Light – Reflection and Refraction

Reflection of Light

- Reflection is the phenomenon of bouncing back of light into the same medium on striking the surface of any object.

**Laws of Reflection**
- First law: The incident ray, the normal to the surface at the point of incidence and the reflected ray, all lie in the same plane.
- Second law: The angle of reflection ($r$) is always equal to the angle of incidence ($i$).
  \[ \angle i = \angle r \]

- The image formed by a plane mirror is always
  - virtual and erect
  - of the same size as the object
  - as far behind the mirror as the object is in front of it
  - laterally inverted

- **Spherical mirrors** are of two types:
  - Convex mirrors or diverging mirrors in which the reflecting surface is curved outwards.
  - Concave mirrors or converging mirrors in which the reflecting surface is curved inwards.

- Some terms related to spherical mirrors:
  - The centre of curvature (C) of a spherical mirror is the centre of the hollow sphere of glass, of which the spherical mirror is a part.
  - The radius of curvature (R) of a spherical mirror is the radius of the hollow sphere of glass, of which the spherical mirror is a part.
  - The pole (P) of a spherical mirror is the centre of the mirror.
  - The principal axis of a spherical mirror is a straight line passing through the centre of curvature C and pole P of the spherical mirror.
  - The principal focus (F) of a concave mirror is a point on the principal axis at which the rays of light incident on the mirror, in a direction parallel to the principal axis, actually meet after reflection from the mirror.
  - The principal focus (F) of a convex mirror is a point on the principal axis from which the rays of light incident on the mirror, in a direction parallel to the principal axis, appear to diverge after reflection from the mirror.
  - The focal length (f) of a mirror is the distance between its pole (P) and principal focus (F).
  - For spherical mirrors of small aperture, \[ R = 2f. \]
- **Sign Conventions for Spherical Mirrors**
  According to **New Cartesian Sign Conventions**,
  - All distances are measured from the pole of the mirror.
  - The distances measured in the direction of incidence of light are taken as positive and *vice versa*.
  - The heights above the principal axis are taken as positive and *vice versa*.

- **Rules for tracing images formed by spherical mirrors**
  **Rule 1**: A ray which is parallel to the principal axis after reflection passes through the principal focus in case of a concave mirror or appears to diverge from the principal focus in case of a convex mirror.

  ![Concave Mirror](image1) ![Convex Mirror](image2)

  **Rule 2**: A ray passing through the principal focus of a concave mirror or a ray which is directed towards the principal focus of a convex mirror emerges parallel to the principal axis after reflection.

  ![Concave Mirror](image3) ![Convex Mirror](image4)

  **Rule 3**: A ray passing through the centre of curvature of a concave mirror or directed towards the centre of curvature of a convex mirror is reflected back along the same path.

  ![Concave Mirror](image5) ![Convex Mirror](image6)
Rule 4: A ray incident obliquely towards the pole of a concave mirror or a convex mirror is reflected obliquely as per the laws of reflection.

- Image formation by a concave mirror
  - Ray Diagrams
o Characteristics of images formed

<table>
<thead>
<tr>
<th>Position of object</th>
<th>Position of image</th>
<th>Size of image</th>
<th>Nature of image</th>
</tr>
</thead>
<tbody>
<tr>
<td>At infinity</td>
<td>At focus F</td>
<td>Highly diminished</td>
<td>Real and inverted</td>
</tr>
<tr>
<td>Beyond C</td>
<td>Between F and C</td>
<td>Diminished</td>
<td>Real and inverted</td>
</tr>
<tr>
<td>At C</td>
<td>At C</td>
<td>Equal to size of object</td>
<td>Real and inverted</td>
</tr>
<tr>
<td>Between C and F</td>
<td>Beyond C</td>
<td>Enlarged</td>
<td>Real and inverted</td>
</tr>
<tr>
<td>At F</td>
<td>At infinity</td>
<td>Highly enlarged</td>
<td>Real and inverted</td>
</tr>
<tr>
<td>Between F and P</td>
<td>Behind the mirror</td>
<td>Enlarged</td>
<td>Virtual and erect</td>
</tr>
</tbody>
</table>

• Image formation by a convex mirror
  o Ray Diagrams

  ![Ray Diagrams](image)

  - Object at infinity
  - Object anywhere between infinity and P

  ![Ray Diagrams](image)

  - At infinity
  - Anywhere between infinity and the pole of the mirror

  **Characteristics of images formed**

<table>
<thead>
<tr>
<th>Position of object</th>
<th>Position of image</th>
<th>Size of image</th>
<th>Nature of image</th>
</tr>
</thead>
<tbody>
<tr>
<td>At infinity</td>
<td>At focus F behind the mirror</td>
<td>Highly diminished, point sized</td>
<td>Virtual and erect</td>
</tr>
<tr>
<td>Anywhere between infinity and the pole of the mirror</td>
<td>Between P and F behind the mirror</td>
<td>Diminished</td>
<td>Virtual and erect</td>
</tr>
</tbody>
</table>

• Mirror Formula
  The object distance ($u$), image distance ($v$) and focal length ($f$) of a spherical mirror are related as
  \[
  \frac{1}{u} + \frac{1}{v} = \frac{1}{f}
  \]

  • Linear Magnification ($m$) produced by a spherical mirror is
  \[
  m = \frac{\text{size of image (}h_2\text{)}}{\text{size of object (}h_1\text{)}} = \frac{\text{image distance (}v\text{)}}{\text{object distance (}u\text{)}}
  \]
  
  $m$ is negative for real images and positive for virtual images.
Refraction of Light

- The phenomenon of change in the path of a beam of light as it passes from one medium to another is called refraction of light.
- The **cause of refraction** is the change in the speed of light as it goes from one medium to another.
- **Laws of Refraction**
  - First Law: The incident ray, the refracted ray and the normal to the interface of two media at the point of incidence, all lie in the same plane.
  - Second Law: The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for a given pair of media.
    \[
    \frac{\sin i}{\sin r} = \text{constant} = \frac{n_1}{n_2}
    \]
    This law is also known as **Snell’s law**.
    The constant, written as \( \frac{n_1}{n_2} \), is called the **refractive index** of the second medium (in which the refracted ray lies) with respect to the first medium (in which the incident ray lies).
- **Absolute refractive index** (n) of a medium is given as
  \[
  n = \frac{\text{speed of light in vacuum}}{\text{speed of light in the medium}} = \frac{c}{v}
  \]
- When a beam of light passes from medium 1 to medium 2, the refractive index of medium 2 with respect to medium 1 is called the **relative refractive index**, represented by \( \frac{n_2}{n_1} \), where
  \[
  \frac{n_2}{n_1} = \frac{c/v_2}{c/v_1} = \frac{v_1}{v_2}
  \]
  Similarly, the refractive index of medium 1 with respect to medium 2 is
  \[
  \frac{n_1}{n_2} = \frac{c/v_1}{c/v_2} = \frac{v_2}{v_1}
  \]
  \[
  \Rightarrow \quad \frac{n_2}{n_1} \times \frac{n_1}{n_2} = 1
  \]
  or, \( n_2 = \frac{1}{n_1} \)
- While going from a **rarer to a denser medium**, the ray of light bends towards the normal. While going from a **denser to a rarer medium**, the ray of light bends away from the normal.
- **Conditions for no refraction**
  - When light is incident normally on a boundary.
  - When the refractive indices of the two media are equal.
- In the case of a **rectangular glass slab**, a ray of light suffers **two refractions**, one at the air–glass interface and the other at the glass–air interface. The emergent ray is **parallel** to the direction of the incident ray.
- Convex lens or converging lens which is thick at the centre and thin at the edges.
- Concave lens or diverging lens which is thin at the centre and thick at the edges.

Some terms related to spherical lenses:
- The central point of the lens is known as its **optical centre (O)**.
- Each of the two spherical surfaces of a lens forms a part of a sphere. The centres of these spheres are called **centres of curvature** of the lens. These are represented as $C_1$ and $C_2$.
- The **principal axis** of a lens is a straight line passing through its two centres of curvature.
- The **principal focus of a convex lens** is a point on its principal axis to which light rays parallel to the principal axis converge after passing through the lens.
- The **principal focus of a concave lens** is a point on its principal axis from which light rays, originally parallel to the principal axis appear to diverge after passing through the lens.
- The **focal length (f)** of a lens is the distance of the principal focus from the optical centre.

**Sign Conventions for Spherical Lenses**
According to **New Cartesian Sign Conventions**,
- All distances are measured from the optical centre of the lens.
- The distances measured in the direction of incidence of light are taken as positive and *vice versa*.
- The heights above the principal axis are taken as positive and *vice versa*.

**Rules for tracing images formed by spherical lens**
**Rule 1:** A ray which is parallel to the principal axis, after refraction passes through the principal focus on the other side of the lens in case of a convex lens or appears to diverge from the principal focus on the same side of the lens in case of a concave lens.

**Rule 2:** A ray passing through the principal focus of a convex lens or appearing to meet at the principal focus of a concave lens after refraction emerges parallel to the principal axis.
Rule 3: A ray passing through the optical centre of a convex lens or a concave lens emerges without any deviation.

- Image formation by a convex lens
  - Ray Diagrams
Characteristics of images formed

<table>
<thead>
<tr>
<th>Position of object</th>
<th>Position of image</th>
<th>Size of image</th>
<th>Nature of image</th>
</tr>
</thead>
<tbody>
<tr>
<td>At infinity</td>
<td>At focus $F_2$</td>
<td>Highly diminished</td>
<td>Real and inverted</td>
</tr>
<tr>
<td>Beyond $2F_1$</td>
<td>Between $F_2$ and $2F_2$</td>
<td>Diminished</td>
<td>Real and inverted</td>
</tr>
<tr>
<td>At $2F_1$</td>
<td>At $2F_2$</td>
<td>Equal to size of object</td>
<td>Real and inverted</td>
</tr>
<tr>
<td>Between $F_1$ and $2F_1$</td>
<td>Beyond $2F_2$</td>
<td>Enlarged</td>
<td>Real and inverted</td>
</tr>
<tr>
<td>At focus $F_1$</td>
<td>At infinity</td>
<td>Highly enlarged</td>
<td>Real and inverted</td>
</tr>
<tr>
<td>Between $F_1$ and O</td>
<td>Beyond $F_1$ on the same side as the object</td>
<td>Enlarged</td>
<td>Virtual and erect</td>
</tr>
</tbody>
</table>

Image formation by a concave lens

- Ray Diagrams

![Ray Diagrams](image)

Characteristics of images formed

<table>
<thead>
<tr>
<th>Position of object</th>
<th>Position of image</th>
<th>Size of image</th>
<th>Nature of image</th>
</tr>
</thead>
<tbody>
<tr>
<td>At infinity</td>
<td>At focus $F_1$</td>
<td>Highly diminished</td>
<td>Virtual and erect</td>
</tr>
<tr>
<td>Between infinity and O</td>
<td>Between focus $F_1$ and O</td>
<td>Diminished</td>
<td>Virtual and erect</td>
</tr>
</tbody>
</table>

Lens Formula

Object distance ($u$), image distance ($v$) and focal length ($f$) of a spherical lens are related as

\[ \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \]

Linear Magnification ($m$) produced by a spherical lens is

\[ m = \frac{\text{size of image} (h_2)}{\text{size of object} (h_1)} = \frac{\text{image distance} (v)}{\text{object distance} (u)} \]

$m$ is **negative** for real images and **positive** for virtual images.
• **Power of a lens**
  o Power of a lens is the reciprocal of the focal length of the lens. Its S.I. unit is **dioptre (D)**.

\[
P \text{ (dioptre)} = \frac{1}{f \text{ (metre)}}
\]

o Power of a **convex lens** is **positive** and that of a **concave lens** is **negative**.

o When several thin lenses are placed in contact with one another, the **power of the combination of lenses** is equal to the algebraic sum of the powers of the individual lenses.

\[
P = P_1 + P_2 + P_3 + P_4 + \ldots
\]