PHYSICS

REFRACTION OF LIGHT

Concepts Covered

- Refraction of light and its laws
- Refraction through a glass slab
- Lenses and types of lenses
- Image formation by convex and concave lenses
- Sign convention for spherical lenses
- Lens formula
- Magnification
- power of the lens.

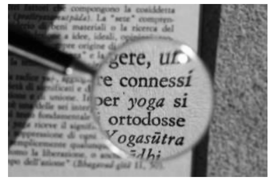
Refraction

The phenomenon of bending of light when it enters obliquely from one medium to another is called Refraction of Light.

It is due to a change in the velocity of light while travelling from one medium to another. Speed of light is maximum in vaccum and is equal to $\mathbf{3 \times 10^8\ m/s}$.

Some examples where refraction is involved:

(i) The bottom of the swimming pool appears higher.	
(ii) A pencil partially immersed in water appears to be bent at the interface of water and air.	
(iii) Lemons placed in a glass tumbler appear bigger.	

(iv) Letters of a book appear to be raised and magnified when seen through a convex lens.	

Laws of Refraction

(1) 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.

(2) **Snell's Law:** The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant, for a light of given colour and a given pair of media.

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

Refractive Index $(\mathbf{n})$: The ratio of the speed of light in a given pair of media

$$\mathbf{n} = \frac{\text{Velocity of light in medium } \mathbf{1}}{\text{Velocity of light in medium } \mathbf{2}}$$

- $\mathbf{n_{21}}$ means the refractive index of the second medium with respect to the first medium, and $\mathbf{n_{21}} = \frac{\mathbf{v_1}}{\mathbf{v_2}}$
- $\mathbf{n_{12}}$ means the refractive index of the first medium with respect to the second medium. $\mathbf{n_{12}} = \frac{\mathbf{v_2}}{\mathbf{v_1}}$
- Absolute Refractive Index: Refractive index of a medium with respect to vaccum or air. This is calculated as the ratio of the speed of light in a vaccum to the speed of light in medium n = $\frac{\mathbf{c}}{\mathbf{v}}$ $(\mathbf{c} = \mathbf{3} \times \mathbf{10^8}\ \mathbf{ms^{-1}})$.
- If the refractive index of medium 1 w.r.t. air is given as $_{1}\mathbf{n}^{air}$
- If the refractive index of medium 2 w.r.t. air is given as $_{2}\mathbf{n}^{air}$
- Then, the refractive index of medium 1 w.r.t. medium $\mathbf{2} = \frac{_{1}\mathbf{n}^{air}}{_{2}\mathbf{n}^{air}}$

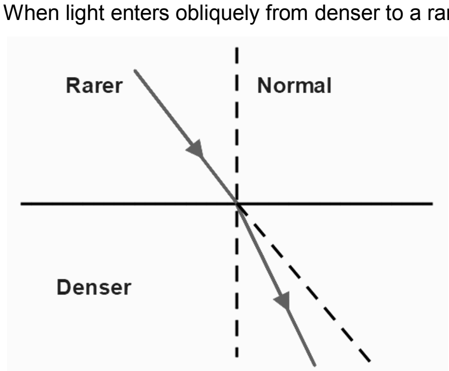
Note: Refractive index of diamonds is highest. It is $\mathbf{2.42}$. It means the speed of light is $\frac{\mathbf{1}}{\mathbf{2.42}}$ times less in diamond than in vaccum.

Optically denser medium: Out of two given media, the medium with a higher value of the refractive index is called an optically denser medium.

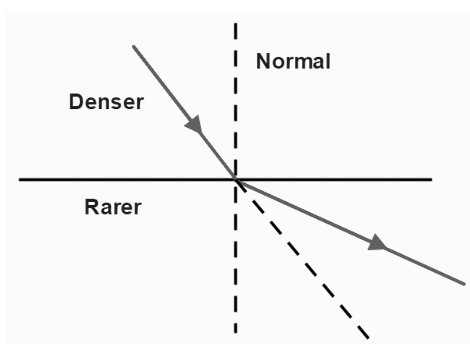
Optically rarer medium: Out of two given media, the medium with the lower value of the refractive index is called an optically rarer medium.

(1) When light enters obliquely from a rarer to a denser medium, it bends towards the normal.

(2) When light enters obliquely from denser to a rarer medium, it bends away from the normal.



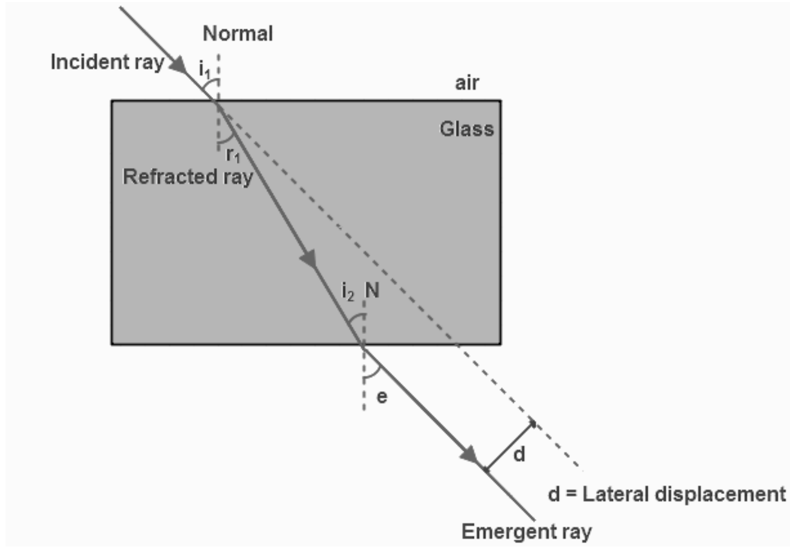
(1)



(2)

Refraction through a Glass Slab

- The extent of bending of a ray of light at the opposite parallel faces of a rectangular glass slab is equal and opposite, so the ray emerges parallel to the incident ray and is shifted parallel to it by some distance. This distance is called lateral displacement
- Lateral displacement depends on:
  (a) Refractive index of glass slab
  (b) Thickness of the glass slab



Example:

(1) Calculate the speed of light in a medium of a refractive index of 1.25

Solution: $n = \frac{c}{v} \Rightarrow v = \frac{c}{n}$

$v = 3 \times 10^8 / 1.25 = 2.4 \times 10^8$ m/s

(2) If the refractive index of medium 1 with respect to vaccum is 1.5 and of medium 2 with respect to vaccum is 2. Then, calculate the refractive index of medium 1 with respect to medium 2

Solution: Refractive index of medium 1 with respect to medium 2 = $\frac{{}_1n^{air}}{{}_2n^{air}} = \frac{1.5}{2} = 0.75$

(1) If speed of light in a medium is 1.25×10^8 m/s then find the refractive index of that medium.

(2) If incident angle in air-water interface is 30° then find angle of refraction? (Refractive index of water is 1.33).

Answer Key

(1) 2.4

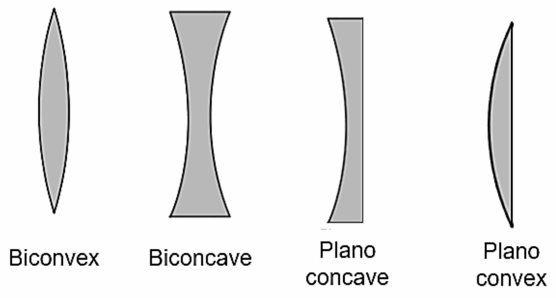
(2) $r = \sin^{-1}\frac{3}{8}$

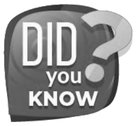
Spherical Lens: A transparent refracting medium bound by two surfaces, of which one or both surfaces are curved.

Spherical lenses

Convex lens	Concave lens
Thin from corners	Thick from corners
Thick at centre	Thin at centre
Converging	Diverging

Types of Lenses





If you travelled at the speed of light, you could travel around the Earth 7.5 times every second.

Terminology for Spherical Lens

Optical Centre: O is a point for a given lens through which any ray passes undeviated.

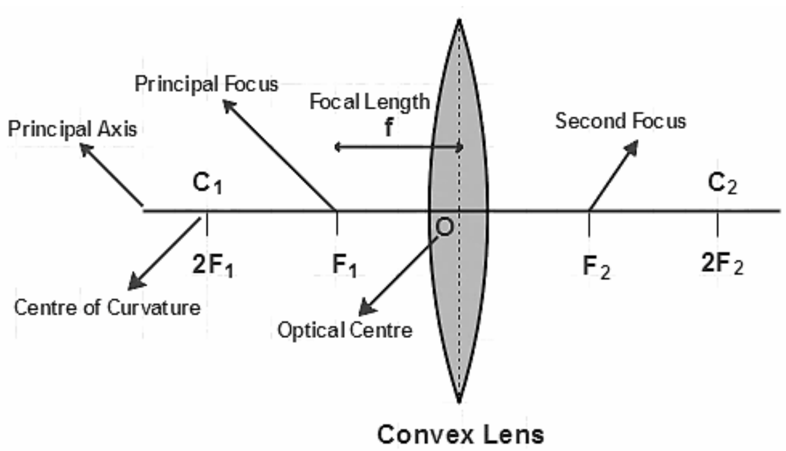
Principal Axis: C_1C_2 line passing through the optical centre and perpendicular to the lens is called the principal axis.

Principal Focus: A lens has two spherical surfaces and hence two focal points. The first focal point or principal focus is an object point on the principal axis for which the image is formed at infinity. While the second focal point is an image point on the principal axis for which the object lies at infinity.

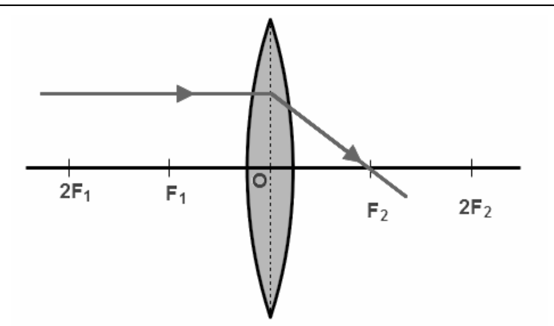
Focal Length (f): The distance between the optical centre of a lens and the point where the parallel beam of light converges or appears to converge is called the focal length.

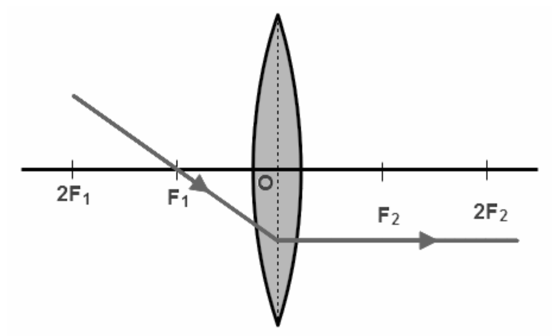
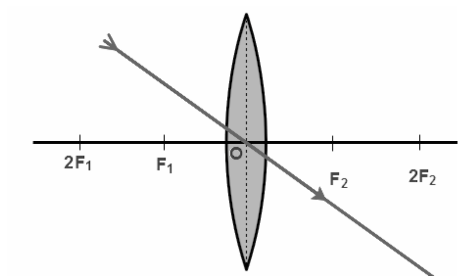
Aperture: In reference to a lens, aperture means the effective diameter. The intensity (brightness) of the image formed by a lens depends on the light passing through the lens which depends on the square of the aperture, i.e.,

$I \propto (\text{Aperture})^2$



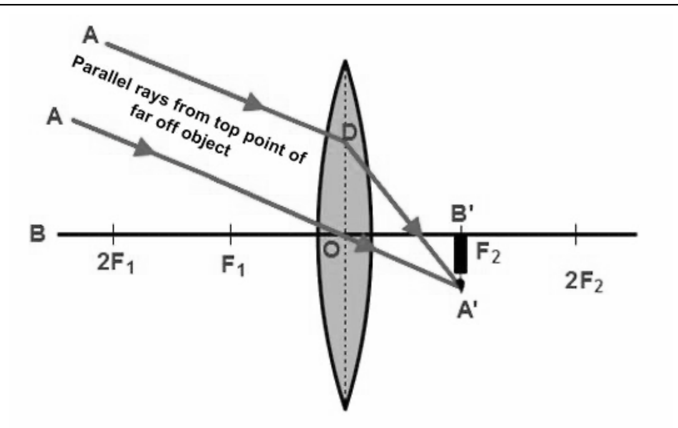
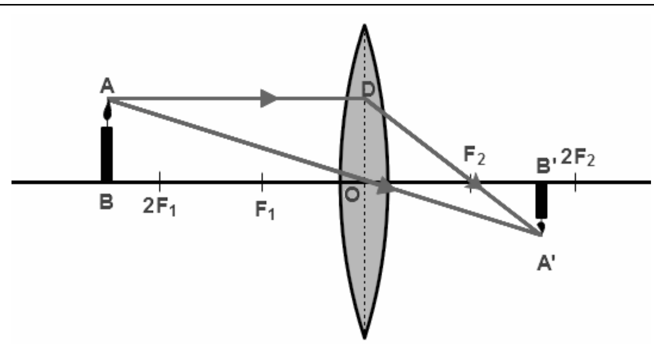
Rules for Image Formation by Convex Lens

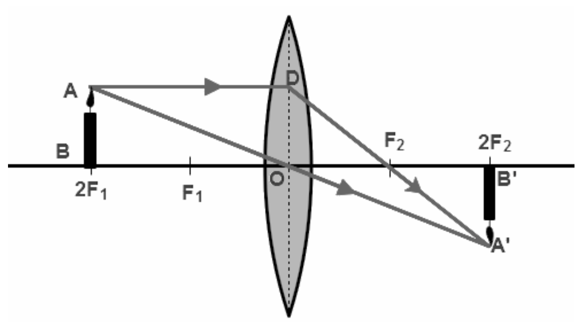
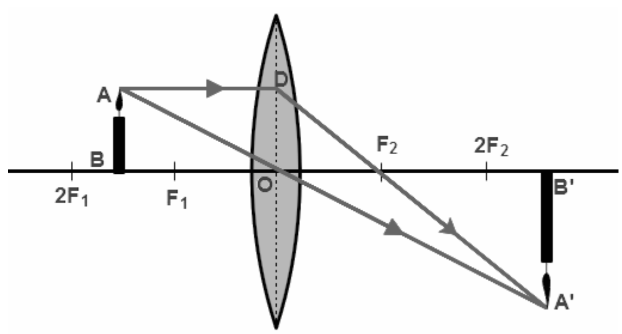
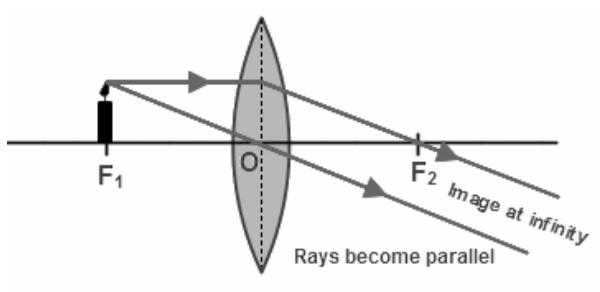
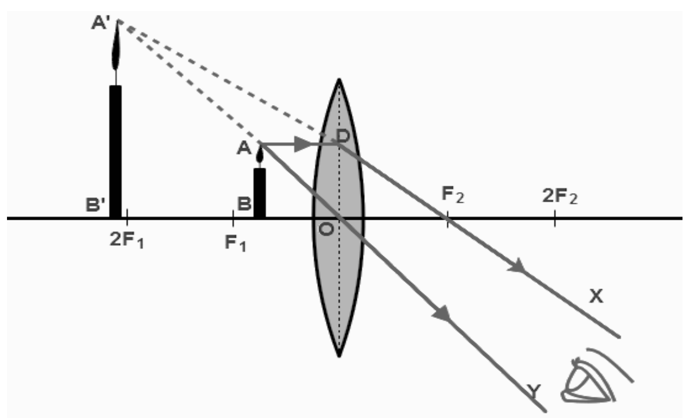
(i) A ray of light parallel to the principal axis of a convex lens after refraction always passes through the focus on the other side of the lens.	

(ii) A ray of light passing through the principal focus after refraction will emerge parallel to the principal axis after refraction.	
(iii) A ray of light passing through the optical center after refraction will emerge without any deviation.	

Ray Diagrams of Images formed by Convex Lens

- To make the ray diagram for image formation by a lens any two-incident rays are sent to the lens and the intersection of refracted rays is seen. The intersection point gives the position of the image.
- When an extended object AB is placed at different positions in front of a convex lens then the following cases arise:

(i) When Object is at Infinity: **Position -** At 'F_2' **Nature –** Real, inverted **Size –** Point size or highly diminished	
(ii) When the Object is beyond '$2F_1$' **Position -** Between 'F_2' and '$2F_2$' **Nature -** Real, inverted **Size –** Diminished	

(iii) When the Object is at '2 F_1' **Position** $-$**At $2F_2$** **Nature -** Real, inverted **Size -** Same size	
(iv) When the Object is between 'F_1' and '$2F_1$' **Position -** Beyond '$2F_2$' **Nature -** Real, inverted **Size –** Enlarged	
(v) When the object is at 'F_1' **Position -** At Infinity **Nature -** Real, inverted **Size -** Highly enlarged	
(vi) When the object is between ' F_1 ' and the Optical centre **Position -** On the same side of the lens as the object **Nature -** Virtual and erect **Size –** Enlarged Based on this position, this lens is also known as a magnifying lens.	

Example:

(1) For what position of the object, an image formed by a convex lens is virtual and erect.

Answer: When the object is between F_1 and O.

(2) What types of images convex lens can form.

Answer: Convex lens can form both real and virtual images and images can be diminished, of the same size, and enlarged as well.

Q. Tell the position and nature of image formed by convex lens in following cases:

(a) When object is beyond $2F_1$.

(b) When object is at $2F_1$.

(c) When object is at F_1.

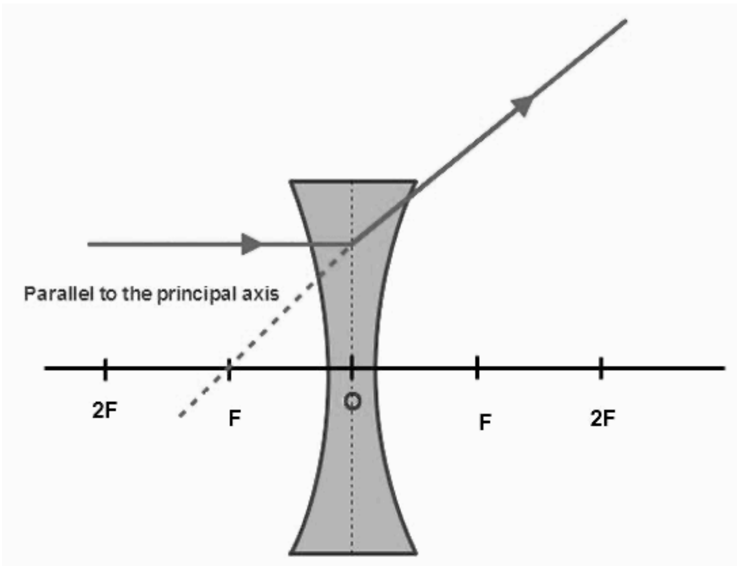
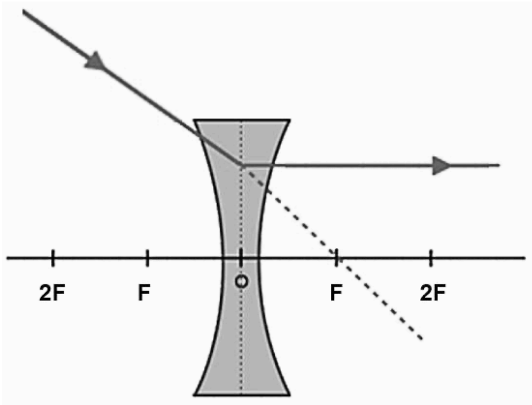
Answer Key

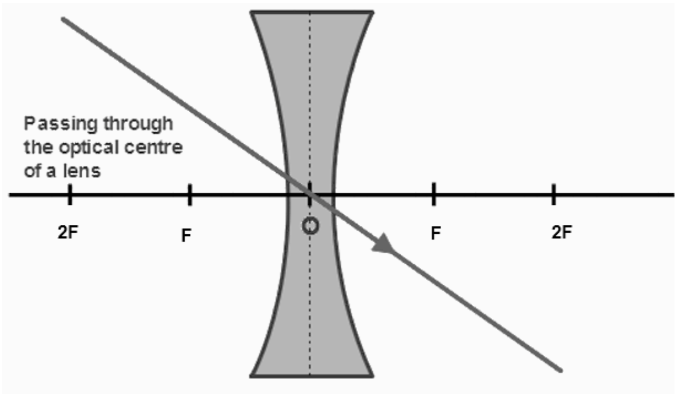
(a) Between 'F_2' and '$2F_2$', Real, inverted.

(b) $2F_2$, Real, inverted.

(c) Infinity, Real, inverted.

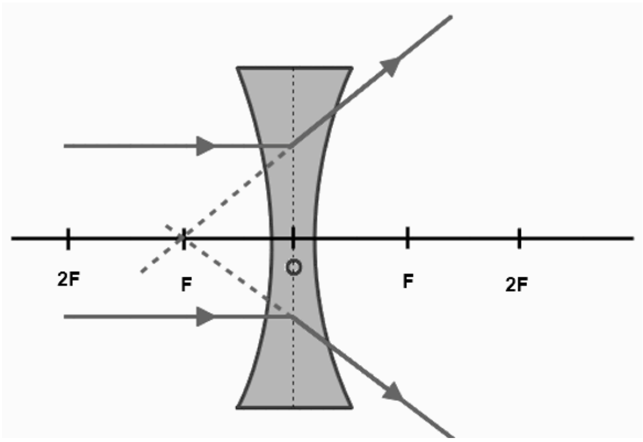
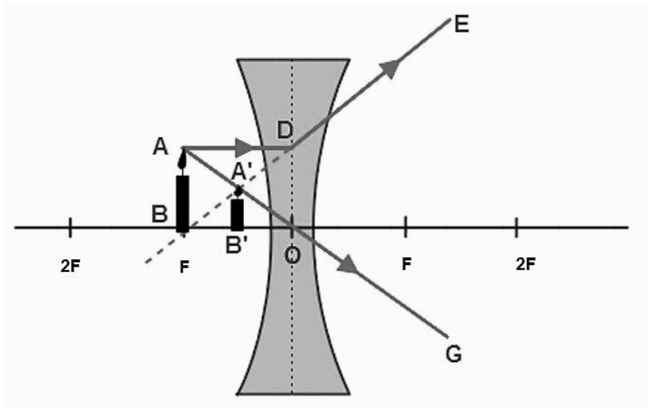
Rules for Image Formation by Concave Lens

(i) A ray of light parallel to the principal axis of the concave lens appears to be coming from focus after refraction through the lens.	
(ii) A ray of light going towards the focus on the other side of the concave lens becomes parallel to the principal axis after refraction through the lens.	

(iii) A ray of light going towards the optical centre of the concave lens will pass undeviated after refraction.	

Ray Diagrams of Images Formed by a Concave Lens

- To make the ray diagram for image formation by a lens any two-incident rays are sent to the lens and the intersection of refracted rays is seen. The intersection point gives the position of the image.
- When an extended object AB is placed at different positions in front of a concave lens then the following cases arise:

(i) When the object is placed at Infinity: **Position -** At **F** on the same side as the object **Nature -** Virtual, erect **Size -** Point sized or highly diminished	
(ii) When the object is placed between Infinity and Optical centre: **Position –** Between object and optical centre **Nature -** Virtual, erect **Size –** Smaller than the object	

Sign convention for Spherical Lenses

- Sign conventions are similar to the ones used for spherical mirrors, except that measurements are taken from the optical center of the lens.

- The focal length of convex lens = Positive
  The focal length of concave lens = Negative

Lens Formula: $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

Magnification of Lens

It is the ratio of the height of the image to the height of the object.

$$m = \frac{\text{Height of image}}{\text{Height of object}}$$

$m = \frac{h_i}{h_o}$

Also, $m = \frac{v}{u}$

Remarks:

If 'm' is negative, the image is real.

If 'm' is positive, the image is virtual.

If $h_i = h_o$ then $m = 1$, i.e., the size of the image is equal to the object.

If $h_i > h_o$ then $m > 1$ i.e., the image is enlarged.

If $h_i < h_o$ then $m < 1$ i.e., image is diminished.

Power of a Lens:

It is defined as the reciprocal of focal length in meter.

The degree of convergence or divergence of light rays is expressed in terms of power.

$$\text{Power} = \frac{1}{\text{focal length (in meter)}}$$

$P = \frac{1}{f}$

SI unit of Power = dioptre = $D \Rightarrow 1D = 1\ m^{-1}$

1 dioptre is the power of a lens whose focal length is one meter

- Power of convex lens = Positive
- Power of concave lens = Negative
- Power $\propto \frac{1}{\text{focal length or thickness}}$

Power of a lenses in combination: $P = P_1 + P_2 + P_3 \ldots\ldots\ldots$

Example:

(1) A concave lens has a focal length of 15 cm. At what distance should the object from the lens be placed so that it forms an image at 10 cm from the lens? Also, find the magnification produced by the lens.

Solution: Since the focal length of the concave lens is negative

Focal length $= f = -15$ cm

An image formed by a concave lens is virtual, erect, and on the same side of the lens as the object.

Hence, the image distance will be negative

Image distance $= v = -10$ cm

Finding object distance

Let the object distance $= u$

$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}\Rightarrow\frac{1}{u}=\frac{1}{(-10)}-\frac{1}{(-15)}$

$\frac{1}{u}=\frac{-1}{10}+\frac{1}{15}\Rightarrow\frac{1}{u}=\frac{-3+2}{30}$

$\frac{1}{u}=\frac{-1}{30}\Rightarrow u=-30\text{ cm}$

The object is placed at a distance of 30 cm

The negative sign indicates that the object is in front of the lens.

Finding Magnification

Magnification of a lens $=\frac{v}{u}=\frac{-10}{-30}=\frac{10}{30}=\frac{1}{3}=+0.33$

(2) Find the power of a convex lens whose focal length is 20cm.

Solution: $P=\frac{100}{f(cm)}$

P = $\frac{100}{20}=5D$

(3) A 2.0 cm tall object is placed perpendicular to the principal axis of a convex lens of focal length 10 cm. The distance of the object from the lens is 15 cm. Find the nature, position, and size of the image. Also, find its magnification.

Solution: Using the lens formula, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ we get

$\frac{1}{v}=\frac{1}{10}-\frac{1}{15}$

$v=30\text{ cm}$

Positive sign of v shows that the image is formed at a distance of 30 cm on the right side of the lens. Therefore the image is real and inverted.

Magnification, $m=\frac{h'}{h}=\frac{v}{u}$

$\frac{h}{2.0}=\frac{+30}{-15}=-2$

$h'=-2\times2=-4\text{ cm}$

Magnification, $m=\frac{v}{u}=\frac{30}{-15}=-2$

Negative sign with the magnification and height of the image shows that the image is inverted and real. Thus, a real image of height of 4 cm is formed at a distance of 30 cm on the right side of the lens. Image is inverted and twice the size of the object.

(1) At what distance from a convex lens of focal length 30 cm, an object should be placed so that the size of the image be $1/2$ of the object.

(2) A convex lens of focal length 25 cm and a coneave lens of focal length 10 cm are joined together. The power of the combination will be.

Answer Key

(1) 90 cm **(2)** 6D

Solved Examples

(1) A lens has the power of - 2.5 D. What is the focal length and nature of the lens?

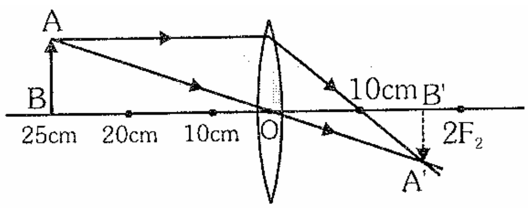
Solution: $\mathbf{P = -2.5D,\ f = ?}$

From relation, $\mathbf{P = \frac{1}{f}}$

$$\mathbf{f = \frac{1}{P} = \frac{1}{-2.5} = -0.4m = -40\ cm}$$

The negative sign indicates that it is a concave lens.

(2) An object 5 cm in length is held 25 cm away from a converging lens of length 10 cm. Draw the ray diagram and find the position, size, and the nature of the image formed.



Solution: $\mathbf{f = +10\ cm}$

$\mathbf{u = -25\ cm}$

Using the lens formula, $\mathbf{\frac{1}{v} - \frac{1}{u} = \frac{1}{f}}$

$$\mathbf{\frac{1}{10} = \frac{1}{v} - \left(\frac{1}{-25}\right) \Rightarrow \frac{1}{v} = \frac{1}{10} - \frac{1}{25}}$$

$$\mathbf{\frac{1}{v} = \frac{3}{50}\ cm \Rightarrow v = \frac{50}{3} = 16.7\ m}$$

The image is real at a distance of $\mathbf{16.7\ cm}$ behind the lens

$$\mathbf{m = \frac{h'}{h} = \frac{v}{u} \Rightarrow \frac{h'}{5} = \frac{50/3}{-25} \Rightarrow h' = \frac{50/3 \times 5}{-25} = -\frac{10}{3}\ cm}$$

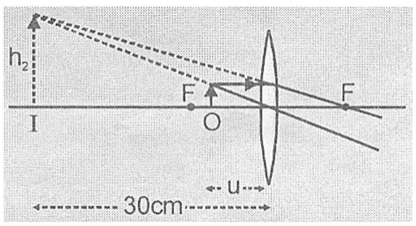
The height of the image is $\mathbf{3.3\ cm}$ in height

(3) A magnifying lens has a focal length of 10cm. **[HOTS]**

(a) Where should the object be if the image is to be 30 cm from the lens?

(b) What will be the magnification?

Solution: (a) In the case of magnifying lenses, the lens is convergent and the image is erect, enlarged, virtual, between infinity and object and on the same side of the lens.



$\mathbf{f = 10\ cm}$ and $\mathbf{v = -30\ cm}$ and hence from the lens formula, $\mathbf{\frac{1}{v} - \frac{1}{u} = \frac{1}{f}}$

we have $\mathbf{\frac{1}{-30} - \frac{1}{u} = \frac{1}{10}}$ i.e., $\mathbf{u = -7.5\ cm}$

So, the object must be placed in front of the lens at a distance of $\mathbf{7.5\ cm}$ (which is $< \mathbf{f}$) from it.

(b) $\mathbf{m = \left[\frac{h_2}{h_1}\right] = \frac{v}{u} = \frac{-3}{-7.5} = 4}$ i.e., the image is erect, virtual, and four times the size of the object.

(4) A needle placed 45 cm from a lens forms an image on a screen placed 90 cm on the other side of the lens. Identify the type of lens and determine its focal length. What is the size of the image, it the size of the needle 5 cm?

Solution: Here, u = - 45 cm, v = 90 cm, f =? h_1 = 5 cm,

$$\mathbf{\because \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{90} + \frac{1}{45} = \frac{1}{f} \Rightarrow \frac{1+2}{90} = \frac{1}{f}}\ \text{or}\ \mathbf{f = 30\ cm}$$

As $\mathbf{f}$ is positive, the lens is converging

$$\mathbf{\because \frac{h_2}{h_1} = \frac{v}{u}\ \therefore\ \frac{h_2}{5} = \frac{90}{-45} = -2 \Rightarrow h_2 = -10\ cm.}$$

Minus sign indicates that the image is real and inverted.

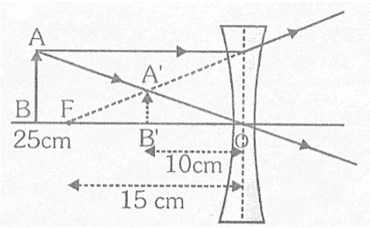
(5) A concave lens of length 15 cm forms an image at 10 cm from the lens. How far is the object placed from the lens? Draw the ray diagram –

Solution: Using the lens formula. $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$$\frac{1}{-10\text{ cm}} - \frac{1}{u} = \frac{1}{-15\text{ cm}}$$

$$\frac{1}{u} = \frac{1}{15} - \frac{1}{10} = \frac{2-3}{30} = -\frac{1}{30} \Rightarrow u = -30\text{ cm}$$

Thus, the object is placed at a distance of 30 cm from the concave lens.



(6) Light enters from air to glass having a refractive index of 1.50. What is the speed of light in the glass? The speed of light in a vacuum is 3 × 10⁸m/s.

Solution: Refractive index

$\mu_g = 1.5$

Speed of light in vacuum c = 3×10^8 m/s

Speed of light in the glass, v =?

$$\mu_g = \frac{c}{v} \Rightarrow v = \frac{c}{\mu_g} = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 \text{ m/s}$$

(7) Light enters from air to a medium having a refractive index of 1.25. What is the speed of light in the glass? The speed of light in vacuum is 3×10^8m/s.

Solution: Refractive index $\mu_g = 1.25$

Speed of light in vacuum c = 3×10^8 m/s

Speed of light in the glass, v =?

$$\mu_g = \frac{c}{v}$$

$$v = \frac{c}{\mu_g} = \frac{3 \times 10^8}{1.25} = 2.4 \times 10^8 \text{ m/s}$$

(8) Find the focal length of a lens of power - 2.0 D. What type of lens is this?

Solution: Here, focal length f = ? power P = - 2 .0 D

As $f = \frac{100}{P}$

$$\therefore f = \frac{100}{-2.0} = -50\text{ cm}$$

(9) Two thin lenses of power + 4D and – 2D are in contact. What is the focal length of the combination? [HOTS]

Solution: $P = P_1 + P_2 = 4 + (-2) = +2D$

Since focal length $f = \frac{1}{P}$

$$\therefore f = \frac{1}{2} = 0.5\text{ m} = 50\text{ cm}$$

(10) Refractive index of diamond is 2.5 and that of glass is 1.5. Calculate the refractive index of diamond with respect to glass.

Solution: Refractive index of glass, $\mu_g = 1.5$

Refractive index of diamond, $\mu_d = 2.5$

From relative refractive index

$${}^g\mu_d = \frac{\mu_d}{\mu_g} = \frac{2.5}{1.5} = 1.667$$

Exercise

OBJECTIVE TYPE QUESTIONS

(1) A ray of light travelling in the air falls obliquely on the surface of a calm pond. It will

(A) go into the water without deviating from its path

(B) deviate away from the normal

(C) deviate toward the normal

(D) turn back on its original path

(2) A ray of light goes from a medium of refractive index μ_1 to a medium of refractive index μ_2. The angle of incidence is i and the angle of refraction is r. Then, $\frac{\sin i}{\sin r}$ is equal to

(A) μ_1

(B) μ_2

(C) $\frac{\mu_1}{\mu_2}$

(D) $\frac{\mu_2}{\mu_1}$

(3) A thin lens and a spherical mirror have a focal length of +15 cm each.

(A) both are convex.

(B) the lens is convex and the mirror is concave.

(C) the lens is concave and the mirror is convex.

(D) both are concave.

(4) A convex is

(A) is thicker in the middle than at the edges

(B) is thicker at the edges than in the middle

(C) is uniform thickness everywhere

(D) is called a diverging lens

(5) A convex lens forms a virtual image when an object is placed at a distance of 18 cm from it. The focal length must be

(A) greater than 36 cm

(B) greater than 18 cm

(C) less than 36 cm

(D) less than 18 cm

(6) An object is placed before a convex lens. The image formed

(A) is always real

(B) may be real or virtual

(C) is always virtual

(D) is always erect

(7) An object is placed before a concave lens. The image formed

(A) is always erect

(B) may be erect or inverted

(C) is always inverted

(D) is always real

(8) A lens has a power of +0.5 D. If is

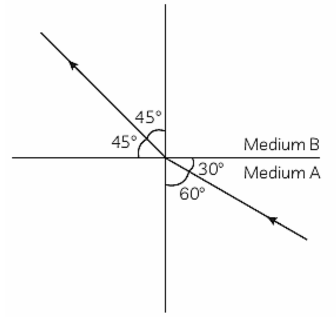
(A) a concave lens of focal length 5 m

(B) a convex lens of focal length 5 cm

(C) a convex lens of focal length 2 m

(D) a concave lens of focal length 2 m

(9) The figure shows a ray of light travels from medium A to medium B. The refractive index of the medium B relative to medium A is: [CBSE 2013]



(A) $\frac{\sqrt{3}}{\sqrt{2}}$

(B) $\frac{\sqrt{2}}{\sqrt{3}}$

(C) $\frac{1}{\sqrt{2}}$

(D) $\sqrt{2}$

(10) The refractive index of medium A is 1.5 and that of medium B is 1.33. If the speed of light in air is $3 \times 10^8\ \mathrm{m/s}$, what is the speed of light in medium A and B respectively? [CBSE 2022]

(A) $2 \times 10^8\ \mathrm{m/s}$ and $1.33 \times 10^8\ \mathrm{m/s}$

(B) $1.33 \times 10^8\ \mathrm{m/s}$ and $2 \times 10^8\ \mathrm{m/s}$

(C) $2.25 \times 10^8\ \mathrm{m/s}$ and $2 \times 10^8\ \mathrm{m/s}$

(D) $2 \times 10^8\ \mathrm{m/s}$ and $2.25 \times 10^8\ \mathrm{m/s}$

(11) A converging lens forms a three-times magnified image of an object, which can be taken on a screen. If the focal length of the lens is $30\ \mathrm{cm}$, then the distance of the object from the lens is [CBSE 2022]

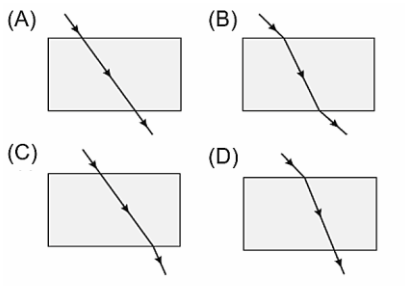
(A) $-55\ \mathrm{cm}$

(B) $-50\ \mathrm{cm}$

(C) $-45\ \mathrm{cm}$

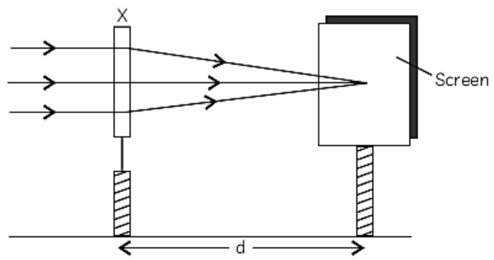
(D) $-40\ \mathrm{cm}$

(12) The path of a ray of light coming from air passing through a rectangular glass slab is traced by four students shown as A, B, C, and D in the figure. Which one of them is correct? [CBSE 2011, 13]



(13) A student determined the focal length of a device 'X' by focusing a bright distant object on the screen as shown in the diagram: [CBSE 2017]

According to the diagram, select the correct statement from the following:



(A) Device '$\mathbf{X}$' is a concave mirror and distance '$\mathbf{d}$' is its focal length.

(B) Device '$\mathbf{X}$' is a concave mirror and distance '$\mathbf{d}$' is its radius of curvature.

(C) Device '$\mathbf{X}$' is a convex lens and distance '$\mathbf{d}$' is its focal length.

(D) Device '$\mathbf{X}$' is a convex lens and distance '$\mathbf{d}$' is its radius of curvature.

(14) If a lens can converge the sun rays at a point $20\ \mathrm{cm}$. away from its optical centre, the power of this lens is - [CBSE 2022]

(A) + 2D

(B) $-2\mathrm{D}$

(C) $+5\mathrm{D}$

(D) $-5\mathrm{D}$

(15) **A student experiments tracing the path of a ray of light through a rectangular glass slab for two different values of angle of incidence $\angle i = 30^\circ$ and $\angle i = 45^\circ$. In the two cases, the student is likely to observe the set of values of angle of refraction and angle of emergence as** **[CBSE 2017]**

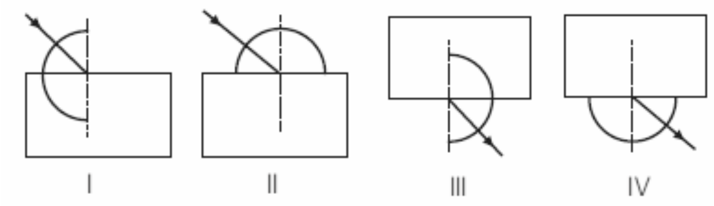
(A) $\angle \mathbf{r} = \mathbf{30}^\circ, \angle \mathbf{e} = \mathbf{20}^\circ$ and $\angle \mathbf{r} = \mathbf{45}^\circ, \angle \mathbf{e} = \mathbf{28}^\circ$

(B) $\angle \mathbf{r} = \mathbf{30}^\circ, \angle \mathbf{e} = \mathbf{30}^\circ$ and $\angle \mathbf{r} = \mathbf{45}^\circ, \angle \mathbf{e} = \mathbf{45}^\circ$

(C) $\angle \mathbf{r} = \mathbf{20}^\circ, \angle \mathbf{e} = \mathbf{30}^\circ$ and $\angle \mathbf{r} = \mathbf{28}^\circ, \angle \mathbf{e} = \mathbf{45}^\circ$

(D) $\angle \mathbf{r} = \mathbf{20}^\circ, \angle \mathbf{e} = \mathbf{20}^\circ$ and $\angle \mathbf{r} = \mathbf{28}^\circ, \angle \mathbf{e} = \mathbf{28}^\circ$

(16) **In which of the following diagrams has the protractor (D) been correctly placed to measure the angle of incidence and the angle of emergence?** **[CBSE 2017]**



(A) I, III
(B) I, IV
(C) II, III
(D) II, IV

Answer Key

(I) OBJECTIVE TYPE QUESTIONS

(1)	(C)	**(6)**	(B)	**(11)**	(D)	**(16)**	(A)
(2)	(D)	**(7)**	(A)	**(12)**	(B)		
(3)	(A)	**(8)**	(C)	**(13)**	(C)		
(4)	(A)	**(9)**	(A)	**(14)**	(C)		
(5)	(B)	**(10)**	(D)	**(15)**	(C)		