RAY OPTICS AND OPTICAL INSTRUMENTS

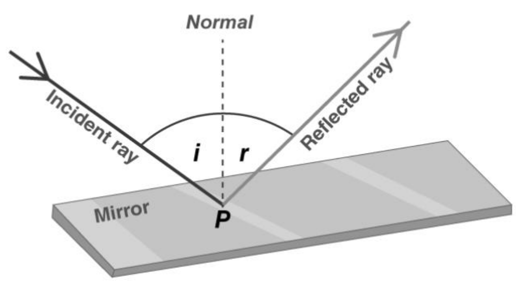
REFLECTION OF LIGHT BY SPHERICAL MIRRORS

INTRODUCTION OF REFLECTION OF LIGHT

When a beam of light encounters a smooth, polished surface and rebounds, this phenomenon is known as the reflection of light. The incoming light ray that strikes the surface is sent back, creating what is termed the reflected ray. If we were to draw a line perpendicular to the reflecting surface, it would be referred to as the normal. In the context of a plane mirror, the figure below illustrates the reflection of a light beam.

REFLECTION OF LIGHT

The terms "angle of incidence" and "angle of reflection" pertain to their measurements concerning both the normal (a line perpendicular to the reflective surface) and the reflective surface itself. The angles are determined based on their positions in relation to these reference points.



Laws of Reflection

The principles governing the reflection of light, known as the laws of reflection, dictate how incident light rays behave upon encountering reflective surfaces such as mirrors, smooth metal surfaces, or clear water. Taking a plane mirror as an example, depicted in the figure above, these laws are defined as follows:

1. Coplanar Alignment: The incident ray, the reflected ray, and the normal (a line perpendicular to the reflective surface) all exist within the same plane. This means they share a common flat surface.

2. Equality of Angles: According to the law of reflection, the angle at which the incident ray strikes the reflective surface is equal to the angle at which the reflected ray departs from the surface. In other words, the angle of incidence is equivalent to the angle of reflection.

Types of Reflection of Light

1. Regular Reflection (Specular Reflection): This type of reflection is often referred to as specular reflection. It occurs when light rays bounce off a smooth and polished surface, such as a mirror. In regular reflection, the reflected rays maintain a uniform direction, resulting in a clear and distinct image.

2. Diffused Reflection: Unlike regular reflection, diffused reflection takes place on rough surfaces. When light encounters an uneven or irregular surface, it scatters in various directions. This phenomenon is common on surfaces like paper, walls, or any material that lacks smoothness. Diffused reflection contributes to the even illumination of an area, as opposed to forming a well-defined image.

3. Multiple Reflection: This occurs when light undergoes successive reflections, either within the same medium or between different media. One common example is the reflection of light within a pair of parallel mirrors, creating multiple images. Multiple reflection plays a role in optical devices like periscopes and kaleidoscopes, where it contributes to the formation of intricate patterns and images.

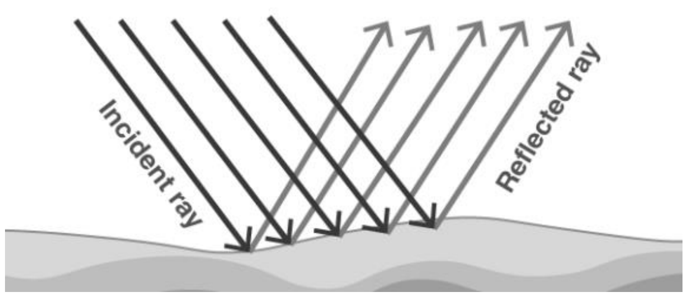
Regular/ Specular Reflection

Specular Reflection, characterized by clear and sharp reflections, is exemplified by the kind observed in mirrors. Mirrors typically consist of glass layered with a uniformly reflective material, often a powdered substance. This reflective surface exhibits a high degree of uniformity in reflecting almost all incident light. The angles of reflection at various points on the surface do not vary significantly. Consequently, this uniformity minimizes haziness and blurring, contributing to the production of distinct and well-defined reflections in specular reflection. Essentially, it results in a mirror's ability to provide crisp and accurate reflections due to the consistent nature of the reflected light across its surface.

DIFFUSED REFLECTION

Diffused Reflection

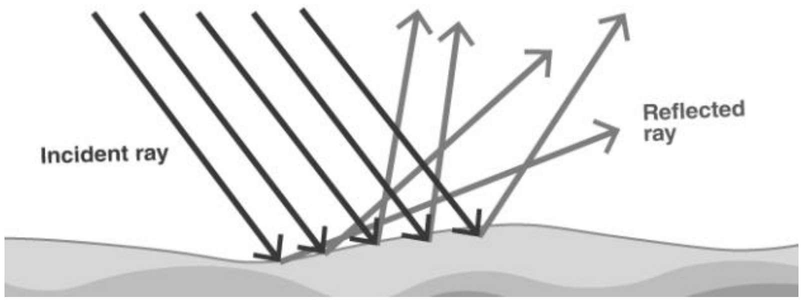
Surfaces that are not mirrors typically exhibit a rough texture, often resulting from factors like wear and tear, such as scratches or dents, or the presence of dirt on the surface. The material composition of the surface can also play a role in its texture. These factors collectively contribute to a reduction in both the brightness and the overall quality of the reflection obtained from such surfaces.



In the case of rough surfaces, the angles of reflection vary randomly when compared between different points on the surface. The irregularities in the surface cause incident rays at slightly different points to be reflected in entirely disparate directions. This phenomenon is termed diffused reflection. Unlike the orderly and well-defined reflections seen on smooth surfaces like mirrors, diffused reflection results in scattered and dispersed light. It is this type of reflection that allows us to perceive non-shiny objects, as the scattered light contributes to a more subdued and spread-out illumination rather than creating distinct, focused reflections.

Multiple reflections:

When we position an object in front of a single mirror, we obtain a solitary image. However, if we introduce a second mirror, a fascinating phenomenon unfolds. Mirrors, being highly effective at maintaining light intensity during reflection, enable a single light source to undergo multiple reflections. This succession of reflections persists until the light intensity diminishes to the extent that the reflections become imperceptible. In essence, this implies the potential for almost infinite reflections, each yielding its own distinct image. In this cascading process, each image is a consequence of the previous image or a series of previous images.



The number of visible images is contingent upon the angle between the two mirrors. As the angle diminishes, the count of images escalates. When the mirrors align perfectly parallel, creating a zero-degree angle, the number of images reaches infinity. This phenomenon is evident in everyday experiences, such as when a barber uses a smaller mirror to reveal the back of your head. In such scenarios, not only do you observe the back of your head, but you also encounter countless reflections of yourself.

A simple formula captures the relationship between the angle separating the mirrors and the number of images.

$$Number\ of\ image = \frac{360^\circ}{angel\ between\ mirroors} - 1$$

SPHERICAL MIRROR

Some Important Definitions

1. Spherical Mirrors:

Spherical mirrors are reflective surfaces shaped like sections of a sphere. These mirrors come in two primary types: concave and convex.

1. Concave Mirrors:

- Shape: Concave mirrors curve inward, resembling the inner surface of a sphere.
- Focal Point: Light rays parallel to the optical axis and incident on a concave mirror converge at a specific point known as the focal point. This point is located on the optical axis, halfway between the mirror's surface and its center.

- Image Formation: Depending on the object's position relative to the focal point, concave mirrors can produce real or virtual, inverted or upright images.

2. Convex Mirrors:

- Shape: Convex mirrors, on the other hand, curve outward, resembling the outer surface of a sphere.

- Focal Point: Unlike concave mirrors, convex mirrors cause parallel light rays to diverge. The extension of these divergent rays appears to converge at a point behind the mirror, creating a virtual focal point.

- Image Formation: Convex mirrors always produce virtual, erect, and diminished images, regardless of the object's position.

Concave mirror Convex mirror

Both types of spherical mirrors play essential roles in various optical devices, including telescopes, cameras, and rearview mirrors. Understanding their reflective properties, focal points, and image formation characteristics is crucial in optics and lens design.

2. Paraxial Rays:

Paraxial rays refer to light rays that exhibit a very small angle of incidence. In other words, these rays approach the optical system with angles so minute that they are considered negligible. The term "paraxial" underscores the proximity of these rays to the optical axis, emphasizing their close alignment with the central path of the optical system. These rays play a crucial role in optical analysis and calculations, particularly in simplified models where small-angle approximations are employed for ease of computation. The study of paraxial rays is fundamental in understanding and predicting the behavior of light within optical systems.

3. Pole or Vertex:

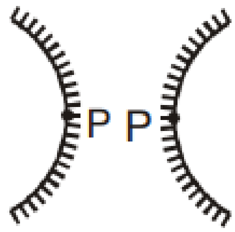
The pole, also known as the vertex, is a specific point on a spherical mirror that serves as a reference for measuring both object and image distances. In the depicted figure, the designated point marked as P represents the pole of the mirror.

Function:

- The pole is a convenient reference point because it simplifies the measurement of distances related to the mirror. Object distance, which is the distance from the object to the mirror, and image distance, which is the distance from the image to the mirror, are commonly measured from this point.

Position:

- The pole is typically located at the center of the mirror. For a concave mirror, where the reflective surface curves inward, the pole is positioned on the inner side of the mirror. In the case of a convex mirror, where the surface curves outward, the pole is situated on the outer side.



Understanding the role and position of the pole is crucial for calculations and analyses in optics, providing a standardized reference point for distance measurements in the context of spherical mirrors.

4. Centre of Curvature:

The center of curvature, denoted as C, is a pivotal point in the context of a spherical mirror. It is identified as the center of the sphere from which the spherical mirror derives its shape.

Definition:

- The center of curvature is situated at the midpoint of the spherical mirror's corresponding sphere. This sphere is the three-dimensional structure of which the mirror is a part.

Relation to the Spherical Mirror:

- For a concave mirror, where the reflective surface curves inward, the center of curvature lies outside the mirror, beyond its reflective surface.

- In the case of a convex mirror, where the reflective surface curves outward, the center of curvature is positioned on the opposite side of the mirror, again beyond the reflective surface.

Significance:

- Understanding the center of curvature is crucial for comprehending the geometry of the spherical mirror. It serves as a reference point for various optical calculations, especially in determining focal lengths and understanding the characteristics of images formed by the mirror.

By recognizing the center of curvature, one gains insights into the fundamental structure and properties of spherical mirrors, contributing to the analysis and application of these mirrors in optics.

5. Radius of Curvature (R):

The radius of curvature, denoted as R, is a fundamental parameter associated with a spherical mirror. It represents the radius of the sphere from which the mirror's curved surface is derived.

Definition:

- The radius of curvature is essentially the distance from the center of curvature (C) to the reflective surface of the spherical mirror. It corresponds to the radius of the sphere of which the mirror is a part.

Calculation:

- In practical terms, the radius of curvature is measured as the distance from the mirror's pole (P) to the center of curvature (C). It is a key geometric characteristic that influences the optical properties of the mirror.

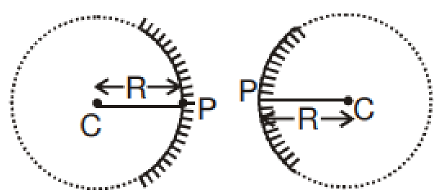
Relation to Mirror Types:

- For a concave mirror, where the reflective surface curves inward, the radius of curvature is considered positive. It extends from the reflective surface to the center of curvature located outside the mirror.

- In the case of a convex mirror, where the reflective surface curves outward, the radius of curvature is treated as negative. It extends from the reflective surface to the center of curvature situated on the opposite side, beyond the mirror.

Significance:

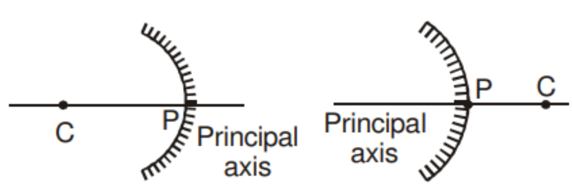
- The radius of curvature plays a crucial role in determining the mirror's focal length and the formation of images. It serves as a key parameter in optical calculations, providing valuable insights into the mirror's optical behavior.



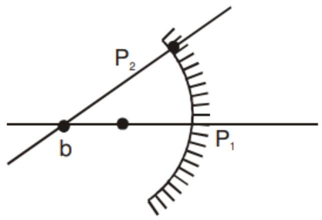
Understanding the radius of curvature enhances our comprehension of the geometric and optical properties of spherical mirrors, contributing to their application and analysis in the field of optics.

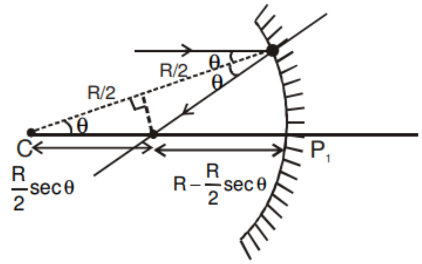
6. Principal Axis:

The principal axis, also referred to as the optical axis, is a significant line associated with a spherical mirror. It is defined as the straight line that connects the pole (P) of the mirror with the center of curvature (C).



If θ is very small: $R-\frac{R}{2}\sec\theta \simeq \frac{R}{2}$





Definition:

- The principal axis serves as a crucial reference line, extending from the pole of the mirror to the center of curvature. This line forms the central axis of symmetry for the spherical mirror.

Direction:

- The principal axis typically passes through the midpoint of the mirror's reflective surface. In the case of a concave mirror, where the reflective surface curves inward, the principal axis extends in the direction from the mirror's pole to the center of curvature outside the mirror. For a convex mirror, where the reflective surface curves outward, the principal axis extends from the pole to the center of curvature located on the opposite side beyond the mirror.

Significance:

- The principal axis is a fundamental reference for various optical measurements and calculations. It plays a crucial role in understanding the geometry of the mirror and is integral to the determination of focal points, image formation, and optical characteristics.

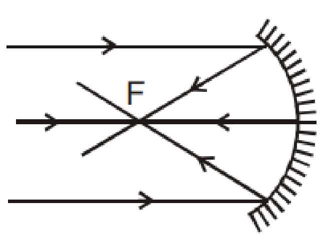
Alignment:

- When discussing the reflection of light and the formation of images by spherical mirrors, the principal axis is a key element in analyzing the behavior of light rays relative to the mirror's surface.

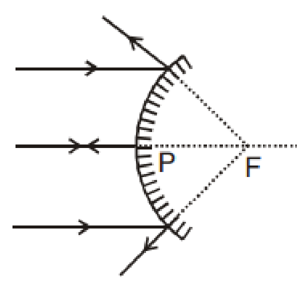
Understanding the principal axis provides valuable insights into the geometric and optical properties of spherical mirrors, facilitating their application and analysis in the field of optics.

7. Focus (F):

The focus, denoted as F, is a critical point associated with a spherical mirror. It is defined as the point where parallel rays that are both parallel to the principal axis and paraxial (having very small angles of incidence) appear to converge or meet after reflection.



concave mirror



Convex mirror

Condition for Focus:

- For a spherical mirror, the condition for the focus is that the incident rays must be parallel to the principal axis and also paraxial. Paraxial rays are those with extremely small angles of incidence.

Formation of Focus:

- When parallel paraxial rays strike a spherical mirror, they reflect in such a way that they seem to converge at a specific point. This point is identified as the focus.

Distance from Pole:

- The distance of the focus from the pole of the mirror is half of the radius of curvature (R/2). This relationship holds true for both concave and convex mirrors.

Significance:

- The focus is a crucial point in understanding image formation by spherical mirrors. It is the point where parallel rays either converge (in the case of concave mirrors) or appear to diverge from (in the case of convex mirrors) after reflection.

Two Types of Focus:

- For a concave mirror, the focus is real, and actual light rays converge at this point. For a convex mirror, the focus is virtual, and the apparent convergence of reflected rays creates the illusion of a diverging beam.

Understanding the concept of focus is fundamental in unraveling the optical behavior of spherical mirrors, influencing calculations related to image formation and the characteristics of reflected light.

8. Focal Length (f):

The focal length, represented as f, is a crucial parameter associated with a spherical mirror. It is defined as the distance along the principal axis from the pole (P) of the mirror to the focus (F).

Definition:

- Focal length specifically measures the distance between the pole and the focus along the principal axis. It is denoted by the symbol f.

Calculation:

- Mathematically, the focal length (f) is determined by the distance PF, where P is the pole and F is the focus. In essence, it quantifies how far the focus is from the mirror's pole.

Relation to Radius of Curvature:

- The focal length is directly related to the radius of curvature (R) of the mirror. For a spherical mirror, the focal length is half of the radius of curvature, expressed as $f = R/2$.

Unit of Measurement:

- Focal length is typically measured in units such as meters or centimeters, depending on the scale of the mirror.

Significance:
- Understanding the focal length is pivotal in optical calculations and analyses. It plays a key role in determining the position and size of images formed by spherical mirrors, influencing various optical applications.

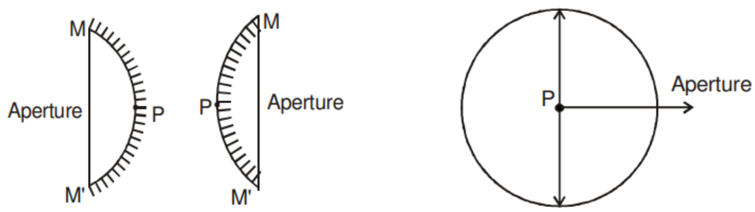
Positive and Negative Focal Length:
- For a concave mirror, the focal length is considered positive, indicating that the focus is on the same side as the incident light. In the case of a convex mirror, the focal length is treated as negative, signifying that the virtual focus is on the opposite side of the mirror.

The focal length is a fundamental parameter that influences the optical behavior of spherical mirrors, providing valuable insights into the formation of images and the characteristics of reflected light.

Certainly! Let's explore the concept of aperture in detail:

9. Aperture:

The aperture, also referred to as linear aperture, is a crucial characteristic associated with a spherical mirror. It is defined as the line that connects the end points of the mirror.



Definition:
- The aperture is essentially the straight line that joins the extremities or end points of a spherical mirror. This line is considered a defining feature of the mirror's structure.

Measurement:
- The length of the aperture represents the span between the two endpoints of the mirror. It quantifies the overall size of the mirror in terms of its lateral extent.

Importance in Mirror Design:
- The aperture plays a significant role in the design and classification of spherical mirrors. It influences the mirror's field of view and the range of incident light that the mirror can effectively reflect.

Relation to Mirror Shape:
- The shape of the aperture is directly related to the curvature of the mirror. For example, in a concave mirror, the aperture would be an arc on the inner side, while in a convex mirror, it would be an arc on the outer side.

Significance in Optics:

- Understanding the aperture is essential in optics, especially in the analysis of how incident light interacts with the mirror's surface. It contributes to considerations related to image formation and the characteristics of the reflected light.

The aperture is a fundamental element that influences the geometric and optical properties of spherical mirrors, playing a role in their design, classification, and application in various optical systems.

10. Focal Plane:

The focal plane is a critical feature associated with a spherical mirror. It is defined as the plane that passes through the focus and is perpendicular to the optical axis.

Definition:

- The focal plane is a two-dimensional surface that extends through the focus of a spherical mirror. It is positioned at a right angle to the optical axis of the mirror.

Location:

- This plane intersects the optical axis at the focus point, creating a flat surface that extends perpendicularly from the mirror.

Significance:

- The focal plane is significant in optics because it represents the specific plane in which all the focused rays converge after reflecting off the mirror.

Image Formation:

- For a concave mirror, the focused rays converge and intersect at the focal plane. In the case of a convex mirror, where virtual rays appear to diverge from the focus, the extension of these divergent rays also intersects at the focal plane.

Application:

- The focal plane is crucial in various optical applications. In photography and imaging systems, for instance, understanding the position and characteristics of the focal plane is essential for achieving sharp and well-focused images.

Alignment with Focus:

- The focal plane is aligned with the focus point, providing a geometric reference for the convergence or divergence of light rays reflected by the mirror.

Understanding the focal plane is fundamental in comprehending the optical behavior of spherical mirrors, contributing to applications in imaging, photography, and other optical systems.

Example.

Discover the point on the focal plane where rays, coming in parallel and at very small angles to the optical axis, meet after bouncing off the mirror.

Solution.

In $\Delta FF'P$ $\tan\theta = \dfrac{h}{f}$

$h = f\,\theta$ (θ is small)

In the event that incident rays exhibit both parallelism and paraxiality but deviate from parallelism with the optical axis, a convergence phenomenon ensues. Specifically, these rays, subsequent to reflection, coalesce at a distinct plane recognized as the focal plane.