inkPhysics

ANSWER BOOK

Lenses and images

Waves · Year 12

21 questions · 63 marks

NAVY EDITION

SECTION A · Warm-up

A1 The principal focus is the point where rays arriving parallel to the principal axis are brought together after passing through the lens (1). The focal length is the distance from the centre of the lens to the principal focus (1). [2]

A2 $f = 40$ cm $= 0.40$ m (1)
$P = 1/f = 1/0.40 = 2.5$ D, dioptres (1) [2]

A3 A real image is formed where rays actually meet, so it can be caught on a screen (1). A virtual image is formed where rays only appear to come from when projected backwards; no rays pass through it and no screen can catch it (1). [2]

A4 Virtual: it forms where the spreading refracted rays appear to come from, on the same side of the lens as the object (1). It is upright and diminished (1). [2]

A5 The image forms in the focal plane: the image distance is (approximately) equal to the focal length, because $1/u$ is negligible for a distant object (1). It is real, inverted and diminished (1). [2]

A6 Magnification is a ratio of two lengths (v/u, or image height over object height), so it has no unit; the metre should not appear (1). [1]

SECTION B · Standard

B1 $1/v = 1/f - 1/u = 1/0.15 - 1/0.45$ (1)
$v = 0.225$ m ≈ 0.23 m (1)
$m = v/u = 0.50$ (1) [3]

B2 A ray parallel to the principal axis refracts to pass through the principal focus on the far side (1). A ray through the centre of the lens continues undeviated (1). A ray passing through the near principal focus leaves the lens parallel to the axis (1). Any two fix the image; the third confirms it. [3]

B3 $1/v = 1/0.25 - 1/0.10 = -6.0\ m^{-1}$ (1)
$v = -0.167$ m ≈ -0.17 m (1)
The negative sign means the image is virtual: upright and on the same side as the object (1)
$m = |v|/u = 1.67$, so the image is magnified (1) [4]

B4 The whole image remains, but dimmer (1). Every point of the object sends rays through every part of the lens, so the uncovered half still forms the complete image with half the light (1). [2]

B5 $f = 1/P = 1/(-4.0) = -0.25$ m (1). The negative sign marks the lens as diverging: parallel rays spread as if from a focus 25 cm on the incoming side (1). [2]

B6 $u = 60$ cm $= 0.60$ m, and $1/f = P$, so $1/v = P - 1/u = 2.5 - 1/0.60$ (1). $v = 1.2$ m (1). $m = v/u = 1.2/0.60 = 2.0$ (1). [3]

B7 $m = v/u = 3$, so $v = 3u$ (1). Substituting into the lens equation: $1/u + 1/(3u) = 1/0.15$, so $(4/3)(1/u) = 1/0.15$ (1). $u = 0.20$ m (1). $v = 3u = 0.60$ m (1). [4]

B8 $1/v = 1/f - 1/u = 1/0.25 - 1/0.80 = 2.75\ m^{-1}$, so $v = 0.36$ m (1). $m = v/u = 0.36/0.80 = 0.45$ (1). Image height $= 0.45 \times 2.0$ cm $= 0.91$ cm; the image is real and inverted (1). [3]

SECTION C · Stretch

C1 [3]
$1/f = 1/u + 1/v = 1/0.30 + 1/0.60$ (1)
$1/f = 5.0\ m^{-1}$ (1)
$f = 0.20$ m, that is 20 cm (1)

C2 [3]
Powers of thin lenses in contact add (1)
$P = 4.0 + (-1.5) = 2.5$ D (1)
$f = 1/P = 1/2.5 = 0.40$ m, converging (1)

C3 [4]
$1/u = 1/f - 1/v = 1/0.050 - 1/3.0$ (1)
$1/u = 19.67\ m^{-1}$ (1)
$u = 0.0508$ m ≈ 5.1 cm (1)
$m = v/u = 3.0/0.0508 \approx 59$ (1)

C4 Inside the focal length the refracted rays diverge, so only their backward projections meet: the image is virtual, upright and magnified, which is what a magnifying glass is for (1). As the object approaches the focal point the projections meet further and further away and the image grows (1); at the focal point itself the rays emerge parallel and the image forms at infinity (1). [3]

C5 For a very distant object $1/u \approx 0$, so the sensor sits at $v = f = 50$ mm $= 0.050$ m (1). For $u = 1.2$ m: $1/v = 1/0.050 - 1/1.2 = 19.2\ m^{-1}$ (1), so $v = 52.2$ mm (1). The lens must move 2.2 mm away from the sensor (1). [4]

C6 For both lenses $v = 2.4$ m. L_1: $1/u = 1/0.10 - 1/2.4$ (1), so $u = 0.104$ m and $m = v/u = 2.4/0.104 = 23$ (1). L_2: $u = 0.279$ m, so $m = 8.6$ (1). Only L_1 gives a magnification of at least 20, so the student should use L_1 (1), with the slide 10.4 cm from the lens (1). [5]

C7 Line up the illuminated object (for example a lamp behind crosswires), the lens and the screen, and move the screen until the image is sharp (1). Measure the object distance u and the image distance v from the centre of the lens with the metre rule (1). Repeat for a range of object distances (1). Calculate $1/u$ and $1/v$ for each pair and plot $1/v$ against $1/u$ (or find f from $1/f = 1/u + 1/v$ for each pair and average) (1). The graph is a straight line whose intercept on each axis equals $1/f$, giving the focal length (1). Check or improve: focus a distant object (a window across the room) onto the screen, where the image distance is approximately f; or approach the sharpest image position from both sides and average (1). [6]