Ray Optics & Optical Instruments – Practice Questions & Answers

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Part 1 – One-Mark MCQs

1. **What is the speed of light in vacuum approximately?**
   a) $2 \times 10^8 \text{m/s}$
   b) $3 \times 10^8 \text{m/s}$
   c) $1.5 \times 10^8 \text{m/s}$
   d) $4 \times 10^8 \text{m/s}$
   Answer: b) $3 \times 10^8 \text{m/s}$
2. **A ray of light is incident on a plane mirror. The angle between the incident ray and reflected ray is 60°. What is the angle of incidence?**
   a) 30°
   b) 60°
   c) 90°
   d) 120°
   Answer: a) 30°
3. **For a concave mirror, if the object is placed at the centre of curvature, the image formed is:**
   a) Real, inverted, and same size
   b) Virtual, erect, and magnified
   c) Real, inverted, and diminished
   d) Virtual, erect, and diminished
   Answer: a) Real, inverted, and same size
4. **The focal length of a spherical mirror is equal to:**
   a) R
   b) $R/2$
   c) $2R$
   d) $R/4$
   Answer: b) $R/2$
5. **Which mirror always produces a virtual, erect, and diminished image?**
   a) Concave mirror
   b) Convex mirror
   c) Plane mirror
   d) Parabolic mirror
   Answer: b) Convex mirror

6. **According to Snell's law, the ratio $\frac{\sin i}{\sin r}$ is equal to:**
   a) Refractive index of the first medium
   b) Refractive index of the second medium
   c) Relative refractive index of the second medium w.r.t the first
   d) Speed of light in vacuum
   Answer: c) Relative refractive index of the second medium w.r.t the first
7. **When light travels from a denser to a rarer medium, the angle of refraction is:**
   a) Less than the angle of incidence
   b) Equal to the angle of incidence
   c) Greater than the angle of incidence
   d) Zero
   Answer: c) Greater than the angle of incidence
8. **Total internal reflection occurs when light travels from:**
   a) Rarer to denser medium
   b) Denser to rarer medium
   c) Same medium to same medium
   d) Air to glass
   Answer: b) Denser to rarer medium
9. **The critical angle for a medium is 45°. Its refractive index is:**
   a) 1
   b) $\sqrt{2}$
   c) 2
   d) 1.5
   Answer: b) $\sqrt{2}$
10. **Which optical device works on the principle of total internal reflection?**
    a) Plane mirror
    b) Convex lens
    c) Optical fibre
    d) Concave mirror
    Answer: c) Optical fibre
11. **The power of a lens is +2.5 D. Its focal length is:**
    a) 40 cm
    b) 25 cm
    c) 2.5 cm
    d) 0.4 m
    Answer: a) 40 cm
12. **A lens forms a virtual, erect, and magnified image. The lens is:**
    a) Convex lens with object between F and O
    b) Concave lens
    c) Convex lens with object beyond 2F
    d) Convex lens with object at F
    Answer: a) Convex lens with object between F and O

13. **For a thin convex lens, if the object is at infinity, the image is formed at:**
    a) Focus
    b) Centre of curvature
    c) Between F and 2F
    d) Beyond 2F
    Answer: a) Focus
14. **The magnifying power of a simple microscope when the image is at infinity is:**
    a) $1 + \frac{D}{f}$
    b) $\frac{D}{f}$
    c) $\frac{f}{D}$
    d) $1 - \frac{D}{f}$
    Answer: b) $\frac{D}{f}$
15. **In a compound microscope, the lens closer to the object is called:**
    a) Eyepiece
    b) Objective
    c) Condenser
    d) Field lens
    Answer: b) Objective
16. **The magnifying power of an astronomical telescope in normal adjustment is given by:**
    a) $\frac{f_o}{f_e}$
    b) $\frac{f_e}{f_o}$
    c) $1 + \frac{f_o}{f_e}$
    d) $\frac{f_o + f_e}{f_o}$
    Answer: a) $\frac{f_o}{f_e}$
17. **A prism disperses white light because different colours have different:**
    a) Speeds in the prism
    b) Intensities
    c) Angles of incidence
    d) Wavelengths in vacuum
    Answer: a) Speeds in the prism
18. **The mirror formula is given by:**
    a) $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$
    b) $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$
    c) $\frac{1}{f} = \frac{1}{u} - \frac{1}{v}$
    d) $\frac{1}{u} + \frac{1}{v} = f$
    Answer: a) $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

19. **For a convex lens, if the object is placed at 2F, the image is formed at:**
    a) F
    b) 2F
    c) Between F and 2F
    d) Infinity
    Answer: b) 2F
20. **The SI unit of power of a lens is:**
    a) Watt
    b) Dioptre
    c) Joule
    d) Hertz
    Answer: b) Dioptre

Part 2 – Theory & Numerical Questions

Theory Questions

1. What is a ray of light? How does it relate to the wave nature of light?

- A ray is a straight line along which light energy travels.
- It is an idealization used when the wavelength is much smaller than object sizes.
- It represents the direction of propagation of a light wave.

2. State the laws of reflection for spherical mirrors.

- Incident ray, reflected ray, and normal at the point of incidence lie in the same plane.
- Angle of incidence = Angle of reflection.

3. What is the Cartesian sign convention for mirrors?

- Distances measured in the direction of incident light are positive.
- Distances measured opposite to incident light are negative.
- Heights above principal axis are positive; below are negative.
- All distances measured from the pole.

4. Define critical angle. When does total internal reflection occur?

- Critical angle is the angle of incidence in a denser medium for which the angle of refraction in the rarer medium is 90°.

- TIR occurs when:
    - Light travels from denser to rarer medium.
    - Angle of incidence > critical angle.

5. How does an optical fibre work? Mention one application.

- Works on total internal reflection.
- Light enters at an angle > critical angle and undergoes repeated TIR along the fibre.
- Application: Telecommunications, endoscopy.

6. Differentiate between real and virtual images.

- **Real image:** Rays actually converge; can be obtained on a screen; inverted.
- **Virtual image:** Rays appear to diverge; cannot be obtained on screen; erect.

7. What is the lens maker's formula?

$$\frac{1}{f} = (n_{21} - 1)(\frac{1}{R_1} - \frac{1}{R_2})$$

Where n_{21} = refractive index of lens material relative to surrounding medium.

8. Why does a concave mirror have a positive focal length in the Cartesian convention?

- Incorrect — Concave mirror has **negative** focal length because focus is in front of mirror (opposite to incident light direction).

9. What is the power of a lens? Write its SI unit.

- Power $P = \frac{1}{f}$ where f is in meters.
- SI unit: Dioptre (D).

10. Explain why a diamond sparkles more than glass.

- Diamond has high refractive index (~2.42) and small critical angle (~24°).
- Light undergoes multiple TIR, causing high dispersion and brilliance.

Numerical Problems

11. Object 30 cm in front of concave mirror (f = 15 cm). Find image distance and magnification.

- $u = -30$ cm, $f = -15$ cm
- $\frac{1}{v} + \frac{1}{-30} = \frac{1}{-15} \rightarrow v = -30$ cm
- $m = -\frac{v}{u} = -1$
- Image: real, inverted, same size, 30 cm in front.

12. Convex mirror R = 40 cm, object at 20 cm. Find image distance.

- $f = +20$ cm, $u = -20$ cm
- $\frac{1}{v} + \frac{1}{-20} = \frac{1}{20} \rightarrow v = +10$ cm
- Virtual image, behind mirror.

13. Light from water (n=1.33) to air. Find critical angle.

- $\sin i_c = \frac{1}{1.33} \approx 0.7519 \rightarrow i_c \approx 48.75^\circ$

14. Convex lens f=20 cm, image at 40 cm. Find object distance.

- $v = +40$ cm, $f = +20$ cm
- $\frac{1}{40} - \frac{1}{u} = \frac{1}{20} \rightarrow u = -40$ cm

15. Power of lens = –4 D. Find f and type.

- $f = \frac{1}{-4} = -0.25$ m $= -25$ cm
- Concave lens.

16. Two lenses: +2 D and –1 D in contact. Find effective P and f.

- $P_{\text{total}} = 2 + (-1) = +1$ D
- $f = 1$ m $= 100$ cm (converging).

17. Prism A=60°, n=1.5. Find angle of minimum deviation.

- $D_m = (n-1)A = 0.5 \times 60 = 30^\circ$

18. Simple microscope f=5 cm. Magnifying power for image at infinity.

- $m = \frac{D}{f} = \frac{25}{5} = 5$

19. Astronomical telescope: $f_o = 100$ cm, $f_e = 5$ cm. Find magnifying power.

- $m = \frac{f_o}{f_e} = \frac{100}{5} = 20$

20. Needle at bottom of tank: real depth=12 cm, apparent shift=4 cm. Find n.

- Apparent depth = 12 – 4 = 8 cm
- $n = \frac{12}{8} = 1.5$

Part 3 – Advanced Numerical Problems

1. Compound microscope: $f_o = 1.25$ cm, $f_e = 5$ cm, $L = 15$ cm, image at infinity. Find m and u_o.

- $m_o = \frac{L}{f_o} = 12, m_e = \frac{D}{f_e} = 5 \rightarrow m = 60$
- $v_o = L + f_o = 16.25$ cm
- $\frac{1}{16.25} - \frac{1}{u_o} = \frac{1}{1.25} \rightarrow u_o \approx -1.354$ cm

2. Convex lens (f=20 cm) and concave lens (f=-30 cm) separated by 10 cm. Object 30 cm in front of convex lens. Find final image.

- For convex: $u_1 = -30, f_1 = 20 \rightarrow v_1 = +60$ cm
- For concave: $u_2 = 50$ cm, $f_2 = -30 \rightarrow v_2 = -75$ cm
- Final image virtual, 75 cm left of concave lens.

3. Prism A=60°, $D_m = 40°$. Find n. If placed in water (n=1.33), find new D'_m.

- $n = \frac{\sin 50°}{\sin 30°} = 1.532$
- In water: $n_{\text{rel}} = \frac{1.532}{1.33} \approx 1.152$
- $\sin\left(\frac{60+D'_m}{2}\right) = 1.152 \times 0.5 = 0.576$
- $D'_m \approx 10.34°$

4. Concave mirror (R=40 cm) and convex lens (f=20 cm) 30 cm apart. Object 30 cm in front of mirror. Find final image.

- Mirror: $u = -30, f = -20 \rightarrow v = -60$ cm
- Object for lens: $u_{\text{lens}} = -30$ cm
- Lens: $u = -30, f = +20 \rightarrow v = +60$ cm
- Final image 60 cm right of lens.

5. Glass slab (n=1.5, t=6 cm) with liquid above it. Apparent shift=3 cm. Find n of liquid (assuming same thickness).

- Shift = $t\left(1 - \frac{1}{n}\right) = 3$
- $1 - \frac{1}{n} = 0.5 \rightarrow n = 2$

6. Telescope: $f_o = 100\ \text{cm}, f_e = 5\ \text{cm}$**, normal adjustment. Separation? View building 2 km away, height 50 m. Find angular magnification and image height by objective.**

- Separation = $105\ \text{cm}$
- $m = 20$
- $\theta = \frac{50}{2000} = 0.025\ \text{rad}$
- $h' = \theta \times f_o = 2.5\ \text{cm}$

7. Double convex lens n=1.5, $R_1 = 20\ \text{cm}, R_2 = -30\ \text{cm}$**. Find f in air and in liquid (n=1.6).**

- In air: $\frac{1}{f} = 0.5(\frac{1}{20} - \frac{1}{-30}) = 0.04165 \rightarrow f \approx 24\ \text{cm}$
- In liquid: $n_{\text{rel}} = 0.9375 \rightarrow \frac{1}{f'} = -0.005206 \rightarrow f' \approx -192\ \text{cm}$ (diverging)

8. Convex lens (f=10 cm) cut into two halves, one shifted vertically by 0.5 cm. Object at 20 cm. Find images.

- Each half: $u = -20, f = +10 \rightarrow v = +20\ \text{cm}$
- Magnification $m = -1$
- Images 20 cm right, separated vertically by $0.5 \times |\ m\ | \times 2 = 1\ \text{cm}$
- Two real inverted images.

9. Prism A=60°, n=1.6 in water (n=1.33). Find i for TIR at second face.

- $n_{\text{rel}} \approx 1.203 \rightarrow \sin\ i_c' \approx 0.831 \rightarrow i_c' \approx 56.2°$
- $r_1 = 60 - 56.2 = 3.8°$
- $1.33 \sin\ i = 1.6 \sin\ 3.8° \rightarrow i \approx 4.58°$

10. Microscope: $f_o = 1\ \text{cm}, f_e = 2\ \text{cm}, L = 15\ \text{cm}$**, final image at D=25 cm. Find** u_o **and total m.**

- Eyepiece: $v_e = -25, f_e = 2 \rightarrow u_e \approx -1.852\ \text{cm}$
- $v_o = 15 + 1.852 = 16.852\ \text{cm}$
- Objective: $v_o = 16.852, f_o = 1 \rightarrow u_o \approx -1.063\ \text{cm}$
- $m_o \approx 15.85, m_e = 1 + \frac{25}{2} = 13.5 \rightarrow$ Total $m \approx 214$

Part 4 – Four-Mark Questions

1. Derive mirror formula for concave mirror using ray diagram.

- Diagram with object beyond C, rays through F, C, and parallel.

- From similar triangles $\triangle A'B'F$ and $\triangle MPF$:
$$\frac{B'A'}{MP} = \frac{B'F}{FP}$$
- From similar triangles $\triangle A'B'P$ and $\triangle ABP$:
$$\frac{B'A'}{AB} = \frac{B'P}{BP}$$
- Using sign convention: $BP = -u, B'P = -v, FP = -f$
- Combine to get $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

2. Prove $f = R/2$ for spherical mirror.

- Diagram: incident ray parallel to axis, reflected through F.
- Let $\angle MCP = \theta$, $\angle MFP = 2\theta$.
- For small θ: $\tan\ \theta \approx \frac{MD}{CD}$, $\tan\ 2\theta \approx \frac{MD}{FD}$
- $\frac{MD/FD}{MD/CD} = \frac{2\theta}{\theta} \rightarrow \frac{CD}{FD} = 2$
- For small θ, D≈P $\rightarrow CD \approx R, FD \approx f \rightarrow f = R/2$

3. Derive lens maker's formula for thin lens in air.

- Refraction at first surface: $\frac{n}{v_1} - \frac{1}{u} = \frac{n-1}{R_1}$
- Refraction at second surface: $\frac{1}{v} - \frac{n}{v_1} = \frac{1-n}{R_2}$
- Add, simplify: $\frac{1}{f} = (n-1)(\frac{1}{R_1} - \frac{1}{R_2})$

4. Derive magnifying power of compound microscope for image at near point.

- Diagram: objective forms real image I_1, eyepiece forms final virtual image at D.
- $m_o = \frac{L}{f_o}$
- $m_e = 1 + \frac{D}{f_e}$
- Total $m = m_o \times m_e = \frac{L}{f_o}(1 + \frac{D}{f_e})$

5. Prove minimum deviation occurs when ray passes symmetrically through prism.

- Given $\delta = i + e - A, r_1 + r_2 = A$
- For min δ, $\frac{d\delta}{di} = 0 \rightarrow$ symmetry: $i = e, r_1 = r_2 = A/2$
- $\delta_m = 2i - A$
- $n = \frac{\sin(\frac{A+\delta_m}{2})}{\sin\ (A/2)}$

6. Draw Cassegrain telescope diagram, explain working and advantages.

- Diagram: large concave primary with hole, small convex secondary, eyepiece.

- Working: primary focuses light to secondary, reflects through hole to eyepiece.
- Advantages: no chromatic aberration, large aperture possible, shorter tube, lighter.

7. Derive apparent depth formula for normal viewing.

- Diagram: object O at depth h in medium n, appears at I at depth h'.
- Snell: $n\sin\ \theta_1 = \sin\ \theta_2$
- Small angles: $n \cdot \frac{x}{h} \approx \frac{x}{h'} \rightarrow h' = \frac{h}{n}$

8. Prove $n_{12} = 1/n_{21}$ using reversibility of light.

- Forward: $n_{21} = \frac{\sin i}{\sin r}$
- Reverse: $n_{12} = \frac{\sin r}{\sin i}$
- Hence $n_{12} = 1/n_{21}$

9. Show emergent ray from glass slab is parallel to incident ray, derive lateral shift.

- At faces: $\sin\ i = n\sin\ r_1, n\sin\ r_2 = \sin\ e$
- Parallel faces → $r_1 = r_2 \rightarrow i = e$ (parallel emergent)
- Lateral shift $d = \frac{t\sin\,(i-r)}{\cos r}$

10. Convex lens: object between F and 2F, deduce m negative and |m|>1.

- Diagram: object between F and 2F, image beyond 2F (real, inverted, magnified).
- $m = \frac{v}{u'}$, both u and v negative → m negative (inverted).
- Since |v| > |u|, |m| > 1 (magnified).