Physics Standard X: Lenses Chapter Notes

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Contents

1 Introduction to Lenses

Lenses are transparent media that refract light to form images, used in devices like spectacles, telescopes, and microscopes. Unlike a glass sheet, lenses converge or diverge light, enabling magnification or image formation.

1.1 Uses of Lenses

- Spectacles: Correct vision.
- Telescopes: View distant objects.
- Microscopes: Magnify small objects.
- Cameras: Capture images.
- Door lenses: View outside.
- Toys: Create optical effects.

2 Types of Lenses

Lenses are classified based on their shape and light behavior.

2.1 Convex Lens

- **Shape**: Thicker in the middle, thinner at edges.
- **Function**: Converges light rays to a point (principal focus).
- **Observation**: Magnifies objects; can burn paper by focusing sunlight.
- **Example**: Reading lens, telescope objective.

2.2 Concave Lens

- **Shape**: Thinner in the middle, thicker at edges.
- **Function**: Diverges light rays, appearing to come from a point (principal focus).
- **Observation**: Cannot burn paper; reduces image size.
- **Example**: Used in spectacles for myopia.

Table 1: Comparison of Convex and Concave Lenses

Feature	Convex Lens	Concave Lens
Shape	Thicker in middle	Thinner in middle
Light Behavior	Converges rays	Diverges rays
Principal Focus	Real, on opposite side	Virtual, on same side
Image Type	Real or virtual	Always virtual
Magnification	Can magnify or diminish	Always diminishes
Paper Burning	Possible	Not possible
Letter Movement	Opposite direction	Same direction

2.3 Distinguishing Test

Move a lens sideward while observing letters:

- **Convex**: Letters move in the opposite direction.
- **Concave**: Letters move in the same direction.

3 Lens Structure

A lens has two refracting surfaces, each part of a sphere, causing light refraction.

- **Refracting Surfaces**: Parts of spheres.
- **Optic Centre (O)**: Midpoint of the lens.
- **Centres of Curvature (C_1, C_2)**: Centers of the spheres forming the lens surfaces.
- **Optic Axis**: Imaginary line through optic centre and centres of curvature.
- **Aperture**: Area of lens through which light passes, adjustable in cameras/microscopes.

Table 2: Lens Terminology

Term	Definition
Optic Centre (O)	Midpoint of the lens
Centres of Curvature (C_1, C_2)	Centers of spherical surfaces
Optic Axis	Line through O and C_1, C_2
Aperture	Light-passing area of lens

4 Principal Focus and Focal Length

4.1 Convex Lens

- **Principal Focus (F)**: Point where parallel rays converge after refraction, real, on the opposite side.
- **Focal Length (f)**: Distance from optic centre to principal focus, positive.
- **Experiment**: Use a smoke box with a laser torch. Parallel rays converge at F after passing through a convex lens.
- **Distant Object Method**: Image of a distant object (e.g., tree) on a screen gives approximate focal length (lens-to-screen distance).

4.2 Concave Lens

- **Principal Focus (F)**: Point from which parallel rays appear to diverge, virtual, on the same side.
- **Focal Length (f)**: Distance from optic centre to principal focus, negative.
- **Experiment**: In a smoke box, refracted rays diverge, appearing to originate from F.

Table 3: Principal Focus Comparison

Lens	**Principal Focus**	**Focal Length Sign**
Convex	Real, opposite side	Positive
Concave	Virtual, same side	Negative

5 Image Formation by Lenses

5.1 Convex Lens

Images vary based on object position relative to focal points (F, 2F).

Table 4: Image Formation by Convex Lens

Object Position	**Image Position**	**Characteristics**
Beyond 2F	Between F and 2F	Real, inverted, diminished
At 2F	At 2F	Real, inverted, same size
Between F and 2F	Beyond 2F	Real, inverted, magnified
At F	At infinity	Real, inverted, highly magnified
Between F and O	Same side	Virtual, erect, magnified

Ray Diagram Rules:

1. Ray parallel to optic axis: Passes through principal focus after refraction.
2. Ray through optic centre: Passes undeviated.
3. Ray through focus (same side): Becomes parallel after refraction.

5.2 Concave Lens

Images are always virtual, erect, and diminished, located between F and the lens.

Table 5: Image Formation by Concave Lens

Object Position	**Image Position**	**Characteristics**
Between F and 2F	Between F and O	Virtual, erect, diminished
Between F and O	Between F and O	Virtual, erect, diminished

Ray Diagram Rules:

1. Ray parallel to optic axis: Diverges, appears to come from principal focus (same side).
2. Ray through optic centre: Passes undeviated.
3. Ray directed toward focus (opposite side): Becomes parallel after refraction.

6 Lens Equation and Magnification

6.1 Lens Equation

Relates focal length (f), object distance (u), and image distance (v):

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad \text{or} \quad f = \frac{uv}{u - v}$$

6.2 Cartesian Sign Convention

- Distances measured from optic centre.
- **Positive**: Distances in the direction of incident rays (e.g., v for convex lens real image), heights above optic axis (h_o).
- **Negative**: Distances opposite to incident rays (e.g., u, f for concave lens), heights below optic axis (h_i for inverted image).

Table 6: Cartesian Sign Convention Example

Measurement	Sign	Reason
Object distance (u)	Negative	Opposite to incident ray
Image distance (v)	Positive (convex, real)	Same direction as incident ray
Focal length (f)	Positive (convex)	Real focus
Object height (h_o)	Positive	Above optic axis
Image height (h_i)	Negative (inverted)	Below optic axis

6.3 Magnification

$$m = \frac{h_i}{h_o} = \frac{v}{u}$$

- **Positive** m: Erect image (virtual).
- **Negative** m: Inverted image (real).
- $|\mathbf{m}| > \mathbf{1}$: Magnified; $|\mathbf{m}| < \mathbf{1}$: Diminished; $|\mathbf{m}| = \mathbf{1}$: Same size.

Table 7: Magnification and Image Nature

Nature of Image	Sign of Magnification
Erect	Positive
Inverted	Negative
Real	Negative (convex lens)
Virtual	Positive

7 Power of a Lens

Power (P) measures a lens's ability to converge or diverge light:

$$P = \frac{1}{f} \quad \text{(f in meters)}$$

- **Unit**: Dioptre (D).
- **Convex Lens**: Positive power (e.g., $f = 0.25\,\text{m}$, $P = \frac{1}{0.25} = +4\,\text{D}$).
- **Concave Lens**: Negative power (e.g., $f = -0.25\,\text{m}$, $P = \frac{1}{-0.25} = -4\,\text{D}$).

8 Optical Instruments

8.1 Compound Microscope

- **Purpose**: Magnifies small objects.
- **Components**:
  - **Objective**: Convex lens, short focal length, forms real, inverted, magnified image.
  - **Eyepiece**: Convex lens, longer focal length, forms virtual, magnified image.
- **Image Formation**:
  - Object between F_o and $2F_o$: Objective forms real, inverted, magnified image beyond $2F_o$.
  - This image, between eyepiece's F_e and O, forms a virtual, magnified, erect image via eyepiece.

Table 8: Compound Microscope Lenses

Lens	Type	Focal Length	Image Characteristics
Objective	Convex	Shorter	Real, inverted, magnified
Eyepiece	Convex	Longer	Virtual, erect, magnified

8.2 Refracting Telescope

- **Purpose**: Views distant objects clearly.
- **Components**:
  - **Objective**: Convex lens, long focal length, large aperture, forms small, real, inverted image.
  - **Eyepiece**: Convex lens, shorter focal length, smaller aperture, forms virtual, magnified image.
- **Image Formation**:
  - Object at infinity: Objective forms small, real, inverted image at its focus.
  - Eyepiece uses this image (between F_e and O) to form a virtual, magnified image.
- **Telescope Length**: Sum of focal lengths of objective and eyepiece.

Table 9: Telescope Lenses

Lens	Focal Length	Aperture	Image Characteristics
Objective	Longer	Larger	Small, real, inverted
Eyepiece	Shorter	Smaller	Virtual, magnified

8.3 Telescope Construction

- **Materials**: 1 m PVC pipe, convex lens (10 cm diameter, 100 cm focal length) for objective, small convex lens (e.g., watch repair eyepiece) for eyepiece, plastic bottle.
- **Method**: Fix objective at pipe's end, attach eyepiece to bottle's mouth, adjust distance by sliding bottle to view distant objects.
- **Precaution**: Avoid viewing the sun to prevent eye damage due to intense focused light.

9 Activities and Observations

9.1 Activity: Glass Sheet vs. Convex Lens

- **Glass Sheet**: Sunlight on paper shows no change in illuminated area size with distance.
- **Convex Lens**: At a specific distance, light focuses to a small, intense spot, capable of burning paper.
- **Conclusion**: Convex lenses converge light, unlike glass sheets.

9.2 Activity: Smoke Box Experiment

- **Setup**: Laser torch, smoke-filled box, convex/concave lens.
- **Convex Lens**: Parallel rays converge at principal focus (real).
- **Concave Lens**: Parallel rays diverge, appear to originate from principal focus (virtual).

9.3 Activity: Image Formation

- **Convex Lens**: Forms real images on a screen (e.g., window image), characteristics vary by object position.
- **Concave Lens**: Cannot form images on a screen; images are virtual, seen through the lens.

10 Key Formulas

- **Lens Equation**: $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$
- **Magnification**: $m = \frac{h_i}{h_o} = \frac{v}{u}$

- **Power**: $P = \frac{1}{f}$ (f in meters, P in dioptres)

11 Applications

- **Spectacles**: Convex (+ power) for hyperopia, concave (- power) for myopia.
- **Microscopes**: Magnify tiny objects for scientific study.
- **Telescopes**: Enable observation of celestial bodies.
- **Cameras**: Capture real images on sensors or film.