Answers to exam-style questions

Option C

1 ✓ = 1 mark

1 a Rays of light parallel to the principal axis of the lens will, upon refraction through the lens, pass through the same point on the principal axis on the other side of the lens. ✓

The distance of this point from the middle of the lens is the focal length. ✓

b $M = +5.0 = -\frac{v}{u} = -\frac{v}{2.0}$ ✓

Hence $v = -10$ cm ✓

$\frac{1}{f} = \frac{1}{2.0} + \frac{1}{-10} \Rightarrow f = 2.5 \text{ cm } v = -10 \text{ cm}$ ✓

c $M = -\frac{v}{u} \Rightarrow v = -Mu$ ✓

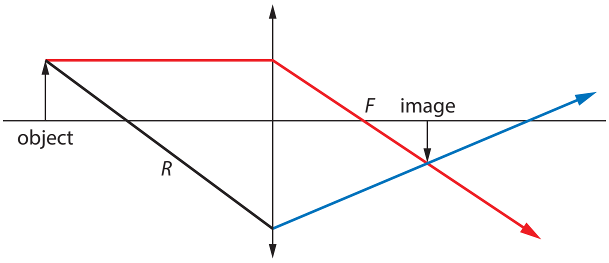
$\frac{1}{f} = \frac{1}{u} - \frac{1}{Mu}$, hence $M = \frac{f}{f-u}$ ✓

To make M as large as possible and still see the image the object must be placed as close to the focal point as possible and in between the focal point and the lens. ✓

2 a Blue line in following diagram. ✓

b Red line in following diagram. ✓

Intersecting the principal axis at the focal point. ✓



c It is real. ✓

Because it is formed by actual rays. ✓

d Since half the light now goes through the lens. ✓

The image will be fully formed but not as bright as before. ✓

e i $v = -25$ cm. ✓

$\frac{1}{u} = \frac{1}{f} - \frac{1}{v} = \frac{1}{4.0} + \frac{1}{25}$ hence $u = 3.45 \approx 3.4$ cm ✓

ii $M = -\frac{v}{u} = -\frac{-25}{3.45} = +7.25$ ✓

Hence $h' = hM = 5.0 \times 7.25 = 36.2 \approx 36$ mm ✓

iii $\theta' = \tan^{-1}\frac{36.2}{250} = 8.2°$ ✓

(which is much preferable to $M = 7.25 = \frac{\theta'}{\theta} = \frac{\theta'}{\frac{5}{250}} \Rightarrow \theta' = 7.25 \times \frac{5}{250} = 0.145 \text{ rad} = 8.3°$)

3 a i $\frac{1}{v_1} = \frac{1}{f_o} - \frac{1}{u_1} = \frac{1}{15} - \frac{1}{20}$ ✓

Hence $v_2 = 60$ mm ✓

ii $v_2 = -250$ mm ✓

$\frac{1}{u_2} = \frac{1}{f_e} - \frac{1}{-250}$ hence $u_2 = 48.4 \approx 48$ mm ✓

b **i** Angular magnification is the ratio of the angle subtended by the final image at the eyepiece. ✓
To the angle the object subtends at the unaided eye at a distance of 25 cm. ✓

ii $M = -\frac{v_1}{u_1} \times \frac{v_2}{u_2} \times \frac{D}{v_2}$ ✓

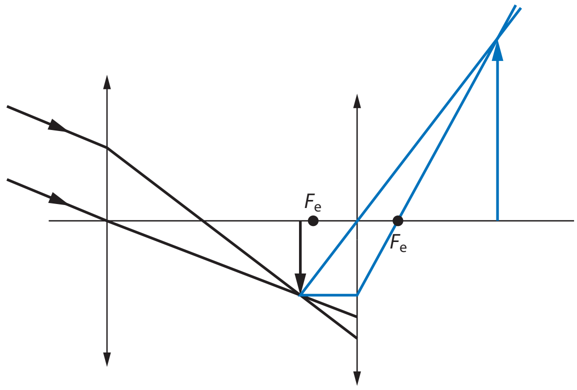
$M = -\frac{60}{20} \times \frac{250}{48.4} = -15.5 \approx -15$ ✓

c **i** $h' = hM = 15.5 \times 8.0 = 124 \approx 120$ mm ✓

ii $\theta' = \tan^{-1}\frac{124}{250} = 26°$ ✓

4 **a** So that it collects a lot of light. ✓

b Line through middle of lens. ✓
Line parallel to PA refracting through the focal point. ✓



c $\frac{1}{u} = \frac{1}{f_e} - \frac{1}{v} = \frac{1}{0.10} - \frac{1}{0.455}$ ✓
Hence $u = 0.128 \approx 0.13$ m ✓

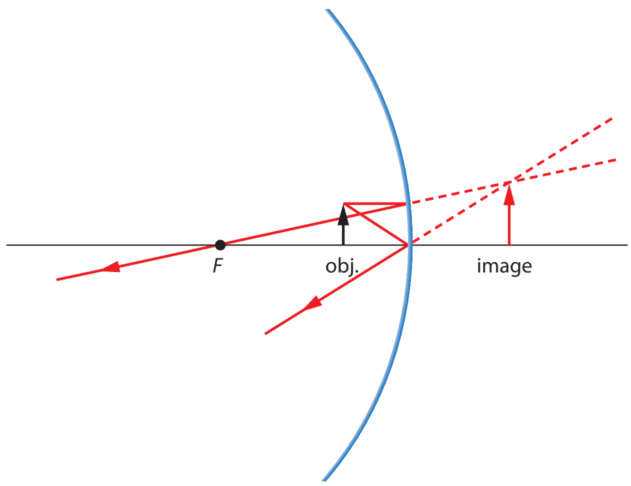
d $0.055 = \frac{h}{f_e} = \frac{h}{1.00} \Rightarrow h = 0.055$ m where h is the size of the image in the objective. ✓
The magnification of the eyepiece is $M = -\frac{0.455}{0.128} = -3.55$ and so $h' = 3.55 \times 0.055 = 0.195 \approx 0.20$ m. ✓

5 **a** **i** $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{24} - \frac{1}{8.0}$, hence $v = -12$ cm ✓

ii The magnification is $M = -\frac{-12}{8.0} = +1.5$ ✓

Hence $h' = Mh = 1.5 \times 3.0 = 4.5$ cm ✓

b One correct ray. ✓
A second correct ray. ✓
Formation of image. ✓



c $M = -\frac{v}{u} = +0.50$, hence $v = -0.50u$. ✓

And $u - v = 120$ cm (v is negative). ✓

Solving for u and v we find $u = 240$ cm, $u = -120$ cm and so $f = -240$ cm (the mirror is convex). ✓

d i Mirrors do not suffer from chromatic aberration. ✓

So the quality of the image is better. ✓

Large mirrors are easier to make compared to lenses. ✓

Large mirrors are needed in order to collect the faint light of distant objects. ✓

ii They do not suffer from spherical aberration. ✓

6 a $\theta = \frac{h}{f}$ hence $1.50 \times 10^{-4} = \frac{h}{10}$ ✓

Giving $h = 1.50$ mm. ✓

b i This image serves as a virtual object for the convex mirror and we have that $u = -1.00$ m and $v = +9.00$ m. ✓

Hence $\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{-1.00} + \frac{1}{9.00}$ leading to $f = -1.125 \approx -1.12$ m. ✓

ii $M = -\frac{v}{u} = -\frac{9.00}{-1.00} = +9.00$ ✓

iii $h' = Mh = 9.00 \times 1.50 = 13.5$ mm ✓

c i The image at C must be at focal point of the converging lens. ✓

Hence $\theta \approx \frac{13.5}{120} = 0.112$ rad ✓

ii $M = \frac{0.112}{1.5 \times 10^{-4}}$ ✓

$M = 747 \approx 750$ ✓

7 a Lens aberrations denote deviations from the perfect geometrical behaviour of lenses in which the focal length is assumed to be the same for all rays and all wavelengths. ✓

b i Spherical aberration refers to the fact that not all paraxial rays have the same focal length. ✓

Rays far from the principal axis have a shorter focal length than rays close to the axis. ✓

Chromatic aberration has to do with the fact that rays of different wavelength have different focal lengths. ✓

Blue wavelengths have a shorter focal length than red. ✓

ii Spherical aberration is reduced by not allowing rays far from the lens to enter the lens and form the image. ✓

Chromatic aberration is corrected by using a second diverging lens of different refractive index adjacent to the first. ✓

8 a i $\frac{1}{v_A} = \frac{1}{f} - \frac{1}{u} = \frac{1}{24} - \frac{1}{40}$ hence $v_A = 60$ cm ✓

$\frac{1}{v_B} = \frac{1}{f} - \frac{1}{u} = \frac{1}{24} - \frac{1}{30}$ hence $v_B = 120$ cm ✓

Hence the difference is 60 cm. ✓

ii $M_A = -\frac{60}{40} = -1.5$ hence $h_A = -1.5 \times 5.0 = -7.5$ cm ✓

$M_B = -\frac{120}{30} = -4.0$ hence $h_B = -4.0 \times 5.0 = -20$ cm ✓

Hence the difference is 12.5 cm. ✓

b i The images of the front and the back of the rod are at 60 cm and 120 cm. ✓

So the length of the image of the rod is different from that of the rod itself. ✓

ii The images of the front and the back of the rod are at different heights. ✓

And so the rod is not parallel. ✓

9 a i $1.58 \times \sin\theta_C = 1.45 \times \sin 90°$ ✓

$\theta_C = \sin^{-1}\frac{1.45}{1.58} = 66.595° \approx 66.6°$ ✓

ii The angle of refraction at the air–core boundary must be $90° - 66.6595° = 23.405° \approx 23.4°$. ✓

Hence $1.00 \times \sin A = 1.58 \times \sin 23.405°$ giving $A = \sin^{-1}(1.58 \times \sin 23.405°) = 38.9°$. ✓

b Material dispersion refers to the fact that rays of different wavelength have different speeds in the same medium. ✓

And so will take different times to complete a given path. ✓

Waveguide dispersion has to do with rays of light following different paths in an optic fibre and hence taking different times to arrive at their destination. ✓

c i Waveguide dispersion may be reduced by using monomode fibres in which all rays essentially follow the same path. ✓

And by using graded index fibres in which the refractive index of the core decreases as one moves from the central axis towards the cladding. ✓

Because rays that move far from the axis now move faster (since the refractive index is less) and so cover the longer distance at higher speed essentially arriving at the same time as the rays close to the axis. ✓

ii Material dispersion may be reduced by using monochromatic light in the transmission. ✓

d i Scattering off impurities in the core. ✓

ii The attenuation is $10\log\frac{P_f}{P_i} = 10\log\frac{25 \times 10^{-3}}{15 \times 10^{-6}}$ ✓

$= 32.2$ dB ✓

Hence we need amplification after $\frac{32.2}{3.50} = 9.2$ km. ✓

10 a i Ultrasound is sound of frequency higher than 20 kHz. ✓

ii X-rays are ionising which means they do damage to cells, ultrasound does not. ✓

b i $\frac{I_t}{I_0} = \frac{(410 - 1.8 \times 10^6)^2}{(410 + 1.8 \times 10^6)^2} \approx 1$ ✓

ii The greatly different impedances imply that essentially all of the ultrasound gets reflected. ✓

Leaving none to be transmitted into the body for imaging. ✓

Thus a gel substance of impedance similar to tissue is placed in between the source of ultrasound and tissue. ✓

c The pulse covers double the required distance. ✓

And so the distance is $\frac{1500 \times 6.5 \times 10^{-3}}{2} = 4.9$ cm. ✓

11 a The distance that X-rays must travel through so that their intensity is reduced by a factor of 2. ✓

b i $\mu x_{1/2} = \ln 2$ so that $\mu = \frac{\ln 2}{x_{1/2}} = \frac{\ln 2}{4.10} = 0.1691$ ✓

$I = I_0 e^{-\mu x}$ so that $0.650 = e^{-0.1691x}$ ✓

$\ln(0.650) = -0.1691x$ so $x = \frac{\ln(0.650)}{-0.1691} = 2.55$ mm ✓

ii A larger HVT value results in smaller attenuation coefficient. ✓

And so a larger distance through which the X-rays would travel to be reduced to 65% in intensity. ✓

c i The blurring of the image is mainly caused by X-rays scattering through the body. ✓

And may be reduced by placing metal strips in the direction of the incident X-rays so that scattered X-rays would be blocked. ✓

ii The exposure time may be reduced by the use of intensifying screens. ✓

In these, X-rays cause the emission of visible light photons which expose photographic film faster than X-rays. ✓

12 Protons in the body align themselves parallel or anti-parallel to an externally supplied strong external field. ✓
A radio frequency signal forces protons to make transitions from the spin up to the spin down state. ✓
Protons make a transition to the spin up state emitting photons. ✓
The frequency of the emitted photons depends on the magnetic field at the point of emission so a second magnetic field is applied so that different parts of the body are exposed to a different net magnetic field. ✓
Knowing the net magnetic field at a given point in the body allows the frequency to be calculated and so measuring the emitted frequency is equivalent to locating the point of emission. ✓
Measuring the rate of transitions allows determination of the tissue type. ✓