Chapter 9: Light - Reflection and Refraction

Comprehensive Study Notes

Introduction

Light is electromagnetic radiation that enables us to see objects around us. We see objects because they reflect light that falls on them, and this reflected light reaches our eyes. In darkness, we cannot see anything because there is no light source to illuminate objects.

Key Observations:

- Light travels in straight lines in a transparent medium
- Small sources cast sharp shadows, indicating straight-line propagation
- Light rays can be represented as straight lines showing the path of light
- When light encounters boundaries between different media, it can reflect or refract

Important Note: The nature of light is complex - it exhibits both wave and particle properties, but for this chapter, we treat light as rays traveling in straight lines.

9.1 Reflection of Light

Basic Concepts

Reflection: The bouncing back of light when it strikes a polished or smooth surface.

Laws of Reflection:

1. **First Law**: The angle of incidence equals the angle of reflection ($\angle i = \angle r$)
2. **Second Law**: The incident ray, reflected ray, and normal to the surface at the point of incidence all lie in the same plane

Image Formation by Plane Mirrors

Characteristics of images formed by plane mirrors:

- Always virtual and erect
- Same size as the object
- Image distance equals object distance from mirror
- Laterally inverted (left appears right and vice versa)

Key Terms:

- **Incident Ray**: Light ray falling on the mirror
- **Reflected Ray**: Light ray bouncing back from the mirror
- **Normal**: Perpendicular line to the mirror surface at point of incidence
- **Angle of Incidence (i)**: Angle between incident ray and normal
- **Angle of Reflection (r)**: Angle between reflected ray and normal

9.2 Spherical Mirrors

Types of Spherical Mirrors

1. Concave Mirror:

- Reflecting surface curves inward (toward center of sphere)
- Also called converging mirror
- Example: Inner surface of a spoon

2. Convex Mirror:

- Reflecting surface curves outward (away from center of sphere)
- Also called diverging mirror

- Example: Outer surface of a spoon

Important Terms and Definitions

Pole (P): Center point of the reflecting surface of a spherical mirror

Center of Curvature (C): Center of the sphere of which the mirror forms a part

- For concave mirrors: Lies in front of the mirror
- For convex mirrors: Lies behind the mirror

Radius of Curvature (R): Radius of the sphere of which the mirror forms a part

Principal Axis: Straight line passing through pole and center of curvature

Principal Focus (F): Point on principal axis where parallel rays converge (concave) or appear to diverge from (convex)

Focal Length (f): Distance between pole and principal focus

Aperture: Diameter of the reflecting surface

Important Relationship:

R = 2f (Radius of curvature = 2 × Focal length)

9.2.1 Image Formation by Concave Mirrors

Object Position	Image Position	Size	Nature
At infinity	At focus F	Highly diminished, point-sized	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	-	No image formed

Object Position	Image Position	Size	Nature
Between P and F	Behind mirror	Enlarged	Virtual and erect

Uses of Concave Mirrors:

- Torches and headlights (produce parallel beams)
- Shaving mirrors (magnified image)
- Dental mirrors (enlarged view)
- Solar furnaces (concentrate sunlight)
- Telescopes (collect light from distant objects)

9.2.2 Image Formation by Convex Mirrors

Object Position	Image Position	Size	Nature
At infinity	At focus F (behind mirror)	Highly diminished, point-sized	Virtual and erect
Between infinity and pole	Between P and F (behind mirror)	Diminished	Virtual and erect

Key Feature: Convex mirrors always form virtual, erect, and diminished images regardless of object position.

Uses of Convex Mirrors:

- Rear-view mirrors in vehicles (wider field of view)
- Security mirrors in shops and corridors
- Side mirrors of automobiles
- Traffic safety mirrors at road intersections

9.2.3 Ray Diagram Rules for Spherical Mirrors

For drawing ray diagrams, use any two of these standard rays:

1. **Ray parallel to principal axis**:
    - Concave: Passes through focus after reflection
    - Convex: Appears to come from focus after reflection
2. **Ray through focus**:
    - Concave: Emerges parallel to principal axis
    - Convex: Ray directed toward focus emerges parallel
3. **Ray through center of curvature**:
    - Reflects back along the same path
4. **Ray hitting the pole**:
    - Reflects at equal angles to principal axis

9.2.4 Sign Convention (New Cartesian Sign Convention)

Reference Point: Pole of the mirror (origin) **Coordinate System**: Principal axis as x-axis

Rules:

- Object always placed to the left
- Distances to the right of pole: **Positive**
- Distances to the left of pole: **Negative**
- Heights above principal axis: **Positive**
- Heights below principal axis: **Negative**

9.2.5 Mirror Formula and Magnification

Mirror Formula:

```
1/v + 1/u = 1/f
```

Where:

- u = object distance
- v = image distance
- f = focal length

Magnification Formula:

```
m = h'/h = -v/u
```

Where:

- h = object height
- h' = image height
- m = magnification

Magnification Interpretation:

- Positive m: Virtual, erect image
- Negative m: Real, inverted image
- |m| > 1: Enlarged image
- |m| < 1: Diminished image
- |m| = 1: Same size image

9.3 Refraction of Light

Basic Concepts

Refraction: The bending of light when it passes from one transparent medium to another.

Cause: Change in speed of light in different media

Observable Phenomena:

- Pencil appears bent in water
- Objects appear raised when viewed through glass
- Pool appears shallower than actual depth
- Stars appear to twinkle due to atmospheric refraction

9.3.1 Laws of Refraction

First Law: The incident ray, refracted ray, and normal at the point of incidence all lie in the same plane.

Second Law (Snell's Law):

```
sin i / sin r = constant
```

Where:

- i = angle of incidence
- r = angle of refraction
- Constant = refractive index

9.3.2 Refractive Index

Definition: Measure of how much light bends when entering a medium

Mathematical Expression:

$$n_{21} = v_1/v_2 = \sin i / \sin r$$

Absolute Refractive Index:

$$n = c/v$$

Where:

- c = speed of light in vacuum (3×10^8 m/s)
- v = speed of light in the medium

Refractive Index Values (Table):

Material	Refractive Index	Material	Refractive Index
Air	1.0003	Canada Balsam	1.53
Ice	1.31	Rock salt	1.54
Water	1.33	Carbon disulphide	1.63
Alcohol	1.36	Dense flint glass	1.65
Kerosene	1.44	Ruby	1.71
Fused quartz	1.46	Sapphire	1.77
Turpentine oil	1.47	Diamond	2.42
Crown glass	1.52		

Optical Density:

- **Optically denser medium**: Higher refractive index
- **Optically rarer medium**: Lower refractive index
- Light slows down in optically denser media

- Light speeds up in optically rarer media

Important: Optical density ≠ Mass density (kerosene is optically denser than water but has lower mass density)

9.3.3 Refraction Through Rectangular Glass Slab

Key Observations:

- Light bends toward normal when entering denser medium (air to glass)
- Light bends away from normal when entering rarer medium (glass to air)
- Emergent ray is parallel to incident ray
- Lateral displacement occurs due to refraction

When incident ray is normal: No bending occurs ($\sin 0° = 0$)

9.4 Spherical Lenses

Types of Lenses

1. Convex Lens (Converging Lens):

- Thicker at center, thinner at edges
- Converges parallel light rays
- Also called double convex lens

2. Concave Lens (Diverging Lens):

- Thinner at center, thicker at edges
- Diverges parallel light rays
- Also called double concave lens

Important Terms

Optical Center (O): Central point of lens where light passes without deviation

Principal Focus (F): Point where parallel rays converge (convex) or appear to diverge from (concave)

Focal Length (f): Distance from optical center to principal focus

Centers of Curvature (C_1, C_2): Centers of the spheres forming the lens surfaces

Principal Axis: Line passing through both centers of curvature

Aperture: Effective diameter of the lens

9.4.1 Image Formation by Convex Lens

Object Position	Image Position	Size	Nature
At infinity	At focus F_2	Highly diminished, point-sized	Real and inverted
Beyond $2F_1$	Between F_2 and $2F_2$	Diminished	Real and inverted
At $2F_1$	At $2F_2$	Same size	Real and inverted
Between F_1 and $2F_1$	Beyond $2F_2$	Enlarged	Real and inverted
At focus F_1	At infinity	-	No image formed
Between F_1 and O	Same side as object	Enlarged	Virtual and erect

Uses of Convex Lenses:

- Camera lenses
- Magnifying glasses
- Microscope objectives
- Telescope eyepieces

- Correcting hypermetropia (farsightedness)
- Compound microscopes

9.4.2 Image Formation by Concave Lens

Object Position	Image Position	Size	Nature
At infinity	At focus F_1	Highly diminished, point-sized	Virtual and erect
Between infinity and O	Between F_1 and O	Diminished	Virtual and erect

Key Feature: Concave lenses always form virtual, erect, and diminished images.

Uses of Concave Lenses:

- Correcting myopia (nearsightedness)
- Peepholes in doors
- Vehicle headlights (with convex mirrors)
- Telescopes (in combination with convex lenses)

9.4.3 Ray Diagram Rules for Lenses

Standard rays for drawing diagrams:

1. **Ray parallel to principal axis**:
   - Convex: Passes through focus after refraction
   - Concave: Appears to diverge from focus
2. **Ray through focus**:
   - Convex: Emerges parallel to principal axis
   - Concave: Ray toward focus emerges parallel
3. **Ray through optical center**:

- Passes through without deviation

9.4.4 Sign Convention for Lenses

Same as mirrors but measured from optical center:

- Convex lens: f is positive
- Concave lens: f is negative
- Object side: Negative distances
- Image side: Positive distances

9.4.5 Lens Formula and Magnification

Lens Formula:

```
1/v - 1/u = 1/f
```

Magnification:

```
m = h'/h = v/u
```

Power of Lens:

```
P = 1/f (in meters)
```

Unit: Dioptre (D) = m^{-1}

Power Relationships:

- Convex lens: Positive power
- Concave lens: Negative power

- Combined lenses: $P = P_1 + P_2 + P_3 + ...$

9.5 Practical Applications and Problem-Solving

Worked Examples

Example 1: Convex Mirror Problem

- Object distance u = -5.00 m
- Radius of curvature R = +3.00 m
- Focal length f = R/2 = +1.50 m
- Using 1/v + 1/u = 1/f
- Image distance v = +1.15 m
- Magnification m = +0.23
- Result: Virtual, erect, diminished image

Example 2: Concave Mirror Problem

- Object size h = +4.0 cm
- Object distance u = -25.0 cm
- Focal length f = -15.0 cm
- Image distance v = -37.5 cm
- Image height h' = -6.0 cm
- Result: Real, inverted, enlarged image

Example 3: Concave Lens Problem

- Focal length f = -15 cm
- Image distance v = -10 cm

- Object distance u = -30 cm
- Magnification m = +0.33
- Result: Virtual, erect, diminished image

9.6 Advanced Concepts

Total Internal Reflection

When light travels from denser to rarer medium:

- If angle of incidence > critical angle
- Complete reflection occurs (no refraction)
- Applications: Optical fibers, prisms, diamonds

Critical Angle:

$$\sin C = 1/n = n_2/n_1 \text{ (where } n_1 > n_2\text{)}$$

Dispersion of Light

- White light splits into constituent colors
- Different colors have different refractive indices
- Red light: least deviation
- Violet light: maximum deviation
- Applications: Prisms, rainbows, spectrometers

9.7 Real-World Applications

Optical Instruments

1. Simple Microscope:

- Uses single convex lens
- Object placed between F and O
- Virtual, erect, magnified image

2. Compound Microscope:

- Two convex lenses (objective + eyepiece)
- High magnification for small objects
- Final image: virtual, inverted, highly magnified

3. Telescope:

- Objective lens + eyepiece
- View distant objects
- Types: Refracting, reflecting telescopes

4. Camera:

- Convex lens system
- Real, inverted image on film/sensor
- Adjustable focal length for focusing

Vision Correction

Common Eye Defects:

1. Myopia (Nearsightedness):

- Far objects appear blurred
- Image forms before retina
- Correction: Concave lens

2. Hypermetropia (Farsightedness):

- Near objects appear blurred
- Image forms behind retina
- Correction: Convex lens

3. Presbyopia:

- Age-related loss of accommodation
- Difficulty focusing on near objects
- Correction: Bifocal or progressive lenses

9.8 Laboratory Activities and Experiments

Activity 1: Mirror Focus Determination

- Use concave mirror to focus sunlight
- Sharp bright spot indicates focus
- Measure distance for focal length

Activity 2: Lens Power Measurement

- Focus distant object using convex lens
- Measure image distance
- Calculate focal length and power

Activity 3: Refractive Index Measurement

- Use glass slab and pins
- Measure angles of incidence and refraction
- Apply Snell's law

Activity 4: Apparent Depth

- Object in water appears raised
- Calculate apparent depth using refractive index
- Real depth = apparent depth × refractive index

9.9 Mathematical Problem-Solving Strategies

Step-by-Step Approach:

1. **Identify given values**: u, v, f, h, h', R, P
2. **Apply sign convention**: Assign proper signs
3. **Choose appropriate formula**: Mirror or lens formula
4. **Substitute values**: Calculate unknown quantities
5. **Interpret results**: Determine image characteristics

Common Formulas Summary:

For Mirrors:

- Mirror formula: $1/v + 1/u = 1/f$
- Magnification: $m = -v/u = h'/h$
- Radius relation: $R = 2f$

For Lenses:

- Lens formula: $1/v - 1/u = 1/f$
- Magnification: $m = v/u = h'/h$
- Power: $P = 1/f$ (in meters)

9.10 Important Phenomena in Nature

Atmospheric Effects:

- **Mirage**: Hot air creates optical illusion
- **Twinkling of stars**: Atmospheric refraction
- **Blue sky**: Scattering of light
- **Rainbow**: Dispersion and total internal reflection

Water Effects:

- **Swimming pool depth**: Appears shallower
- **Fish position**: Appears at different location
- **Underwater vision**: Distorted due to refraction

9.11 Advanced Applications

Fiber Optics:

- Based on total internal reflection
- Light transmission through thin glass fibers
- Applications: Internet, medical endoscopy, sensors

Prisms:

- **Deviation of light**: $\delta = i_1 + i_2 - A$
- **Minimum deviation**: Special condition for symmetric ray path
- **Dispersion**: Separation of white light into colors

Lens Combinations:

- **Power addition**: $P = P_1 + P_2 + P_3 + \ldots$
- **Magnification multiplication**: $M = m_1 \times m_2 \times m_3 \times \ldots$

- **Focal length**: $1/F = 1/f_1 + 1/f_2 - d/(f_1 f_2)$

Chapter Summary

Light travels in straight lines and exhibits reflection and refraction when encountering different surfaces and media. Spherical mirrors (concave and convex) form images through reflection, with characteristics depending on object position relative to focal point and center of curvature.

Refraction occurs when light changes medium, bending toward normal in denser media and away in rarer media. Spherical lenses (convex and concave) form images through refraction, with convex lenses converging light and concave lenses diverging it.

Understanding these principles enables us to design optical instruments like cameras, microscopes, telescopes, and corrective eyewear. The mathematical relationships (mirror formula, lens formula, magnification) allow precise calculations for practical applications.

Study Strategy

1. **Master the terminology**: Know all definitions precisely
2. **Practice ray diagrams**: Draw accurate diagrams for different positions
3. **Apply sign conventions**: Always use correct signs in calculations
4. **Solve numerical problems**: Practice various problem types
5. **Connect theory to applications**: Understand real-world uses
6. **Perform experiments**: Hands-on activities reinforce concepts

Key Equations Summary

Reflection:

- $1/v + 1/u = 1/f$
- $m = -v/u = h'/h$

- $R = 2f$

Refraction:

- $\sin i / \sin r = n_{21}$
- $n = c/v$
- $1/v - 1/u = 1/f$
- $m = v/u = h'/h$
- $P = 1/f$

Review Questions

1. Explain why convex mirrors are preferred for vehicle rear-view mirrors.
2. How does the refractive index relate to the speed of light in different media?
3. Why do we see a virtual image when an object is placed between the pole and focus of a concave mirror?
4. What is the relationship between focal length and radius of curvature for spherical mirrors?
5. How does dispersion lead to the formation of a rainbow?

Source: NCERT Science Textbook - Chapter 9

Complete coverage for comprehensive understanding of reflection and refraction of light