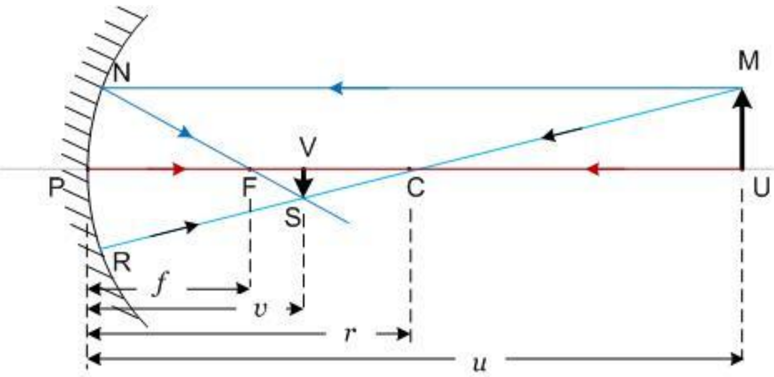


Reflection from spherical surface adds new dimension to image formation for which geometry of the mirror is being defined. Reflection of a parallel beam of light by a concave surface is taken as a base case to define the geometry. Later, it would be used for analysing formation of images for both kinds of mirrors, with different positions of objects.

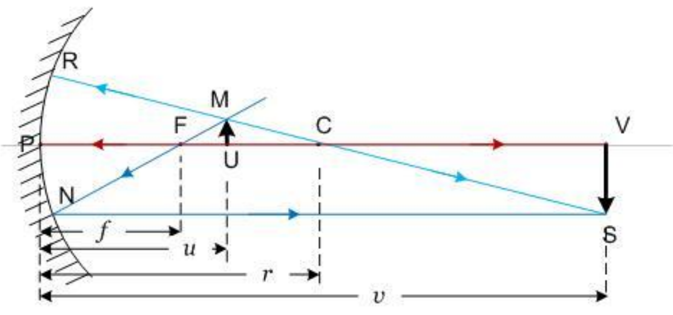
Case I – Concave Mirror-Object at Infinity: *Rays emanating from an object at a distance much larger than radius (**r**)of a concave mirror PC, can be approximated to be parallel to principal axis of the mirror* whose centre of curvature is C, and point P where principal axis intercepts surface of the mirror is called Pole. Parallel rays MN and RS, making an angle $\boldsymbol{\theta}$ with the radial at the point of interception by the mirror. After reflection, these rays shall make an angle $\emptyset$ with the radial such that $\boldsymbol{\theta} = \emptyset$, and converge at point F, called **Focal Point** and distance PF as **Focal Length($\boldsymbol{f}$)**. Further, using property of triangle exterior angle $\beta = \theta + \emptyset = 2\theta$, being sum two opposite-interior angles. Further, length of arc PN on the surface of mirror $\mathbf{len}(\widehat{PN}) = \boldsymbol{r\theta}$, angles are expressed in radians. And , also $\mathbf{len}(\widehat{PN}) \cong \boldsymbol{f\beta}$; *this approximation is valid, as long as beam is narrow*. Accordingly, $\mathrm{len}(\widehat{PN}) \cong f\beta = r\theta$, or $f2\theta = r\theta$, it leads to an important conclusion $\boldsymbol{f} = \frac{\boldsymbol{r}}{\mathbf{2}}$. Thus, a narrow parallel beam, approximated to be coming from an object an infinity, converges at point called **Focal point**.

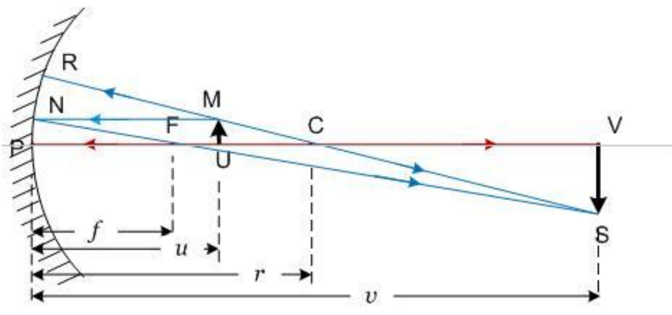


Case II – Concave Mirror-Object Beyond Centre: In this case object MU is placed on *principal axis*. Two rays are considered to be emanating from top of Object such that MN, parallel to principal axis, and this ray after reflection pass through focal point F. Another ray MR is passing through Centre, is since along the radial will be normal to the point of incidence and hence after reflection it would return along the same path. These, two reflected rays since intersect at S, it would form top of the **real image** of the object. As regards, image of bottom, ray along principal axis, being normal to the surface of mirror at the point of incidence P, which is the pole of mirror, V vertically below the image of top of the object. Taking, size of object MN<<f, geometry of rays can be approximated to ΔPNF≈ΔVSF, accordingly, $\frac{\text{PN}}{\text{PF}}=\frac{\text{VS}}{\text{FV}}$, or $\frac{\text{PN}}{\text{VS}}=\frac{\text{PF}}{\text{FV}}$. This is true for absolute values (unsigned) of corresponding lengths, and shall be carried through in elaborations to follow. Likewise, in ΔMUC≈ΔVSC. $\frac{\text{MU}}{\text{VS}}=\frac{\text{UC}}{\text{VC}}$. With the approximation cited above PN≈MU, and it would lead to $\frac{\text{PF}}{\text{FV}}=\frac{\text{UC}}{\text{VC}}$, this proportionality, can be transformed to axial distances indicated in the figure and accordingly, it would lead to $\frac{f}{v-f}=\frac{u-r}{r-v}$. Applying componendo to this ratio-proportion it takes a form $\frac{v}{v-f}=\frac{u-v}{2f-v}$. Making cross-multiplication, $2fv-v^2=uv-v^2-fu+fv$, and it simplifies to $fv+fu=uv$. Dividing this expression by uv, it becomes, $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$; here, all terms are +ve, *are w.r.t. Pole as reference on Principal axis. Further, image is real-inverted.*



Case III –Concave Mirror –Concave Mirror - Object Between Focus and Centre: Conceptually, this case is also a corollary of the Case II and position of image can be obtained by interchanging position of object with image, and reversing directions of rays. Alternatively, same logic of rays, for top of object, one parallel to principal axis and other taken in a direction which is apparently emerging from centre and returning along it, being perpendicular to the point of incidence on the mirror. The alternative ray diagram analysis is also shown, on the right of the corollary ray diagram. Both the analysis are correct, and is matter of convenience for the reader.

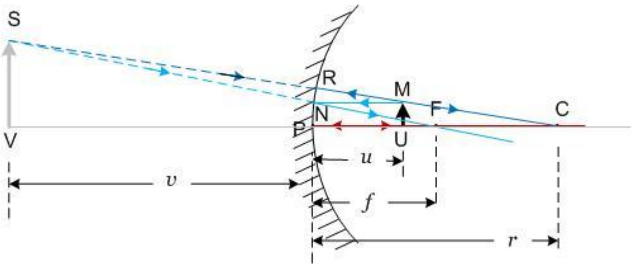




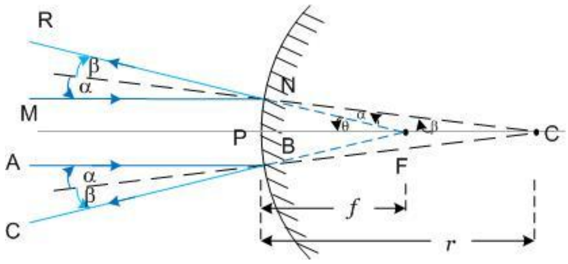
Applying, geometrical analysis, as done in Case II, to similar triangles ΔPNF and ΔMUF, and ΔSVC and ΔMUC, it leads to $\frac{PF}{UF}=\frac{VC}{UC}\rightarrow\frac{f}{u-f}=\frac{v-r}{r-u}\rightarrow\frac{u}{u-f}=\frac{v-u}{2f-u}\rightarrow 2fu-u^2=uv-u^2-fv+fu\rightarrow fu+fv=uv$. Dividing the last expression with uvf, it transforms into $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$. In this expression all terms are +ve, and *are w.r.t Pole as reference on Principal axis. Further, image is real-inverted.*

Case IV – Concave Mirror - Object At Focus Centre: This case is corollary of case 1, where a point object will have image at infinity, and is obtained by just reversing the directions of rays.

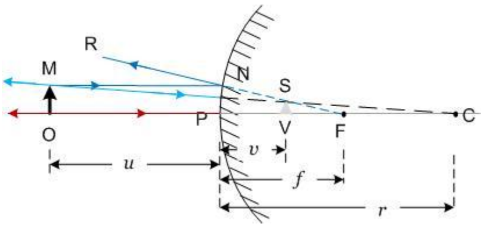
Case V – Concave Mirror -Object Between Pole and Focus: In this case rays MN and MR, from top of the object, are seen to be diverging after reflection and appear to emanating from S, which obtained by projecting the divergent rays in opposite direction. Geometrical analysis of similar ΔPNF and ΔSVF leads to $\frac{SV}{NP}=\frac{v+f}{f}$, while in similar ΔMUC and ΔSVC leads to $\frac{SV}{MU}=\frac{r+v}{r-u}$. Since, MU≈NP, $\frac{v+f}{f}=\frac{r+v}{r-u}\rightarrow\frac{v+f}{f}=\frac{2f+v}{2f-u}\rightarrow\frac{v}{f}=\frac{u+v}{2f-u}$. It leads to $2vf-uv=uf+vf\rightarrow vf-uf=uv$. Dividing the last expression with uvf, it transforms into $\frac{1}{u}-\frac{1}{v}=\frac{1}{f}$. In this expression only $\frac{1}{v}$ occurs with (-)ve sign, while all distances are along principal axis *w.r.t Pole as reference. It is to be noted that VS is on the left of the reference point, while all other terms are on right of the reference. Accordingly, taking* ***v*** *to be* **(–)ve,** *the expression transforms into $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$, general form and it also conforms with convention of number line. In addition in this case, the image is virtual and erect.*



Case VI – Convex Mirror –Object at Infinity: Analysis, in case of convex mirror, is on the same lines as done in concave mirror, except the change of geometry. A beam of light parallel to principal axis, makes an angle α with the radial at the point of incidence and is reflected through an angle β=α with the radial, as shown in the figure. In ΔFBC, θ=α+β=2α. This leads to *r=2f*. In convex mirror, the reflected rays are divergent, and hence focal point (F) is behind the mirror, which in a direction opposite to that of the reflected ray.



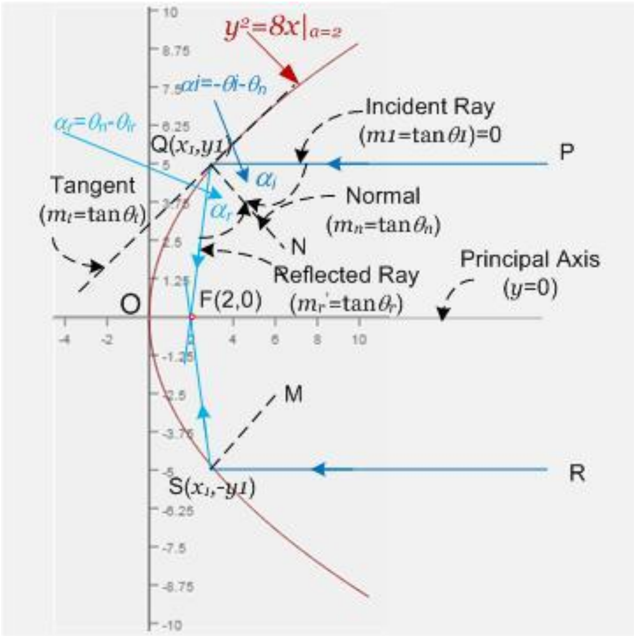
Case VII – Convex Mirror – Near Pole: In this also follows analysis same pattern. In similar ΔPNF and ΔSVF, $\frac{NP}{SV}\approx\frac{PF}{VF}=\frac{f}{f-v}$. This approximation is again due arc PN, considered to be a straight line. Likewise, in similar ΔMOC and ΔSVC, $\frac{MO}{SV}=\frac{u+r}{r-v}=\frac{u+2f}{2f-v}$. Since, $MO\approx NP$, the two proportions are consolidated into $\frac{f}{f-v}=\frac{u+2f}{2f-v}$; applying dividend to this t $\frac{v}{f-v}=\frac{u+v}{2f-v}$. It leads to a form $2fv-v^2=fu+fv-uv-v^2\rightarrow fv-fu=-uv$. Dividing the last form of relation with *uvf,* form it takes is $\frac{1}{u}-\frac{1}{v}=-\frac{1}{f}$. Here, both v and f are (+)ve being along X-axis w.r.t. pole (P), while, u is (-)ve being in opposite direction. These signed values of parameters lead to the relation into its generic form $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$.



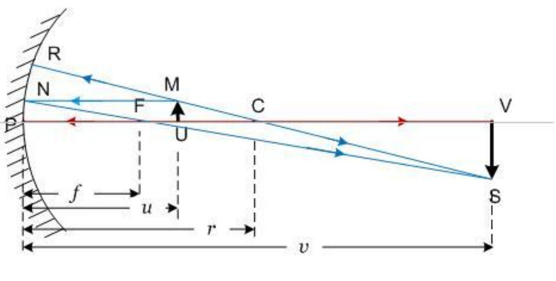
Important Inferences: These observations in mirrors are summarized into ***Five inferences*** – **a)** *image of an object, in case of plane mirror is symmetrically placed behind it*. In this elaboration, the only assumption that mirror, the reflecting surface, is considered to be of negligible thickness. This is not true for glass mirrors, generally seen, but is true for glossy film or metal surface**. b)** *determination of image of a point requires convergence of at least Two rays*. **c)** *actual convergence of rays causes a real image, while apparent convergence for a divergent rays produce virtual image*, and **d)** ***Sign Convention*** where all distances measured w,r,t. pole (P) of the mirror along the (+)ve X-axis are (+)ve and those along (-)ve X-axis are (–)ve., **e)** Direction of Image where- Real images are inverted, while virtual images are erect, and **f)** Accuracy of position of image wherein the relationship $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$, is a fair approximation, when size of object (both height, and or width) is much smaller than ***r.***

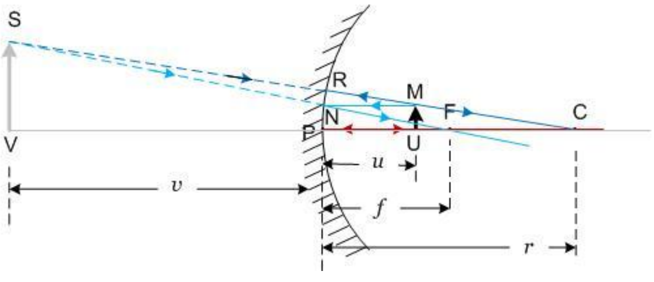
Parabolic Mirrors: It must have experienced that image of Sun, which is at an extremely large distance than radius of mirror (***r***) of a concave mirror, shall cause parallel rays (beam of light) incident on concave mirror, is not a point, rather it a bright spot with highest intensity at the centre, and getting blurred towards outer periphery. The reason being width of beam is comparable to ***r***. This, is a violation of assumption, leading to $r = 2f$, made at the beginning of image formation in spherical mirror. Parabolic Mirrors have a property that a parallel beam converges to its focal point. Concept of Parabola which was elaborated in Chapter-II, Foundation Mathematics, as an integral part of Conic-sections. This property of parabolic reflector is derived here under in an effort to inculcate integration of mathematics and physics.

The parabolic shape of reflector is expressed as $y^2 = 8x|_{a=2}$, of light parallel to principal axis hence, Focus of parabola is defined as (2,0). Taking a ray PQ incident on reflector at Q (x_1,y_1), At point Q, Slope of tangent $m_t = \tan\theta_t = \frac{dy}{dx} = \frac{4}{y_1}\Big|_{y=y_1}$, accordingly slope of normal QN at point Q, a point under consideration, is $m_n = -\frac{1}{m_t} = -\frac{y_1}{4}$. Accordingly, angle of incidence of ray PQ at point Q, $\tan\alpha_i = \tan(\theta_i - \theta_n) = \frac{m_i - m_n}{1+m_i m_n} = \frac{0+\frac{y_1}{4}}{1+0\cdot\frac{y_1}{4}} = \frac{y_1}{4}$. Since, $\therefore \tan\alpha_r = \tan(\theta_n - \theta_r) = \frac{m_n - m_r}{1+m_r m_n} \to \frac{y_1}{4} = \frac{-\frac{y_1}{4} - m_r}{1 - m_r\cdot\frac{y_1}{4}}$. It leads to: $m_r \cdot \left[1 - \left(\frac{y_1}{4}\right)^2\right] = -\frac{y_1}{2} \to m_r = \frac{-\frac{y_1}{2}}{\left[\left(\frac{y_1}{4}\right)^2 - 1\right]} = -\frac{8y_1}{[y_1^2 - 16]}$. Since, it is reflected ray, equation of reflected ray in a direction opposite to it, its slope, for determining the equation of ray is $y - y_1 = m_r(x - x_1)$. Accordingly, intersection of reflected ray with principal axis would be $0 - y_1 = \frac{8y_1}{[y_1^2-16]}(x - x_1) \to y_1^2 - 16 = 8(x - x_1)8x_1$. It leads to $8x_1 + 16 = 8x - 8x_1 \to x = 2$. In the given profile of parabola $a = 2$ a beam parallel to principal axis, converges at its Focus Point (2,0). Further, this ***conclusion is valid for any beam parallel to Principal Axis, parabolic reflectors are the ideal beam concentrator***.



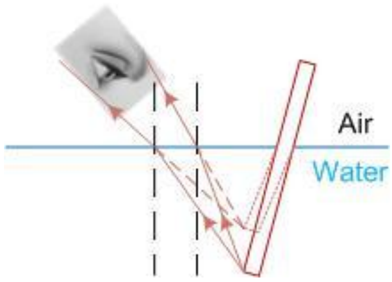
Lateral Magnification: *It is defined as a* ***ratio of height of image to height of object***. Since, the height measured above principal axis is (+)ve, for erect images the Linear Magnification (m) shall be +ve, where for inverted images, it will be (–)ve. In all the images analysed, above, $m = -\frac{MO}{SV}$. A close examination of geometry of images, together with the sign convention, shows that $\boldsymbol{m} = \frac{MO}{SV} = -\frac{\boldsymbol{u}}{\boldsymbol{v}}$ and it takes care of which ever ratio is taken. Accordingly, for final value of ***m*** for erect images is (+/-) ve, based on image is erect/inverted, while for inverted images it is (–)ve. Typical, two cases of real and virtual images which are inverted and erect respectively are reproduced for a ready reference.



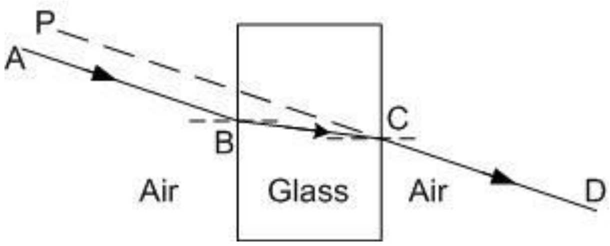


Refraction: It is a widely observed phenomenon, and is experienced in apparent depth of a pond shorter than real, straight wood dipped in apparently bent at surface its surface, Sun after setting apparently larger than normal size, mirage, objects appearing wavy during noon of Summer, and many more are left to be listed by readers through their observations. The basic principle behind all this is refraction and only representative cases shall be elaborated here, and reader to analyse the rest of them using these basic principles. Nevertheless, inquisitive readers are welcome to raise query, in case of any difficulty through ***Contact Us.***

Basic concept of refraction was elaborated soon after Lunar Eclipse, at the beginning. Qualitatively, apparent bending of a straight stick dipped in water is due to rays emanating from each point on dipped stick having varying angle of incidence; larger the angle of incidence, more is the angle of refraction, and eventually rays from the dipped portion of the stick apparently coming from a point above the actual position, so does the stick appears to be bent at surface of immersion. Precisely, this is the reason why does water appears shallow.



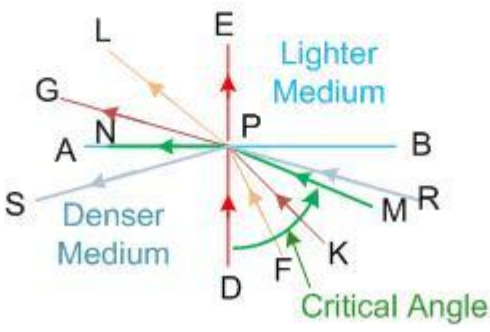
This elaboration shall be taken farther into quantitative analysis of refraction and its various effects. A beginning is made with an apparent shifting of an object seen through a glass slab. Velocity of Light in vacuum is $3.0\text{x}10^8$ m/sec and nearly same as that in the air, while in water it is $2.0\text{x}10^8$ m/sec. Accordingly, ${}_a\mu_g = \frac{v_g}{v_a}$ and ${}_g\mu_a = \frac{v_a}{v_g} = \frac{1}{{}_a\mu_g}$.



Here, v_a is the velocity of light in air, v_g is the velocity of light in glass, ${}_a\mu_g$ is the refractive index of light from air to glass and ${}_g\mu_a$ is refractive index of light from glass to air. It is seen that when light travels from lighter medium to denser medium, following law of refractive index, it bends towards normal at the point of incidence . The refracted ray while travelling from denser medium to lighter medium would depart from normal. The extent of shift is a geometrical deduction and is left for reader for self- study. ***Effective refractive index of cascaded the parallel mediums is product of refractive indices of the interfacing mediums and emerging light is parallel to the incident light if the parallel mediums are immersed in same medium, which is air in the instant case.***

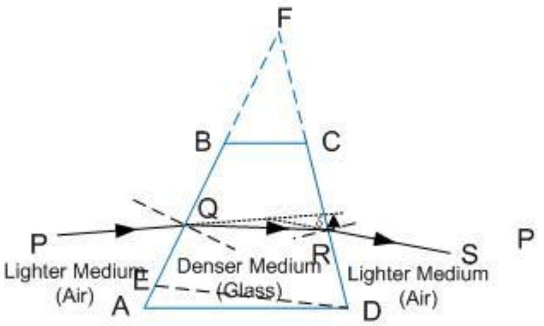
This inference, gives rise to Two cases of automatic consequence. ***One*** when light passes from denser to lighter medium, how long angle of refraction would continue to increase. ***Second***, is when light passes through an intervening medium having non-parallel but plain surfaces.

Taking the **First case**, as shown in figure AB is interface, below which is a denser medium and above it is lighter medium. A ray DP incident on point P is normal to the interface passes through un-deviated since angle of incidence is Zero, and is in conformance with the Law of Refraction. As the angle of incidence increases for rays FP, KP and MP deviates from normal in increasing order along PL, PG and PN, respectively; it is as per the Law of Refraction. It is seen that ray MP after refraction passes along PN making an angle 90° with the normal and is along the interface. Any further, increase in angle of incidence as shown for ray RP will get reflected at the point of incidence and travel along PS and is called ***Total Reflection***. Thus law of refraction is valid in this case until refracted ray is along PN the interface, and angle of incidence corresponding to this ray MP is called ***Critical Angle***. Reflection of light from a hot surface of the earth during noon of gives a feel that there is water ahead. This happens because of heating of earth's surface air gets heated and in turn lighter. Instead, density of air above, i.e. at the level of object and the

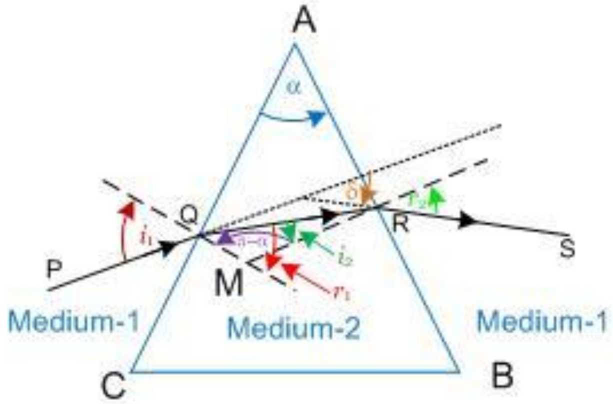


observer, being away from the earth's surface, is relatively denser. This forms an ideal case for total reflection for objects at a distance. As the object and observer move closer, the angle of incidence reduces below critical angle and total reflection stops. This phenomenon of total of reflection on roads is called ***Mirage***.

The **Second Case** when surface of a denser medium are not parallel. A typical quadrilateral cross-section of a glass bar with its lateral four edges are parallel is shown in the figure. The edges are not visible made to be for simplicity of figure. A ray PQ enters the glass bar at point Q on its side AB, and after refraction it deviates towards normal inside denser medium along QR. This ray at point R on the side CD deviates away from the normal along RS. Eventually, the ray PQ undergoes a deviation through an angle δ called ***Angle of Deviation***, *towards the base of the denser medium*. Since, none of the faces are parallel, base of the medium is decided by the side towards smaller of the two supplementary angles formed by the incident ray . In the instant case these angles are ∠PQA and ∠PQB , out of which ∠PQA is smaller and hence AD is the base. *Thus, based on angle of incidence any of the other two sides can become base of prism.* Cross-section ABCD is idealized into a Trapezium BCDE with sides DE||BC and sides CD=BE. This is a section of an isosceles ΔDEF and is an idealized ***Prism***, a 3-D geometry, which has extensive application in Optics.



An ideal Prism ABC is shown with an incident ray PQ on its side AC at an angle of incidence i_1, and after refraction through a medium of refractive index ${}_1\mu_2$ has an angle of refraction r_1 along QR. This ray make an angle of incidence i_2 on side AB, and again undergoes refraction $\left({}_2\mu_1 = \frac{1}{{}_1\mu_2}\right)$ making angle r_1 with the normal at Point R on the side. Since opposite ∠MQA =∠MQA = $\frac{\pi}{2}$, and sum-up to 180°, therefore, $\angle QMA + \angle QMR = \pi \rightarrow \alpha + \angle QMR$. It comes to $\pi \rightarrow \angle QMR = \pi - \alpha$. Further, in ΔMQR, $r_1 + i_2 + (\pi - \alpha) = \pi$. It leads to $\alpha = r_1 + i_2$, and $\delta = (i_1 - r_1) + (r_2 - i_2) = (i_1 + r_2) - \alpha$.



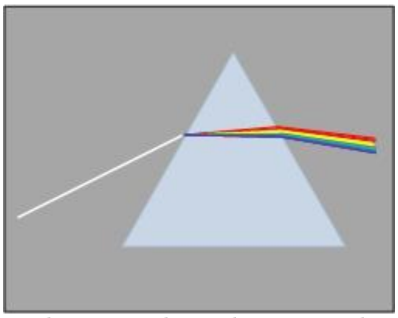
It, raises a natural inquisitiveness as to is there any correspondence between angles δ, i_1, r_2 and α . Differentiating w.r.t. $\delta = (i_1 + r_2) - \alpha$, w.r.t. i_1 and equating it ZERO for a minimum deviation, $0 = 1 + \frac{dr_2}{di_1} - 0$, since **Angle of Prism ($\boldsymbol{\alpha}$),** is constant for a prism. Therefore, $\frac{dr_2}{di_1} = -1$. Differentiating equation of angle of prism α which is a constant w.r.t. i_1, it gives $0 = \frac{dr_1}{di_1} + \frac{di_2}{di_1} \rightarrow \frac{dr_1}{di_1} = -\frac{di_2}{di_1}$. Further, as per bending of ray PQ along QR from rarer to denser medium $\mu = \frac{\sin i_1}{\sin r_1}$ and for bending of ray QR along RS from denser to rarer medium $\frac{1}{\mu} = \frac{\sin i_2}{\sin r_2}$. Differentiating each of this equation of for incident and emerging rays w.r.t. i_1 to utilize condition of optimality of δ, as above, $\mu \cos r_1 \frac{dr_1}{di_1} = \cos i_1$, likewise, $\mu \cos i_2 \frac{di_2}{di_1} = \cos r_2 \frac{dr_2}{di_1}$. Dividing these two derivatives $\frac{\mu \cos r_1 \frac{dr_1}{di_1}}{\mu \cos i_2 \frac{di_2}{di_1}} = \frac{\cos i_1}{\cos r_2 \frac{dr_2}{di_1}}$. Substituting in this proportion values of $\frac{dr_2}{di_1}$ and $\frac{dr_1}{di_1}$, obtained above, $\frac{\cos r_1 \left(-\frac{di_2}{di_1}\right)}{\cos i_2 \frac{di_2}{di_1}} = \frac{\cos i_1}{-\cos r_2} \rightarrow \frac{\cos r_1}{\cos i_2} = \frac{\cos i_1}{\cos r_2} \rightarrow \cos r_1 \cdot \cos r_2 = \cos i_1 \cdot \cos i_2$. Squaring this $\cos^2 r_1 \cdot \cos^2 r_2 = \cos^2 i_1 \cdot \cos^2 i_2 \rightarrow (1 - \sin^2 r_1) \cdot (1 - \sin^2 r_2) = (1 - \sin^2 i_1) \cdot (1 - \sin^2 i_2)$. This equation in terms of refraction of incident and refracted rays is $(1 - \sin^2 r_1) \cdot (1 - \mu \cdot \sin^2 i_2) = (1 - \mu \cdot \sin^2 r_1) \cdot (1 - \sin^2 i_2)$.

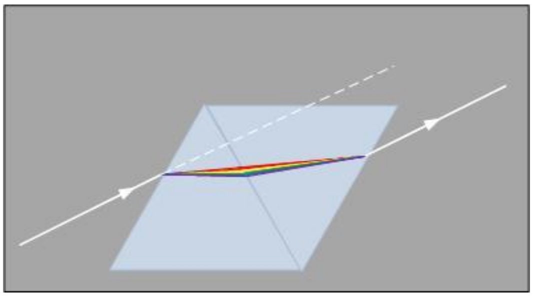
Solving this $1-\mu\cdot\sin^2 i_2-\sin^2 r_1+\mu\cdot\sin^2 i_2\cdot\sin^2 r_1=1-\mu\cdot\sin^2 r_1-\sin^2 i_2+\mu\cdot\sin^2 r_1\cdot\sin^2 i_2$. It simplifies to $(1-\mu)\sin^2 i_2=(1-\mu)\sin^2 r_1\rightarrow\sin^2 i_2=\sin^2 r_1\rightarrow\sin i_2=\sin r_1\rightarrow \boldsymbol{i_2=r_1}$. Further, this together with equation of refraction of refraction of incident and emergent rays it would lead to $\boldsymbol{i_1=r_2}$, this is a condition of geometrical symmetry of the ray with respect to angle of prism α, as shown in the figure above. With this mathematical inference of optimality of δ the angle of prism is $\boldsymbol{\alpha=2\cdot i_2}$**.** Accordingly, angle of incidence (i) for minimum angle of deviation $(\delta_{\min})$ is arrived at $\boldsymbol{i}=\frac{\boldsymbol{\delta_{\min}+\alpha}}{\boldsymbol{2}}$, and refractive index of prism can be determined by experimentally determined $\delta_{\min}$ and measured angle of prism $(\boldsymbol{\alpha})$ substituting relationships of values of e $\boldsymbol{i}$ and $\boldsymbol{r}$ arrived at mathematically and it is $\mu=\frac{\sin\frac{\delta_{\min}+\alpha}{2}}{\sin\frac{\alpha}{2}}$. And if $\boldsymbol{\alpha}$**,** corresponding $\delta_{\min}$ is also small in which case $\mu=\frac{\frac{\delta_{\min}+\alpha}{2}}{\frac{\alpha}{2}}$.

Dispersion of Light Through Prism: Rainbow has been observed since immemorial times as a celestial miracle. It was only with the prism, as shown in the figure, that it was realized that visible white light is a composition of seven colours, called a spectrum with frequencies and in turn wavelength, gradually varying from 620 nm to 380 nm causing a visual effect of Red colour to Violet. As elaborated in heat, every object at any temperature emits a complete spectrum of light and prominence of a frequency depends upon temperature of object. Rays of wavelength above 740 nm are called infrared rays and below 380 nm are called ultra violet rays. Dispersion of light into a spectrum is reversible and white light can be reconstructed, by passing it through a similar prism, placed inverted as shown in the figure. The reason for dispersion of light is that refractive index of light depends upon its wavelength. Light rays have different velocities in different medium, but *with the change of medium frequency of a ray of light remains unaltered. As a result it is the wavelength a* ***composite light*** *(mix of multiple frequencies) that changes with medium and causes deviation of rays, having different wavelength at different angles during refraction at non-parallel surfaces*. A ray of light with single frequency is called **monochromatic light**. Readers inquisitive tp know more about dependence of Refractive Index on wavelength are welcome to write us through *Contact Us*

The Visible Light Spectrum

Color	Wavelength (nm)	Frequency
Red	620 - 750	400-484THz
Orange	590 - 620	484-508 THz
Yellow	570 - 590	508-526 THz
Green	495 - 570	526-606 THz
Blue	450 - 495	606-668 THz
Violet	380 - 450	668-789 THz

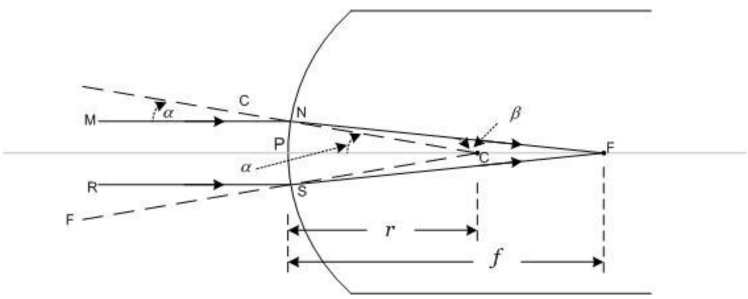




Inferences on Prism: a) Prism is a special case of a transparent medium having non-parallel surfaces, **b)** an incident rays after refraction through prism deviates towards its base, **c)** minimum angle of deviation through prism is a function of the Angle of Prism and refractive index of the medium w.r.t. the medium in which it is placed **d)** angle of deviation through a prism varies with the frequency of light rays.

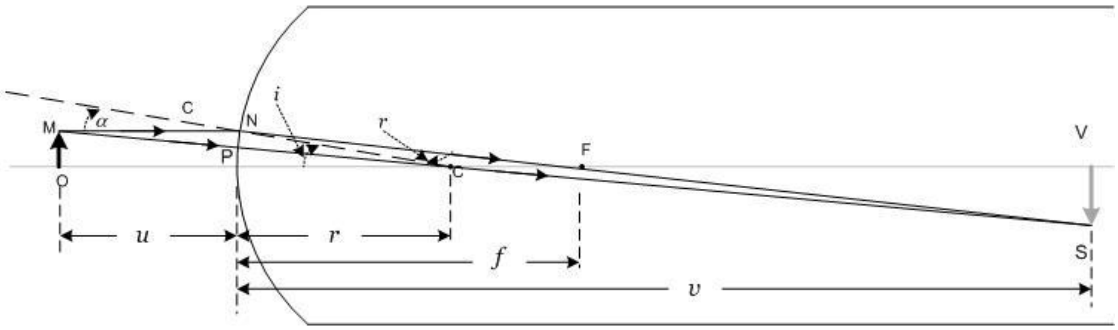
Refraction Through Spherical Surfaces: *Every transparent curved surface can be split into small elements frustum of prisms with each element having different Angle of Prism*. Likewise, spherical surfaces, which are most commonly used, are simple to analyse due to uniformity in its radius of curvature. The analysis of refraction through spherical surfaces is being done using a Two rays, One parallel to principal axis and the other, along the radial. This is on the lines of reflection from spherical surfaces, to maintain a consistency of logic.

Sign Convention: All distances measured along (+)ve direction of X-axis taking pole P of the refracting surface as reference as (+)ve, while those in (-) direction of X-axis w.r.t P as (-)ve and is similar to that used in reflection from spherical surfaces. *A practice to keep object on left of the refracting surface is derived out of convenience, nevertheless it is not necessary*. Reversibility of ray diagram with the appropriate implementation of sign convention, ensures correct results, irrespective of the positioning of the object. This shall become clear when relationship between u, v and r for a l curvature lens is analysed, a little later.



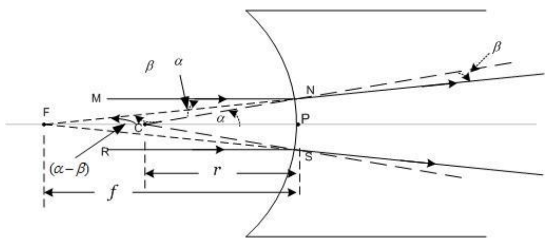
Case 1 – Convex Surface and Object at Infinity: In case of convex surface, a narrow beam of rays parallel principal is taken. The ray along principal axis being radial would pass through un-deviated along the principal axis. The ray MN parallel to principal axis makes an angle i_1 with normal at the point of incidence N, after refraction takes a path along NF and intersects the principal axis at F. So is the case with another ray RS. Refractive index (RI) of medium being μ, the relation for a narrow beam shall be $\mu = \frac{\sin i}{\sin r} \approx \frac{\alpha}{\beta}$, or $\alpha \approx \mu\beta$. In Δ NCF, ∠NCP= α, and α =β +∠NFC. It leads to ∠NFC=α–β. Further, for a narrow beam arc PN≈ $\alpha \times r$, and also PN≈ $(\alpha - \beta)f$. Equating the two, $\alpha r = (\alpha - \beta)f \rightarrow \mu\beta r = \beta(\mu - 1)f \rightarrow f = f = \frac{\mu}{\mu-1}r$.

Case 2 – Convex Surface and Object in Lighter Medium: This case is an extension of Case 1, and would require radial an a parallel ray to determine position of image. It is important to remember that, in this case irrespective of the radius of the curved surface, length of the medium is sufficiently long to have the image inside it. A situation of image formation, when, rays surpass the medium for formation of image shall be elaborated little later.

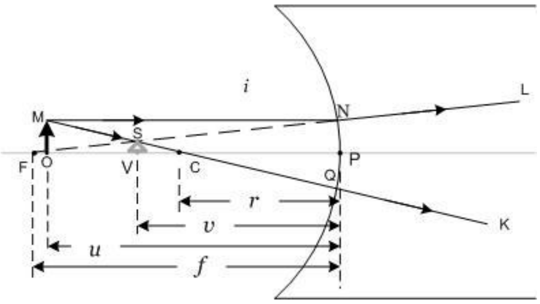


Accordingly, as per geometrical symmetry, in Δs MOC and SVC, $\frac{\text{MO}}{\text{SV}} = \frac{\text{OC}}{\text{VC}} = \frac{\text{OP+PC}}{\text{PV}-\text{PC}}$, and likewise, Δs NPF and SVF $\frac{NP}{SV} = \frac{MO}{SV} = \frac{PF}{PV-PF}$. This relation of geometrical symmetry leads to $\frac{\text{OP+PC}}{\text{PV}-\text{PC}} = \frac{PF}{PV-PF}$. Substituting algebraic values as per sign convention in it becomes an algebraic relation, $\frac{-u+r}{v-r} = \frac{f}{v-f} \rightarrow -uv + rv + fu - fr = vf - fr \rightarrow rv - uv = (v - u)f \rightarrow -uv + rv = \frac{\mu}{\mu-1}(v - u)r$. Dividing this expression with uvr, it becomes, $\frac{\mu-1}{\mu}\left(\frac{1}{u} - \frac{1}{r}\right) = \left(\frac{1}{u} - \frac{1}{v}\right) \rightarrow \left(\frac{\mu-1}{\mu} - 1\right)\frac{1}{u} + \frac{1}{v} = \frac{\mu-1}{\mu} \cdot \frac{1}{r} \rightarrow \frac{1}{v} - \frac{1}{\mu u} = \frac{\mu-1}{\mu} \cdot \frac{1}{r} \rightarrow \boldsymbol{\frac{\mu}{v} - \frac{1}{u} = (\mu - 1) \cdot \frac{1}{r}}$. In this, substituting, $\mu = \frac{\mu_2}{\mu_1}$, this algebraic expression takes a form $\boldsymbol{\frac{(\mu_2-\mu_1)}{r} = \frac{\mu_2}{v} - \frac{\mu_1}{u}}$, where signed values of $\boldsymbol{u}, \boldsymbol{v}$ and $\boldsymbol{r}$ are used.

Case 3 – Concave Surface and Object at Infinity: A typical case of Concave surface of glass having RI μ is shown in the figure. Incident ray MN, parallel to the Principal axis, after refraction makes an angle β with normal at the point of incidence. In view of this in ΔFCN, ∠FNC= β and ∠NFC = α - β. Further, for a narrow beam $\mu = \frac{\sin\alpha}{\sin\beta} = \frac{\alpha}{\beta}$, moreover length of arc NP=f∠NFC → $(\alpha$–$\beta)f$, and NP≈αr. *Thus, with a fair approximation for a narrow beam is* $(\alpha - \beta)f \approx \alpha r$. Accordingly, it leads to a relation $(\mu - 1)\beta f \approx \mu\beta r \rightarrow f = \frac{\mu}{\mu-1}r$. This is of the same form as that derived for convex surface. In this, since both r and f are in direction opposite to the direction of ray, hence as per sign conventions will have –ve values. But, the expression remains unaltered since sign convention affects both sides uniformly.

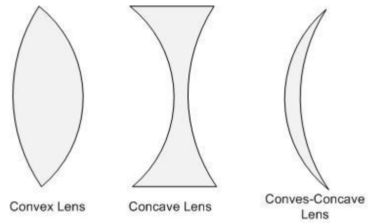


Case 4 – Concave Surface and Object Between Focal Point and Centre Medium: Extending the analysis to image formation by rays MN, parallel to principal axis, which after refraction deviates along NL, as if it is emerging from focal point F. The other ray MQ, through C along radial, goes un-deviated. Intersection of rays NL and QK, creates a



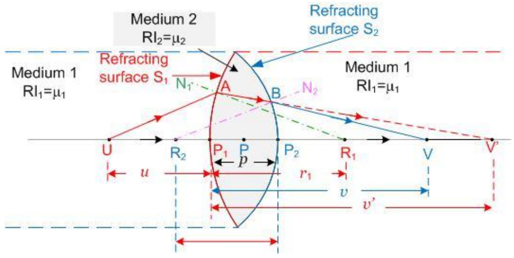
virtual image SV. Utilizing property of similar ΔMOC and ΔSVC and ΔNPF and ΔSVF, we have $\frac{MO}{SV}=\frac{OC}{VC}=\frac{OP-CP}{VP-CP}$, and $\frac{NP}{SV}=\frac{PF}{PF-PV}$. Since, MO=NP, it leads to $\frac{OP-CP}{VP-CP}=\frac{PF}{PF-PV}$, a geometrical relationship. Substituting, algebraic values as per sign convention in the geometrical relationship, $\frac{(-u)-r}{(-v)-r}=\frac{(-f)}{(-f)-v}$. Since, all the variables $\boldsymbol{u}, \boldsymbol{v}$ and $\boldsymbol{r}$ are (-)ve and hence nature of equation will remain unchanged and it shall lead to $\rightarrow vr-uv=(v-u)f$. all the variables T his gets transformed using relationship between μ, r, and f into : $vr-uv=(v-u)\frac{\mu}{\mu-1}r$. It leads to $(1-\mu)uv=vr-\mu ur$. Dividing this *by* uvr, it becomes $\frac{1-\mu}{r}=\frac{1}{u}-\frac{\mu}{v}$. Substituting, $\mu=\frac{\mu_2}{\mu_1}$, on the lines done for convex mirror, ***the relationship takes an algebraic form*** $\frac{\mu_2-\mu_1}{r}=\frac{\mu_2}{v}-\frac{\mu_1}{u}$. This relationship is identical to that arrived at Case 2. *This is a beautiful example of power of algebra to evolve a generic relationship. Use of this generic relationship shall be made to determine position of image in a lens having Two curved surfaces.*

Case 5 – Lenses: Lenses are made of two curved surfaces in various formations as shown in the figure. Generic lenses using concave and convex curved surfaces are shown in the figure. Using the generic relationship between u, v and r formation of image for convex lens most commonly used is being elaborated.

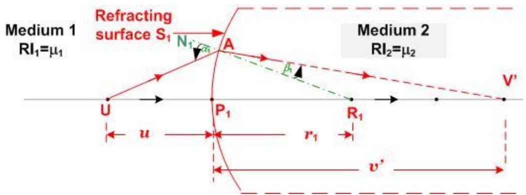


A convex lend of absolute RI μ_2, is placed in a medium having absolute RI μ_1. The left boundary of radius R_1, of the lens, is shown with red line, and the hypothetical spherical medium is extended on the right side encompassing within it image V_1. This image V_1, serves as an object for another convex lens of radius side R2 shown on right shown in blue colour forming an image V. This hypothetical spherical surface is shown extended on the left side with dotted blue lines. Analysis of image formation by the convex lens is decomposed into two separate surfaces S_1 and S_2 as shown below in separate figures, surface S_1 is shown with red boundary and the other surface S_2 with blue boundary as shown in the composite figure. The analysis goes as under.

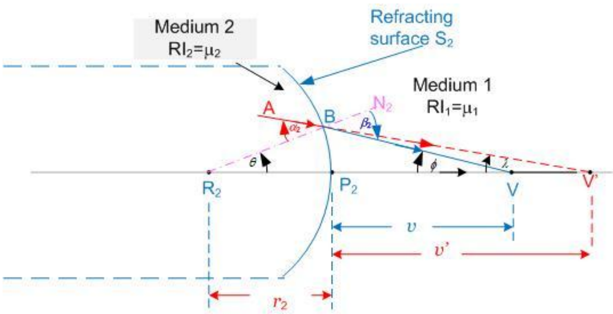
Revised Figures for Lens Maker's Formula



The ray UA from the object incident on the spherical surface of radius R1, is deflected along QV'. Since $\mu_2>\mu_1$ the ray inside medium of RI μ_2 will get deflected towards normal AR_1 and travel along AV' to meet principal axis at V'. Another ray UP1 along principal axis, being radial will travel un-deflected and a real image V' shall be formed inside a virtual medium of RI μ_2. Now directly using generic relationship derived for a convex spherical surface position of image can be determined as $\frac{(\mu_2-\mu_1)}{r_1}=\frac{\mu_2}{v'}-\frac{\mu_1}{u}$.



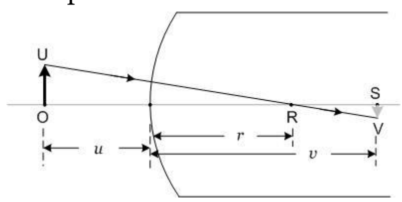
Now extending analysis to spherical surface S_2, having radius R_2, the refracted ray AB is incident on this real surface at point B. An angle α_2 is there between the incident ray AB and the normal R_1B. On right of the surface S_2, there is a real medium having refractive index μ_1. This is the case of refraction along a concave surface with some small differences from the case-4 discussed above and that – a) now the ray is travelling from denser medium to rarer medium and hence refractive index coming into play would be $\mu'=\frac{1}{\mu}=\frac{\mu_1}{\mu_2}$, b) image V' formed by ray AB acts as an object, and c) both object V' and image V are on same side of the pole P_2, in rarer medium. Thus being another variation of case-2 & -4, generic formula for this shall be evolved.



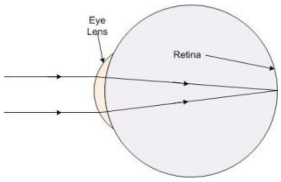
Accordingly, $\mu' = \frac{\mu_1}{\mu_2} = \frac{\sin\alpha_2}{\sin\beta_2} \approx \frac{\alpha_2}{\beta_2}$ for small angles α_2 and β_2. Further, geometrically, $\alpha_2 = \theta + \lambda$ and $\beta_2 = \theta + \emptyset$. Thus, geometrical relations between length of arc BP_2 with angles θ, $\emptyset$ and λ are $BP_2 = \theta \cdot R_2P_2$, $BP_2 \approx \emptyset \cdot P_2V$ and $BP_2 \approx \lambda \cdot P_2V'$. Using these relations between angles in equation of refraction at point B, $\mu_1 \cdot \beta_2 = \mu_2 \cdot \alpha_2 \rightarrow \mu_1 \cdot (\theta + \emptyset.) = \mu_2 \cdot (\theta + \lambda)$. Further, substituting values of angles, $\mu_1 \cdot \left(\frac{BP_2}{R_2P_2} + \frac{BP_2}{P_2V}\right) = \mu_2 \cdot \left(\frac{BP_2}{R_2P_2} + \frac{BP_2}{P_2V'}\right)$ a geometrical equation is arrived. Replacing radials R_2P_2, P_2V and P_2V' with the corresponding algebraic values $(-)r_2$, v and v' the relation transforms into $\mu_1 \cdot \left(\frac{1}{-r_2} + \frac{1}{v}\right) = \mu_2 \cdot \left(\frac{1}{-r_2} + \frac{1}{v'}\right) \rightarrow \frac{\mu_1}{v} - \frac{\mu_2}{v'} = \frac{\mu_1}{r_2} - \frac{\mu_2}{r_2} \rightarrow \frac{\mu_1}{v} - \frac{\mu_2}{v'} = -(\mu_2 - \mu_1)\frac{1}{r_2}$. Adding this equation to the refraction at surface S_1, it leads to $\frac{\mu_1}{v} - \frac{\mu_2}{v'} + \frac{\mu_2}{v'} - \frac{\mu_1}{u} = \frac{(\mu_2 - \mu_1)}{r_1} - \frac{(\mu_2 - \mu_1)}{r_2} \rightarrow \boldsymbol{\mu_1}\left(\frac{1}{v} - \frac{1}{u}\right) = (\boldsymbol{\mu_2} - \boldsymbol{\mu_1})\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$. This relation can also be arrived at by making Four variations in generic formula of case-4 which are – i) μ_1, in the formula, is replaced with μ_2 to represent actual condition of medium on the left of the surface S_2, ii) On the lines of (i) refractive index μ_2 in the formula, of medium on the right of the surface S2, is replaced with μ_1, iii) Object U is replaced with V' with a corresponding replacement of u with v', and using radius of curvature $-r_2$, being on the left of the pole P_2, for refracting surface S2. Thus, the generic formula gets transformed into $\frac{(\mu_1 - \mu_2)}{-r_2} = \frac{\mu_1}{v} - \frac{\mu_2}{v'} \rightarrow \frac{(\mu_2 - \mu_1)}{r_2} = \frac{\mu_1}{v} - \frac{\mu_2}{v'}$. Cascading of these two refractions at surface S_1 and S_2, the net refraction is $\frac{(\mu_2 - \mu_1)}{r_1} + \frac{(\mu_1 - \mu_2)}{r_2} = \frac{\mu_2}{v'} - \frac{\mu_1}{u} + \frac{\mu_1}{v} - \frac{\mu_2}{v'} \rightarrow (\boldsymbol{\mu_2} - \boldsymbol{\mu_1})\left(\frac{1}{r_1} - \frac{1}{r_2}\right) = \boldsymbol{\mu_1}\left(\frac{1}{v} - \frac{1}{u}\right)$. It is another example of power of algebra. In thin lens, thickness of the lens (p) along optical axis is quite small as compared to u, v, r_1 and r_2. In views this approximating these distances from reference point P, pole of the lens goes well in the formula.

Taking, the object to be at a large distance from the lens i.e. $u \rightarrow \infty$, the position of image is taken to be focal point. Accordingly, $\frac{\mu_1}{v} = \frac{\mu_1}{f} = (\mu_2 - \mu_1)\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$, here, $\boldsymbol{f}$ is the distance of **Focal Point of the Lens** from pole (P) i.e. $v = f$. *This formula in a form* $\frac{1}{f} = (\boldsymbol{\mu} - \mathbf{1})\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$ *is known as* ***Lens Makers formula.*** Combining the Lens Makers Formula with the with the distance of object and image w.r.t. pole (P) $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$, and is *known as* ***Characteristic Equation of Lens.*** *This lens formula finds extensive application in* ***Composite Lenses*** *used in* ***Optical Instruments***. Another inference of this characteristic equation of lens is that a parallel beam incident on lens after bending converges at a distance f, and shorter the f more is the bending of light rays, and can be stated as power of bending of light is inversely proportional to focal length, or **Power of Lens** $\boldsymbol{P} = \frac{1}{f}$.

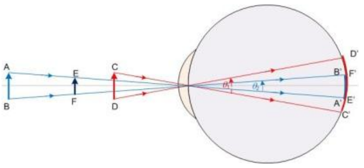
Magnification Power of Lenses: A simplified diagram of a image formed by a convex spherical surface is shown in the figure. As per relationship already proved $\frac{\mu_2}{v} + \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{r} \rightarrow r = \frac{(\mu_2 - \mu_1)uv}{\mu_2 u + \mu_1 v}$. Further, from the geometry of image formation, **Lateral or transverse Magnification Factor** $\boldsymbol{m} = -\frac{\text{SV}}{\text{UO}} = -\frac{v - r}{u + r}$. Substituting value of r from the above, $m = -\frac{v - \frac{(\mu_2 - \mu_1)uv}{\mu_2 u + \mu_1 v}}{u + \frac{(\mu_2 - \mu_1)uv}{\mu_2 u + \mu_1 v}} = -\frac{\mu_2 uv + \mu_1 v^2 - \mu_2 uv + \mu_1 uv}{\mu_2 u^2 + \mu_1 vu + \mu_2 uv - \mu_1 uv}$. It resolves into $\boldsymbol{m} = -\frac{\mu_1 v^2 + \mu_1 uv}{\mu_2 u^2 + \mu_2 uv} = -\frac{\boldsymbol{\mu_1 v}}{\boldsymbol{\mu_2 u}}$. *In this –ve sign indicates that the image is inverted, and signed values of u and v, would correctly signify the nature of image erect or inverted.* This is identical to that in spherical mirrors.



Application of Optics: These principles have found extensive application in enhancing visibility and it starts with human body. Eye is an optical organ, an excellent natural sense of vision. Primarily it *has a lens which creates image of the object being observed on the retina*, as shown in the conceptual diagram, while bio-technical details are skipped, deliberately. It has capability to adjust its focal length and the overall eye structure adjusts aperture, exposer to, depending upon intensity of light. *Communication of the image on retina to brain and its processing is all a biological intelligence which continues to be matter of investigation and its replication as artificial intelligence; it is outside the subject matter of the Manual.* The vision human eye is affected either by age or otherwise and is corrected by external lenses and is a kind of **Optical Instrument**.



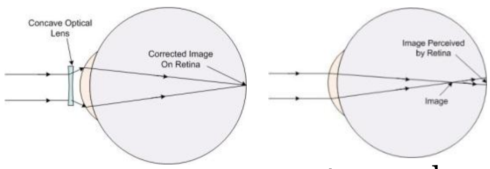
Size of an object perceived by eye is based on the extent of retina is sensitized, and mathematically it is an angle that the image on retina forms. In the figure Two objects of same size AB and CD are shown, the latter being closer to the eye, and their images A'B' and C'D' form angles θ_1 and θ_2 , respectively; this angle is called **Visual Angle**. Since, $\theta_2 > \theta_1$, the eye perceives CD bigger than AB. Taking another object EF of smaller size, whose rays coincide with rays from AB forms, its image E'F' has the same visual angle as that of A'B'; apparently the eye perceives the two objects to be of the same sizes. If an object invisible to a normal eye could be due to two reasons – a) Object being far away from the observer, or b) the size of object being too small. Eventually in both the cases visual angle formed by objects are too small to sensitize retina. ***Optical Instruments, basically manipulate visual angle of object to a desired value to create visibility of objects which are otherwise invisible***, shall be discussed little later.



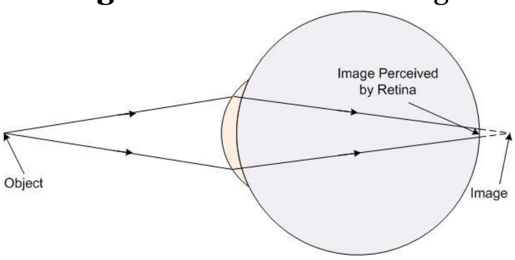
An eye perceives an object only if its image is formed on retina conforming to characteristic equation of a convex lens $\frac{1}{u_o}+\frac{1}{v_o}=\frac{1}{f}$. In case of an object at infinity $u_o \to \infty$, it leads to $\frac{1}{u_o} \to 0$, and $\frac{1}{v_o}=\frac{1}{f_{max}}$, or $v_o = f_{max}$, and it depends upon the shape of the eye. Further, as object moves closer, the eye adjusts its focal length (*f*) so as to form its image on the retina. Minimum distance for a clear visibility for a normal eye is $u_{0-min} = 25$ cm, and it is called ***Near Point,*** *and its distance from pole of lens is expressed as* ***D***. Accordingly, minimum focal length of a normal eye shall be $\frac{1}{25}+\frac{1}{f_{max}}=\frac{1}{f_{min}}$. This is reason that blinking of eyes, which within the maximum time of persistence of image (1/50sec) does not obstructs vision, until eyes are closed.

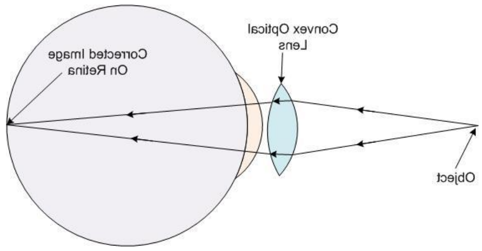
Broadly, there are Four types of **Visual Problems- a)**Far-Sightedness or Hypermetropia, **b)** Short-Sightedness or Myopia, **c)** Presbyopia and **d)** Astigmatism. Each of these are being elaborated separately.

Short-Sightedness: In this image is formed before the retina, as a result retina perceives a blurred image. Geometrically it would require reducing angle of rays coming from object, in turn deflecting them upwards. This is achieved through a concave lens, an inverted elemental frustum of prisms in its upper-half, while erect elemental prisms in lower-half. Correct choice of lens helps to create a corrected image on the retina, as shown in the figure.



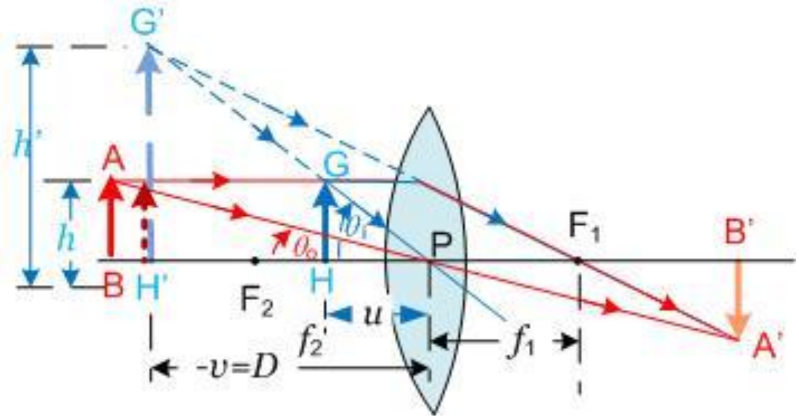
Far-Sightedness: In this image is formed behind the retina, while retina intercepts the rays causing unfocussed image leading to perceiving a blurred image. Geometrically it would require reducing angle of rays coming from object, in turn deflecting them upwards. This is achieved through a convex lens, which is conceptually an erect elemental frustum of prisms in its upper-half, while inverted elemental prisms in lower-half. Correct choice of lens helps to create a corrected image on the retina, as shown in the figure.





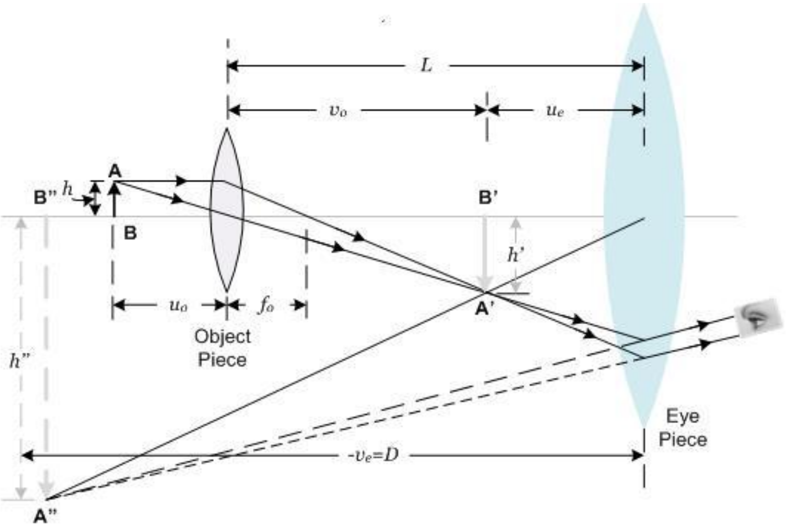
Presbyopia: It is a vision problem involving both Short-Sightedness and Far-Sightedness for which remedy lied in bifocal lens. Latest technology supports progressive lenses which have gradual change of focal length, adjusted to movement of eyeball, and objects at different length can be viewed without movement of neck.

Astigmatism: This problem is related *change in spherical shape of the retina causing different curvature along different planes*. This affects vision in different directions. This is remedied with **cylindrical lenses** having different curvature corresponding to the need of correction.



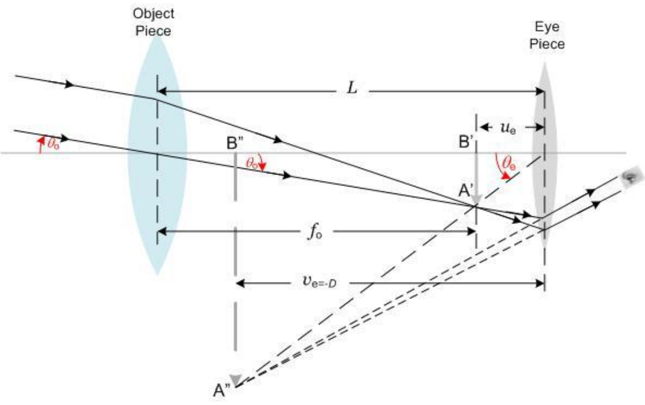
Simple Magnifying Lens: Simple Magnifier: At times a simple magnifier is required to view extremely small components as might have been seen with repairers of watch and electronic devices, who uses a simple convex lens. This is explained in figure with two objects AB and GH, of same size; the object AB uses all rays in direction of their propagation to form image and have all u, v and f values +ve, as per sign convention. But, as the object GH is placed between F1 and P a virtual image is formed by extending rays in a direction, opposite to that of their propagation. In this focal point F_1 is important in determining position of the image, while the Other focal point F_2 towards objects decides formation of image, as clearly visible from the ray diagram. Accordingly, while u and f_1 are +ve, there is –ve value of v. Magnification of an object is $m = \frac{h'}{h} = \frac{D}{u}$., while as per characteristic formula of lens $\frac{1}{u} + \frac{1}{-v} = \frac{1}{f} \rightarrow \frac{1}{u} = \frac{1}{D} + \frac{1}{f}$. It leads to $m = D\left(\frac{1}{D} + \frac{1}{f}\right) = 1 + \frac{D}{f} \approx \frac{D}{f}\Big|_{D \gg f}$. Further, $\theta_i \approx \frac{h'}{D}$, and visual angle of the object seen without magnifier, otherwise at Near Point, is $\theta_o \approx \frac{h}{D}$. Thus, ***Angular Magnification*** $m = \frac{\theta_i}{\theta_o} = \frac{h'/_D}{h/_D} = \frac{h'}{h}$, is same as derived above. Generally value of $\boldsymbol{m}$ *for a Simple Magnifier is <9*, and is insufficient for view in minute objects, particles or organism. This has led to development of *Compound Microscope*.

Compound Microscope: This is a manipulation of visual angle using more than one lens, called composite lenses and hence it is called ***Compound Microscope.*** It comprises of Two Convex lenses One facing the object is called **Object Piece** and other used for viewing is called **Eye Piece**. Positions of the two lenses with respect to object are so manipulated that real-magnified image of object is formed by Object Piece between the Two lenses and Eye Piece acts Simple Magnifier to create virtual image beyond Object Piece but at a Near Point (distance D) from eye piece. Aperture of Object piece is smaller than eye piece. *Magnification by Object Piece* $m_0 = \frac{v_0}{u_0}$, accordingly, $\frac{\boldsymbol{1}}{\boldsymbol{u_o}} + \frac{\boldsymbol{1}}{\boldsymbol{v_o}} = \frac{\boldsymbol{1}}{\boldsymbol{f_o}} \rightarrow \frac{\boldsymbol{v_o}}{\boldsymbol{u_o}} + 1 = \frac{v_o}{f_o} \rightarrow -m_o + 1 = \frac{\boldsymbol{v_o}}{\boldsymbol{f_o}} \rightarrow m_o = 1 - \frac{\boldsymbol{v_o}}{\boldsymbol{f_o}}$. While *Magnification of Eye Piece* $m_e = \frac{v_e}{u_e} = \frac{D}{u_e} = \frac{D}{L - v_o} = 1 + \frac{D}{f_e}$. Overall Magnification of Compound Microscope $m = m_0 m_e$. It thus leads to $m = \left(1 - \frac{\boldsymbol{v_o}}{\boldsymbol{f_o}}\right)\left(1 + \frac{D}{f_e}\right)$. In Compound Microscope$1 - \frac{v_o}{f_o} \rightarrow -\frac{L}{f_0}$, and this approximation is valid for Two reasons – **a)** $\frac{v_o}{f_o}$ and, **b)** image formed by Object piece is very close to eye piece. Thus Overall ***Magnification***



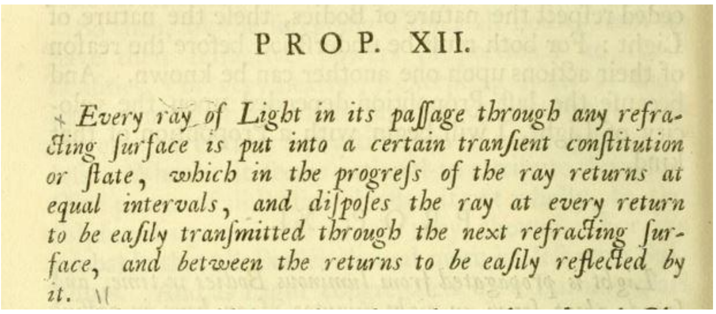
of Microscope *$m \approx -\frac{L}{f_0}\left(1+\frac{D}{f_e}\right)$. Microscope has provision to adjust its length (L) to create a clear vision.* This formulation of Magnification is parametric in nature and hence order of magnification can be determined using values of the parameters.

Telescope: An instrument is used to observe object at a far distance otherwise either invisible or visible without clarity is called Telescope. This Two device also has Two convex lenses, one is called Object Piece, facing towards Object and has longer focal length (f_o) with larger aperture which allows more rays to be capture to enhance intensity of the real image of the distant object created by it. The other lens has a shorter focal length (f_e) and acts like a *simple magnifier* that creates a virtual image if the object. The object being far emits parallel ray making a small angle θ_o and is practically same as that on the ey**e**, with the principal axis of the Telescope, such that $\tan\theta_o = \frac{A'B'}{f_o} \approx \theta_o$. Thus magnification by *Eye Piece* is $\tan\theta_e = \frac{A''B''}{A'B'} = \frac{A'B'}{-f_e} \approx -\theta_e$. Thus in this case since position and size of object cannot be estimate magnification ***Angular Magnification,*** *as defined in Simple Magnifier,* is being considered. It is a ratio of angle subtended by image on the eye $(-\theta_e)$ to the angle subtended by object on the eye (θ_o). Accordingly, $\boldsymbol{m} = \frac{\theta_e}{-\theta_o} = \frac{\left(A'B'/_{f_e}\right)}{-\left(A'B'/_{f_0}\right)} = -\frac{\boldsymbol{f_o}}{\boldsymbol{f_e}}$. In case, the image formed by Object Piece is at Focal Point of Eye Piece, the image though magnified would create problems of clarity of vision. In view of this Eye Piece is so positioned that it acts like a Simple Magnifiers and image is created at Near Point distance D and it shall have $\frac{1}{u_e} - \frac{1}{D} = \frac{1}{f_e} \to \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{D} \to u_e = \frac{Df_e}{D+f_e}$ and $\theta_e \approx \frac{A'B'}{u_e}$. It, further, leads to $\theta_e \approx A'B'\left(\frac{D+f_e}{Df_e}\right)$, and $m = \frac{A'B'\left(\frac{D+f_e}{Df_e}\right)}{-\left(A'B'/_{f_0}\right)} = -\frac{f_o}{f_e}\left(1+\frac{f_e}{D}\right)$. Thus, all these parameters being fixed, length of Telescope shall also be fixed at $L = f_0 + u_e \to f_0 + \frac{Df_e}{D+f_e}$.



These are generic optical instruments, where Angle of Vision is manipulated by proper choice of lenses, their focal length and position. There are many variants of these optical instrument evolved by different scientists and inventors to meet specific needs of discoveries and are available in references coted at the end. Nevertheless, readers are welcome to raise their specific inquisitiveness through ***Contact Us***

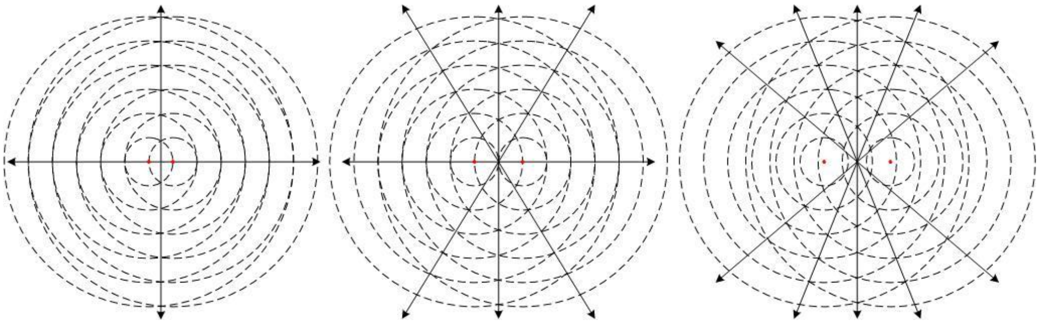
Special Phenomenon: Newton had observed formation of alternate bright and dark rings by monochromatic light when passed through Planoconvex Lens, and reflected by plane mirror. He explained firmation of these rings with Cosposcular Theory, known as **Newton's Rings** and gave a qualitative explanations, unlike to his rest of the contributions, as shown in the extract of his publication.



PROP. XII.

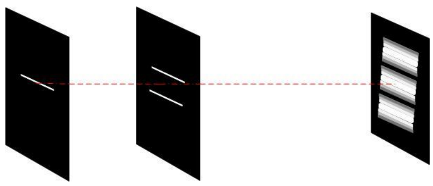
Every ray of Light in its paſſage through any refracting ſurface is put into a certain tranſient conſtitution or ſtate, which in the progreſs of the ray returns at equal intervals, and diſpoſes the ray at every return to be eaſily tranſmitted through the next refracting ſurface, and between the returns to be eaſily reflected by it.

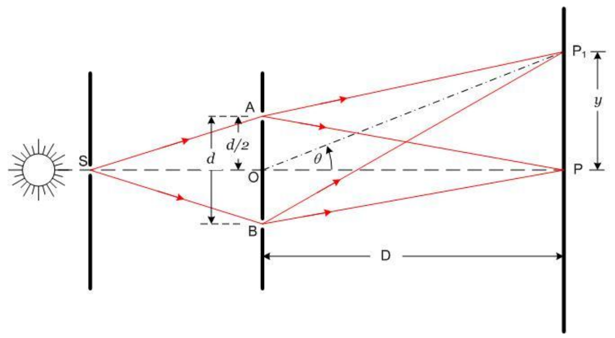
Later, in 1801, ***Thomas Young*** demonstrated this ***Optical Interference Phemnomena*** with a *landmark* ***Double Slit Experiment.*** This was explained mathematically with the use of wave equation and could corroborate interference through thin film, and also Newton's Ring which will be elaborated after Young's Experiment. Net effect of wave at any point is resultant of the incident waves with the principle of superimposition of the wave. Wave equstion $[e = E\sin(kx - \omega t).]$ is function of magnitude and phase angle at any point at any instant of time, and therefore ***interference*** *can be analyzed by taking each ray as a vector or simply superimposition of wave-function.* Going ahead with two rays from **Coherent sources**, whose light rays having same amplitude and phase angle at any instant are considered and is visulaized through waves created in a still water pond by two sticks of equal length cyclically dipped and taken out at same frequency for equal depth, maintaining unform distance and phase between them. Patterns of waves generated, with varrying distance (d) between two sticks, and constructive interference caused by them is conceptualized in the diagram with - **a)** distance is equal to wavelength (d= λ) , **b)** Twice the wave length (d= 2λ) and **c)** distance (2λ <d<3λ). It is seen that as distance between increases, number of constructive coherence depited by intersection of wavefronts increase.



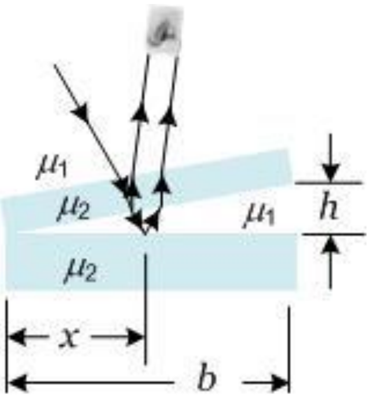
Wave is nothing but a cyclic disturbance that perpetuates. In string the disturbance is in the form of transverese displacenent of medium along a line, in water waves it is similar to that of string but ot is along a plane, sound wave causes longitudinal displacement in space, while light waves cause disturbance, in three dimensional space like that of sound wave. Light waves, are disturbance is of electrical and magnetic field as per Maxwell's Theory, cited in the beginning of this section, and hence are classified as Electro-magnetic wave.

Light is a progressive wave, electrical disturbance caused at a point at distance $\boldsymbol{x}$ from the source at any point of time $\boldsymbol{t}$ is $e = E\sin(kx - \omega t)$. Moreover, every point on wavefronts from a light source, behaves like a secondary light source, as per Huyguns Theory. Therefore, at any point light from each of the two sources may have different phase value and net effect would be superimposition of Two waves and is mathematically expressed as $e' = E\sin(kx_1 - \omega t + \varphi_1) + E\sin(kx_2 - \omega t + \varphi_2)$. Since, the primary source is same each of the component shall have same frequency and amplitude, but, the net effect could be:– **a)** ***Constructive Interference*** – when each component is in same phase producing bright spot, **b)** ***Destructive Interference*** – when the Two component are out of phase with respect to each other, or **c)** ***Resultant***- where each component is neither constructive nor destructive, i.e. phase diffrence $0^0 < \emptyset < 180^0$, and accordingly, intensity of brightness of the resultant light wave varies between bightest to darkest and was demonstrated by **Thomas Young** in 1801 with a *landmark Double Slit Experiment*, to demonstrate ***Optical Interfence*** is shown in the figure.

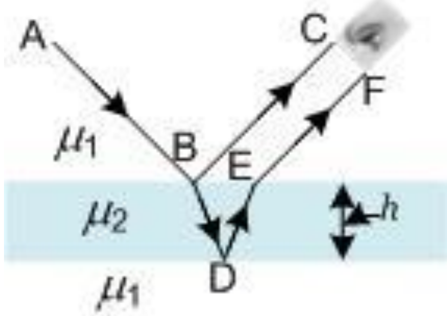


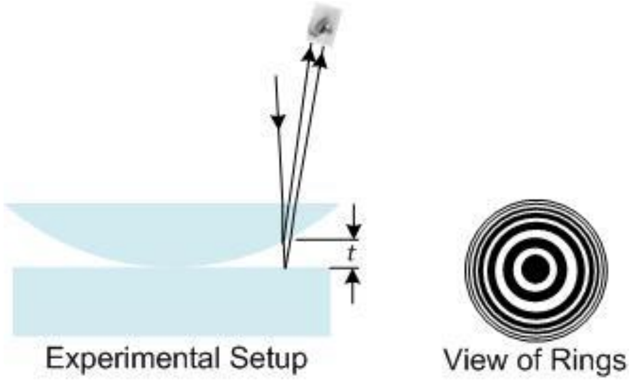


Two coherent sources A and B are created through Two narrow slits. Light from these sources travel a disnace $\boldsymbol{x_1}$ and $\boldsymbol{x_2}$, to reach a point P_1 on the screen, while for point P on screen placed symmetrically w.r.t. the Two sources, are equidistant by geometrical symmetry. Thus net electrical disturbance at any point , say P_1, as per trigonometric identity $\left(\sin A + \sin B = 2\sin\frac{A+B}{2}\cdot\cos\frac{A-B}{2}\right)$ would be $e' = 2E\sin\left(k\frac{x_1+x_2}{2} - \omega t + \frac{\varphi_1+\varphi_2}{2}\right)\cdot\cos\left(\frac{x_2-x_1}{2} + \frac{\varphi_2-\varphi_1}{2}\right)$. Since, sources are coherent $\varphi_2 = \varphi_1$. Accordingly, the net electric field at the point shall be $e' = 2E\sin\left(k\frac{x_1+x_2}{2} - \omega t + \varphi\right)\cdot\cos\left(k\cdot\frac{x_2-x_1}{2}\right)$. Here , $\frac{x_1+x_2}{2} = x_1 + \frac{\Delta x}{2}$, while, $x_2 - x_1 = \Delta x$. Thus, the net field has one sinusoidal component proportional to $\sin\left(k\left(x_1+\frac{\Delta x}{2}\right)-\omega t+\varphi\right)$, with the other component is proportional to $\cos\left(k\cdot\frac{\Delta x}{2}\right)$. Thus, geometrically, $x_1^2 = D^2+\left(y-\frac{d}{2}\right)^2$, and $x_2^2 = D^2+\left(y+\frac{d}{2}\right)^2$, or $\Delta x = \frac{yd}{x_2+x_1}$. Thus, $\Delta x \to \frac{yd}{D}\Big|_{D\gg d \text{ and hence } x_2+x_1\to D}$. Accordingly, if $\Delta x = \frac{yd}{D} = n\lambda$, it is case of *constructive interference* since $k\cdot\frac{\Delta x}{2} = \frac{2\pi}{\lambda}\cdot\frac{n\lambda}{2} = \pi n$. And if $\Delta x = (2n+1)\cdot\frac{\lambda}{2} \to k\cdot\frac{\Delta x}{2} = \frac{2\pi}{\lambda}\cdot(2n+1)\frac{\lambda}{2} = (2n+1)\frac{\pi}{2}$, it is a case of *destructive interference*. Mathematically, for *Destructive Interfenence* $\cos\left(\frac{\pi}{2}\right) = 0$ and hence sign does not matter, but in case *Constructive Interference, while Cosine term* $[cos(n\pi)]$ *in the resultant expression is (-/+)ve the Sine term* $[cos(n\pi+\theta)]$ *in the expression is also (−/+)ve; as a consequence net result is always (+)ve value and is in conformity with logic used for determining Interference*. Sets of Bright to dark slits, in varying degree are called ***Fringes***. In both the cases of constructive/destructive interference ***n*** is an odd number. Further, distance between bright slit and **n^th^** Bright Slit on either side is caused by Constructive Interference shall be $y_n = \frac{n\lambda D}{d}$. Thus distance between Two consecutive bright fringes shall be $y = y_n - y_{n-1} = \frac{\lambda D}{d}$, and this is called Fringe Width. Essential conditions of Interference are – **a)** The sources of the waves must be ***coherent***, which means they emit identical waves with a constant phase difference, **b)** The waves should be ***monochromatic*** - they should be of a single wavelength.



It is seen that soap bubles look bright, certain thin films look very bright while other look dark. This is the phenomenon of optical ***interference caused by thin films*** and is shown in the figure for elaboration. In the figure angles rays are shown have been far from normal, for clarity, else rays are nearly normal. The incident light AB undergoes partly reflection along BC and partly refraction along BD. The ray BD undergoes reflection at an interface from denser to lighter medium. During analysis of reflection of waves, it was seen that $A_r = \frac{Z_1-Z_2}{Z_1+Z_2}A_i$. Thus if $Z_1 > Z_2$ the reflected wave is in phase with the incident wave, while if $Z_1 > Z_2$, it leads to $Z_1 - Z_2 < 0$, i.e (-) ve and thus reflected wave would be anti-phase having undergone phase shift of 180°. This discussion is of relevance in analysis of interference caused by thin films. The ray BC is a reflected wave against a medium of higher refractive index $(\mu_2 > \mu_1)$, and hence $\mu_1 - \mu_2$ which corresponds to $Z_1 - Z_2$ shall be (-) ve and hence will have undergone a phase shift of 180°. The ray BD, which continues to be in phase with incident wave, on reflection at point D traverses along DE and in phase with the incident ray, since in this case $\mu_2 - \mu_1$ shall be +ve. Thus, a phase shift, if any, in refreacted wave EF shall be caused due to its optical inside the film. The rays are since nearly perpendicular, optical path of the film is equal to $2t\cdot\mu_2$. This *Optical Path* if equal to $\frac{1}{2}\lambda$ the ray EF shall have under gone a phase shift of 180° which will make it in phase with ray BC and the result is *Constructive Intereference,* i.e. $\boldsymbol{\frac{1}{2}\lambda = 2t\cdot\mu_2}$. However, if $2t\cdot\mu_2 = \lambda$ the phase shift in ray BC, in its optical path inside the thin film, shall be 2π which will cause *Destructive Interference*. This sequence of Constructive and Destrutive

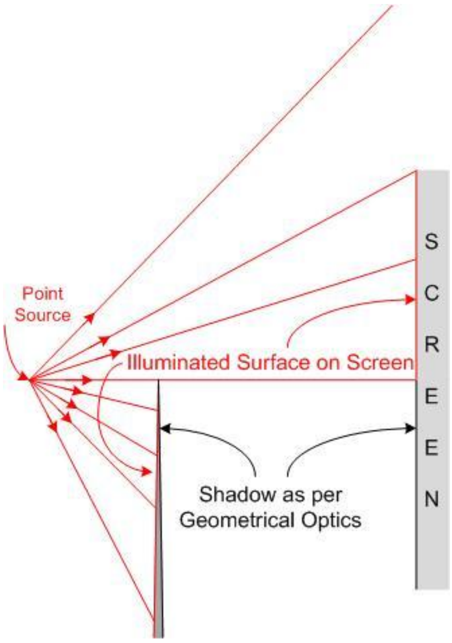


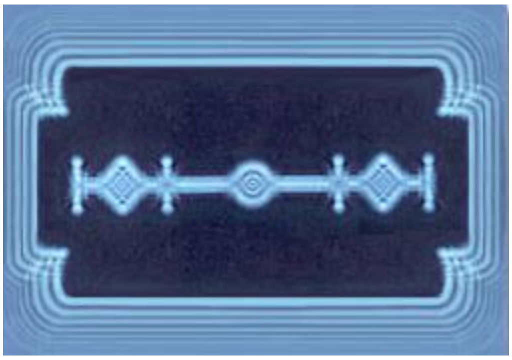


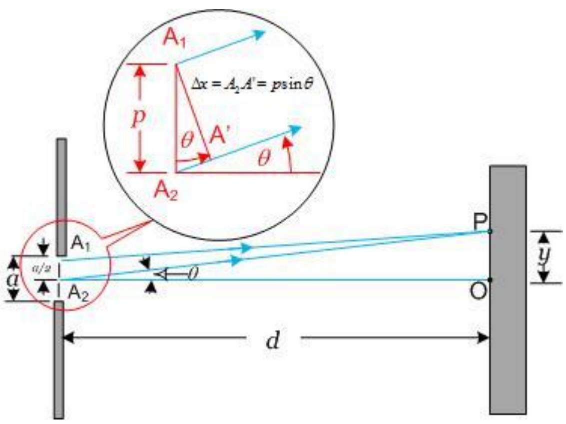
Newton's Rings

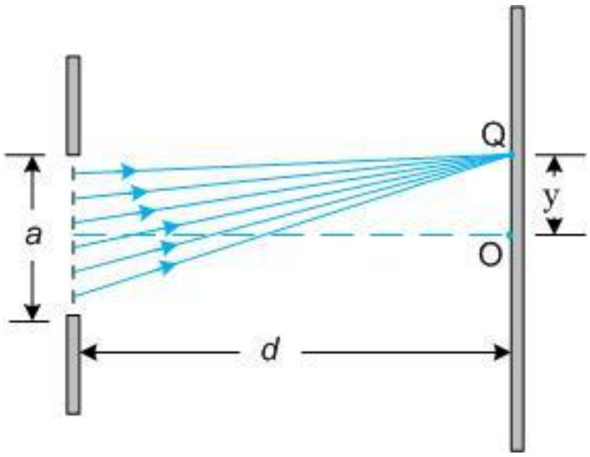
interference shall continue on increase in thickness of the film or multiple reflections and can be generalized into $\left(n+\frac{1}{2}\right)\lambda = 2t\cdot\mu_2$ **for Constructive Intereference and** $n\lambda = 2t\cdot\mu_2$ **for Destructive Interference**; here n is an integer. In case of a small-angle-wedge kind of configuration exposed to nearly vertical light ray diagram is also shown for elaboration. The difference in this case is $\boldsymbol{x}$ increases from $0 \rightarrow d$, the phase difference caused by the optical path increases, and thus spacing between bright fringes varies. In a semilar setup using plano-convex lens, as shown in the figure, Newton was first to experience this and is known as ***Newton's Rings***, brought out at the beginning of this section *Special Phenomenon*. Reader inquisitive to know more the mathematical formulation are requested to write us through *Contact Us.*

Geometrical Optics, as discussed to describe eclipse, creates an illuminated surface at the point of incidence of light. And just behind any obstruction it creates a dark shadow. Accordingly, shadow formation as per geometrical optics should go in accordance with the figure. And in case of large sources ctions and large obstruit creates umbra and peumbra as demonstrated in eclipse at the beginning. But, in object having sharp edges, experience is different as shown in the figure of razor blade, having a sharp edge, is seen with a point source behind it. A bright edge is seen and bridgness across sharp edge is brighter than than remaining part of the blade. *This phenomenon also known as* ***bending of light*** is ***called Diffraction*** *was investigated by* ***Augustein Frensel***, in 1815, based on Huyguns Wave Theory, which was propounded much ealier, and after Young who had demonstrated wave nature of light through Double Slit Experiment. Around the same period ***Joseph von Fraunhofer*** independently investigated the diffraction phenomenon. This Diffraction Phenomenon occurs in sound waves also, which causes audibility of a sound across the wall, but did not receive much attention. Nevertheless, *in optics Diffraction got into prominence across sharp edges and this discovery is credited to* ***Frensel and Fraunhofer***. *Basic concept of diffraction, is not different from principle of superposition applied to Interference, but it is exclusive beause it takes a microview of same source, and this is possible only because of extremely short wavelengths of light waves, a part of electromagnetic radiation.*



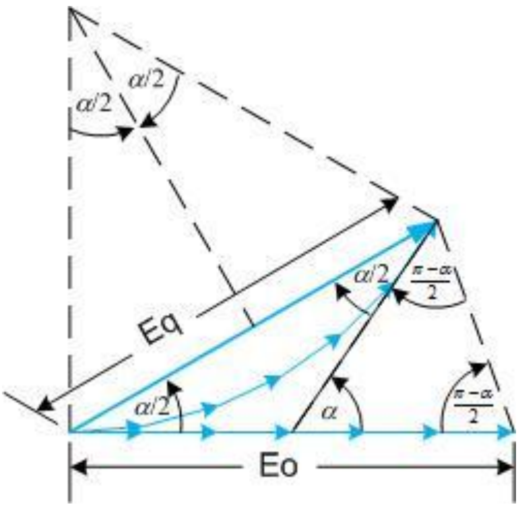


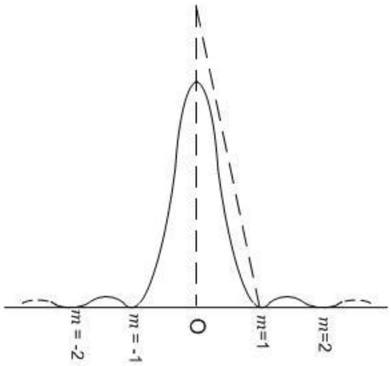




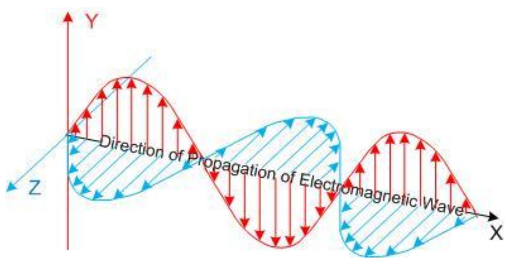
In diffraction dark and bright fringes to occur because of fragments of a *Coherent Sources* and is in accordance with *Huyguns Wave Theory* which stipulates that every point on wavefront acts like a wave source.

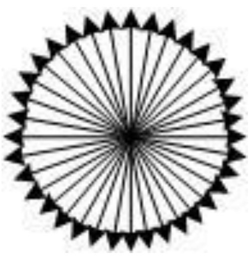
Accordingly, in figure, Wavefront over width is initially split into Two Slits. Number such sub-slits, *can be any logically any even integer number* $\boldsymbol{n}$. Thus, taking Two rays from edges A_1 and A_2, of upper half slit, an essential condition for dark fringe is $\Delta x = A_1P - A_1P = \frac{a}{2}\sin\theta = \frac{\lambda}{2}$. In optics, range of wavelengths are such that $\lambda \ll a$ and $d >> y$, it leads to $\sin\theta = \pm\frac{\lambda}{a} \rightarrow \theta = \pm\frac{\lambda}{a}$. Here, $\pm$ sign indicates that Two dark fringes shall be there symmetric about point O, One above it for which $\boldsymbol{\theta}$ is (+) ve and one below for which $\boldsymbol{\theta}$ is (-) ve Conceptually screen can be divided in to Four, Six, Eight ..., even integer parts ($2m$). *Rays from the edges of each of the successive part, shall produce, a dark fringe so long it is at an angle* $\theta = \pm\frac{m\lambda}{a}$, *between Central bright fringe and dark fringe*, and thus total $\boldsymbol{2m}$ fringes shall be created. Investigation of intensity of light at any point Q on the screen, at an angle θ *with the central line*be the phase shift in rays coming from edges of firstand the last imaginary slit. It has been elaboreated that wave function is a vector, and at point O, rays from each pair of the conceptual slit, one above and other symetrically below the central line, are of same intensity and in phase and would colinearly add to an amplitude of the vector represented by **Eo**. But, *at any other point* **Q**, cumulative phase difference due path difference in adjacent slits would be $\boldsymbol{\alpha}$. Thus net phase difference between **Eq** and **Eo** vectors shall be $\boldsymbol{\alpha/2}$, as shown in the figure. Here, **Eq** represents resultant amplitude, of the waves from each slit, at Point Q, and wavelets from each constituent slit tend to align along the arc as shown in the figure. Going ahead with this logic, width of each slit can be considered to be of infintely small so as to produce a smooth arc, as against discrete arc as shown in the figure. Thus length of the arc, having chord **Eq** ahall be equal to magnitude of **Eo**. Geometrically, $\mathrm{E_q}\cdot\frac{\alpha}{2} = \mathrm{E_0}\cdot\sin\frac{\alpha}{2}$, or $\mathrm{E_q} = \frac{\mathrm{E_0}\cdot\sin\frac{\alpha}{2}}{\frac{\alpha}{2}}$. Further, optically $\frac{\text{Phase Difference}}{2\pi} = \frac{\text{Path Difference}}{\lambda}$, and accordingly, $\alpha = \frac{2\pi}{\lambda}.(a\sin\theta)$, as shown in the inset above. Thus intensity of light, which is square of amplitude, at a point is Q is expressed $I_q = I_0\left(\frac{\sin\frac{\alpha}{2}}{\frac{\alpha}{2}}\right)^2\Bigg|_{\alpha=\frac{2\pi}{\lambda}.(a\sin\theta)}$, and varies with angle θ joining slit and point under consideration. Typical pattern of intensity of diffraction pattern is shown in the figure. Reader inquisitive to know more about *Diffracton* are requested to write us through ***Contact Us.***



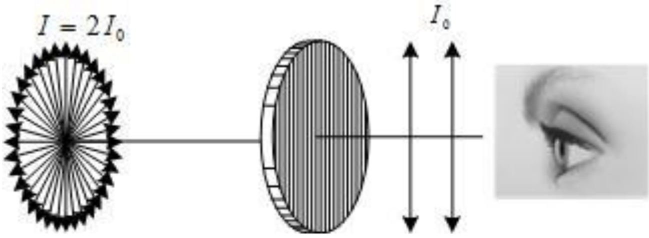


Polarization: Until this topic, nature of light could be explained with corpescular theory or wave theory. But, ploarization phenomenon calls for understanding of Electromagnetic Field Theory of light waves propounded by Maxwell and was, referred to earlier. Understanding of Maxwell equation is outside scope of this manual, as much as Electricti and Magnetism are yet to be elaboreated. In view of this at this stage elaboration of Electo-Magnetic wave is just limited to brief introduction. An electro-magnetic wave is graphically represnted with Two sinusoidal pulsating fields, One Electrical Field along Z axis in X-Z plane and Magnetic Field Y-X plane, both the planes are s perpendicular to each other. The direction of propogation of light wave along the line of intersection of the Two planes as shown in figure. It is must have been seen that in case of reception problem in TV or radio direction of antenna is adjusted to align it with the direction of signal. Further, if antenna is move 90° with respect to best alignment, signal

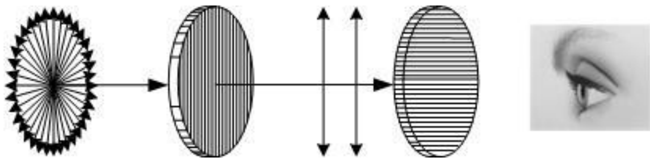




reception stops. This is kind of electro-magnetic radiation produced by coherent movement of electrons and is called linaerly polarized radiation. But, in other source of light, atoms behave independently, it produces light waves with its Electric Field almost uniformly aligned in a plane in all directions perpendicular to its direction of propogation, and so its complementrary magnetic field.



A flexible plastic sheet of long molecular chain is works as polarizing sheet. When an unpolarized light is passed through a polarizing sheet then result is a uni-polarized light as shown above. Let, I_0 be the intensity of light in one direction, then overall intensity of unpolarized light $I = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} I_0 \cos\theta \, d\theta = I_0[\sin\theta]_{-\frac{\pi}{2}}^{\frac{\pi}{2}} = 2I_0$. But, when unipolarized light is passed a through second polarizing sheet placed such that its direction of polarization perpedicular to the direction light Electric field, the incoming light becomes invisible, as shown in the figure. Reader inquisitive to know more the *Polarization* are requested to write us through [Contact Us.]



Scattering of Light: Scattering of light is redistribution of optical energy in the form of aborption radiation. It is basically an energy balance phenomenon. Colour of an object is precisely the visible frequency of light scattered by a medium. I there were no scattering, background of a source of light would look completely black. i.e. absence of light. Scattering is basically caused by two phenomenin- **a)** ***elastic collison*** and **b)** ***inelastic collision***. Scattering of light caused by elastic collision is chacatersized as ***Rayliegh Effect*** which stipulates scattering depending upon- **i)** sizeof obstructing particles in medium and is propotion Sixth power of diameter and **ii)** inversly proportional to Fourth power of incident wavelength. The inelastic collision is caused by periodic perturbtion of electronic cloud and relaxation, and involves understanding of quantim mechanics and is called ***Raman Effect***. Further elaboration on scattering is out of scope of this manual is left for inquistive readers to know more through [Contact Us]

Summary: *As journey into Physics advances there is an increasing order of integration of Mathematics into Physics. It was with this ability James Clerk Maxwell which made it possible to use his ingenuity to relate various experimental observations of electricity, magnetism and electromagnetism into an integrated set of mathematical equations, known as Electro Magnetic Field Theory. Likewise, Albert Einstein could question classical mechanics to evolve Theory of Relativity, which was proved experimentally later. This* ***beauty of integration of mathematics and physics needs to be appreciated and to be cultivated*** *to discover many more secrets of nature. And every scientist who has contributed in discovery of nature had proficiency in integration of mathematics into observation and visualization of physical world.*

Sign convention used in this is consistent and so is the practice in reference books. Reader, while getting across different books must take care to carefully note the sign convention.

In Part-I concepts of waves and in Part- II Sound Waves were elaborated. This theory has been extended to Light Waves and its applications in this Part-III of the series. Nevertheless, readers are welcome to raise their inquisitiveness, beyond the contents, through [Contact Us].

Examples, during elaborations, have been drawn from real life experiences help to build visualization and an insight into the phenomenon occurring around. Solving of problems, is an integral part of a deeper journey to make integration and application of concepts intuitive. This is absolutely true for any real life situations, *which requires multi-disciplinary knowledge, in skill for evolving solution. Thus, problem solving process is more a conditioning of the thought process, rather than just learning the subject. Practice with wide range of problems is the only pre-requisite to develop proficiency and speed of problem solving, and making formulations more intuitive rather than a burden on memory, as much as overall personality of a person. References cited below provide an excellent repository of problems. Readers are welcome to pose their difficulties to solve any-problem from anywhere, but only after two attempts to solve. It is our endeavour to stand by upcoming student in their journey to become a scientist, engineer and professional, whatever they choose to be.*

Looking forward, these articles are being integrated into Mentors' Manual. After completion of series of such articles on Physics, representative problems from contemporary text books and Question papers from various competitive examinations shall be drawn and supported with necessary guidance to evolve solutions as a dynamic exercise which is contemplated to accelerate the conceptual thought process.

References:

1. *NCERT; PHYSICS, Text Book for Class XI (Part I and II), and Exemplar Problems.*
2. *भौतिक शास्त्र, कक्षा ११, मध्य प्रदेश पाठ्यपुस्तक निगम, 2016*
3. *S.L.Loney; The Elements of Statistics and Dynamics: Part 1 – Statics and Part 2 – Dynamics.*
4. *H.C. Verma; Concepts of Physics, (Vol 1 & 2).*
3. *Resnick, Halliday, Resnick and Krane; Physics (Vol I and II).*
4. *Sears & Zemansky; University Physics with Modern Physics.*
5. *I.E. Irodov; Problems in General Physics*

Author is Coordinator of this initiative Gyan-Vigyan Sarita, a non-organizational entity of co-passionate persons who are dedicated to the selfless mission through ***Online Mentoring*** *Session (OMS)* to unprivileged children. **e-Mail ID**: subhashjoshi2107@gmail.com