Class 10 Reflection and refraction of Light

Light is the form of energy having both wave and particle nature. Speed of light in vacuum is 3 lakhs km/s

Reflection of Light by plane and Spherical Mirrors

Mirror is a object having one highly polished surface and other painted. Polished surface of mirror reflects most of the light falling on it and form image.

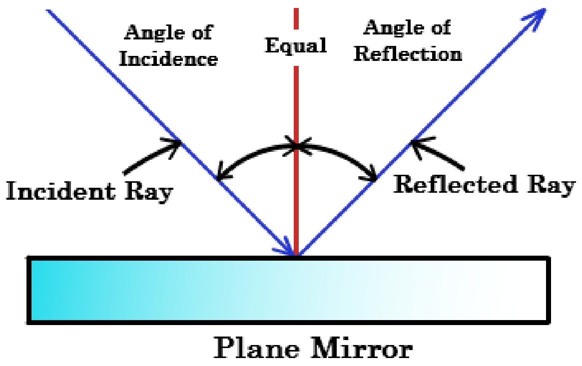
The phenomenon of the bouncing back of light from polished surface is called reflection.

The laws of reflection of light:

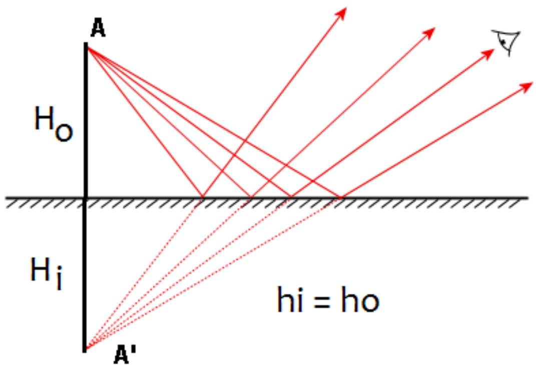
(i) The angle of incidence is equal to the angle of reflection, and

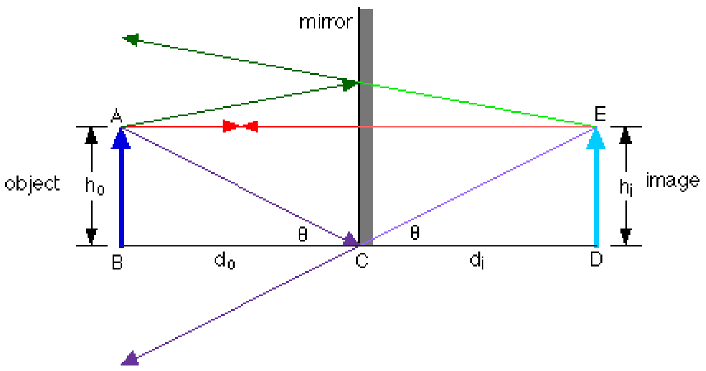
(ii) The incident ray, the normal to the mirror at the point of incidence and the reflected ray, all lie in the same plane.

These laws of reflection are applicable to all types of reflecting surfaces including spherical surfaces.



Mirror having plane polished surface is called plane mirror.





Magnification = hi/ho = +1

Image formed by a plane mirror is always virtual and erect. The size of the image is equal to that of the object. The image formed is as far behind the mirror as the object is in front of it .The image is laterally inverted.

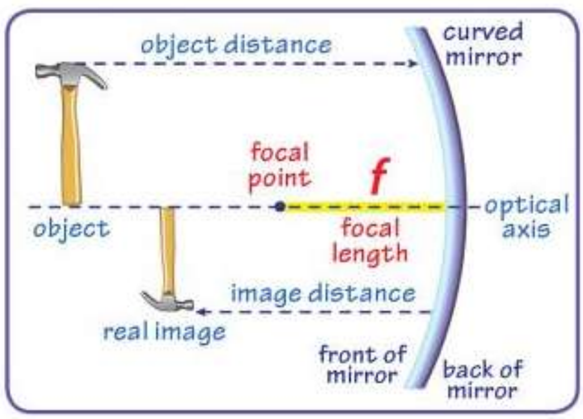
The exchange of right and left portion of object into image formed by plane mirror is called lateral inversion.

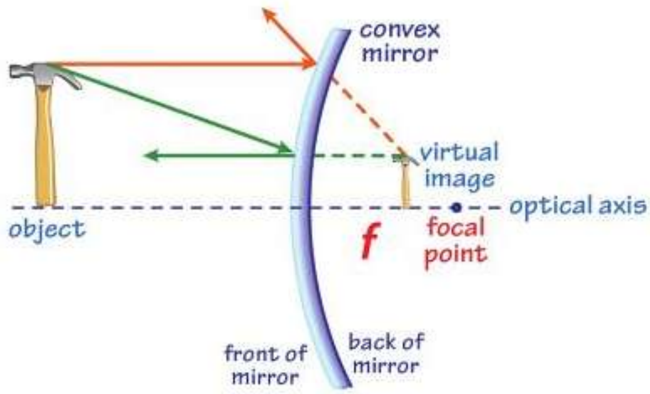
Spherical Mirror: Mirror having curve reflecting surface are called Spherical Mirror. A spherical mirror can be made from a hollow spherical ball of glass.

There are two types of spherical mirrors (i) Concave mirrors (ii) Convex mirrors

A concave mirror is a spherical mirror whose reflecting surface is curved inwards.

A convex mirror is a spherical mirror whose reflecting surface is curved outwards.

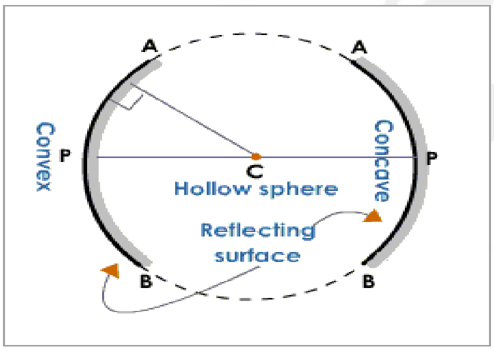


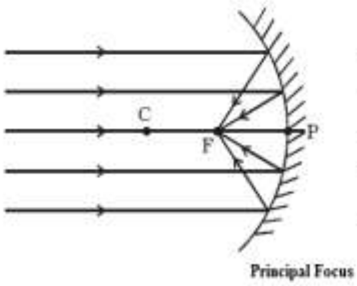


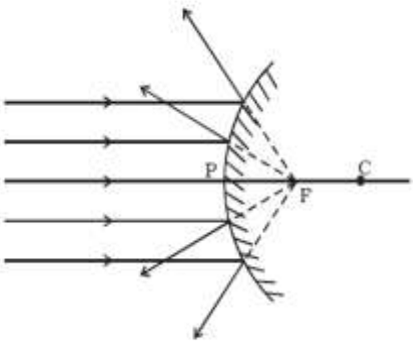
Compare the characteristics of the image on the two surfaces of spoon:

The inward surface of the steel bowl or a spoon acts as a concave mirror, while its outer surface acts as a convex mirror.

The centre of the reflecting surface of a spherical mirror is a point called the pole. The pole is usually represented by the letter P.







The centre of sphere of which spherical mirror is a part is called the centre of curvature of the spherical mirror. It is represented by the letter C.

The straight line joining the pole (P) and the centre of curvature (C) is termed as the principal axis.

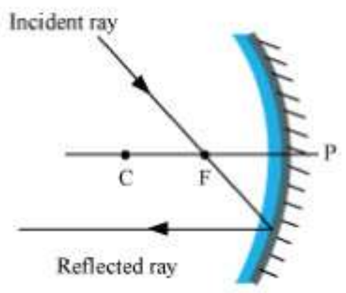
The distance between the centre of curvature and pole is known as the radius of curvature.

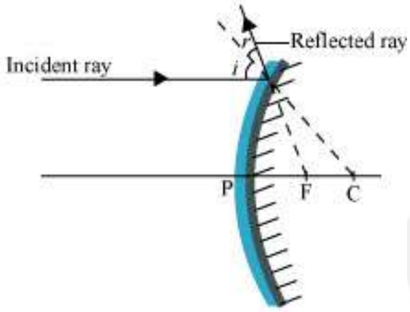
Focus The focus (F) is the point on the principal axis of a spherical mirror where all the incident rays parallel to the principal axis meet (real) or appear to meet (virtual) after reflection.

The different ways in which a ray of light is reflected from a spherical mirror are:

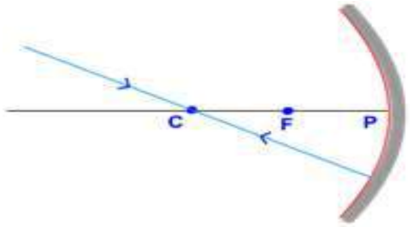
Case I: When the incident light ray is parallel to the principal axis**.** In this case, the reflected ray will pass through the focus of a concave mirror, or it appears to pass through the focus of a convex mirror. (see above image)

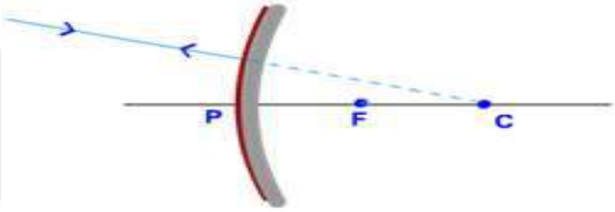
Case II: When the incident light ray passes through the focus of a concave mirror, or appears to pass through the focus of a convex mirror.



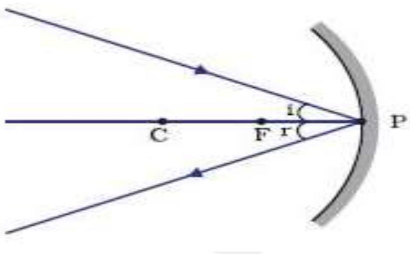


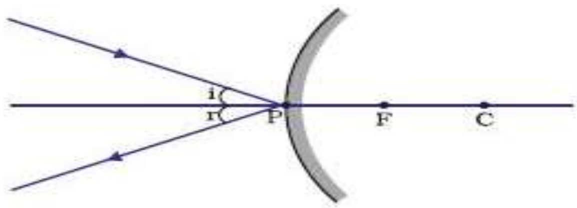
Case III: When the incident ray passes through or appears to pass through the centre of curvature. In this case, light after reflecting from the spherical surface moves back in the same path. This happens because light is incident perpendicularly on the mirror surface.





Case IV: When the incident ray is normal to the reflecting surface In this case, the incident light ray will be reflected back by the reflecting surface of the spherical mirror, as in the case of plane mirror.





<u>Ponder over It:</u> Four spherical mirrors of radius of curvature *R*1, *R*2, *R*3, and *R*4 (*R*1 > *R*3 > *R*2 > *R*4) are placed against the sunlight. Try to obtain the bright spot on a paper sheet for each mirror. **Which mirror forms the brightest spot at a maximum distance from the pole of the mirror?** Explain.

For spherical mirrors the focal length is half the radius of curvature. Light parallel to the principal axis (rays from sun) are converged at the focus. So, larger the radius of curvature larger the focal length, hence, the focus point is at a greater distance from the pole.

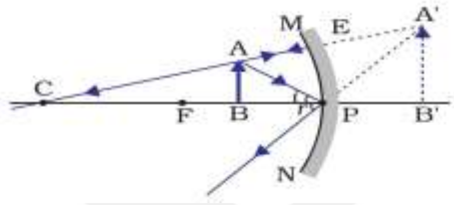
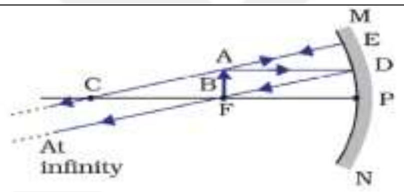
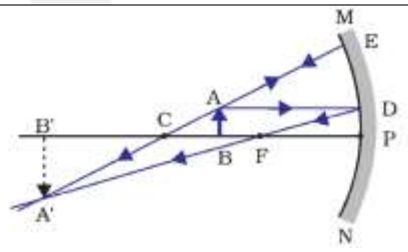
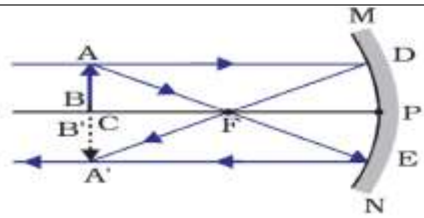
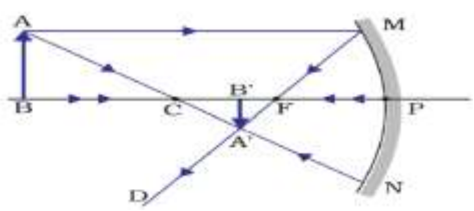
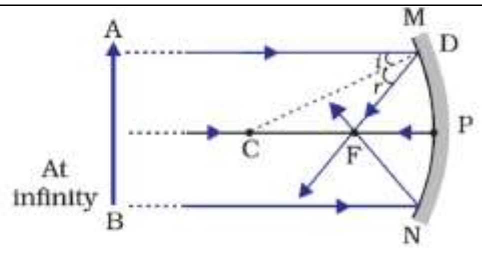
We have, *R*1 > *R*3 > *R*2 > *R*4 ; R1 is the largest radius of curvature. So, mirror with radius of curvature R forms the brightest spot at a maximum distance from the pole of the mirror.

Activity to find focus of concave mirror:

Hold a concave mirror in your hand and direct its reflecting surface towards the Sun. Adjust the concave mirror in such a way you find bright , sharp spot of light on the sheet of paper . This point is the focus of the concave mirror. The heat produced due to the concentration of sunlight ignites the paper. The distance of this image from the position of the mirror gives the approximate value of focal length of the mirror.

Q. What type of images formed when object moves from infinity to mirror?

Ans: The type of image formed by a concave mirror depends on the position of object in front of the mirror. There are six positions of the object:

Case–1: Object is in between P and F : Image formed is : (i) Behind the mirror (ii) virtual and erect and (iii) larger than the object (or magnified)	
Case–2: Object is at the focus(F): The image formed is (i) at infinity (ii) real and inverted, and (iii) highly magnified (or highly enlarged)	
Case–3: Object is in between focus (F) and centre of curvature(C) The image formed is : (i) beyond the centre of curvature (ii) real and inverted, and (iii) larger than the object (or magnified)	
Case–4: Object is at the centre of curvature(C), the image formed is (i) at the centre of curvature (ii) real and inverted, and (iii) same size as the object	
Case–5: Object is beyond the centre of curvature(C) : Image will be (i) between the focus and centre of curvature (ii) real and inverted, and (iii) smaller than the object (or diminished)	
Case–6: Object is at infinity. the image formed is (i) between the focus and centre of curvature (ii) real and inverted, and(iii) much smaller than the object (or highly diminished)	

The type of image formed by a convex mirror depends on the position of object in front of the mirror. There are six positions of the object:

<table>
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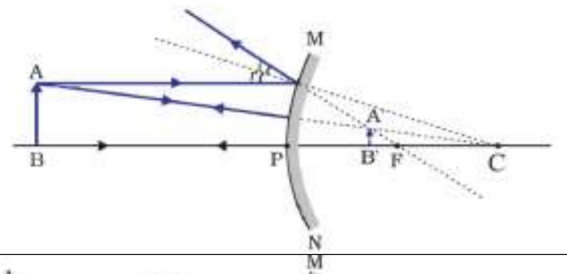
<td>Case–1: Object is placed between P and infinity in front of a convex mirror, the image formed is

(i) between the pole and focus

(ii) virtual and erect, and

(iii) smaller than the object (or diminished)</td>
<td>
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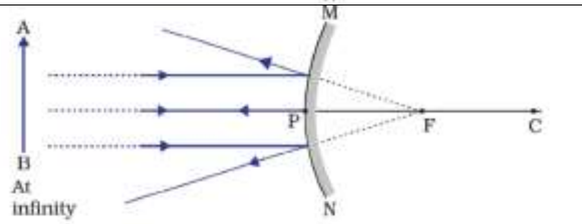
<tr>
<td>Case–2: Object is at infinity convex mirror, the image formed is

(i) behind the mirror at focus (ii) virtual and erect, and

(iii) much smaller than the object (or highly diminished)</td>
<td>
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Uses of concave mirror are:

1. Concave mirrors are commonly used in torches, search-lights and vehicles headlights to get powerful parallel beams of light.

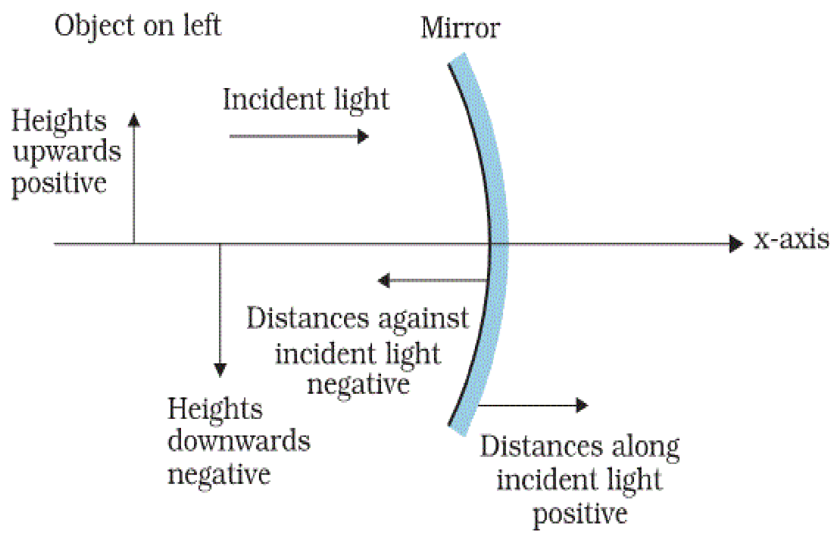
2. Concave mirrors are used as shaving mirrors to see a larger virtual image of the face when a person placed between pole and focus.

3. The dentists use concave mirrors to see large images of the teeth of patients. this is because concave mirror form virtual magnified image of the object placed between pole and focus.

4. Concave dishes are used in TV dish antennas to receive TV signals from the distant communications satellite. as it converge light rays coming from infinity at a point.

5. Large concave mirrors are used to concentrate sunlight to produce heat in solar furnaces.

<table>
<tr>
<td>Q. Why do we prefer a convex mirror as a rear-view mirror in vehicles?

Ans. Convex mirrors give a virtual, erect, and diminished image of the objects placed in front of them. They are preferred as a rear-view mirror in vehicles because they give a wider field of view, which allows the driver to see most of the traffic behind him.
Sign Convention in the Mirror Formula and Magnification</td>
<td>
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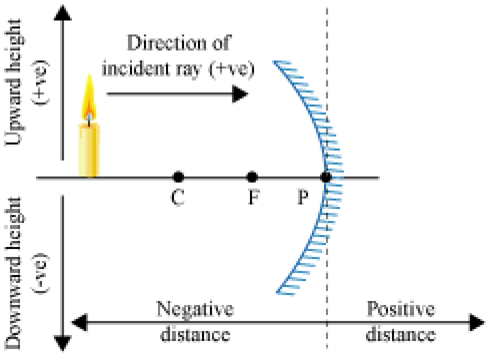
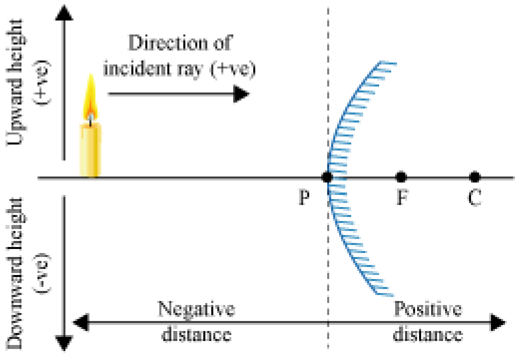
Career Launcher



Concave mirror



Convex mirror

Derive mirror formula (a) R=2f (b)1/v-1/u = 1/f

Proof-of- the relation between focal length and radius of curvature(X) physics [R=2f]

Consider a ray of light AB, parallel to the principal axis, incident on a spherical mirror at point B. The normal to the surface at point B is CB and CP = CB = R, is the radius of curvature. The ray AB, after reflection from mirror will pass through F (concave mirror) or will appear to diverge from F (convex mirror)
from the figure,

According to law of reflection,< i = <r

<i = <θ [Since, AB ||CP] ⇒ <r= <θ

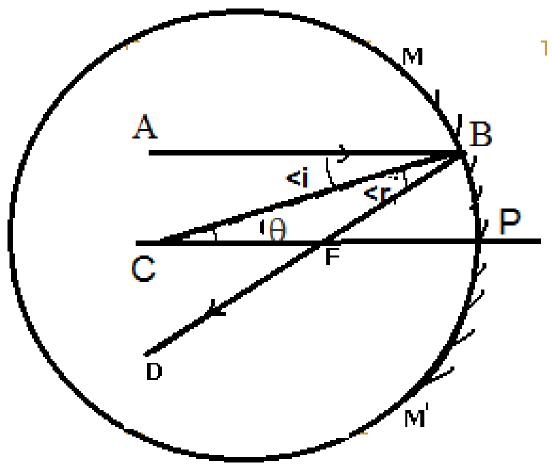
So, In Δ BCF, CF = BF ---------------(i)

If the aperture of the mirror is small, B lies close to P,

Then, BF = PF -----------------(ii)

From (i) and (ii), In ΔBCF, CF = FP

Now, PC = PF + FC = 2 PF or R = 2f



Derivation or Proof-of-Mirror formula:

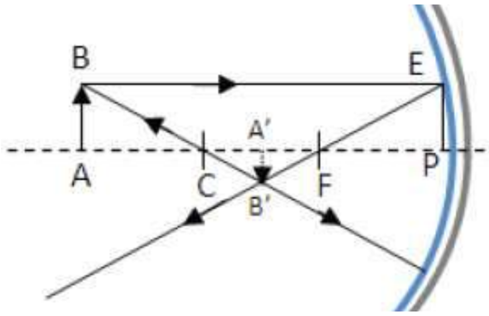
Mirror formula is the relationship between object distance (u), image distance (v) and focal length. 1/v + 1/u = 1/f

In Δ ABC and Δ A'B'C we have,

<A = <A' = 90^0 and <C =<C (vert. opp. <s]

ΔABC ~ΔA'B'C [AA similarity] Then, AB /A'B' = AC/A'C ----(I)

Similarly, In ΔFPE ~ A'B'F we get, EP /A'B' = PF/A'F



AB /A'B' = PF/A'F [AB=EP] ----(II)

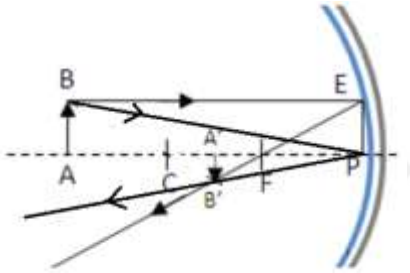
From (i) &(ii) AC/A'C = PF/A'F ⇒ A'C/AC = A'F/PF

⇒(CP-A'P)/(AP- CP) = (A'P – PF)/PF

Now put the value, , PF = -f ; CP = 2PF = -2f ; AP = -u ; and A'P = -v

[(-2f) –(-v)] /(-u)-(-2f) = {(-v) –(-f) }/(-f) ⇒ uv = fv +uf (dividing each term by uvf) ⇒ 1/f = 1/u + 1/v

Derivation or Proof-of-Magnification of image formed by mirror:



ΔABP ~ Δ A'B'P [AAA similarity]
AB/A'B' = AP/A'P
or, ho/-hi = - u/-v
But magnification is the ratio of the image to that of object
m = hi/ho = -v/u
m is – ve for real and +ve for virtual image
If (i) m >1 image is magnified
(ii) m < 1 image is smaller than object

Find Nature and position of object:

Q. A convex mirror is used as a safety mirror in a shop. It has a focal length of 15 m. A person is standing 12 m away from this mirror. Find the position of his image.

Solution: For the given convex mirror, Focal length (*f*) = + 15 m Object distance (*u*) = – 12 m Image distance (*v*) =?

i/f = 1/v + 1/u ⇒ 1/15 = 1/v + 1/(-12) ⇒ v = + 20/3

m = -v/u ⇒ (- 20/3) ÷ (-12) = 20/36 = 0.55m

Therefore, image is formed 6.67 m behind the mirror. Image is virtual erect and smaller than object

Q. An object of height 6 cm is placed 18 cm away from a concave mirror. The image is formed 12 cm before the mirror. Find out the following: (i) Focal length of the mirror (f) (ii) Radius of curvature (R) (iii) Magnification of the mirror (m) (iv) Image height (HI)

Solution: Ho = 6cm, u = – 18 cm and v = -12cm

i/f = 1/v + 1/u ⇒ 1/f = 1/(-12) + 1/(-18) ⇒ 1/f = - 5/36 ⇒ f = -36/5 = - 7.2 cm

Thus, the focal length of the given concave mirror is 7.2 cm.

(ii) Radius of curvature is given by R = 2f = 2 × 7.2 = 14.4 cm

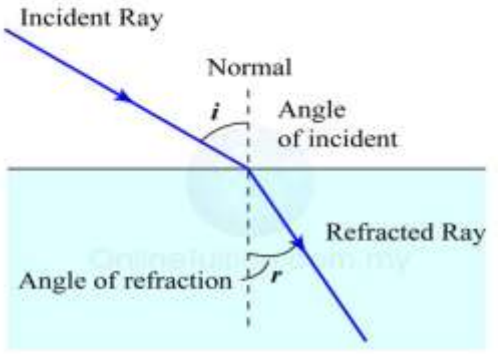
(iii) Magnification (*m*) = - v/u = -{(-12) ÷ (-18)} = - 2/3 cm (iv) m = hi/ho ⇒ -2/3 = hi/6 ⇒ Hi = - 4 c m

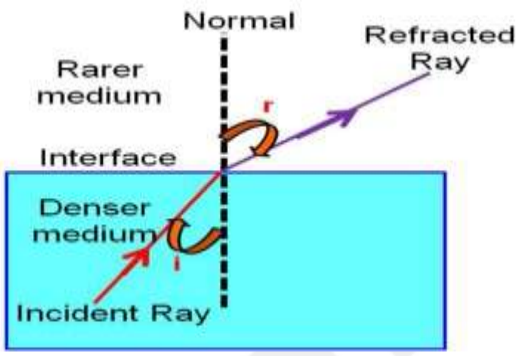
Q. Describe phenomenon of refraction of light?

Ans: The change in direction of light when it passes from one medium to another medium obliquely is called refraction of light. In other words, the bending of light when it goes from one medium to another obliquely is called refraction of light.

The refraction of light is due to the change in the speed of light on going from one medium to another. Remember only speed and wave length of light changes but frequency remain unchanged during phenomenon of refraction of light

The refraction takes place when light enters from air to water (see below figure).





Rule - 1 : When a light ray travels from a rarer medium to a denser medium, the light ray bends towards the normal as velocity of light decreases wrt rare medium.

Rule - 2: When a light ray travels from a denser medium to a rarer medium, the light ray bends away from the normal as velocity of light increases w .r .t denser medium.

The laws of refraction:

(i) The incident ray, the refracted ray and the normal to the interface of two transparent media at the point of incidence, all lie in the same plane.

(ii) The ratio of sine of angle of incidence to the sine of angle of refraction is a constant, for the light of a given colour and for the given pair of media. This law is also known as Snell's law of refraction.

Refractive index thus give us information that how much speed of light increases or decreases when passes from one medium to other.

If < i is the angle of incidence and <r is the angle of refraction, then,μ_{21} $\frac{Sin\ i}{Sin\ r}$ = Constant .= $\frac{v_1}{v_2}$

This constant value is called the refractive index of the second medium with respect to the first.

The absolute refractive index:

If medium 1 is vacuum or air, then the refractive index of medium 2 is called the absolute refractive index of the medium. It is simply represented as n_2

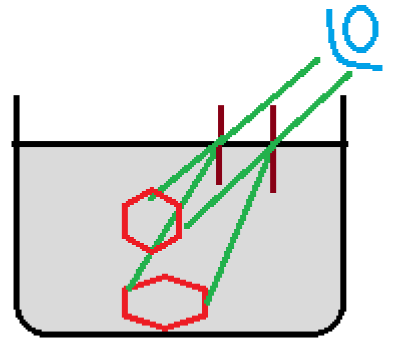
Thus, absolute refractive index of the medium = $n_m = \frac{\text{spped of light in vacuum /air}}{\text{spped of light in medium}} = \frac{c}{v}$

Relative refractive index of medium 2 w.r.t. medium 1 is written as $^1n_2 = (n_2)/(n_1) = (v_1)/(v_2)$.

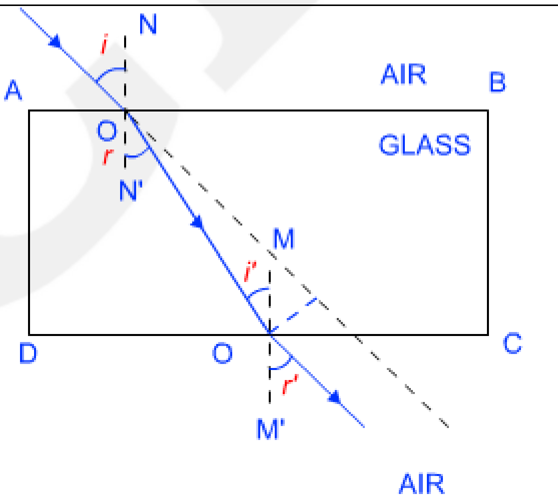
This is known as Snell's Law.

The refractive index of diamond is 2.42. The meaning of this statement is that speed of light decreases by factor of 2.42 when pass to diamond from air.

Q. A coin in a glass beaker appears to rise as the beaker is slowly filled with water. Why?
Ans: It happens on account of refraction of light. A ray of light starting from the coin goes from water to air and bends away from normal. Therefore, bottom of the beaker on which the coin lies appears to be raised.



Refraction through glass Slab
On passing through a rectangular glass slab, a ray of light suffers two refractions.
Light emerges from rectangular slab in a direction parallel to that in which it entered the glass slab. However the final emergent ray is slightly shifted sideways from the direction of original incident ray by a distance H called lateral shift.



The perpendicular distance between the original path of incident ray and the emergent ray coming out of the glass slab is called lateral displacement of the emergent ray of light.
Lateral displacement depends mainly on three factors:
Actually lateral displacement is directly proportional to-->
(i) angle of incidence (ii) thickness of glass slab (iii) Refractive index of glass slab.

Q. When a ray of light passes through a parallel sided glass slab of transparent medium then show that angle of incidence is equals to angle of emergence.

Solution: Proof:

Applying Snell's Law at surface B, n_{21} = Sin<i/Sin<r ---(i)

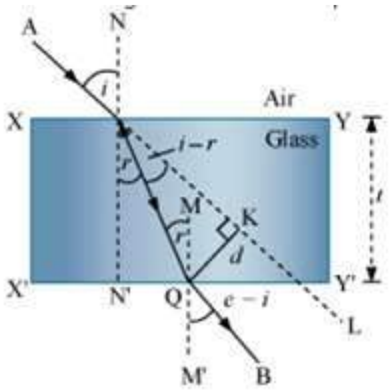
Applying Snell's Law at at surface C, n_{21} = Sin <i'/Sin<e ⇒ n_{21} = Sin <e /Sin<i' ---------(ii)

NN' II MM' ⇒ <r = <I' ------------(iii)

From (i) ,(ii) & (iii) we get Sin<I = Sin <e ⇒ <I = <e ⇒ Hence incident ray is parallel to emergent ray.

Q. What is lateral shift? Explain with the help of a diagram.

Ans: When a ray of light travels through a glass slab from air, it bends towards the normal and when it comes out of the other side of the glass slab it bends away from the normal. It is found that the incident ray and the emergent ray are not along the same straight line, but the emergent ray seems to be displaced with respect to the incident ray. This shift in the emergent ray with respect to the incident ray is called lateral shift or lateral displacement. The incident and the emergent rays, however, remain parallel.



Lateral Shift: The perpendicular distance between incident and emergent ray is known as lateral shift. Lateral Shift d = BC and t = thickness of slab

In Δ BOC, sin (i - r) = BC/OB = d/OB

$\Rightarrow$ d = OB sin (i - r) -------------(i)

In Δ OBD, (cos r) =OD/OB = t/OB

$\Rightarrow$ OB = t /(Cos r) -------------(ii)

From (i) and (ii) d = t sin (i - r) / (Cos r)

Q. An object under water appears to be at lesser depth than in reality. Explain why?

Ans: This is due to refraction of light.

We know Real depth / Apparent depth = n

Or Apparent depth = Real depth / n

Since n > 1, so apparent depth < real depth.

Q. When does Snell's law fail?

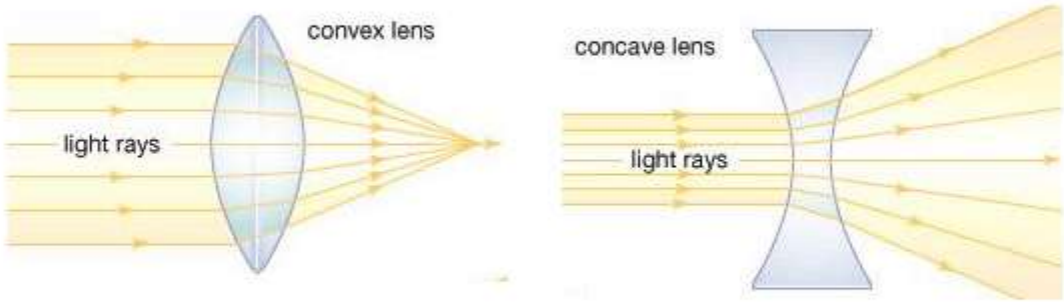
Ans: Snell's law fails when light is incident normally on surface of a refracting medium.

Refraction Of Light By Spherical Lenses (Concave And Convex)

A lens is a transparent material bound by two curved surfaces. Lenses are broadly classified into two categories depending on their surfaces.

Convex lens : A convex lens is made by joining two spherical surfaces in such a way that it is thicker at the centre. Its thickness gradually reduces as we move towards the edge.

A convex lens has the ability to converge the light rays to a point that are incident on it. Thus, it is called a **converging lens**.



Concave lens: A concave lens is made by joining two curved surfaces in such a way that it is thinner at the centre. Its thickness gradually increases as we move towards the edge.

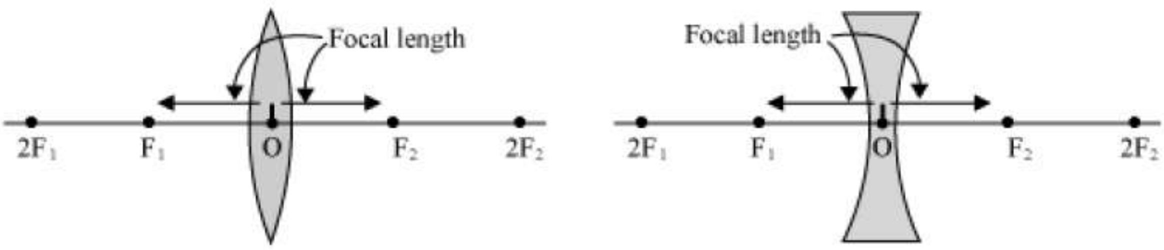
A concave lens has the ability to diverge a beam of light rays incident on it. Thus, it is called a **diverging lens**.

Optical centre Optical centre is a point at the centre of the lens. It always lies inside the lens and not on the surface. It is denoted by **'O'**.

Centre of curvature It is the centre point of arcs of the two spheres from which the given spherical lens (concave or convex) is made. Since a lens constitutes two spherical surfaces, it has two centers of curvature. The distance of the optical centre from either of the centre of curvatures is termed as the **radius of curvature**.

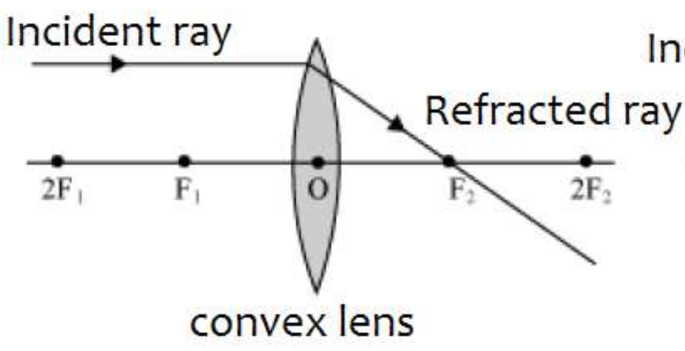
Principal axis The straight line joining the two centers of curvature and the optical centre **(O)** is called the **principal axis** of the lens.

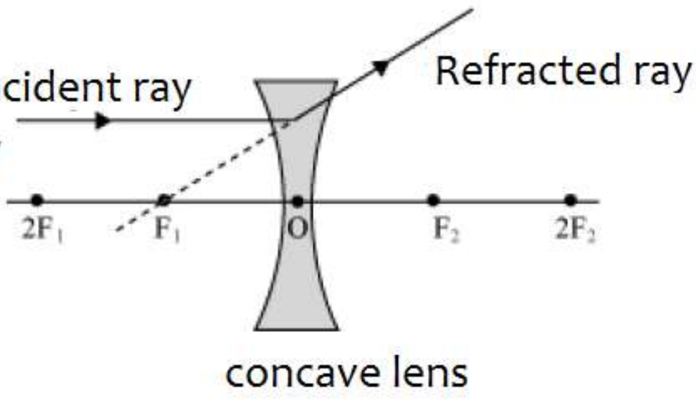
Hold a convex lens and direct it against the sunlight. You will find a bright spot appear on the wall. **Can you explain the formation of this bright spot?** Light, after refracting through the lens, converges at a very sharp point.This point is called focus of convex lens. The distance between the focus (F1 or F2) and the optical centre (**O)** is known as the **focal length** of the lens.



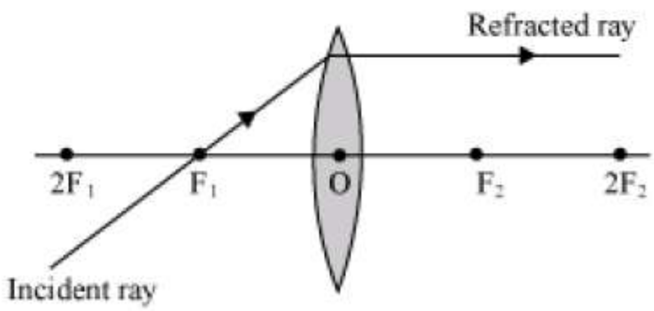
Refraction by a spherical lens can be categorized into three cases.

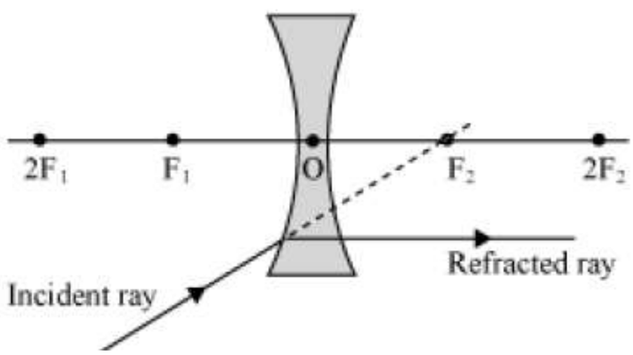
Case I. *When the incident light ray is parallel to the principal axis* In this case, the refracted ray will pass through the second focus *F*2 for a convex lens, and appear to diverge from the first focus *F*1 for a concave lens.



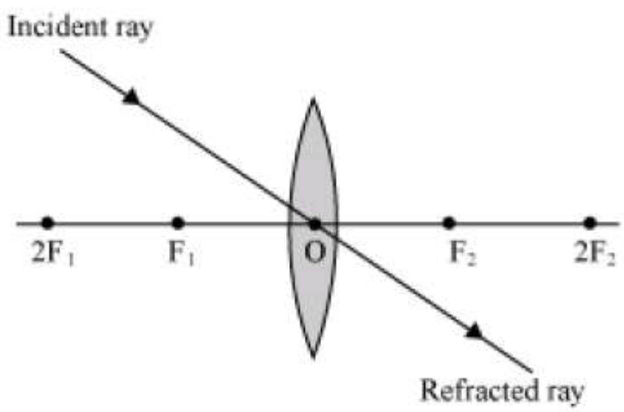


Case II. *When the incident light ray emerges from the first focus F1 of a convex lens, or appears to emerge from the second focus F2 of a concave lens*





Case III. *When the light ray passes through the optical centre (O) of a lens* In this case, the light ray will pass through both the lenses without suffering any deviation.



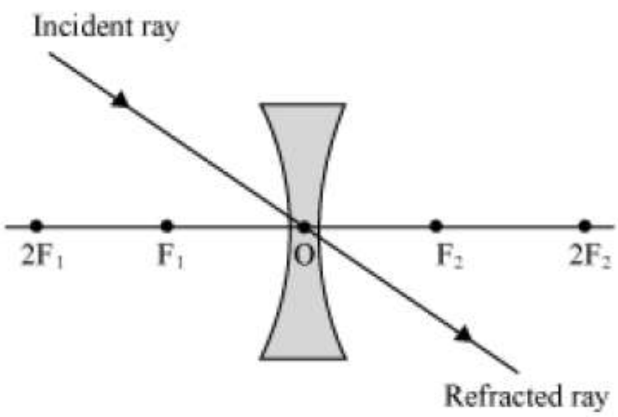
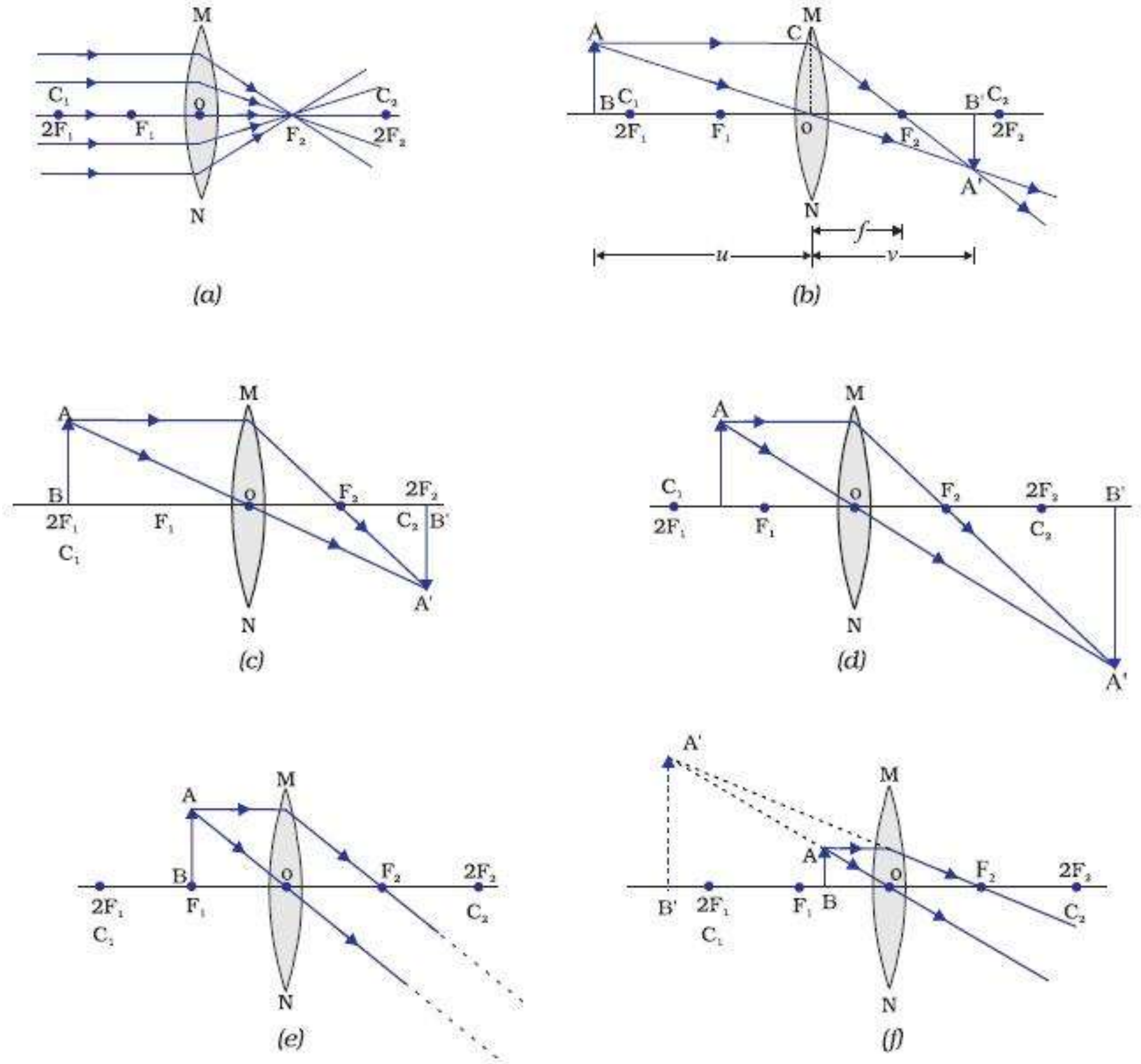
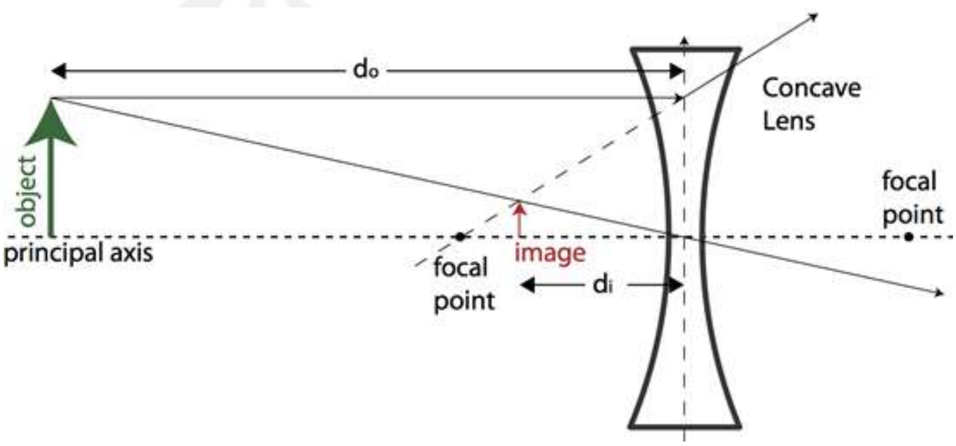


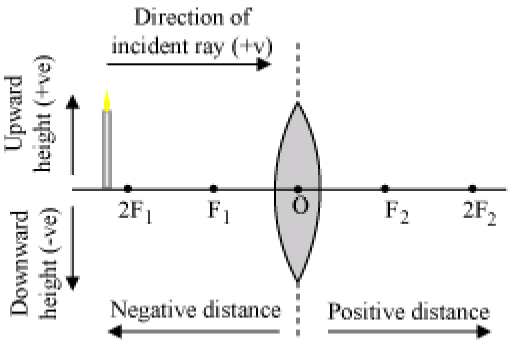
Image Formation by Lenses



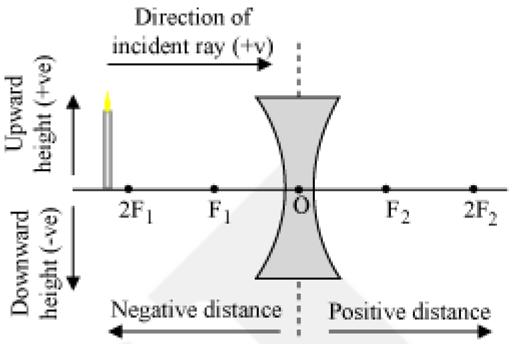


Lens Formula, Magnification, and Power :

Sigh Convention for Lenses

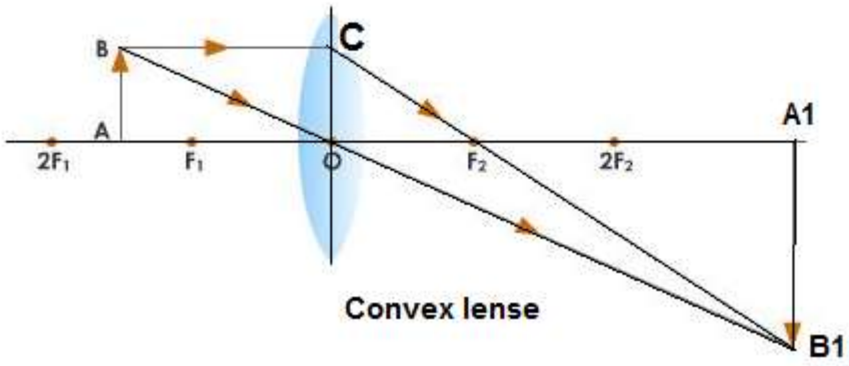


Convex mirror



Concave mirror

Derivation or Proof-of- Lens formula (X) physics



Let AB is an object placed between f1 and f2 of the convex lens. The image A1B1 is formed beyond $2F_2$ and is real and inverted.

OA = Object distance = u ; OA1 = Image distance = v ; OF_2 = Focal length = f

In ΔOAB and ΔOA_1B_1 are similar as, $<BAO = <B_1A_1O = 90^0$ and $<AOB = <A_1OB_1$ [vertically opp. <s]

$\Delta OAB \sim \Delta OA_1B_1 \Rightarrow A_1B_1/AB = OA_1/OA$ -------------------(i)

Similarly, $\Delta OCF_2 \sim \Delta F_2A_1B_1 \Rightarrow A_1B_1/OC = F_2A_1/OF_2$

But we know that OC = AB $\Rightarrow A_1B_1/AB = F_2A_1/OF_2$ -------------------(ii)

From equation (i) and (ii), we get , $OA_1/OA = F_2A_1/OF_2$

$OA_1/OA = (OA_1 - OF_2)/OF_2$

$v/-u = (v-u)/f \Rightarrow vf = -u(v-f) \Rightarrow vf = -uv + uf$

Dividing equation (3) throughout by uvf $\Rightarrow 1/v - 1/u = 1/f$

Magnification produced by a lens is also related to the object-distance u, and the image-distance v. This relationship is given by Magnification ⇒ (m) = hi/ho = v/u

In ∆OAB and $∆OA_1B_1$ are similar as, <BAO = $<B_1A_1O = 90^0$ and <AOB = $<A_1OB_1$ [vertically opp. <s]

$∆OAB \sim ∆OA_1B_1 \Rightarrow AB/ A_1B_1 = OA/OA_1 \Rightarrow$ ho/(- hi) = - u / v ⇒ hi/ho = v/u = m

Note: If magnification is positive, the image will be virtual and erect. If magnification is negative, the image will be real and inverted.

Power of a Lens :

A convex lens of short focal length bends the light rays through large angles, by focusing them closer to the optical centre.

Similarly, concave lens of very short focal length causes higher divergence than the one with longer focal length.

The degree of convergence or divergence of light rays achieved by a lens is expressed in terms of its power.

⇒ The ability of a lens to converge/diverge a beam of light rays is expressed in terms of its **power** (***P***). It is the inverse of focal length, ***f***(in meters). Hence, power of a lens is given by the relation = $P = \frac{1}{f(m)}$

The SI unit of power is **dioptre** (**D)**.

⇒ 1 dioptre is the power of a lens whose focal length is 1 metre

The net power (*P*) of the lenses placed in contact is given by the algebraic sum of the individual powers *P1*, *P2*, *P3*, … as *P* = *P1* + *P2* + *P3* + ………

Example: A convex lens has a focal length of 10 cm. If the image produced by it is 15 cm behind from the optical centre, then determine the distance at which the object is placed? Also, find the magnification produced by the lens.

Solution: For the given convex lens, Focal length (*f*) = 10 cm Image distance (*v*) = 15 cm

I/f = 1/v – 1/u ⇒ 1/10 = 1/15 – 1/(-u) ⇒ 1/15 – 1/10 = 1/u ⇒ 1/u = -1/30 ⇒u = - 30 cm

Here, the negative sign indicates that the object was placed to the left of the lens.

Now, magnification = m =v//u =15/-30 = - ½ = hi/ho ⇒ hi = - ho/2

Hence, the image size will be half of the object size. The negative sign of magnification implies that the image formed is real and inverted.

Example: What is the power of a convex mirror whose focal length is 25 cm?

Solution: f = (25/100) But, D = 1/f(m) = 100/25 = 4D

if the lens was concave, then the focal length would have been, *f* = –25 cm = –0.25 m

In this case, power will be –4 **D**.