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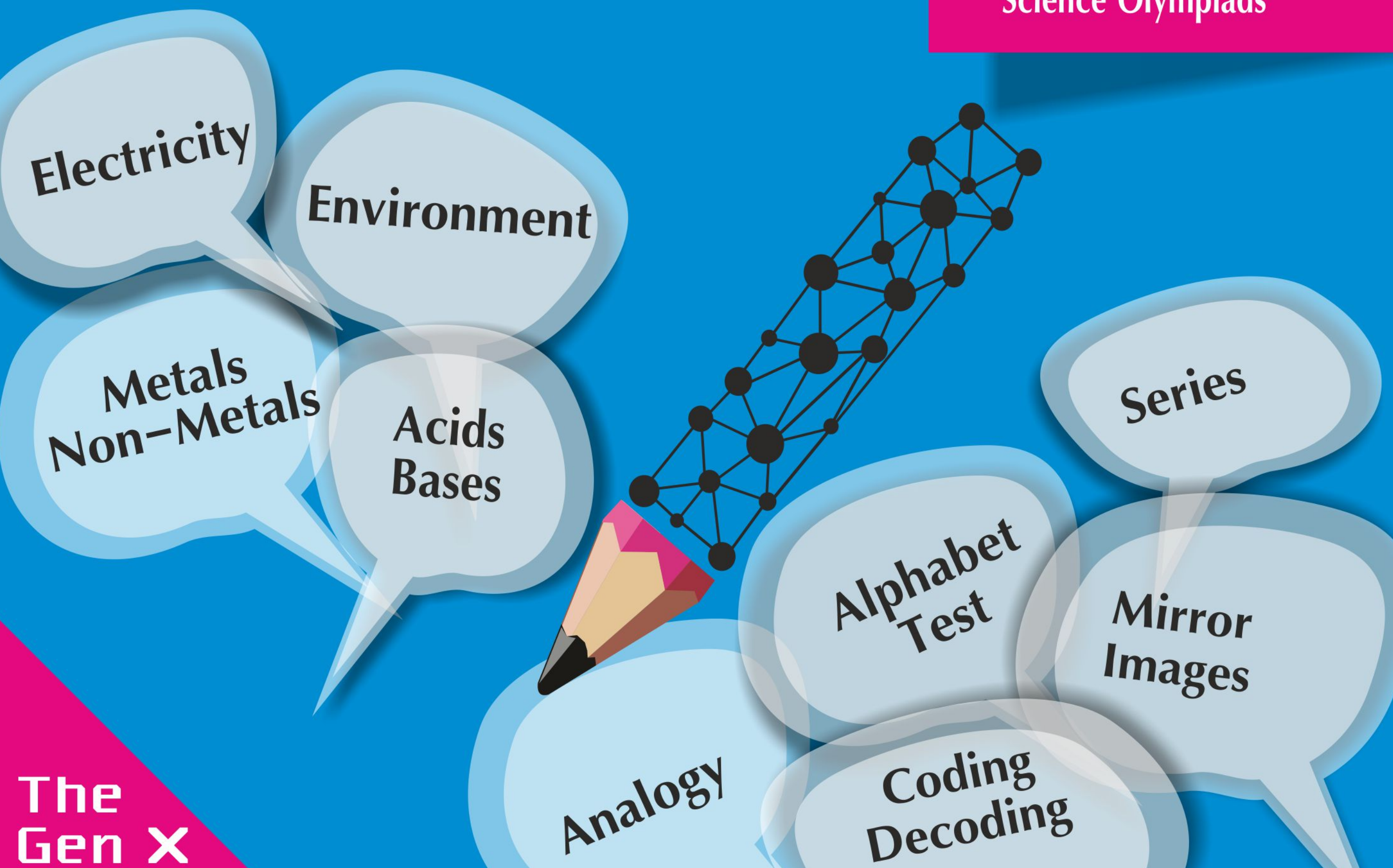
SCIENCE OLYMPIAD

National Science Olympiad

10

Strictly according to the latest syllabus of Science Olympiads



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NATIONAL SCIENCE OLYMPIAD

Exploring the World of Science

Class 10

Preeti Agarwal

V&S PUBLISHERS

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Publisher's Note

V&S Publishers, after the grand success of a number of Academic and General books, is pleased to bring out a series of *Science Olympiad books* under *The Gen X series – generating Xcellence in generation X* – which has been designed to focus on the problems faced by students. In all books the concepts have been explained clearly through various examples, illustrations and diagrams wherever required. Each book has been developed to meet specific needs of students who aspire to get distinctions in the field of science and want to become Olympiad champs at national level.

To go through Science Olympiads, students need to do thorough study of topics covered in the *Olympiad syllabus and the topics covered in the school syllabus as well*. The Olympiads not only tests subjective knowledge but Reasoning skills of students also. So the students are required to comprehend the depth of concepts and problems. The Olympiads check efficiency of candidates in problem solving. These exams are conducted in different stages at regional, and national levels. At each stage of the test, a candidate should be fully prepared to go through the exam. Therefore, this test requires careful attention towards comprehension of concepts, thorough practice, and application of concepts and rules.

While other books in market focus selectively on questions or theory; V&S Science Olympiad books are rather comprehensive. Each book has been divided into five sections namely *Science, Logical Reasoning, Achievers section, Subjective section, and Model Papers.* The theory has been explained through solved examples. To enhance problem solving skills of candidates, *Multiple Choice Questions (MCQs)* with detailed solutions are given at the end of each chapter. Two *Mock Test Papers* have been included to understand the pattern of exam. A CD containing Study Chart for systematic preparation, Tips & Tricks to crack Science Olympiad, Pattern of exam, and links of Previous Years Papers is accompanied with this book. The books are also useful for various other competitive exams such as NTSE, NSTSE, and SLSTSE as well.

We wish you all success in the examination and a very bright future in the field of science.

All the best

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Section 1

Science

1

Light

Learning Objectives

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- ❒ Reflection, its Types and Laws of Reflection
- ❒ Plane Mirrors and its Characteristics
- ❒ Spherical Mirrors – Convex and Concave
- ❒ Image Formation by Concave and Convex Mirrors
- ❒ Use of Mirrors, Mirror Formula, Linear Magnification
- ❒ Refraction of Light, Laws of Refraction of Light
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Light

It is a form of radiant energy which produces sensation in eyes and makes us able to see the object around us. Whenever light falls on an object, it gets reflected by the object and received by our eyes, therefore enable us to see that object.

Dual Property of Light

Light exhibits two properties, known as dual property. These are:

Wave Nature: Light is electromagnetic waves which do not require any medium to travel.

Particle Nature: Light travels in a straight line and cannot pass through the opaque object or any other barrier. Reflection and refraction also shows the particle nature of light.

Reflection of Light

Whenever a light falls on a polished surface such as mirror, it gets reflected back in the same plane from where it is incidented. This **bouncing back of light, after striking a polished surface, is called reflection of light.**

An object placed in the dark cannot be seen as there is no light incident on the object that gets reflected back to our eyes to make it visible.

Silver is considered as one of the best reflector of light as it reflects most of the light falling on it.

Types of Reflection

In reflection, path of light rays changes without any change in the medium.

Regular reflection

When the reflecting surface is smooth and well polished, the parallel incident rays falling on it are reflected back in the same medium with all the reflected rays parallel to each other. This is called regular reflection.

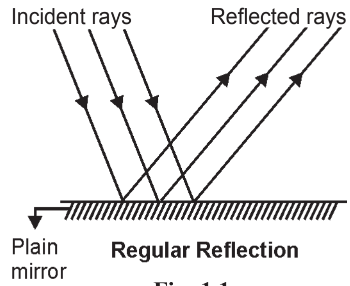


Fig: 1.1

Irregular reflection

When the reflecting surface is rough, the parallel rays falling on it gets reflected in different directions, such a reflection is called diffuse reflection or irregular reflection and sometimes called scattering of light.

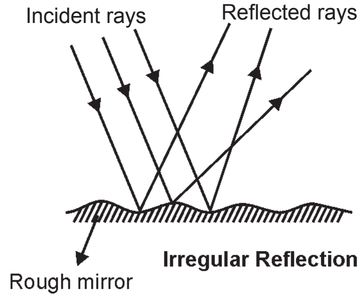


Fig: 1.2

Key Note: Any object in a room can be seen from all parts of the room. This is because surface of the object is rough and it scatters or reflects light in all the directions.

Laws of Reflection of Light

First law

According to the first law of reflection, the incident ray, the reflected ray and the normal (at the point of incidence), all lie in the same plane.

PP′ – Plane mirror

AO – Incident ray

OB – Reflected ray

ON – Normal to the mirror at O.

AO, OB and ON lie in the plane of the paper

$\angle AON = \angle i$ = Angle of incidence

$\angle NOB = \angle r$ = Angle of reflection

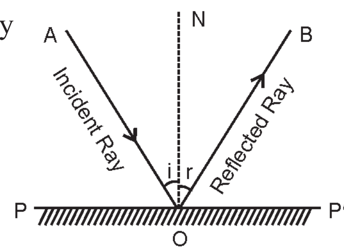


Fig: 1.3

Second law

According to the second law of reflection, the angle of incidence (*i*) is always equal to angle of reflection (*r*).

Note: When a ray of light is falling perpendicularly (normally) on a mirror, $\angle i = 0°$. It means, the reflected ray would also go along the normal itself. Thus, $\angle i = \angle r = 0°$. It means that a ray of light incident normally on the mirror, retraces its path on reflection.

Types of Mirrors

- Plane Mirror
- Spherial Mirror

Plane Mirrors

- When a ray of light emerging from a point A, after reflection from a mirror, **meet actually at another point B,** then the point B is called *real image* of the point A.
- When rays of light starting from a point A, after reflection from the mirror, **appear to come from another point B,** then the point B is called *virtual image* of the point A.
- In a plane mirror, the image of a real object is always:
  - Virtual
  - Erect
  - Of same size as the object
  - As far behind the mirror as the object in the front of the mirror
  - Laterally inverted.

Spherical Mirrors

A spherical mirrors is that mirror whose reflecting surface is a part of a hollow sphere of glass. One side of the mirror is well polished and reflecting; and other side of the mirror is opaque (often pointed red). There are two types of spherical mirrors.

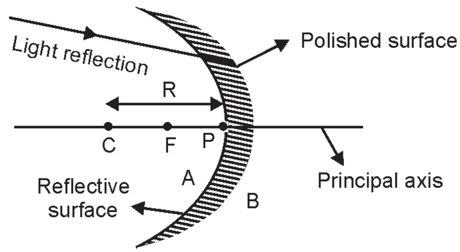


Fig: 1.4

Concave mirror

It is the mirror which is curved inwards. In this mirror, **reflecting surface is towards the centre of the sphere,** i.e. reflection of light occurs from concave surface or the **bent in surface A.** Surface B is opaque. It converges the ray of light falling on its surface at a point on the surface.

C is the centre of curvature and CP is the radius of curvature (R). F is the focal points, mid way between the centre of curvature and pole of the mirror.

$$FP = F, CP = 2F = R$$

Concave mirror is converging: The principal focus of a concave mirror is a point on the principle axis of the mirror, at which rays of light incident on the mirror in a direction parallel to the principle axis, actually meet after reflection from the mirror. The principal focus F of a concave mirror is a *real point.* It always lies in front of the concave mirror.

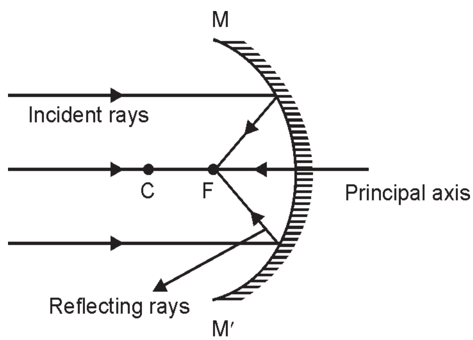


Fig: 1.5

Convex mirror

It is curved outward and the reflecting surface is away from the centre of the sphere *i.e.*, reflection of light occurs at bulging out surface 'A' and the inner surface 'B' is opaque. This mirror is also known as diverging mirror. The centre of curvature does not lay on the mirror, it lies infront of the concave mirror and behind the convex mirror. Pole P is defined as the centre of the mirror. The centre of curvature C, focal point F and pole P lies on the imaginary line passing through the mirror which is principle axis.

$$PF = \text{focal length } F$$

$$PC = \text{radius } R = 2F$$

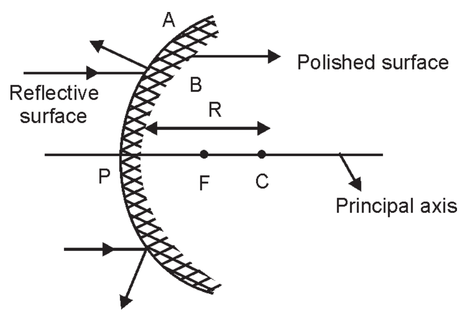


Fig: 1.6

Convex mirror is diverging: The principal focus of a convex mirror is a point on the principal axis of the mirror, from which rays of light incident on the mirror in a direction parallel to the principal axis, appear to diverge, after reflecting from the mirror. When the diverging reflected rays are produced back by dotted lines, they appear to meet at F. The principal focus of a convex mirror is a *virtual point*.

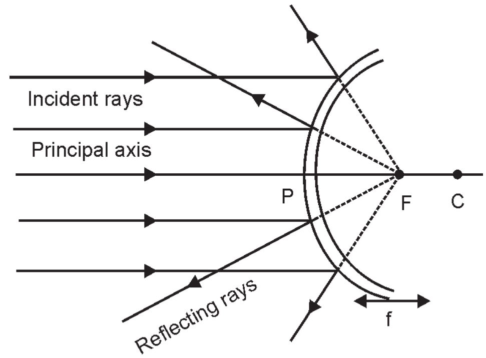


Fig: 1.7

Key Note: **(i)** The reflected rays appear to diverge from F. Thus it is called diverging mirror. It can be assumed as the outer surface of spoon.

(ii) As a concave mirror converges the parallel beam of light falling on it, therefore it is called a converging mirror. The inner surface of a silver spoon can be assumed as a converging mirror.

Rules for Tracing Image Formed by Concave Mirrors

Rule 1: A ray of light falling on a concave mirror in a direction parallel to the principal axis of the mirror, passes actually through the principal focus of the mirror after reflection.

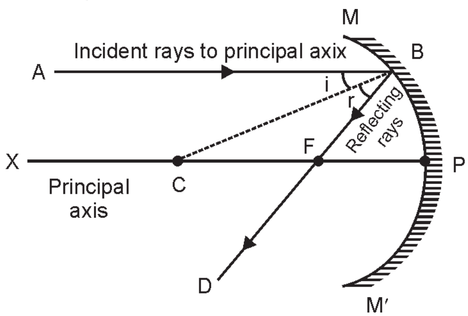


Fig: 1.8

A ray of light AB falls on the concave mirror MM', having principal axis XP and focal point F, in a direction parallel to XP. After reflection, it passes through F. Thus BFD is the reflected ray.

Rule 2: A ray of light incident on a concave mirror on passing through the centre of curvature of the mirror is reflected back along the same path *i.e.*, such a ray retraces its path in reverse direction.

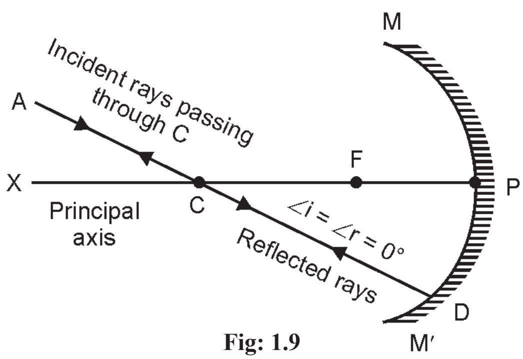


Fig: 1.9

A ray of light AD passing through C strikes the mirror MM' at D, normally and perpendicularly. It is reflected by the mirror along the same path i.e., DCA.

Rule 3: A ray of light incident on a concave mirror on passing through of focus of the mirror becomes parallel to the principal axis of the mirror after reflection.

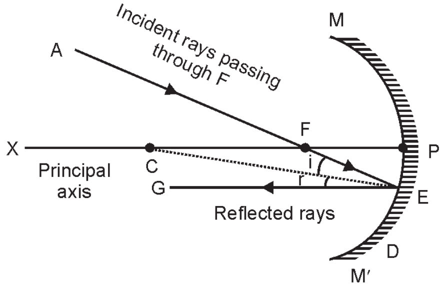


Fig: 1.10

AE is a ray, passing through the focus F of the concave mirror MM' and striking the mirror at E, reflect along EG in a direction parallel to principal axis XP.

Rule 4: A ray of light incident obliquely towards the pole P of concave mirror is reflected obliquely as per the laws of reflection such that angle of incidence equals angle of reflection.

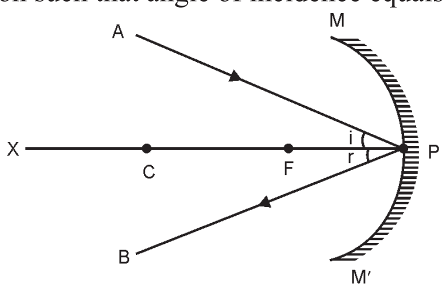


Fig: 1.11

A ray of light AP is incident obliquely on the concave mirror at $\angle APX = i$. *This ray is reflected along PB at* $\angle XPB = r$ *such that* $\angle i = \angle r$.

Image Formation by a Concave Mirrors

The type of image formed by a concave mirror depends chiefly on the position of the object in front of the mirror. The position of image is obtained by intersection of at least two of the reflected rays.

Case 1: When the object is at infinity: When an object is at a very large distance from a concave mirror, it is said to be at infinity.

In this figure, AB is an object placed very far off from the mirror. Two rays AD and AP from the top of the object A are parallel to one another and inclined to the principal axis. These rays are reflected at points D and P on the mirror and intersect at a point A′, which is the real image of the top A of the object. Therefore, A′B′ is the inverted image of an object AB at infinity. **This image is formed at the principal focus F; is real and inverted; and is much smaller in size than the actual object.**

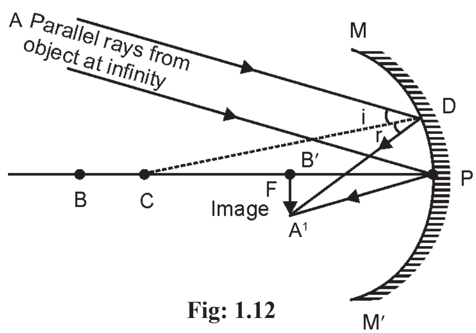


Fig: 1.12

Case 2: **When the object is beyond the centre of curvature:** The figure shows two rays starting from the top end A of the object AB placed beyond the centre of curvature C of the mirror on the principal axis. One ray AD incident at point D, parallel to the principal axis, reflects at focus F of the mirror MM′. The second ray AE passes through the centre of curvature C of the mirror, falling normally on it, retraces its path of reflection. The two reflected rays intersect at A′ which is the real image of A. To get the complete image, we draw A′B′. **The image is real and inverted; smaller in size than the object; and is lying between the focus F and centre of curvature C of the mirror.**

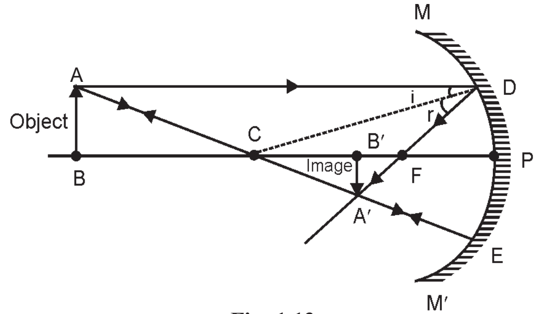


Fig: 1.13

Case 3: **When the object is at the centre of curvature:** The object AB is held at the centre of curvature C of concave mirror MM′. **The image formed by intersection of two reflected rays is real and inverted; at the centre of curvature of the mirror; and of the same size as the object; at the centre of curvature of the mirror; and of the same size as the object (AB = A′B′).**

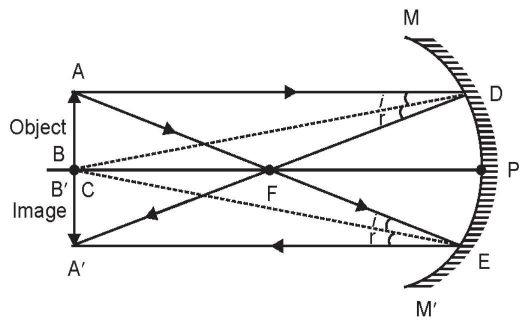


Fig: 1.14

Case 4: **When the object lies between centre of curvature and focus of mirror :** In the figure, object AB is held between focus F and centre of curvature C of concave mirror MM′, in direction perpendicular to the principal axis of the mirror.

We find that when an object is placed between C and F of concave mirror, **the image formed is real and inverted; larger in size than the object; and situated beyond C.**

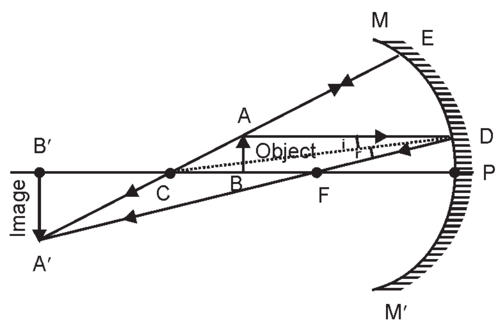


Fig: 1.15

Case 5: **When the object is at the focus of concave mirror:** Object AB is positioned at point B on the principal axis perpendicular to it. A ray of light AD falling on the mirror in the direction parallel to the principal axis is reflected at D and passes through the focus F of the mirror. Another ray of light starting from A is incident on the mirror along AE and passes through the centre of curvature C of the mirror. As their rays falls normally on the mirror, it retraces its path on reflection at E. The two reflected rays DBG and EACH are parallel to each other and would meet at very far off point, say infinity. **The image formed is at infinity is; real and inverted; and is highly enlarged.**

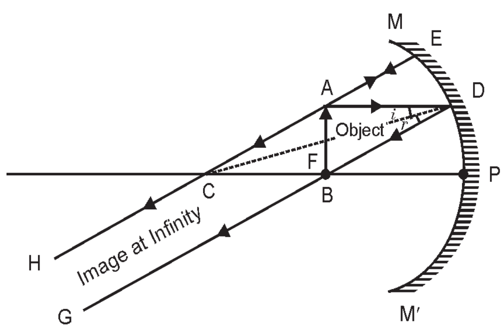


Fig: 1.16

Case 6: **When the object is held between focus of pole of the mirror:** In the figure is shown two reflected rays DF and EAC diverge and cannot meet in reality. However, when these two reflected rays are produced back, they appear to come from point A´. Therefore, A´ is the virtual image of A. To get complete image, draw A´B´ perpendicular to the principal axis. **The image formed is virtual and erect; is larger than the size of the object; and is behind the mirror.**

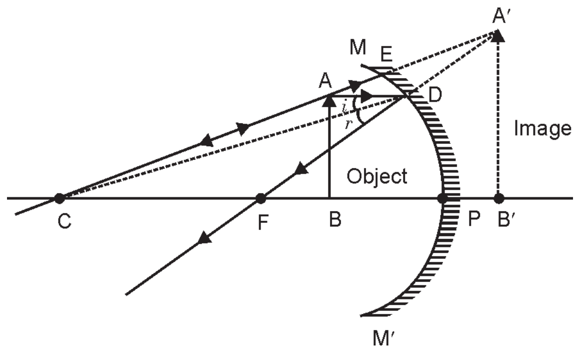


Fig: 1.17

Position of the object	Position of the image	Size of the image	Nature of the image
At infinity	At F	Highly diminished	Real and inverted
Beyond C	Between F and C	Diminished	Real and inverted
At C	At C	Same size	Real and inverted
Between C and F	Beyond C	Enlarged	Real and inverted
At F	At infinity	Highly enlarged	Real and inverted
Between F and P	Behind the mirror	Enlarged	Virtual and erect

Uses of Concave Mirror

- A concave mirror is used as a reflector in search light, torches, head lights of motor vehicles etc.
- A concave mirror is used a doctor's head mirror to focus light on body parts like eyes, nose, throat to be examined.
- A concave mirror is also used us a shaving mirror, as it can form an erect and magnified image of the face. It is also used as makeup mirror.
- Large concave mirrors are used in solar cookers and in reflecting type telescopes.
- The dentists use concave mirrors to observe large images of the teeth of patients.

Rules for Tracing Images Formed by a Convex Mirror

Rule 1: A ray of light falling on the convex mirror in a direction **parallel to the principal axis** of the mirror **appears to be coming from its focus after reflection from the mirror.**

Rule 2: A ray of light falling on a convex mirror **on passing through the centre of curvature** of the mirror is **reflected back along the same path** *i.e.*, retraces its path on reflection.

Rule 3: A ray of light falling on convex mirror **on passing through the focus** of the mirror becomes **parallel to the principle axis** after reflection.

Rule 4: A ray of light **incident obliquely towards the pole P** of a convex mirror is reflected obliquely such that the incident and reflected rays make equal angles $\angle \mathbf{i} = \angle \mathbf{r}$ **with the principal axis.**

We can observe these four rules in the image formation process for a convex mirror.

Image Formation by a Convex Mirror

Case 1: **When the object is placed at infinity:** An object is placed at infinity, *i.e.*, at far distance in front of the mirror, **the image formed is highly diminished, pointed virtual and erect.**

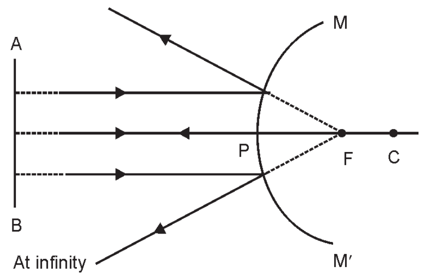


Fig: 1.18

Case 2: When the object is at finite distance from the mirror: AB is an object kept in front of the convex mirror at some distance. A parallel ray AD reflected along. DE on producing back appears to emerge from F. An incident ray AG, tending to pass through C, retraces its path on reflection at G. The two reflected ray DE and GA when produced back appears to intersect at A′ between P and F. Therefore, A′ is the virtual image of point A. **The image formed is diminished virtual and erect.**

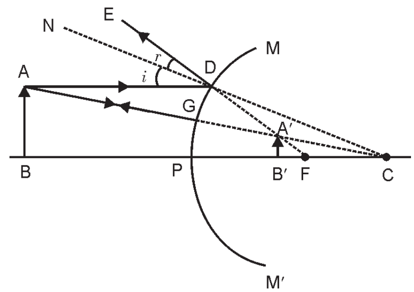


Fig: 1.19

Uses of a Convex Mirror

- It is used as a reflector in street lamps. Light from the lamp diverges over a large area.
- It is used in cars, buses and trucks as a rear view mirror. These mirrors are fitted on the sides of the vehicle enabling the driver to see traffic behind for safe driving.

Mirror Formula

The formula which gives us a relation between the object distance (u) image distance (v) and focal length (f) is called the mirror formula.

This formula can be written as

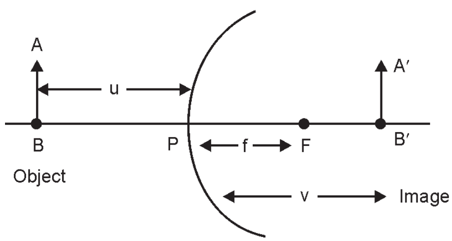


Fig: 1.20

$$\frac{\mathbf{1}}{\textbf{Object distance}} + \frac{\mathbf{1}}{\textbf{image distance}} = \frac{\mathbf{1}}{\textbf{Focal lenght}}$$

i.e., $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

All these distances are measured from the centre of the mirror at pole P on the principal axis.

If R is the radius of curvature of the spherical mirror, then

$$f = \frac{R}{2}$$

$$\therefore \quad \frac{1}{u} + \frac{1}{v} = \frac{2}{R}$$

This formula is valid in all situation for all types of spherical mirror for all positions of the object. Always remember the New Cartesian Sign conventions which says all distances to the left of the mirror are negative and to the right of the mirror are positive. Distances above the principal axis are positive and below the axis are negative.

***Example* 1:** An object 4 cm in size is placed at a distance of 25 cm from a concave mirror of focal length 15 cm. Find the nature and position of the image.

***Solution*:**

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

$$f = -15 \text{ cm}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\Rightarrow \quad \frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{(-15)} - \frac{1}{(-25)} = \frac{-5+3}{75} = \frac{2}{75}$$

$$\therefore \quad v = \frac{75}{-2} = -37.5 \text{ cm.}$$

Thus image is formed at distance 37.5 cm from the mirror, in front of the mirror as v is negative. Image formed is real and inverted.

Linear Magnification Produced by a Spherical Mirror

Magnification can be defined as the extent to which an image can be enlarged, or diminished by a mirror. The linear magnification produced by a spherical mirror is defined as 'the ratio of height of the image (h_2) to the height of the object (h_1), represented by m.'

$$\text{Linear magnification (m)} = \frac{\text{height of image } (h_2)}{\text{height of image} (h_1)}$$

$$m = \frac{h_2}{h_1}$$

Case 1: When the image is magnified or enlarged, size of image is greater than the size of the object *i.e.*, $h_2 > h_1$ or $m > 1$.

Case 2: When image is of the same size as that the object *i.e.*, $h_2 = h_1$ or $m = 1$.

Case 3: When image is smaller than the object *i.e.*, $h_2 < h_1$ or $m < 1$.

Sign of linear magnification

Case 1: When the image is real, it is inverted *i.e.*, the image lies below the principal axis *i.e.*, h_2 is negative. Height of the object is always positive. Therefore, $m = \frac{h_2}{h_1}$ is negative. Thus, we can say **when linear magnification is negative, the image formed by spherical mirror must be real and inverted.**

Case 2: When the image is virtual, it is erect *i.e.*, the image lies above the principal axis and h_2 is positive. Therefore, $m = \frac{h_2}{h_1}$ is also positive. Thus we can say that **When linear magnification is positive, the image formed by spherical mirror is virtual and erect.**

Linear magnification is also related to the object distance (u) and the image distance (v) as

$$m = -\frac{v}{u}$$

***Example* 2:** A converging mirror forms a real image of height 4 cm of an object of height 1 cm placed 20 cm away from the mirror. Calculate the image distance and the focal length of the mirror.

***Solution*:** $h_2 = -4$ cm (image is real *i.e.*, inverted below axis)

$$h_1 = +1 \text{ cm}, u = -20 \text{ cm}$$

$$m = \frac{h_2}{h_1} = -\frac{v}{u}$$

$$\Rightarrow \frac{-4}{1} = \frac{-v}{-20} \Rightarrow v = -80 \text{ cm}$$

Negative sign of the v indicates that the image is on the side of the object and must be real and inverted.

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \Rightarrow \frac{1}{f} = \frac{1}{-20} + \frac{1}{-80} = \frac{-4-1}{80} = \frac{-5}{80} = \frac{-1}{16}$$

$$f = -16 \text{ m.}$$

Negative sign of f indicates that the mirror is concave.

***Example* 3:** The image formed by a convex mirror of focal length 20 cm is a quarter of the object. What is the distance of the object from the mirror ?

***Solution*:** $f = 20 \text{ cm}, m = \frac{h_2}{h_1} = \frac{-v}{u} = \frac{1}{4}\left[h_2 = \left(\frac{1}{4}\right)h_1 \text{ given}\right]$

Or $\quad v = \frac{-u}{4} \Rightarrow \frac{1}{v} = \frac{-4}{u}$

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{u} + \left(\frac{-4}{u}\right) = \frac{-3}{u}$$

$$\Rightarrow \quad \frac{1}{20} = \frac{-3}{u} \Rightarrow u = -60 \text{ cm.}$$

Refraction of Light

The change in the direction of light in going from one transparent medium to another is called refrection of light. This phenomenon of refraction occurs right at the boundary of the two mediums. Thus, when light travels from air to glass, glass to water, water to air, etc. each time the ray undergoes refraction. This we can show with the help of a glass slab placed in the air.

The diagram shows a glass slab ABCD placed on a table. A light ray EF has entered from a rarer medium (air) to denser medium (glass) at point O at an angle of incidence i_1 to the normal NN′. At O the light ray has bent towards the normal making an angle of refraction r_1.

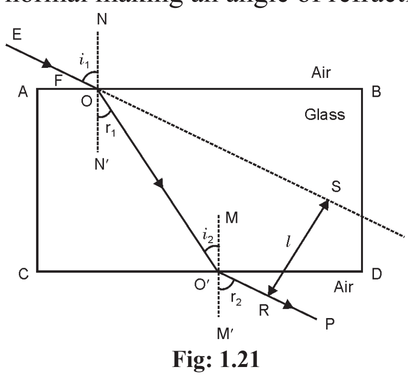


Fig: 1.21

This refracted ray now passes from denser medium (glass) to the rare medium (air) at O′ at an angle i_2 and refracted away from the normal MM′ at angle r_2.

EO is the incident ray, OO′ is the refracted ray, and O′P is the emergent ray. You may observe that emergent ray is parallel to the incident ray. The extent of bending of the light ray at the opposite parallel faces AB and CD of a rectangular glass slab is equal and opposite. In case of refraction, $\angle i$ is never equal to $\angle r$.

Why does Refraction Happens?

Refraction is due to **change in speed of light** as it enters from one transparent medium to another. This change in speed is due to the difference in the density of the two medium. The medium in which the speed of light is more is called the **rarer medium** and the medium in which the speed of light is less is called the **denser medium.**

Lateral displacement

When the light goes from rarer to denser medium, it bends towards the normal; and when it goes from denser to the rarer medium, it bends away from the normal. **The distance between the emergent ray and the original direction of ray of light (RS as shown in Fig. 1.21) is called the lateral displacement.**

Laws of Refraction of Light

Law 1: The incident ray, the refracted ray and normal all lie in the same plane.

Law 2: The ratio of sine of angle of incidence to the sine of angle of refraction is always a constant for the two given medium, in which refraction takes place.

$\frac{\text{Sin i}}{\text{Sin r}} = \text{constant} = \mu;$ Refractive index can also be represented as n_2

This constant is called the **refractive index.** This law is known as the **Snell's Law.**

- When light goes from one medium to another, the value of refractive index is called the **relative refractive index.**
- If the light is going from vacuum to another medium, the value of refractive index in called **absolute refractive index**.
- An object with greater refractive index is **optically denser** than another object having smaller refractive index.

Law 3: Whenever light goes from one medium to another, the frequency of light does not change. However, the velocity of light and the wavelength of light change.

Velocity of light and refractive index

The refractive index can be linked to the relative speed of propagation of light in different media. Light travels fastest in vacuum with speed of 3×10^8 ms^{-1}. Speed of light in water is 2.25×10^8 ms^{-1}. Speed of light in glass is 2×10^8 ms^{-1}. Therefore, air is optically a rarer medium compared to both water and glass. Glass is optically denser than air and water.

Absolute refractive index of a medium is defined as the ratio of speed of light in vaccum to the speed of light in the medium, represented by n.

$$n = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}} = \frac{C}{v}$$

$$n = \frac{C}{v}$$

$$n_{glass} = \frac{C}{v_{glass}} = \frac{3 \times 10^8 \text{ ms}^{-1}}{2 \times 10^8 \text{ ms}^{-1}} = 1.5$$

$$n_{water} = \frac{C}{v_{water}} = \frac{3 \times 10^8\ ms^{-1}}{2.25 \times 10^8\ ms^{-1}} = \frac{4}{3} = 1.33$$

A medium with higher value of n is said to be optically denser compared to a medium with lower value of n.

$$n = \frac{C}{v} \Rightarrow \boxed{v = \frac{C}{n}}$$

Larger the value of n, small is the value of v. It means in a denser medium, speed of light is lower than in a rare medium.

Key Note: Refractive index is a characteristics property of the medium, whose value depends only on nature of material of the medium and the colour or wavelength of light.

Relative refractive index

When light passes from one medium (say 1) to another medium 2, the refractive index of medium 2 w.r.t. medium 1 is written as ${}^1n_2$ or n_{21} and is called relative refractive index; where

$${}^1n_2 = n_{21} = \frac{n_2}{n_1} = \frac{C/v_2}{C/v_1} = \frac{v_1}{v_2}$$

$${}^1n_2 = \frac{v_1}{v_2} \quad {}^1n_2 \times {}^2n_1 = 1$$

$${}^2n_1 = \frac{v_2}{v_1} \quad {}^1n_2 = \frac{1}{{}^2n_1}$$

Therefore, relative refractive index of medium 2 w.r.t. medium 1 is equal to the ratio of speeds of air in medium 1 and medium 2.

Refractive index of medium 2 w.r.t. medium 1 is the reciprocal of refractive index of medium 1 w.r.t. medium 2.

Key Notes: Refractive index represents the extent of the change in direction that takes place in a given pair of mediums. **No refraction occurs** when light is incident normally on a boundary of two media or when refractive indices of the two media in contact are equal.

Experiences due to refraction of light

- A word written on a paper appears to be raised, when viewed through a glass slab
- A glass slab appears to be less thick than it actually is. This is because bottom of the glass slab appears to be raised.
- Twinkling of stars and shape of sun at sunrise and sunset
- A coin placed at bottom of a container appears to be raised when the container is filled slowly with water.

$${}^{air}n_{water} = \frac{\text{real depth}}{\text{apparent depth}} = \frac{4}{3}$$

$$\text{apparent depth} = \frac{3}{4}\ \text{real depth.}$$

***Example* 4:** Light travels from a rarer medium 1 to denser medium 2. The angle of incidence and refraction are respectively 45° and 30°. Calculate the refractive index of second medium w.r.t. first medium, and also the refractive index of first medium w.r.t. second medium.

***Solution*:** Angle of incidence, i = 45°

Angle of refraction, r = 30°;

According to Snell's Law $^1n_2 = \frac{\text{Sin i}}{\text{Sin r}}$

Therefore, $^1n_2 = \frac{\text{Sin } 45°}{\text{Sin } 30°} = \frac{1/\sqrt{2}}{1/2} = \frac{1}{\sqrt{2}} \times \frac{(\sqrt{2}\times\sqrt{2})}{1} = \sqrt{2}$

$^1n_2 = 1.414 \Rightarrow {}^2n_1 = \frac{1}{^1n_2} = \frac{1}{1.41} = 0.707$

***Example* 5:** A pond of depth 16 cm is filled with water of refractive index $\frac{4}{3}$. Calculate the apparent depth of the tank when viewed normally.

***Solution*:** Real depth = 16 cm, $^an_w = \frac{4}{3}$

$$^an_w = \frac{\text{real depth}}{\text{apparent depth}} \Rightarrow \text{apparent depth} = \frac{\text{real depth}}{^an_w}$$

Thus, apparent depth = $\frac{16}{4/3}$ = 12 cm.

***Example* 6:** How much time will light take to cross 2 mm thick glass pane if refractive index of glass is 3/2 ?

***Solution*:** $n = \frac{C}{v} \Rightarrow v = \frac{C}{n} = \frac{3\times10^8}{3/2}\text{m/s} = 2 \times 10^8$ m/s

Distance travelled, x = 2 mm = 2×10^{-3} m

Speed in glass, v = 2×10^8 m/s

Therefore, time taken to cover x with speed v is

$$t = \frac{x}{v} = \frac{2\times10^{-3}}{2\times10^8} = 10^{-11} \text{ s.}$$

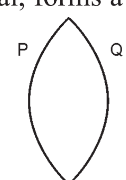
Absolute refractive index of some material media

Material medium	Refractive index
Air	1.0003
Ice	1.31
Water	1.33
Alcohol	1.36
Benzene	1.50
Crown glass	1.52
Diamond	2.42

Spherical Lenses

Lens

A transparent material bound by two surfaces, of which one or both the surface are spherical, forms a lens. On passing through a lens, light is refracted twice at the two surfaces of the lens.



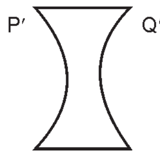
Lenses are of two types:

Convex lens

A lens having two spherical surface **bulging outwards** is called convex lens. Such a lens is

thick at the centre and thin at the edges. The two surfaces P and Q binding the lens are convex (*i.e.*, bulging out) A convex lens is called **converging lens** as it converges the rays of light falling on it.

Concave lens

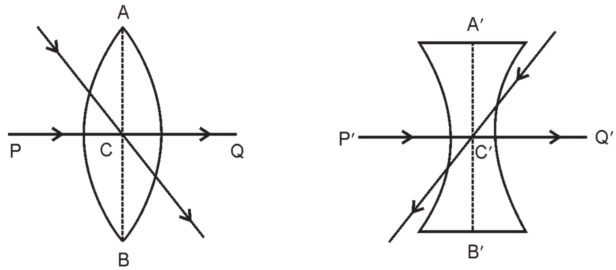


A lens having the spherical surfaces **bulging inwards** is called concave lens. Such a lens is **thick at the edges and thin at the centre.** The two surfaces P′ and Q′ binding the lens are concave (*i.e.*, curved inwards). A concave lens is also called **diverging lens** because it diverges the rays of light falling on it.

Key Note: Both surfaces of the two lenses have their own centres of curvature and radii of curvature. The radii of curvature of two surfaces of both the lenses may be equal or unequal.

Optical centre of the lens

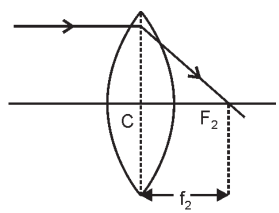
The optical centre of a lens is a point on the principal axis of the lens such that ray of light passing through it goes undeviated (without any refraction). In the figure we can see that AB and A′B′. are the apertures; PQ and P′Q′ are the principal axes; and C and C′ are the optical centres of both the lenses.



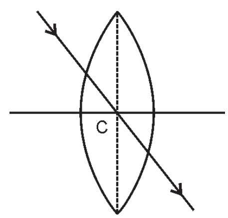
Two rays of light have been shown, passing through the centres of both the lenses, undeviated but straight.

Image formation by a convex lens

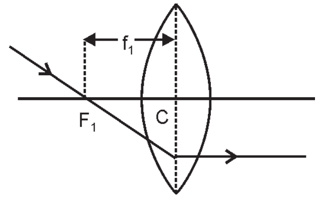
There are three rules which shows the refraction of light rays incident on the convex lens.



Rule 1: Ray incident on the lens in a direction parallel to the principal axis, on refraction passes through second principal focus (F_2) of the lens located on the other side of the lens $CF_2 = f_2$.



Rule 2: Ray passing through optical centre C of convex lens passes straight (undeviated) after refraction through the lens.

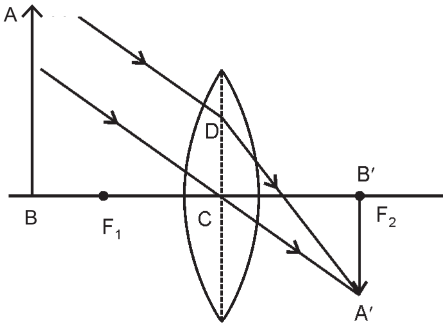


Rule 3: Ray passing through first principal focus f_1 of convex lens, incident on the lens becomes parallel to the principal axis of the lens, after refraction through the lens.

The image is formed at a point where any two of the refracted rays actually meet (for real image) or appear to meet (for virtual image).

Note: The position, size and nature of the image depend upon the position of the object in front of the lens. Following six cases arise.

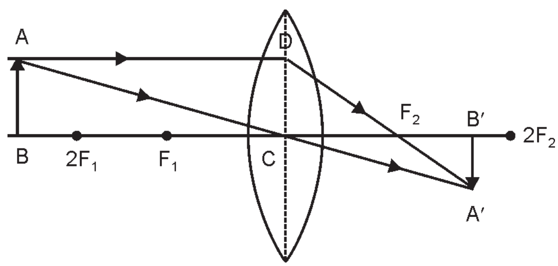
Case 1: When the object is at infinity : Suppose the object is placed far off from the lens consisting of an arrow AB pointing upwards.



Two rays coming from infinity appears parallel. The ray AC passing through C goes underviated. The ray AD converges on refraction through the convex lens. The two refracted rays actually meet at A´ which would be the real image of the top point A, of the object. Draw A´B´ perpendicular to the principal axis of the lens.

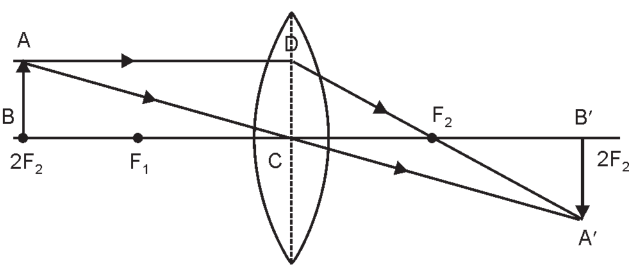
The image formed is at second principal focus; is real and inverted; and highly diminished (much smaller in size than the object).

Case 2: When the object is held beyond $2F_1$: The distance of the object is more than the focal length ($2F_1$) of the lens.

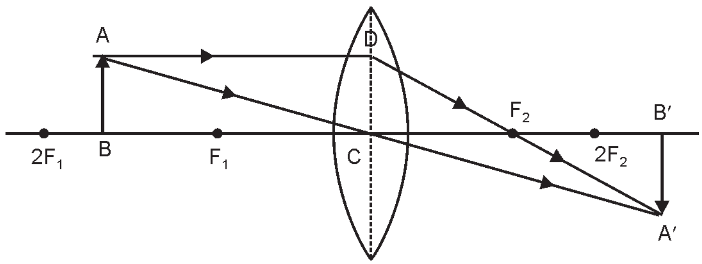


The image is formed between F_2 and 2 F_2 on the other side of the lens; is real and inverted; and is smaller in size than the actual object.

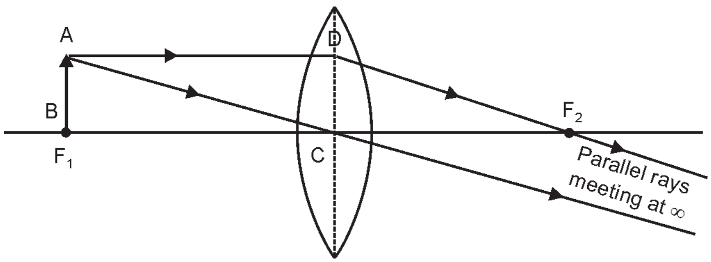
Case 3: When the object is held at 2 F_1 *:* The distance of the object from the convex lens is equal to twice the focal length of the lens. **The image is formed on the other side of the lens of $2F_2$; is real and inverted; and of the same size of the object.**



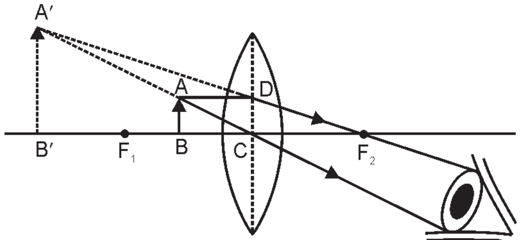
Case 4: **When the object is held between F_1 and 2 F_1 :** Here, the distance of the object from the convex lens is more than the focal length of the lens, but less than thrice the focal length of the lens. The two refracted rays meet actually at point A′ which is the real image of the point A, of the object. **The image is formed beyond 2 F_2 on the other side of the convex lens; is real and inverted; and is large in size than the object.**



Case 5: **When the object is at F_1:** Here, the distance of the object from the lens is equal to focal length of the lens. The two refracted rays emerge from the lens in a direction parallel to each other. These rays would meet at very large distance from the lens, say at infinity. **The image is formed at infinity on the other side of the lens; is real and inverted; and is highly magnified *i.e.*, much larger in size than the object.**



Case 6: **When the object is between F_1 and C:** Here, the distance of the object from the lens is less than the focal length of the lens. The two refracted rays from the lens are diverging and not parallel and would not meet on the right side of the lens. However, when we produce the two refracted rays in the backward direction, they appear to come from the point A′. Therefore, point A′ is the virtual iamge of the point A of the object. The image formed is beyond F_1 on the same side of the lens as the object is; virtual and erect; and magnified.

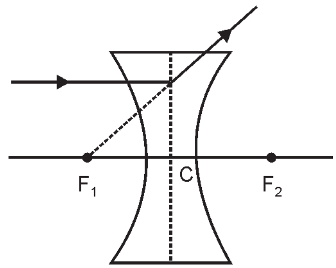


Summary table of images formed by a convex lens

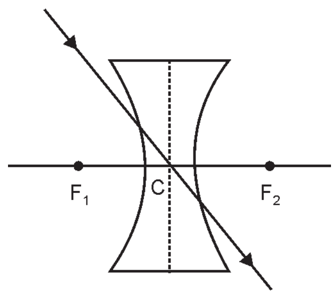
S. No.	Position of the object	Position of image	Size of image	Nature of image
1.	At infinity	At F_2	Highly reduced	Real and inverted
2.	Beyond 2 F_1	Between F_2 and 2 F_2	Diminished	Real and inverted
3.	At 2 F_1	At 2 F_2	Equal in size	Real and inverted
4.	Between F_1 and 2 F_1	Beyond 2 F_2	Enlarged	Real and inverted
5.	At F_1	At infinity	Highly magnified	Real and inverted
6.	Between F_1 and C	Beyond F_1 on the same side of the object	Enlarged	Virtual and erect

Rules for Refraction in a Concave Lens

1. **A ray incident on the concave lens in a direction parallel to the principal axis, on refraction,** it appears to come from the first principal focus F_1 of concave lens.



2. **A ray passing through optical centre C of concave lens,** passes straight without any deviation after refraction through the lens.



3. **A ray of light appearing to meet at the second principal focus F_2 of a concave lens,** after refraction will emerge parallel to the principal axis of the lens.

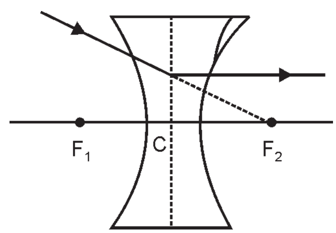
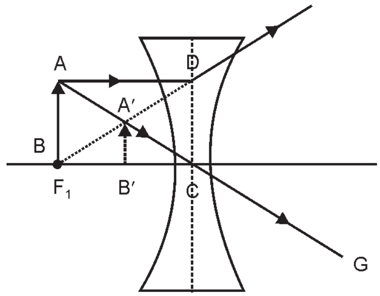


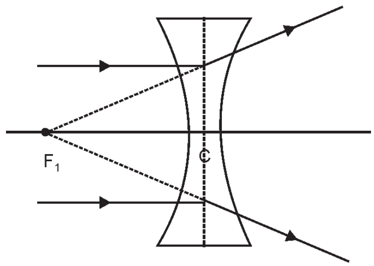
Image Formation by Concave Lens

Case 1: When the object lies between optical centre C and infinity: A ray of light, AD, starting from the top point A of the object placed between infinity and C, is falling on the concave lens in a direction parallel to principal axis of the lens. This ray diverges along DE, and on producing back, it appears to come from F_1. Another ray of light AC, starting from A, on passing through C goes undeviated along ACG. The two refracted rays intersect at A′.

Therefore A′ is the virtual image of point A on the object. **The image formed is between C and F_1, is on the same side of the lens as the object, is virtual, erect and highly diminished to almost point size (show as A′B′).**



Case 2: When the object is at infinity: As the object is moved away from the concave lens, the image A′B′ becomes still smaller in size and moves towards F_1. **The image is formed at F_1, is much smaller than the object; virtual and erect.**



Lens Formula

An equation which shows the relation between object distance (u), image distance (v) and focal length (f) of a lens is called lens formula. It can be written as

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

This formula is valid for any spherical lens, whenever the object may be placed. A convex lens may form a real or virtual image depending on the position of the object. A concave lens forms a virtual image, whenever the object may be.

***Example* 7:** A concave lens has focal length of 15 cm. At what distance should an object be placed from the lens so that it forms an image at 10 cm from the lens.

Solution: A concave lens always form a virtual and erect image i.e., on the same side of the object.

Image distance v = – 10 cm

Focal length f = – 15 cm

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}, \quad \frac{1}{u} = \frac{1}{v} - \frac{1}{f} = \frac{1}{(-10)} - \frac{1}{(-15)} = \frac{-1}{10} + \frac{1}{15}$$

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

$$u = -30 \text{ cm.}$$

Linear magnification produced by lenses

The linear magnification produced by lens in defined as the ratio of the size of the mage (I) as formed by refraction through the lens to the size of the object (O). It is represented by m.

$$m = \frac{I}{O} = \frac{\text{Size of image}}{\text{Size of object}}$$

If we take size of object as h_1 and size of image as h_2, then

$$m = \frac{h_2}{h_1}$$

For concave lens, image formed is always smaller, thus linear magnification, m is always less than one ($h_2 < h_1$).

For convex lens, image formed can be

(i) Equal in size of the object ($h_2 = h_1$), then m = 1

(ii) Bigger in size to the object ($h_2 > h_1$), then m > 1

(iii) Smaller in size of the object ($h_2 < h_1$), then m < 1

Key Note: (i) Linear magnification produced by any type of lens is equal to the ratio of image distance (v) to the object distance (u), *i.e.*,

$$M = \frac{h_2}{h_1} = \frac{v}{u}$$

(ii) For concave lens both h_1 and h_2 are positive. Therefore, m is always positive.

(iii) For concave lens, m is positive when image is virtual; and m is negative when the image is real.

***Example* 8:** A 2 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 its magnificance.

***Solution*:** Here size of object, h_1 = 2 cm, f = 10 cm

$$u = -15 \text{ cm}$$

$$\frac{1}{v} - \frac{1}{u} = \Rightarrow \frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{10} + \left(\frac{1}{-15}\right) = \frac{1}{30}$$

v = 30 cm. As v is positive, the image formed is on the right side of the lens and is real and inverted.

Linear magnification, $m = \frac{h_2}{h_1} = \frac{v}{u}$

$$\frac{h_2}{2} = \frac{30}{-15} \Rightarrow h_2 = -4 \text{ cm.}$$

Negative sign of m and h_2 shows that image is inverted. Thus image formed is enlarged two times.

Power of a lens

Power of a lens can be defined as the ability of the lens to converge the rays of light falling on a convex lens or to diverge the rays of light falling on the concave lens. Power of a convex lens is positive and of a concave lens is said to be negative.

If the point of convergence lies close to the optical centre of convex lens its power is more. If the point of convergence of rays lies away from the optical centre, its power is less. **The degree of convergence or divergence of light rays is a measure of power of lens.**

Hence, power of a lens is the reciprocal of focal length of the lens.

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

P = power of lens

f = focal length of the lens

smaller the focal length, greater is its power and vice-versa.

For a convex lens, f is positive. Therefore P is positive

For a concave lens, f is negative. Therefore P is negative

S.I. unit of power of lens is **dioptre** represented by symbol D.

When f = 1 m, P = 1 dioptre. Thus, one dioptre is the power of a lens whose focal length is one metre. This power can be measured using an instrument called dioptremeter, used often by opticians to measure the power of spectacles. In general, power of a lens in dioptres is called the **number of the lens.**

Note : $P = \frac{100}{f}$ when f is in centimetres.

***Example* 9:** A convex lens has a focal length 50 cm. Calculate its number.

***Solution*:** f = 50 cm = 0.5 m

Power, $P = \frac{1}{0.5} = 2$ dioptre = 2D

Thus, its number is said to be + 2.

Power of a combination of lenses

When a number of thin lenses are place in contact with each other, the power of the combination is equal the sum of the powers of all individual lenses used. These are used in cameras, microscopes and telescopes.

It increases the sharpness and clarity of images.

$$P = P_1 + P_2 + P_3 + \ldots\ldots\ldots. \Rightarrow \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \ldots..$$

Note that all the individual powers have to be taken with proper signs, positive for a convex lens and negative for concave lens, while adding them.

***Example* 10:** A concave lens of focal length 25 cm and a convex lens of focal length 20 cm are placed in contact with each other. What is the power of this combination and its focal length ?

***Solution*:** $f_1 = 25$ cm (concave lens)

$f_2 = +20$ cm (convex lens)

$$P_1 = \frac{100}{-25} = -4\text{ D},\ P_2 = \frac{100}{+20} = +5\text{ D}$$

$$P = P_1 + P_2 = -4\text{ D} + 5\text{ D} = 1\text{ D}$$

$$F = \frac{100}{P} = \frac{100}{1} = 100\text{ cm} = 1\text{m}$$

Positive sign of P and F indicates that the combination is behaving like a convex lens.

Key Points

- ✓ The two laws of refraction are:
  - The incident ray, the reflected ray and the normal (at the point of the incidence), all lie in the same plane.
  - The angle of reflection (r) is always equal to the angle of incidence (i) *i.e.*, $\angle r = \angle i$
- ✓ For a normal incidence, $\angle i = \angle r = 0°$
- ✓ In plane mirror, the image of real object is always
  - Virtual and erect
  - Laterally inverted
  - Of the same size as of the object
  - As far behind the mirror as the object is in front of the mirror.
- ✓ In concave mirror, reflecting surface is towards the centre of the sphere of which the mirror is a part.
- ✓ Convex mirror has the reflecting surface away from the centre of the sphere of which the mirror is a part.
- ✓ In a spherical mirror, focal length (f) is half the radius of curvature (R) of the mirror *i.e.*, $f = R / 2$.
- ✓ The image formed by a concave mirror may be real, inverted and smaller / equal / larger in size than the object, depending on position of the object. Only when the object is between pole P and focus F of concave mirror, the image formal is virtual, erect and magnified.
- ✓ The image formed by a convex mirror is virtual, erect and smaller than the object, whatever be the position of the object.
- ✓ If u is the object distance, v is the image distance and f is focal length of as spherical mirror, then $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$.
- ✓ Linear magnification produced by a spherical mirror, m is given by

  $$M = \frac{h_2}{h_1} = \frac{-v}{u}$$
- ✓ For convex mirror, m is positive and less than one, as the image formed is virtual, erect and shorter than the object.
- ✓ For a concave mirror, m can be positive or negative.
- ✓ Absolute refractive index (n) of a medium is the ratio of speed of light in vacuum or air (C) to the speed of light in the medium (v) *i.e.*, $n = \frac{C}{v}$. It is simply called refractive index of medium.
- ✓ When speed of light in a medium is smaller, its refractive index is larger. The medium is said to be optically denser. When v is larger, n is smaller; the medium is said to be optically rarer.
- ✓ When light passed from one medium 1 to another medium 2, the refractive index medium 2 w.r.t medium 1 is called relative refractive index, represented by ${}^1n_2$

  $${}^1n_2 = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{1}{{}^2n_1}.$$
- ✓ Refraction of light is the phenomenon of change in the path of the light in going from one medium to another. The basic cause of refraction is the change in the speed of light in going from one medium to another.