CLASS XII – PHYSICS (042)
STEP-BY-STEP SOLUTIONS AND MARKING SCHEME

Chapter 9: Ray Optics and Optical Instruments – Practice Paper (35 Marks)

Answer key – Section A

Q.	1	2	3	4	5	6	7	8	9
Ans.	(c)	(a)	(c)	(b)	(d)	(a)	(d)	(c)	(d)

Marks are shown in square brackets. Equivalent correct methods are acceptable. The Cartesian sign convention is used: distances are measured from the pole/optical centre, positive along the incident light. Mirror equation $1/v + 1/u = 1/f$; thin lens formula $1/v - 1/u = 1/f$.

SECTION A

Q.1 (c)

$f = -15$ cm and $u = -20$ cm. $1/v = 1/f - 1/u = -1/15 + 1/20 = -1/60$, so $v = -60$ cm: the image is 60 cm in front of the mirror and real. $m = -v/u = -(-60)/(-20) = -3$: inverted and 3 times the size of the object. **[1]**

Q.2 (a)

For a thin lens $1/v = 1/u + 1/f$, a straight line of unit slope with intercept $1/f$ on the $1/v$ axis. The intercept is $+0.05\ \text{cm}^{-1}$, so $f = +20$ cm: a convex lens. **[1]**

Q.3 (c)

$n = \sin i/\sin r = \sin 60°/\sin 30° = (\sqrt{3}/2)/(1/2) = \sqrt{3} = 1.73$. **[1]**

Q.4 (b)

The ray strikes the hypotenuse at 45°. For total internal reflection the critical angle must be less than 45°: $\sin i_c = 1/n < \sin 45° = 1/\sqrt{2}$, so $n > \sqrt{2} = 1.41$. Media B (1.52), C (1.62) and D (2.42) qualify; water (1.33) does not. **[1]**

Q.5 (d)

From the graph $D_m = 30°$ (the minimum of the curve) with $A = 60°$. $n = \sin[(A + D_m)/2]/\sin(A/2) = \sin 45°/\sin 30° = (1/\sqrt{2})/(1/2) = \sqrt{2} = 1.41$. (Check: $i = 45°$ at the minimum, $i = (A + D_m)/2$.) **[1]**

Q.6 (a)

$P_1 = 1/0.20 = +5$ D and $P_2 = 1/(-0.25) = -4$ D. $P = P_1 + P_2 = +1$ D, so $f = +100$ cm: a converging lens of focal length 100 cm. **[1]**

Q.7 (d)

$1/f = (n_g/n_l - 1)(1/R_1 - 1/R_2)$. With $n_g = n_l = 1.5$ the bracket $(n_g/n_l - 1)$ is zero, so $1/f = 0$ and f is infinite. The lens behaves like a plane sheet of glass in the liquid and does not bend the rays. **[1]**

Q.8 (c)

A is true: diamond has a high refractive index (2.42), so its critical angle is small (about 24.4°); most rays inside undergo repeated total internal reflection and emerge in selected directions, so it sparkles. R is false: the critical angle is small, not large. **[1]**

Q.9 (d)

A is false: $1/f = (n_{21} - 1)(1/R_1 - 1/R_2)$. If the surrounding medium is optically denser than the lens ($n_{21} < 1$) a convex lens behaves as a diverging lens. R is true. **[1]**

SECTION B

Q.10

Apparent depth = real depth/n = 24/(4/3) = 18 cm. **[1]**

The coin appears raised by $24 - 18 = 6$ cm. **[1]**

Q.11

At the core–cladding boundary the ray goes from the denser core to the rarer cladding: $\sin i_c = n_2/n_1 = 1.2/1.5 = 0.8$, so $i_c \approx 53°$. **[1]**

The angle of incidence on the core–cladding interface must be greater than i_c ($\approx 53°$) so that the ray is totally internally reflected every time it strikes the interface; this needs the core to have the higher refractive index. **[1]**

Q.12 (A)

$f = R/2 = -20$ cm and $u = -10$ cm: $1/v = 1/f - 1/u = -1/20 + 1/10 = 1/20$, so $v = +20$ cm: the image is 20 cm behind the mirror. **[1]**

$m = -v/u = -20/(-10) = +2$. The image is virtual, erect and twice the size of the object. **[1]**

Q.12 (B)

For a convex mirror f is positive and u is negative (real object): $1/v = 1/f - 1/u = 1/f + 1/|u|$, which is positive, so v is positive: the image is virtual (behind the mirror). **[1]**

$v = f|u|/(f + |u|) < f$, so the image lies between the pole and the focus. $m = -v/u = v/|u| = f/(f + |u|)$, which is positive (erect) and less than 1 (diminished). **[1]**

Q.13

$1/v = 1/u + 1/f = -1/15 + 1/10 = 1/30$, so $v = +30$ cm: a real image 30 cm on the other side of the lens. **[1]**

$m = v/u = 30/(-15) = -2$, so the image size is $h' = mh = -2 \times 2 = -4$ cm: 4 cm tall and inverted. **[1]**

SECTION C

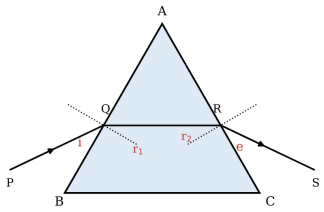
Q.14

(a) $1/f = 1/v - 1/u$. Reading 1: $1/60 + 1/30 = 3/60 = 1/20$. Reading 2: $1/40 + 1/40 = 1/20$. Reading 3: $1/30 + 1/60 = 1/20$. Each gives $f = +20$ cm, so the readings are consistent. **[1]**

(b) $m = v/u$: reading 1: $60/(-30) = -2$; reading 2: $40/(-40) = -1$; reading 3: $30/(-60) = -0.5$. Reading 2 gives an image of the same size as the object (inverted); here $u = -2f = -40$ cm and $v = 2f$. **[1]**

(c) $P = 1/f = 1/0.20$ m $= +5$ D (a converging lens). **[1]**

Q.15 (A)

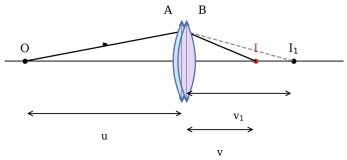


The normals at Q and R meet at N. In quadrilateral AQNR the angles at Q and R are 90°, so $A + \angle QNR = 180°$. In triangle QNR, $r_1 + r_2 + \angle QNR = 180°$. Hence $r_1 + r_2 = A$. **[1]**

The deviation at the first face is $(i - r_1)$ and at the second face $(e - r_2)$, so $\delta = (i - r_1) + (e - r_2) = i + e - A$. At minimum deviation $\delta = D_m$, $i = e$ and hence $r_1 = r_2 = r$. **[1]**

Then $2r = A$, so $r = A/2$, and $D_m = 2i - A$, so $i = (A + D_m)/2$. By Snell's law $n = \sin i/\sin r = \sin[(A + D_m)/2]/\sin(A/2)$. **[1]**

Q.15 (B)



Let the object O be at distance u from the lens A. Lens A forms an image I_1 at distance v_1: $1/v_1 - 1/u = 1/f_1$. **[1]**

I_1 is a (virtual) object for lens B, which is in contact with A (the lenses are thin, so the same centre is used) and forms the final image I at distance v: $1/v - 1/v_1 = 1/f_2$. **[1]**
Adding: $1/v - 1/u = 1/f_1 + 1/f_2$. For a single equivalent lens $1/v - 1/u = 1/f$, so $1/f = 1/f_1 + 1/f_2$. The power of the combination is $P = P_1 + P_2$. **[1]**

Q.16

(a) $m = f_o/f_e = 100/2 = 50$. **[1]**
(b) In normal adjustment the length of the tube is $f_o + f_e = 100 + 2 = 102$ cm. **[1]**
(c) The angular separation is magnified 50 times: $50 \times 2' = 100' = 1° 40'$ (about 1.67°). **[1]**

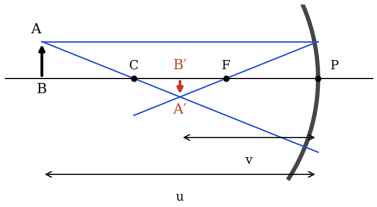
SECTION D

Q.17 (Case study)

(i) **(b)** The objective forms a real, inverted and magnified image, which lies near the focal plane of the eyepiece. **[1]**
(ii) **(c)** $m_o = L/f_o = 20/1.0 = 20$. **[1]**
(iii) **(a)** $m = (L/f_o)(D/f_e) = 20 \times (25/4) = 20 \times 6.25 = 125$. **[1]**
(iv) **(b)** $m_e = 1 + D/f_e = 1 + 25/4 = 7.25$. **[1]**
OR (iv) (a) For the final image at infinity the first image must lie at the first focal point of the eyepiece, i.e. at a distance $f_e = 4$ cm from it. **[1]**

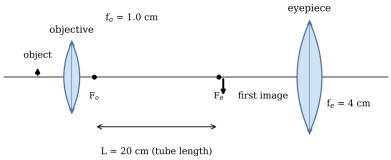
SECTION E

Q.18 (A)



Ray diagram (as above): the ray from A parallel to the principal axis is reflected through F, and the ray through C returns along its own path; they meet at A′, so A′B′ is the real, inverted image. **[1]**
Triangles A′B′F and MPF are similar (PM = AB): B′A′/BA = B′F/FP. Triangles A′B′P and ABP are similar: B′A′/BA = B′P/BP. So B′F/FP = (B′P − FP)/FP = B′P/BP. **[1]**
With the sign convention B′P = −v, FP = −f, BP = −u: (v − f)/f = v/u, so v/f = 1 + v/u; dividing by v gives 1/v + 1/u = 1/f. From the similar triangles A′B′P and ABP, −h′/h = B′P/BP = (−v)/(−u), so m = h′/h = −v/u. **[1]**
Numerical: f = −20 cm, u = −25 cm: 1/v = 1/f − 1/u = −1/20 + 1/25 = −1/100, so v = −100 cm: the image is 100 cm in front of the mirror, real. **[1]**
m = −v/u = −(−100)/(−25) = −4, so h′ = −4 × 4 = −16 cm: the image is inverted, magnified and 16 cm tall. **[1]**

Q.18 (B)



Ray diagram: the objective forms a real, inverted, magnified image A′B′ at (or just within) the focal point of the eyepiece; the eyepiece acts as a simple magnifier and forms the final virtual image at infinity (diagram as above, with the eyepiece image at infinity). **[1]**
The objective's magnification: $m_o = h'/h = L/f_o$ (since $\tan\beta = h/f_o = h'/L$), where L is the tube length. For the eyepiece with the image at infinity, $m_e = D/f_e$. **[1]**
The total magnification is the product: $m = m_o m_e = (L/f_o)(D/f_e)$. **[1]**
Numerical: $m = (15/1.0)(25/5.0) = 15 \times 5 = 75$. **[1]**
With $f_e = 2.5$ cm: $m = (15/1.0)(25/2.5) = 15 \times 10 = 150$. **[1]**

— End of Solutions —