Chapter 9

Ray Optics

REFLECTION

Recap of Waves

A wave is a perturbation that travels through space, transferring both energy and momentum without transporting matter. Ex. Sound waves, sea tides, the motion of strings in musical instruments (guitars, piano, harp, etc.), light waves, radio waves, etc.

Classification of waves

Based on the requirement of the medium

1. Non-mechanical waves (No medium is required for propagation of waves)
2. Mechanical waves (Medium is required for propagation of waves)

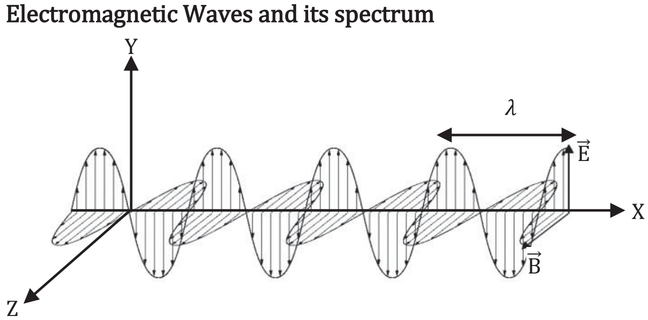
Based on the direction of the motion of the particles

1. Transverse waves (The oscillation of the particles within the medium occurs perpendicular to the direction of wave propagation.)
2. Longitudinal waves (The oscillation of the medium's particles is in the same direction as the wave propagation.)

Based on the direction of the propagation of waves

1. One-dimensional waves (waves propagate in one direction)
2. Two-dimensional waves (waves propagate in a two-dimensional space) 3. Three-dimensional waves (the waves propagate all over the space)

Electromagnetic Waves and its spectrum



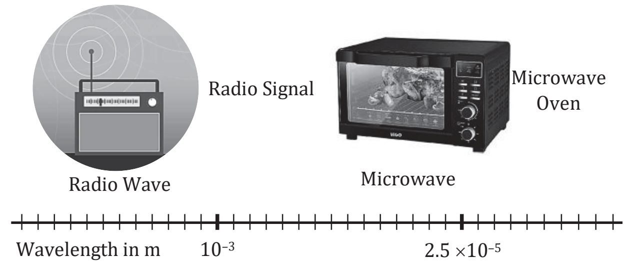
All electromagnetic waves travel at the same speed through a vacuum. $C = v\lambda$

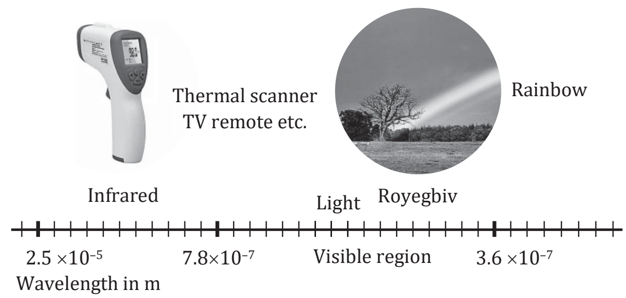
$C = 3 \times 10^8 ms^{-1}$ same for all EM waves)

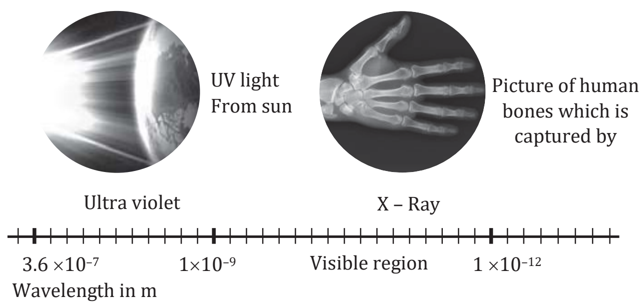
Electromagnetic waves can be differentiated according to their frequencies or wavelengths.

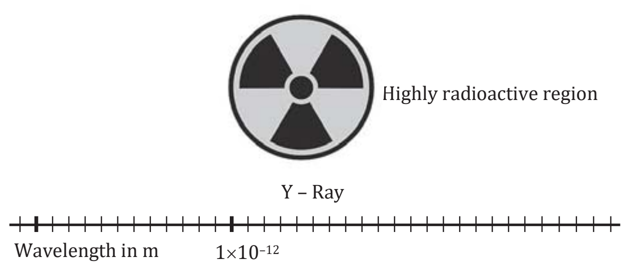
- Image formation by Convex mirror
  - Image formation by concave mirror
  - Image formation by convex mirror
- Combinations of Mirror
  - Velocity in Spherical Mirror
  - Combination of Mirrors
  - Cutting of Mirror
- Laws of Refraction
  - Cutting of Mirror
  - Laws of Refraction
- Apparent Depth
  - Apparent Depth & speed
  - Shift from a slab
- Shift from a slab
  - Shift from a slab
  - Shift in a composite slab
  - Shift from a slab-Object and observer in different medium
  - Lateral Shift from a slab`
- Total Internal Reflection
  - Critical Angle
  - Total Internal Reflection
  - Grazing Incidence
  - Min. and Max. Lateral Shift
  - Graph between δ and i
- Refraction of Light through multiple Media
  - Refraction of light through multiple Media
  - Mirage Formation
  - Looming Formation
  - Applications of TIR(Diamond)
- Angle of Deviation in Prism
  - Net Angle of Deviation in prism
  - Angle of deviation:- Graph Representation of δ and i
- Thin Prism, Optical Fiber
  - Prism
  - Optical Fiber
  - Thin prism
  - Shift from a thin prism
- Dispersion
  - Dispersion
  - Angular Dispersion
  - Dispersive Power
  - Dispersion and deviation
  - Dispersion without deviation
  - Deviation without Dispersion
  - Application of TIR(Primary and Secondary Rainbow)

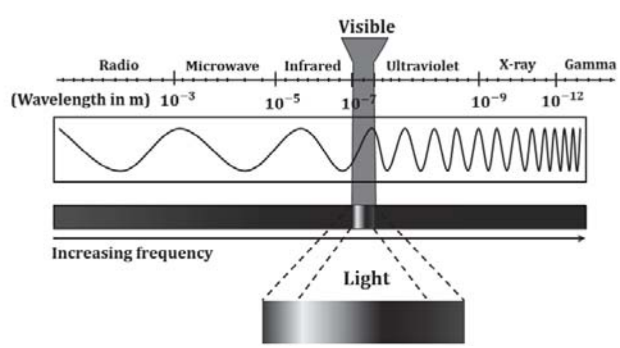
Electromagnetic spectrum











$\lambda_{light} = 360\text{ nm} - 780\text{ nm}$

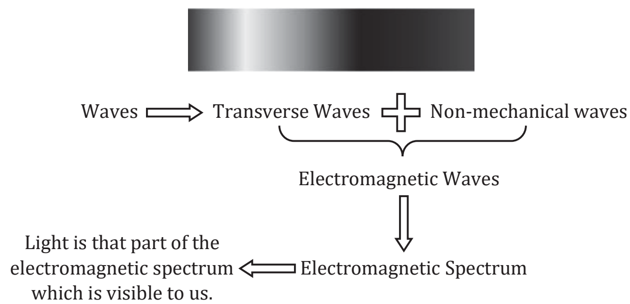
Speed of light $= 3 \times 10^8\text{ ms}^{-1}$ (same for all EM waves)

- Spherical Refraction
  - Spherical Refraction
- Lenses
  - Magnification in spherical refraction
  - Velocity in spherical refraction
  - Lenses
  - Types of lenses, concave and convex lens
  - Optical Axis
  - Thin Lens
  - Lens maker's formula
- Converging and Diverging Lens
  - Converging and diverging lens
  - First focus and second focus
  - Standard Ray diagram
  - Transverse magnification
  - Cases for converging lens
- Velocity of Image, Power of lens and lens cutting
  - Image formation by diverging lens
  - Newton's Formula(lens)
  - Longitudinal Magnification
  - Velocity of Images
  - Power of Lens
  - Cutting of Lens
  - Focal length after parallel and perpendicular cutting
- Combination of Lenses
  - Combinations of lenses
  - Silvering of Lenses
  - $u{-}v$ method
- Chromatic aberration and Oblique vision
  - Chromatic Aberration
  - Condition for Achromatism or
  - Achromatic Combination
  - Lenses kept with separation

Since $\lambda = \frac{v}{f}$ The higher the frequency, the shorter the wavelength.

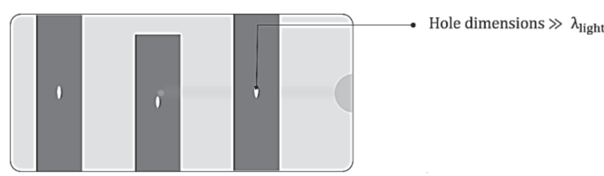
From the illustration on the preceding slide, it's evident that red light corresponds to a longer wavelength (or lower frequency), while violet light corresponds to a shorter wavelength (or higher frequency).

To recall the spectrum in the correct order of increasing wavelengths, the mnemonic 'V I B G Y O R' is used, where V represents violet and R represents red, as depicted in the accompanying figure.



Light $\lambda_{light} = 360\text{nm} - 780\text{ nm}$

Hole dimensions $\gg \boldsymbol{\lambda}_{\textbf{liaht}}$



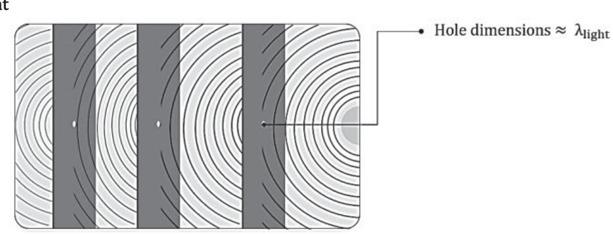
When light traverses through an aperture with dimensions larger than the wavelength of light, it moves in straight paths without altering its direction.

The linear movement of light in straight lines is referred to as rectilinear propagation of light.

The straight lines that depict the propagation of light are termed as rays.

"Geometrical optics" is the branch of optics concerned with the straight-line propagation of light.

Hole dimensions $\approx \boldsymbol{\lambda}_{\textbf{light}}$



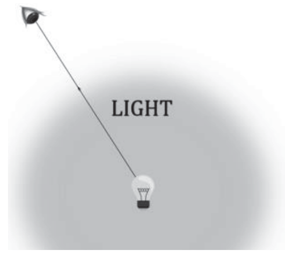
When light passes through a hole with dimensions comparable to the wavelength of light, it does not follow a straight-line path. For instance, when sunlight enters a room through a small hole in the roof, it creates a circular spot on the floor with a diameter larger than that of the hole itself.

To explain this characteristic of light, we must take into account the wave nature of light, where light emanates from the source in spherical waves, as depicted in the figure. The branch of optics that addresses the wave nature of light is referred to as "Wave optics".

Optics
Study of the behavior and properties of light.

Geometrical Optics | Wave Optics

Geometrical optics uses rays to depict the propagation of light, with an arrow indicating the direction of propagation.



Luminous Objects

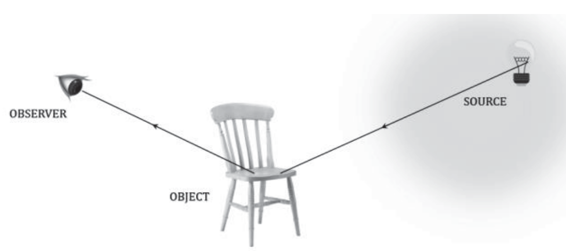
Luminous objects are those that emit light or produce light on their own. Examples include the Sun, light bulbs, candles, and so forth.

Non-Luminous Objects

Non-luminous objects are those that do not generate their own light. Examples include tables, chairs, and similar items.

Reflection

If light rays encounter the boundary between two mediums, a portion of the light is absorbed while another portion reflects back into the same medium. This occurrence is referred to as the reflection of light.



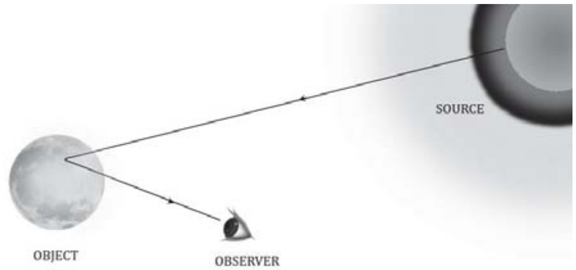
REFLECTION

As non-luminous objects such as chairs do not emit light, they become visible when illuminated by light from luminous sources like bulbs. When this light reflects off the objects and reaches the eye, it creates the sensation of vision. This process is illustrated in the provided figure.

We perceive objects, whether luminous or non-luminous, due to the following two reasons:

1. Due to reflection of light
2. If the radiation from the luminous heated object lies in visible region.

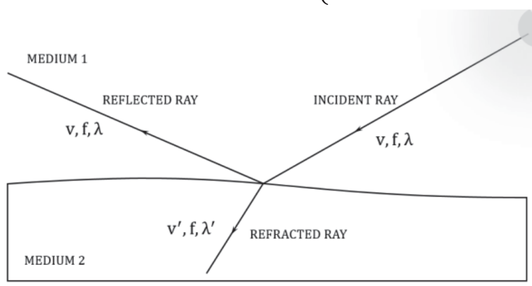
Ex. Consider a scenario where two balloons, one red and the other blue, are positioned in front of two red lasers. The blue balloon will burst prior to the red one due to its absorption of the red laser light, causing it to heat up, whereas the red balloon will only partially reflect the light.

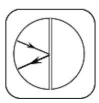


Properties Of Light

When a light ray strikes the interface between two mediums, two potential outcomes arise:

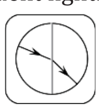
1. The ray reflects back to the same medium (Reflection)
2. The ray transmits into the other medium (Refraction



Reflection 

The occurrence where the incoming ray bounces back into the same medium from which the light originated is termed reflection, and the ray itself is denoted as the reflected ray.

In reflection, the velocity, frequency, and wavelength of the light remain consistent with those of the incident light.

Refraction 

The occurrence where the incident ray passes through the interface of two mediums and continues into the other medium is termed as refraction, with the ray referred to as the refracted ray.

Refraction is a phenomenon characterized by a change in the velocity of light resulting from a transition between mediums. Consequently, only the frequency of light remains constant following refraction.

Reflection

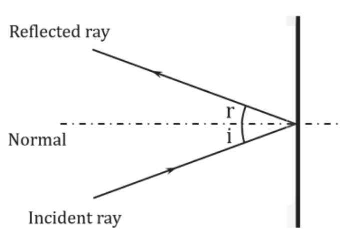
Terminology:

Angle of incidence:

The angle formed by the incident ray and the normal line is termed as the angle of incidence, denoted by the symbol i.

Angle of reflection:

The angle formed by the reflected ray and the normal line is referred to as the angle of reflection, denoted by the symbol r.



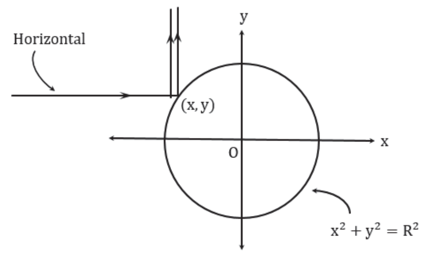
Law Of Reflection

1. $\angle i = \angle r$ [The angle of incidence equals the angle of reflection.]

2. The incident ray, reflected ray, and the normal at the point of incidence all lie within the same plane.
i – Angle of Incidence
r – Angle of Reflection
Laws of reflection are valid for reflecting surfaces of any shape.

Ex. A ray of light is incident on a circle $x^2 + y^2 = R^2$ polished from inside as shown in the figure. Find the coordinates x and y of the point at which the incident ray should fall, such that the reflected ray becomes vertical after reflection.

Sol. For any spherical surfaces, we know that the line joining the centre and any point on its periphery is normal to that spherical surface. Hence, we draw a straight line from O to A, as shown in the adjacent figure.



By applying the 1st law of reflection, we can say that the normal OA becomes the angle bisector of the angle ∠PAO. Since the reflected rav become vertical ∠PAO = 90°, therefore ∠PAS = ∠SAQ = 45°
Therefore, the coordinate of point A is given by,

$$(x, y) = (-R\cos 45°, R\sin 45°) = [-\frac{R}{\sqrt{2}}, \frac{R}{\sqrt{2}}]$$

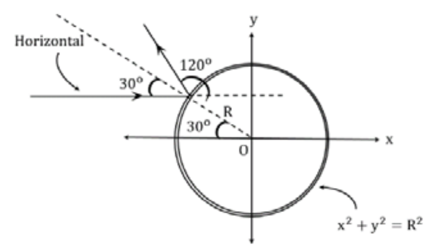
Similarly, the coordinate of point C will be,

$$(x, y) = (-R\cos 45°, -R\sin 45°) = [-\frac{R}{\sqrt{2}}, -\frac{R}{\sqrt{2}}]$$

$$(x, y) = (\frac{-R}{\sqrt{2}}, \frac{\pm R}{\sqrt{2}})$$

Ex. A ray of light is incident on a circle $x^2 + y^2 = R^2$polished from inside as shown in the figure. Find the coordinates x and y of the point at which the incident ray should fall, such that the reflected ray deviates by 120o after reflection.

Sol. Given, The angle of deviation, ∠QAB = 120° Therefore, ∠PAQ = 60°



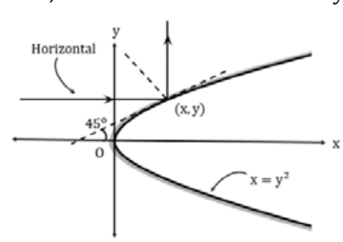
By applying the 1st law of reflection, we can say that
∠PAS = ∠SAQ
Hence, $\angle PAS = \angle SAQ = \frac{\angle PAQ}{2} = 30°$
∠AOC = 30°
Therefore, the coordinate of point A i.e., (x, y) is given by,

$$(x, y) = (-R\cos 30°, R\sin 30°) = [-\frac{\sqrt{3}R}{2}, \frac{R}{2}]$$

$$(x, y) = (-\frac{\sqrt{3}R}{2}, \frac{R}{2})$$

Ex. A ray of light is incident on a parabola $x = y^2$ polished from inside as shown in the figure. Find the coordinates x and y of the point at which the incident ray should fall, such that the reflected ray becomes vertical after reflection.

Sol. For the reflected ray to be vertical, normal should be inclined at 45° with vertical. Thus, the tangent should make 45° with horizontal, i.e., it should have slope 1.



Equation of parabola, $x = y^2$
Differentiating w.r.t. x

$$1 = 2y \cdot \frac{dy}{dx}$$

$$\frac{dy}{dx} = \frac{1}{2y}\frac{dy}{dx} = \frac{1}{2y}$$

We have,

$$\frac{dy}{dx} = 1 = \frac{1}{2y}$$

$$(y = \frac{1}{2})$$

$$x = \frac{1}{4}$$