SL Paper 3

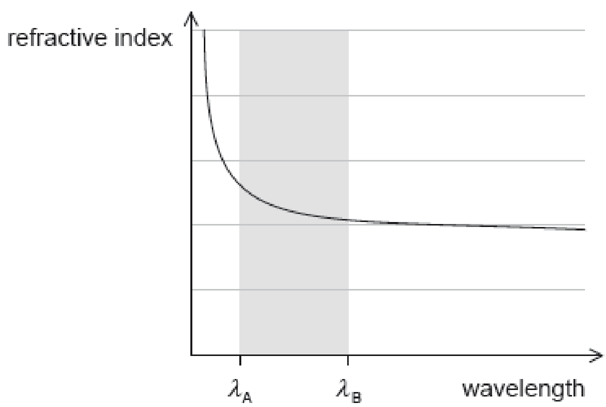
An optic fibre of length 185 km has an attenuation of 0.200 dB km^{-1}. The input power to the cable is 400.0 μW. The output power from the cable must not fall below 2.0 μW.

a. An optic fibre of refractive index 1.4475 is surrounded by air. The critical angle for the core – air boundary interface is 44°. Suggest, with a calculation, why the use of cladding with refractive index 1.4444 improves the performance of the optic fibre. [3]

b.i. Calculate the maximum attenuation allowed for the signal. [2]

b.ii. An amplifier can increase the power of the signal by 12 dB. Determine the minimum number of amplifiers required. [2]

b.iii. The graph shows the variation with wavelength of the refractive index of the glass from which the optic fibre is made. [2]



Two light rays enter the fibre at the same instant along the axes. Ray A has a wavelength of λ_A and ray B has a wavelength of λ_B. Discuss the effect that the difference in wavelength has on the rays as they pass along the fibre.

c. In many places clad optic fibres are replacing copper cables. State **one** example of how fibre optic technology has impacted society. [1]

Markscheme

a. sin *c* = $\frac{1.4444}{1.4475}$ ***or*** sin *c* = 0.9978

critical angle = 86.2«°»

with cladding only rays travelling nearly parallel to fibre axis are transmitted

OR

pulse broadening/dispersion will be reduced

OWTTE

[3 marks]

b.i. attenuation = «10 log$\frac{I}{I_0}$» = 10 log$\frac{2.0\times10^{-6}}{400\times10^{-6}}$

attenuation = «–»23 «dB»

Accept 10 log $\frac{400}{2.0}$ for first marking point

[2 marks]

b.ii. 185 × 0.200 = 37 loss over length of cable

«$\frac{37-23}{12}$ = 1.17» so two amplifiers are sufficient

[2 marks]

b.iii. mention of material dispersion

mention that rays become separated in time

OR

mention that ray A travels slower/arrives later than ray B

[2 marks]

c. high bandwidth/data transfer rates

low distortion/Low noise/Faithful reproduction

high security

fast «fibre» broadband/internet

high quality optical audio

medical endoscopy

Allow any other verifiable sensible advantage

[1 mark]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
b.iii. [N/A]
c. [N/A]

Communication signals are transmitted through optic fibres using infrared radiation.

a.i. State **two** advantages of optic fibres over coaxial cables for these transmissions. [2]

1: . . . .

. . . .

2: . . . .

. . . .

a.ii. Suggest why infrared radiation rather than visible light is used in these transmissions. [1]

b. A signal with an input power of 15 mW is transmitted along an optic fibre which has an attenuation per unit length of 0.30 dB km^{-1}. The power at the receiver is 2.4 mW. [2]

Calculate the length of the fibre.

c. State and explain why it is an advantage for the core of an optic fibre to be extremely thin. [2]

Markscheme

a.i. longer distance without amplification

signal cannot easily be interfered with

less noise

no cross talk

higher data transfer rate

[2 marks]

a.ii. infrared radiation suffers lower attenuation

[1 mark]

b. loss = $10 \log \frac{2.4}{15}$ «= –7.959 dB»

length = «$\frac{7.959}{0.30}$ =» 26.53 ≈ 27 «km»

[2 marks]

c. a thin core means that rays follow essentially the same path / OWTTE

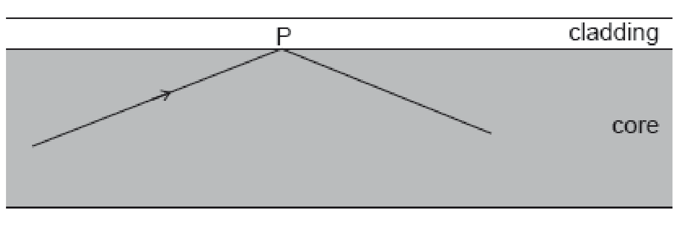
and so waveguide (modal) dispersion is minimal / OWTTE

[2 marks]

Examiners report

a.i. [N/A]
a.ii. [N/A]
b. [N/A]
c. [N/A]

A ray of light travelling in an optic fibre undergoes total internal reflection at point P.



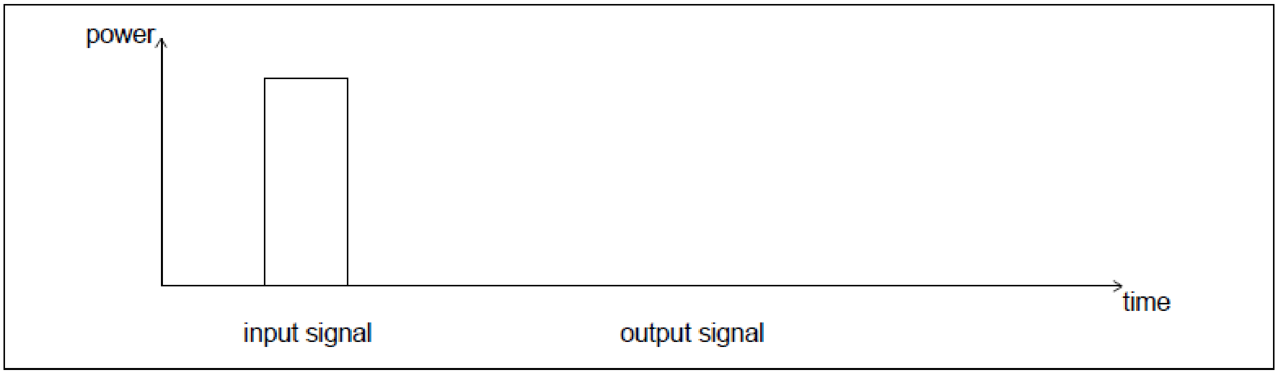
The refractive index of the core is 1.56 and that of the cladding 1.34.

The input signal in the fibre has a power of 15.0 mW and the attenuation per unit length is 1.24 dB km^{-1}.

a. Calculate the critical angle at the core–cladding boundary. [1]

b. The use of optical fibres has led to a revolution in communications across the globe. Outline **two** advantages of optical fibres over electrical conductors for the purpose of data transfer. [2]

c.i. Draw on the axes an output signal to illustrate the effect of waveguide dispersion. [1]



c.ii. Calculate the power of the output signal after the signal has travelled a distance of 3.40 km in the fibre. [3]

c.iii Explain how the use of a graded-index fibre will improve the performance of this fibre optic system. [3]

Markscheme

a. «sin $c = \frac{1.34}{1.56}$»

c = 59.2«°»

Accept values in the range: 59.0 to 59.5.

Accept answer 1.0 rad.

[1 mark]

b. optic fibres are not susceptible to earthing problems

optic fibres are very thin and so do not require the physical space of electrical cables

optic fibres offer greater security as the lines cannot be tapped

optic fibres are not affected by external electric/magnetic fields/interference

optic fibres have lower attenuation than electrical conductors/require less energy

the bandwidth of an optic fibre is large and so it can carry many communications at once/in a shorter time interval/faster data transfer

[2 marks]

c.i. a signal that is wider and lower, not necessarily rectangular, but not a larger area

[1 mark]

c.ii. attenuation = –1.24 × 3.4 «= –4.216 dB»

$-4.216 = 10 \log \frac{I}{15}$

I = 5.68 «mW»

Need negative attenuation for MP1, may be shown in MP2.

For mp3 answer must be less than 15 mW (even with ECF) to earn mark.

*Allow **[3]** for BCA.*

[3 marks]

c.iii. refractive index near the edge of the core is less than at the centre

speed of rays which are reflected from the cladding are greater than the speed of rays which travel along the centre of the core

the time difference for the rays that reflect from the cladding layer compared to those that travel along the centre of the core is less

OR

the signal will remain more compact/be less spread out/dispersion is lower

bit rate of the system may be greater

[3 marks]

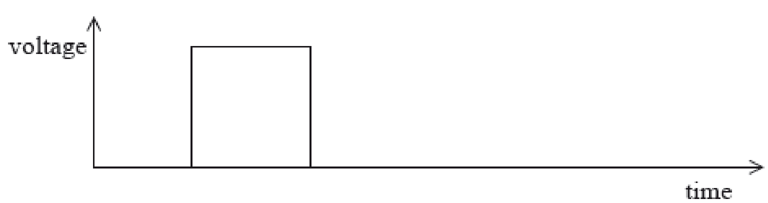
Examiners report

a. [N/A]
b. [N/A]
c.i. [N/A]
c.ii. [N/A]
c.iii. [N/A]

This question is about optical fibres.

a. State what is meant by material dispersion. [3]

c. (i) The signal shown below is fed into a monomode optical fibre. [3]



On the diagram above, show the effects of material dispersion on the input signal by drawing the shape of the signal after it has travelled a long distance in the optical fibre.

(ii) State and explain how the effects on the signal drawn in (c)(i) may be reduced.

e. The data in (d) are confidential and must be protected. Without taking financial costs into account, outline whether a direct optical fibre connection **or** a transmission through a geosynchronous satellite would be more suitable for the transfer of these data. [2]

Markscheme

a. speed of propagation depends on frequency/wavelength;

(and so after some time) different frequencies cover different distances;

c. (i) pulse with longer duration and shorter height shown;

Ignore shape of pulse.

(ii) dispersion is caused by a range of signal frequencies/wavelengths;

so reduce range of frequencies/wavelengths / use monochromatic signal;

e. an optical fibre might be preferable because the data are transmitted along a protected line;

in a satellite transmission the data can be intercepted by anyone;

or

a satellite is preferable provided that it has an encryption system/encoded signal;

wider coverage than cable / any other sensible suggestion;

Examiners report

a. Material dispersion was often confused with modal dispersion.

c. In part (a) material dispersion was often confused with modal dispersion and this confusion carried through to answers to part (b) and c(ii).

e. The confidential transfer of data, was usually answered well.

Two converging lenses placed a distance 90 cm apart are used as a simple astronomical refracting telescope at normal adjustment. The angular magnification of this arrangement is 17.

a. Determine the focal length of each lens. [2]

b. The telescope is used to form an image of the Moon. The angle subtended by the image of the Moon at the eyepiece is 0.16 rad. The distance to the Moon is 3.8 x 10^8 m. Estimate the diameter of the Moon. [3]

c. State **two** advantages of the use of satellite-borne telescopes compared to Earth-based telescopes. [2]

1.

2.

Markscheme

a. states $f_o + f_e = 90$ ***AND*** $\frac{f_o}{f_e} = 17$

solves to give $f_o = 85$ ***AND*** $f_e = 5$ «cm»

Both needed.

Both needed.

[2 marks]

b. angle subtended by Moon is $\frac{0.16}{17} = 0.0094$ «rad»

$0.0094 = \frac{D}{3.8 \times 10^8}$

D = 3.6 x 10^6 «m»

Allow ECF from MP1.

*Allow **[2]** for an answer of 6.1 x 10^7 «m» if the factor of 17 is missing in MP1.*

[3 marks]

c. operation day and night

operation at all wavelengths/no atmospheric absorption

operation without atmospheric turbulence/light pollution

Accept any other sensible advantages.

[2 marks]

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

This question is about lasers and diffraction gratings.

(i) Describe the pattern produced on a screen by a red laser beam incident on a diffraction grating.

(ii) Laser light of wavelength 632 nm is incident on a diffraction grating having 600 lines per mm. Determine the angular separation between the first and second order maxima.

Markscheme

(i) equally spaced;

(red) spots/maxima/bright fringes;

and wide minima/dark fringes;

(ii) use of diffraction grating equation;
correct use of number of lines per mm or calculation of grating spacing;
one angle correctly calculated (angles are 22.3° and 49.3°);
27°;

Examiners report

[N/A]

This question is about a converging lens.

a. Define *angular magnification.* [2]

b. A thin converging lens of focal length 4.5 cm is to be used as a magnifying glass. The observer places the lens close to her eye. The least distance of distinct vision is 24 cm. [5]

(i) Show that the distance of the object from the lens is 3.8 cm.

(ii) Determine the angular magnification produced by the lens.

c. Suggest **two** reasons why, for high magnifications, a combination of lenses is used rather than a single lens. [2]

Markscheme

a. ratio of angle subtended by image and angle subtended by object;

angles measured at eye;

b. (i) $\frac{1}{u} - \frac{1}{24} = \frac{1}{4.5}$;

distance=3.8 cm

(ii) angular magnification $= \frac{h_{\mathrm{I}}}{D} \div \frac{h_{\mathrm{O}}}{D}$;
= linear magnification;
$= \frac{v}{u}$;
$= \frac{24}{3.8}$
=6.3;
*Award **[2 max]** for use of linear magnification alone.*

c. less spherical/chromatic aberration (than single lens);

greater aperture can be used/greater light-collecting ability (than single lens);

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

This question is about properties of electromagnetic waves.

a. State **two** properties that are common to all electromagnetic waves. [2]

b. A single lens is used to form a magnified real image of an object. Explain, with reference to the dispersion of light, why the image has coloured edges. [3]

Markscheme

a. transverse;

can be polarized;

all have same speed in a vacuum;

b. each colour/wavelength has different refractive index;

different focal lengths/amount of diffraction for each wavelength/colour;

so all coloured images do not overlap completely/not at same place;

Examiners report

a. [N/A]
b. [N/A]

This question is about optic fibre transmission.

a. Explain, with reference to the critical angle, what is meant by total internal reflection [3]

b. In an optic fibre the refractive index of the core is 1.62. The refractive index for the cladding is 1.50. Determine the critical angle for the boundary between the core and the cladding. [2]

c. State **one** effect of dispersion on a pulse that has travelled along an optic fibre. [1]

Markscheme

a. for a ray attempting to move from a high to a low refractive index medium;

the phenomena in which the angle of incidence is greater than the critical angle;

(critical angle is) the angle of incidence for which the angle of refraction is 90° / *OWTTE;*
leading to a reflected but not to a refracted ray;
*Award **[3 max]** for a clearly drawn annotated diagram.*

b. $\frac{\sin\theta_c}{\sin 90^\circ} = \left(\frac{\sin\theta_c}{1} =\right) \frac{1.50}{1.62}$;
$\theta_c = 67.8^\circ$;

*Award **[2]** for a bald correct answer.*

c. pulse width/duration increases / pulse amplitude decreases / colour separation;

Examiners report

a. Total internal reflection was not usually well explained. Far too many candidates gave disorganised accounts and were unsure which angle was the critical angle.

b. The value of critical angle was frequently wrong in part (b) as the wrong pair of refractive indices was used.

c. In (c) there was often confusion between attenuation and dispersion.

This question is about a magnifying glass.

a. (i) Define the *angular magnification* of a magnifying glass. [4]

(ii) Derive an equation for the angular magnification of a magnifying glass with the image at infinity.

b. An object is positioned 8.00 cm from a magnifying glass of focal length 15.0 cm. [4]

(i) Calculate the position of the image.

(ii) Calculate the linear magnification.

(iii) The image is upright and magnified. State a further property of the image.

Markscheme

a. (i) ratio of angle subtended by image at eye to angle subtended by object at the near point;

(ii) $\theta_o = \frac{h_o}{25}$;
$\theta_i = \frac{h_o}{f}$;
$M = \frac{\theta_i}{\theta_o} = \frac{h_o}{f} \times \frac{25}{h_o} = \frac{25}{f}$;
*Award **[3]** for use of symbol (e.g. D) to represent distance to near point (25 cm).*

or

realizes object is at *f*;
obtains at least 1 correct angle as either $\frac{h}{25}$ or $\frac{h}{D}$ or $\frac{h}{f}$;

shows that $M = \frac{D}{f}$ or $M = \frac{25}{f}$;

b. (i) $\left(\frac{1}{f} = \frac{1}{v} + \frac{1}{u}\right)$
$\frac{1}{15} = \frac{1}{v} + \frac{1}{8}$;

$v = (-)\,17.1\text{cm}$;

(ii) 2.14 or –2.14;

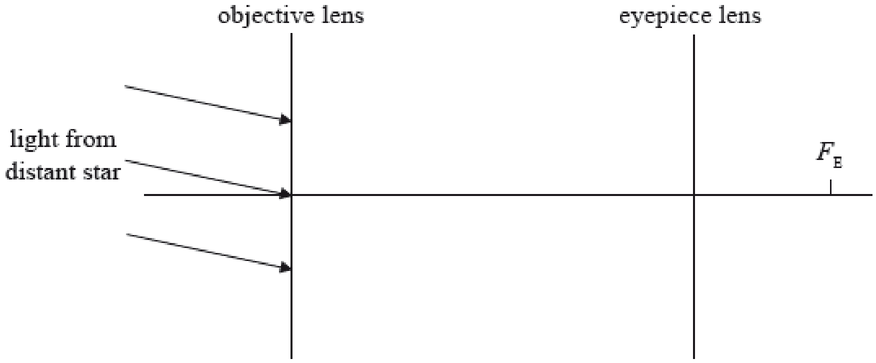
(iii) virtual;

Examiners report

a. [N/A]
b. [N/A]

This question is about an astronomical telescope.

The diagram (not to scale) shows the arrangement of the two convex lenses in an astronomical telescope in normal adjustment.



The telescope is used to observe a distant star. One of the focal points of the eyepiece lens is labelled F_E.

On the diagram above,

a. (i) label, with the symbol F_E, the position of the other focal point of the eyepiece lens. [5]

(ii) label, with the symbol F_O, the position of the focal point of the objective lens that is in between the two lenses.

(iii) construct rays to locate the final image of the star.

b. In a particular astronomical telescope, the eyepiece lens has a power of 40 dioptres and the objective lens a power of 0.80 dioptres. Determine the angular magnification of the telescope in normal adjustment. [2]

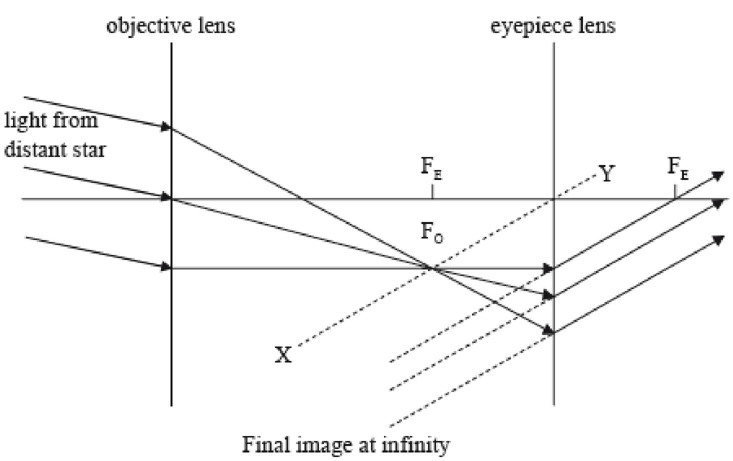
c. In an astronomical telescope the objective is often made up from a diverging and a converging lens, whereas the aperture of the eyepiece is usually restricted such that only rays close to the principal axis are viewed. State the reasons for this. [2]

Objective lens:

Eyepiece lens:

Markscheme

a.



(i) same distance to left of eyepiece as F_E is to the right; *(judge by eye)*

(ii) coincident with F_E as labelled in (a)(i);

(iii) three rays meeting at focal plane of the two lenses;

construction line XY;

rays refracted at eyepiece;

extrapolation to indicate final image at infinity with label;

Do not penalize if rays do not have arrows.

b. $f_e = \left(\frac{1}{40} =\right)$ 2.5 cm and $f_o = \left(\frac{1}{0.80} =\right)$ 125 cm;

$M = \left(\frac{f_o}{f_e} =\right) \left(\frac{125}{2.5} =\right)$ 50;

c. *objective lens*: to eliminate/minimize chromatic aberration;

eyepiece lens: to eliminate/minimize spherical aberration;

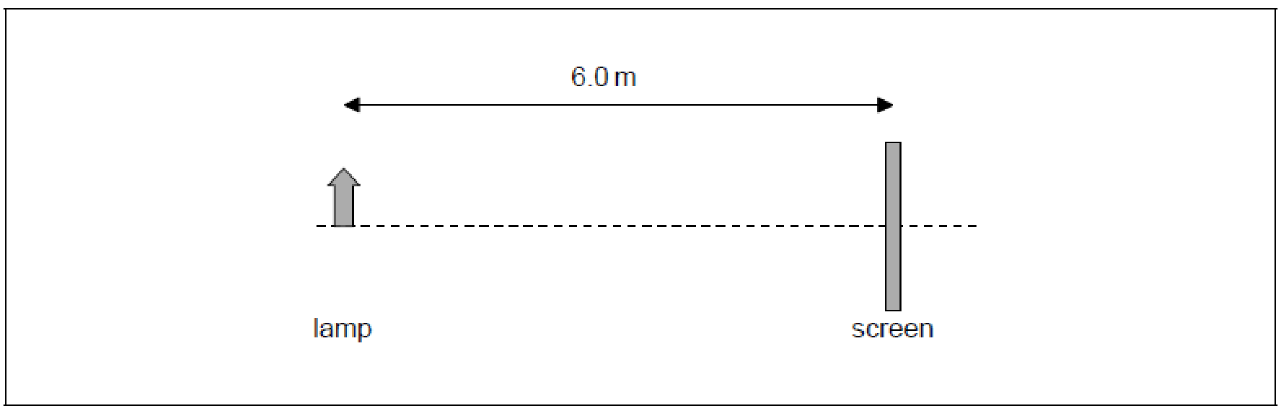
Examiners report

a. In part (a), as in past papers, ray diagrams were often poor. Many candidates failed to identify the correct locations of the two focal points.

b. Candidates who recognised that the power of a lens is the reciprocal of its focal length had little difficulty with the problem on angular magnification.

c. Most candidates were aware of chromatic and spherical aberration.

A lamp is located 6.0 m from a screen.



Somewhere between the lamp and the screen, a lens is placed so that it produces a real inverted image on the screen. The image produced is 4.0 times larger than the lamp.

a. Identify the nature of the lens. [1]

b. Determine the distance between the lamp and the lens. [3]

c. Calculate the focal length of the lens. [1]

d. The lens is moved to a second position where the image on the screen is again focused. The lamp–screen distance does not change. Compare the characteristics of this new image with the original image. [2]

Markscheme

a. converging/positive/biconvex/plane convex

Do not accept convex.

b. $\frac{v}{u} = 4$

*Award **[3]** for a bald correct answer.*

v + *u* = 6
*Allow **[1]** if the answer is 4.8 «m».*

so lens is 1.2 «m» from object ***or*** u = 1.2 «m»

c. «$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$, so $\frac{1}{1.2} + \frac{1}{4.8} = \frac{1}{f}$, so» *f* = 0.96 «m» ***or*** 1 «m»

Watch for ECF from (b)

d. real ***AND*** inverted

smaller ***OR*** diminished

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

An astronomical telescope is used in normal adjustment. The separation of the lenses in the telescope is 0.84m. The objective lens has a focal length of 0.82m.

a. Calculate the magnification of this telescope. [2]

b. Outline why sign convention is necessary in optics. [1]

c. A student decides to reverse the positions of the same lenses without changing the separation to form an optical microscope in normal adjustment. The student's near point is 0.25 m from her eye. [6]

(i) Show, using a calculation, that the image formed by the objective lens is about 0.19 m from the eyepiece.

(ii) Calculate the distance between the objective lens of the microscope and the object.

(iii) Determine the overall magnification of the microscope.

Markscheme

a. $F_o + f_e = 84$ so $f_e = 84 - 82 = 2$cm

$$\ll M = \frac{f_O}{f_e} = \frac{82}{2} = \gg 41$$

b. a sign convention is a way to distinguish between real and virtual objects ***or*** images ***or*** converging and diverging lenses

c. (i) image will be virtual *v*=–25 cm

$\frac{1}{u} = \frac{1}{82} + \frac{1}{25}$

«=19cm ***or*** 0.19m»

*Award **[1 max]** if v = +25 cm used to give u = –36 cm.*

(ii) image will be real v=84-19=65cm
$\ll \frac{1}{u} = \frac{1}{2} - \frac{1}{65} \gg$ so u=2.1cm

(iii) $M_e = \ll \frac{D}{f_e} + 1 = \frac{25}{82} + 1 = \gg 1.3$ ***AND*** $m_o = \ll \frac{v}{f_o} - 1 = \frac{65}{2} - 1 = \gg 31$ ***or*** 32

so $M = \ll M_e m_o = 1.3 \times 31 = \gg 40$ ***or*** 41

*Far point adjustment gives M = 9.3 (accept answers from interval 9.3 to 9.6), award **[1 max]** for full working.*

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

This question is about a converging (convex) lens.

A small object is placed a distance 2.0 cm from a thin convex lens. The focal length of the lens is 5.0 cm.

b. (i) Deduce the magnification of the lens. [5]

(ii) State and explain the nature of the image formed by this lens with the object at this position.

c. The object is coloured and the image shows chromatic aberration. Explain what is meant by chromatic aberration. [2]

d. Describe how the effects of chromatic aberration may be reduced. [1]

Markscheme

b. (i) attempted substitution into thin lens equation; *(allow incorrect signs)*

$v = \left(\frac{2\times5}{2-5}\right) = (-)\,3.3;$
$m\left(= -\frac{v}{u}\right) = \frac{3.3}{2} = 1.7;$

(ii) virtual because v is negative;
erect/upright because virtual/because m is positive;
enlarged/magnified because m is greater than 1;
Do not allow correct properties without an explanation.

c. different colours/wavelengths/frequencies have different refractive indices/speed of light (in glass);

(image with colour distortions due to the) different focal points (of said colours/wavelengths/frequencies);

d. use of a chromatic doublet / use of a combination of lenses;

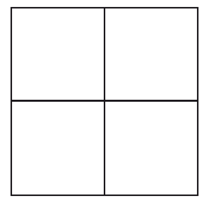
Examiners report

b. [N/A]
c. [N/A]
d. [N/A]

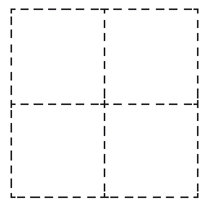
This question is about convex lenses.

A convex (converging) lens is used to project an image onto a screen. The focal length of the lens is 10 cm. The object is placed at a distance of 15 cm from the centre of the lens on the principal axis.

Another object, as shown, is positioned so that the centre of the object lies on the principal axis of the lens. The object is normal to the principal axis. The lens has not been corrected for spherical aberration.

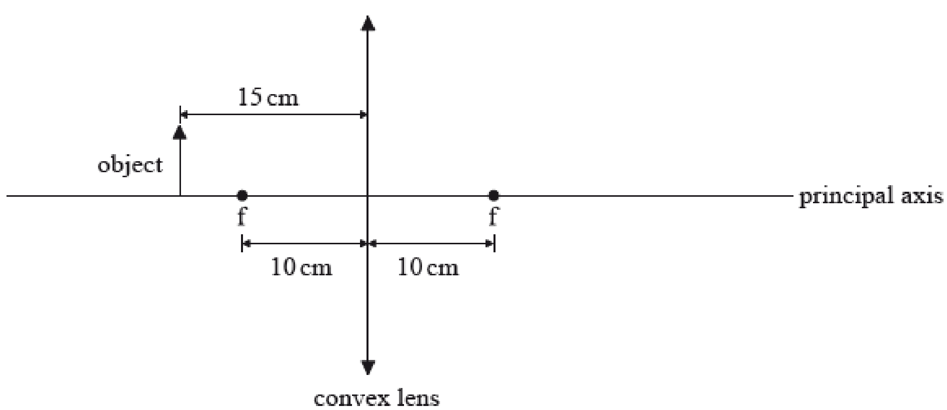


The diagram shows what would be seen on the screen if the lens produced no aberrations in the image.



a.i. Define *principal axis*. [1]

a.ii. Construct rays to locate the position of the image. [3]



a.iii. Identify the nature of the image. [1]

b.i. The lens is covered with a wide aperture. Using the diagram, sketch the likely appearance of the image if the lens **produces** spherical aberrations. [2]

b.ii. Outline why reducing the size of the aperture will reduce the effects of spherical aberration. [2]

Markscheme

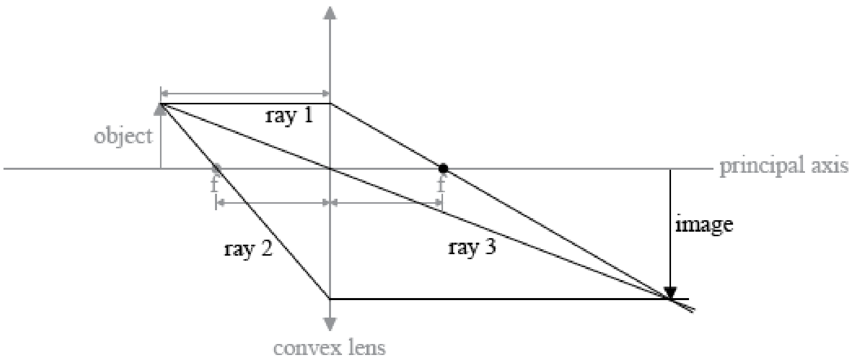
a.i. one point on axis identified – centre of curvature/focus/centre of lens <u>and</u> second point on axis identified – centre of curvature/focus/centre of lens/perpendicular to flat side of lens;

It is acceptable to choose 2 foci, 2 centres of curvature or a mixture.

a.ii. one ray drawn correctly;

a second ray drawn correctly;

image correctly located and shown;



a.iii. real/inverted/magnified;

Allow ECF from (a)(ii).

b.i. central cross shown straight;

sides curved (inwards or outwards);

b.ii. rays passing through the edge of the lens are brought to a different focal point than those passing through the centre;

by covering the outer edge of the lens/reducing the aperture (only the centre of the lens is used) bringing the light to one focus;

Examiners report

a.i. Rarely did candidates give a precise definition in (a)(i).

a.ii. (a)(ii) was generally well answered.

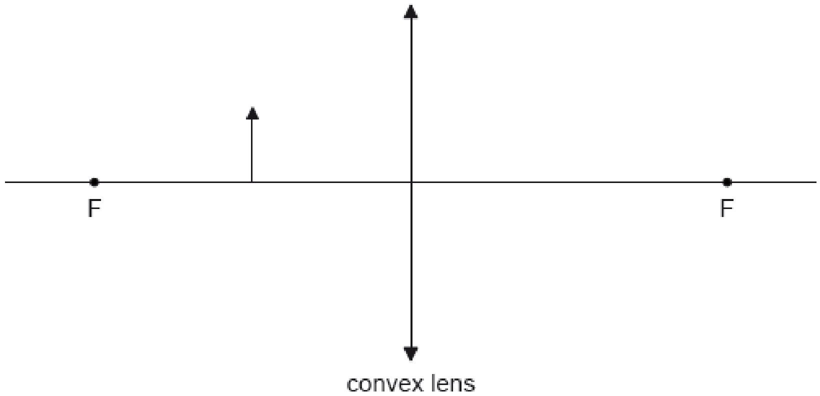
a.iii. (a)(iii) was generally well answered.

b.i. Many drew correct outer lines in (b)(i) but failed to draw the correct central cross.

b.ii. In (b)(ii), most could not relate spherical aberration to different focal lengths.

This question is about a converging (convex) lens.

Anna is unable to read small print in a newspaper. She uses a convex lens to read text more easily. Anna looks through the lens at an arrow on the page.



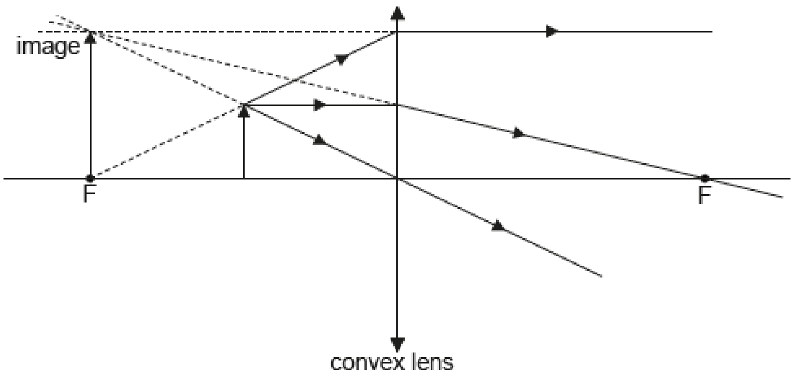
a.i. On the diagram, construct rays to locate the image of the arrow. The focal points of the lens are labelled F. [3]

a.ii. Anna places a screen at the image position. Outline why she cannot see an image on the screen. [2]

b. Anna uses the same lens with an illuminated object. She finds that a clear image of the object is formed when the lens is placed a distance of 20 cm from the screen. The lens has a focal length of 5 cm. Determine the magnification of the image. [3]

Markscheme

a.i.



any correct ray out of the three shown above;

second ray correct;

image correctly located and labelled;

Accept rays without arrows and solid construction lines back to image.

Accept correctly constructed image even if not located in the focus.

a.ii. the image is virtual;

no light rays pass through this point;

b. $\frac{1}{u} = \frac{1}{f} - \frac{1}{v}$;

$u = \frac{20}{3}$;

$m = \left(-\frac{v}{u} = -\frac{60}{20} =\right)\ (-)3$;

Examiners report

a.i. As usual, geometrical optics is well managed by all candidates, but weaker candidates made some mistakes in calculation and in explanation of the virtual image.

a.ii.As usual, geometrical optics is well managed by all candidates, but weaker candidates made some mistakes in calculation and in explanation of the virtual image.

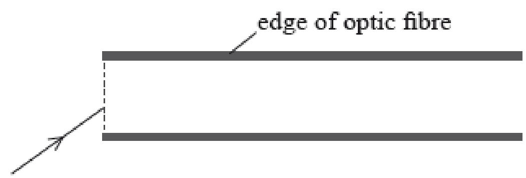
b. As usual, geometrical optics is well managed by all candidates, but weaker candidates made some mistakes in calculation and in explanation of the virtual image.

This question is about optic fibres.

An optic fibre consists of a thin glass fibre surrounded by a cladding material. The refractive index of the glass is 1.62.

a.i. Calculate the critical angle for this optic fibre. [1]

a.ii.The diagram shows a straight optic fibre. Sketch the passage of a ray of light through the fibre. [[N/A



b. The input power to the fibre is 150 mW. The attenuation per unit length of the glass fibre is $12.0\ \text{dB km}^{-1}$. When the light has travelled a distance l its power has fallen to 3.00 mW, at which point amplification of the signal is required. Determine l. [2]

Markscheme

a.i. $\left(\sin C = \frac{1}{n} = \frac{1}{1.62} \Rightarrow C = \right)\ 38(.1)^{\circ}$ ***or*** 0.665 rad;

a.ii.rays with an angle of greater than 38° shown with total internal reflection;

normal drawn onto diagram for at least one point;

pairs of angles of incidence and reflection the same;

Judge by eye.

b. $\text{attenuation/dB} = \left(10 \log \frac{I_1}{I_2} = \right)\ 10 \log \frac{3\text{ mW}}{150\text{ mW}}$ ***or*** $-17.0\text{ dB};$

$\text{length} = \left(\frac{\text{attenuation}}{\text{attenuation per unit length}} = \frac{-17.0}{12} = \right)\ 1.42\text{ km};$

Examiners report

a.i. (a)(i) was well answered.

a.ii.In (a)(ii), many candidates were not careful to obey the law of reflection.

b. Most failed to determine the attenuation in (b).

Optical fibres can be classified, based on the way the light travels through them, as single-mode or multimode fibres. Multimode fibres can be classified as step-index or graded-index fibres.

a. State the main physical difference between step-index and graded-index fibres. [1]

b. Explain why graded-index fibres help reduce waveguide dispersion. [2]

Markscheme

a. step-index fibres have constant «core» refracting index, graded index fibres have refracting index that reduces/decreases/gets smaller away from axis

OWTTE but refractive index is variable is not enough for the mark.

Award the mark if these ideas are evident in the answer to 14(b).

b. «in graded index fibres» rays travelling longer paths travel faster

so that rays travelling different paths arrive at same/similar time

Ignore statements about different colours/wavelengths.

Examiners report

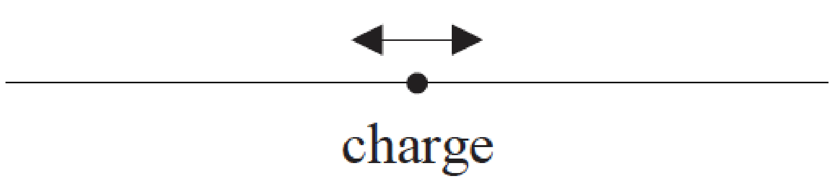
a. [N/A]

b. [N/A]

This question is about the nature and properties of electromagnetic waves.

a. Electromagnetic waves propagating in a medium suffer dispersion. Describe what is meant by dispersion. [2]

b. A charge moves backwards and forwards along a wire, as shown in the diagram below. [2]



Outline, with reference to the motion of the charge, why electromagnetic radiation is produced by the moving charge.

Markscheme

a. waves of different wavelength/frequency;

travel at different velocities;

the index of refraction of the medium depends on the wavelength/frequency;

b. during simple harmonic motion the charge oscillates/accelerates;

(oscillating/accelerating) charges radiate/produce (varying) electric/magnetic fields / produce electromagnetic waves;

Examiners report

a. Too many candidates showed that they do not know the terminology and vaguely described other phenomena instead of dispersion, quite often scattering. Breaking into component colours was sometimes mentioned by the candidates but this was not accepted as correct as the question was about electromagnetic waves, not only about light. A reasonable number of correct answers were seen with reference of both different speed and index of refraction.

b. In (b) only the stronger HL candidates clearly connected accelerated charge with the production of electromagnetic radiation. Most SL answers simply repeated the production of electromagnetic waves, missing the importance of the acceleration of the electron and not relating it to electric and magnetic fields.

This question is about digital transmission and optical fibres.

A digital signal is to be transmitted along an optic fibre. The signal to noise ratio $\left(\text{that is } 10\text{l g}\frac{P_{\text{signal}}}{P_{\text{noise}}}\right)$ in the fibre must not fall below 35 dB.

The following data are available.

Attenuation per unit length of the optic fibre $= 2.6\ \text{dB km}^{-1}$

Power of the input signal is $P_{\text{signal}} = 88\ \text{mW}$

Noise power in the fibre is constant at $P_{\text{noise}} = 52\ \text{pW}$

a. State what is meant by attenuation. [1]

b. (i) Determine, using the data, the greatest distance the signal can travel before it must be amplified. [5]

(ii) The optic fibre has a total length of 5600 km. The total transmission time along the length of the fibre is 28 ms. Estimate the refractive index of the core of the fibre.

Markscheme

a. the loss of power in the transmission of a signal / *OWTTE*;

b. (i) power when signal to noise ratio is 35 dB is $\left(10\text{lg}\frac{P_{\text{signal}}}{52\times10^{-12}} = 35 \Rightarrow P_{\text{signal}} = 52\times10^{-12}\times10^{3.5} =\right)\ 1.6\times10^{-7}\ (\text{W})$;

attenuation is $\left(10\text{lg}\frac{88\times10^{-3}}{1.6\times10^{-7}} =\right)\ 57.4\ (\text{dB})$;

distance $= \left(\frac{57.4}{2.6} =\right)\ 22\ (\text{km})$;

*Award **[3]** for a bald correct answer.*

Accept alternative approaches eg:

$10\text{lg}\left(\frac{P_s}{P_n}\right) = 92.3\ (\text{dB})$;

$92.3 - 35 = 57$ (dB);

$\frac{57}{2.6} = 22$ (km);

*Award **[3]** for a bald correct answer.*

(ii) speed of light in core of fibre is $\left(\frac{5.6 \times 10^6}{28 \times 10^{-3}} =\right)$ 2.0×10^{-8} (ms^{-1});

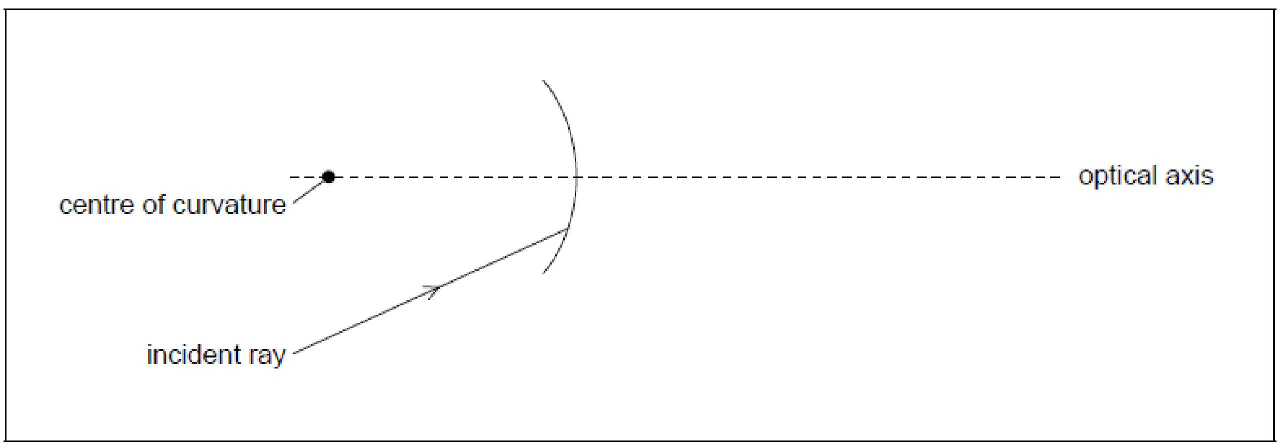
$n = \left(\frac{3.0 \times 10^8}{2.0 \times 10^8} =\right)$ 1.5;

Examiners report

a. [N/A]
b. [N/A]

Spherical converging mirrors are reflecting surfaces which are cut out of a sphere. The diagram shows a mirror, where the dot represents the centre of curvature of the mirror.

a. A ray of light is incident on a converging mirror. On the diagram, draw the reflection of the incident ray shown. [2]



b. The incident ray shown in the diagram makes a significant angle with the optical axis. [2]

(i) State the aberration produced by these kind of rays.

(ii) Outline how this aberration is overcome.

Markscheme

a. ***ALTERNATIVE 1***

for incident ray, normal drawn which pass through C

reflected ray drawn such as *i=r*

i = r by eye
If normal is not visibly constructed using C,do not award MP1.
If no normal is drawn then grazing angles must be equal for MP2.

ALTERNATIVE 2

drawn second ray through C, parallel to incident ray

adds focal plane and draws reflected ray so that it meets 2nd ray at focal plane

Focal plane position by eye, half-way between C and mirror.

b. i

spherical «aberration»

ii

using parabolic mirror
OR
reducing the aperture

Examiners report

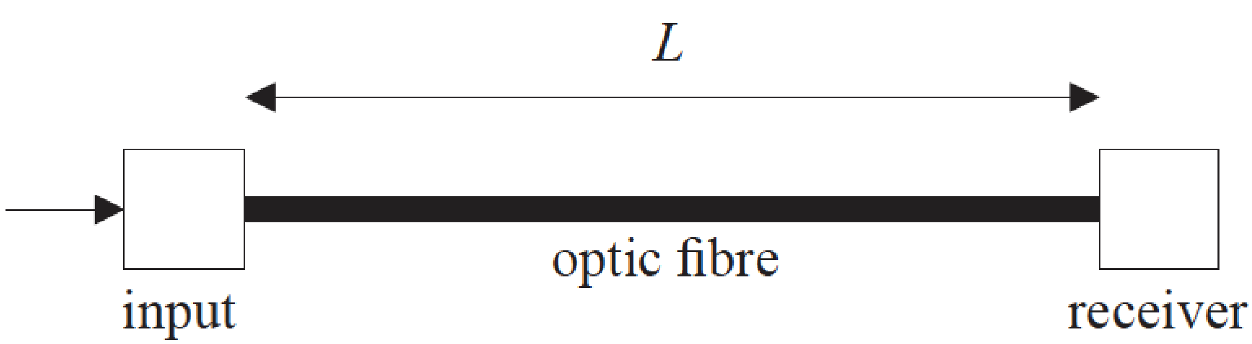
a. [N/A]
b. [N/A]

This question is about optic fibres.

a. State **one** advantage of the use of an optic fibre rather than a coaxial cable for the transmission of information. [1]

b. Suggest why, in transmitting information in an optic fibre, infrared electromagnetic radiation rather than visible light is used. [2]

c. A signal is fed into an optic fibre of length *L*. [4]



The noise power at the receiver is P_{noise}=4.2 μW. The signal to noise ratio $\left(i.e. 10 \log \frac{P_{signal}}{P_{noise}}\right)$ at the receiver must exceed 25 dB.

(i) Show that the minimum signal power at the receiver is 1.3 mW.

(ii) A signal of power 25 mW is input to the optic fibre. The attenuation per unit length of the optic fibre is 0.30 dB km^{-1}. Determine the maximum length *L* of the optic fibre.

Markscheme

a. <u>less</u> noise/attenuation per unit length/crosstalk;

<u>greater</u> bandwidth/security (though encryption);

b. attenuation/loss of energy depends on wavelength;

and is least for infrared wavelengths;

c. (i) $10\log\frac{P_{\text{signal}}}{P_{\text{noise}}} \Rightarrow P_{\text{signal}} = 4.2\times10^{-6}\times10^{2.5}$;

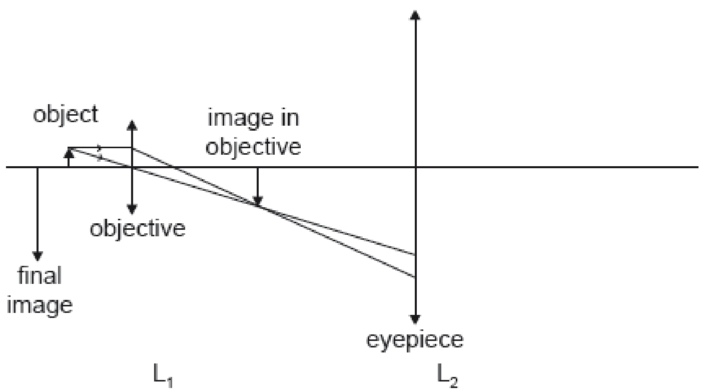
(=1.3mW)

(ii) loss in dB=$10\log\frac{25}{1.3}$;
loss=12.8 dB;
$L=\frac{12.8}{0.30}=43\text{km}$;
*Award **[3]** for a bald correct answer.*

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

The diagram is a partially-completed ray diagram for a compound microscope that consists of two thin converging lenses. The objective lens L_1 has a focal length of 3.0 cm. The object is placed 4.0 cm to the left of L_1. The final virtual image is formed at the near point of the observer, a distance of 24 cm from the eyepiece lens L_2.



(not to scale)

Two converging lenses are used to make an astronomical telescope. The focal length of the objective is 85.0 cm and that of the eyepiece is 2.50 cm. The telescope is used to form a final image of the Moon at infinity.

a.i. State what is meant by a virtual image. [1]

a.ii. Show that the image of the object formed by L_1 is 12 cm to the right of L_1. [1]

a.iii. The distance between the lenses is 18 cm. Determine the focal length of L_2. [3]

a.iv. On the diagram draw rays to locate the focal point of L_2. Label this point F. [2]

b.i. Explain why, for the final image to form at infinity, the distance between the lenses must be 87.5 cm. [2]

b.ii. The angular diameter of the Moon at the naked eye is 7.8×10^{-3} rad. [2]

Calculate the angular diameter of the final image of the Moon.

c. By reference to chromatic aberration, explain **one** advantage of a reflecting telescope over a refracting telescope. [2]

Markscheme

a.i. an image formed by extensions of rays, not rays themselves

OR

an image that cannot be projected on a screen

[1 mark]

a.ii. $\frac{1}{v} = \frac{1}{3.0} - \frac{1}{4.0}$

«*v* = 12 cm»

[1 mark]

a.iii. *u* = 18 – 12 = 6.0 «cm»

v = –24 «cm»

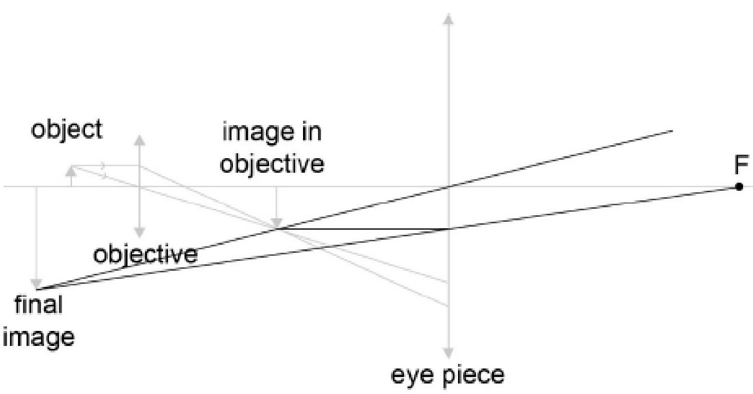
«$\frac{1}{f} = \frac{1}{6.0} - \frac{1}{24} \Rightarrow$» *f* = 8.0 «cm»

*Award **[2 max]** for answer of 4.8 cm.*
Minus sign required for MP2.

[3 marks]

a.iv. line parallel to principal axis from intermediate image meeting eyepiece lens at P

line from arrow of final image to P intersecting principal axis at F



[2 marks]

b.i. object is far away so intermediate image forms at focal plane of objective

for final image at infinity object must also be at focal point of eyepiece

«hence 87.5 cm»

No mark for simple addition of focal lengths without explanation.

[2 marks]

b.ii. angular magnification = $\frac{85.0}{2.50}$ = 34

angular diameter 3.4 × 7.8 × 10^{-3} = 0.2652 ≈ 0.27 «rad»

[2 marks]

c. chromatic aberration is the dependence of refractive index on wavelength

but mirrors rely on reflection
OR
mirrors do not involve refraction

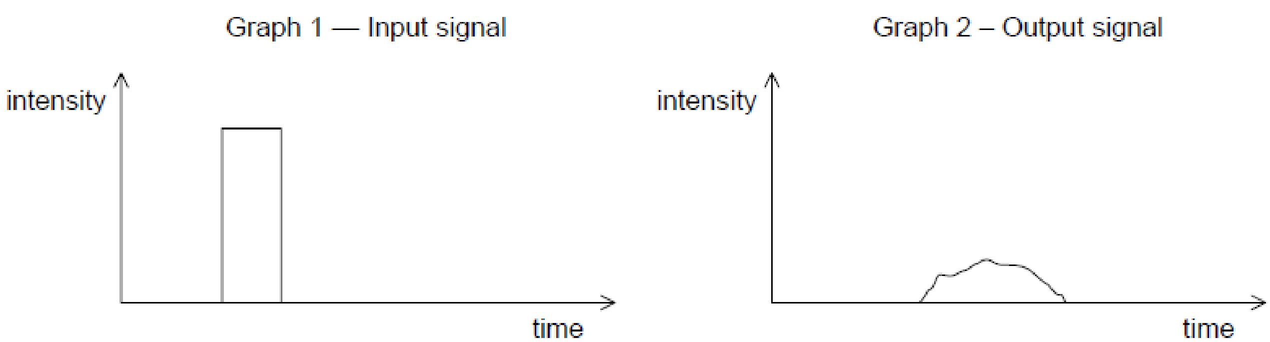
«so do not suffer chromatic aberration»

[2 marks]

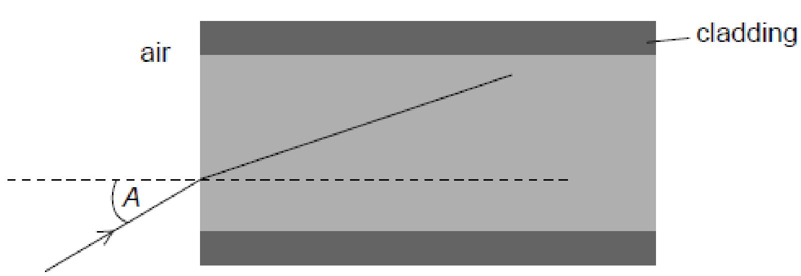
Examiners report

a.i. [N/A]
a.ii. [N/A]
a.iii. [N/A]
a.iv. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]

The graphs show the variation with time of the intensity of a signal that is being transmitted through an optic fibre. Graph 1 shows the input signal to the fibre and Graph 2 shows the output signal from the fibre. The scales of both graphs are identical.



a. The diagram shows a ray of light in air that enters the core of an optic fibre. [3]



The ray makes an angle *A* with the normal at the air–core boundary. The refractive index of the core is 1.52 and that of the cladding is 1.48.

Determine the largest angle *A* for which the light ray will stay within the core of the fibre.

b.i. Identify the features of the output signal that indicate the presence of attenuation and dispersion. [2]

attenuation: ....

....

dispersion: ....

....

b.ii.The length of the optic fibre is 5.1 km. The input power of the signal is 320 mW. The output power is 77 mW. Calculate the attenuation per unit length of the fibre in dB km^{-1}. [2]

Markscheme

a. calculation of critical angle at core–cladding boundary «$1.52 \times \sin \theta_C = 1.48$» θ_C = 76.8°

refraction angle at air–core boundary 90° – 76.8° = 13.2°

«$1.52 \times \sin 13.2^\circ = \sin A$» A = 20.3°

Allow ECF from MP1 to MP2 to MP3.

[3 marks]

b.i.*attenuation:* output signal has smaller area

dispersion: output signal is wider than input signal

OWTTE

OWTTE

[2 marks]

b.ii.attenuation = «$10 \log \frac{I}{I_0} = 10 \log \frac{77}{320} =$» «–» 6.2 «dB»

$\frac{-6.2}{5.1}$ = «–» 1.2 «dB km^{-1}»

Allow intensity ratio to be inverted.

Allow ECF from MP1 to MP2.

[2 marks]

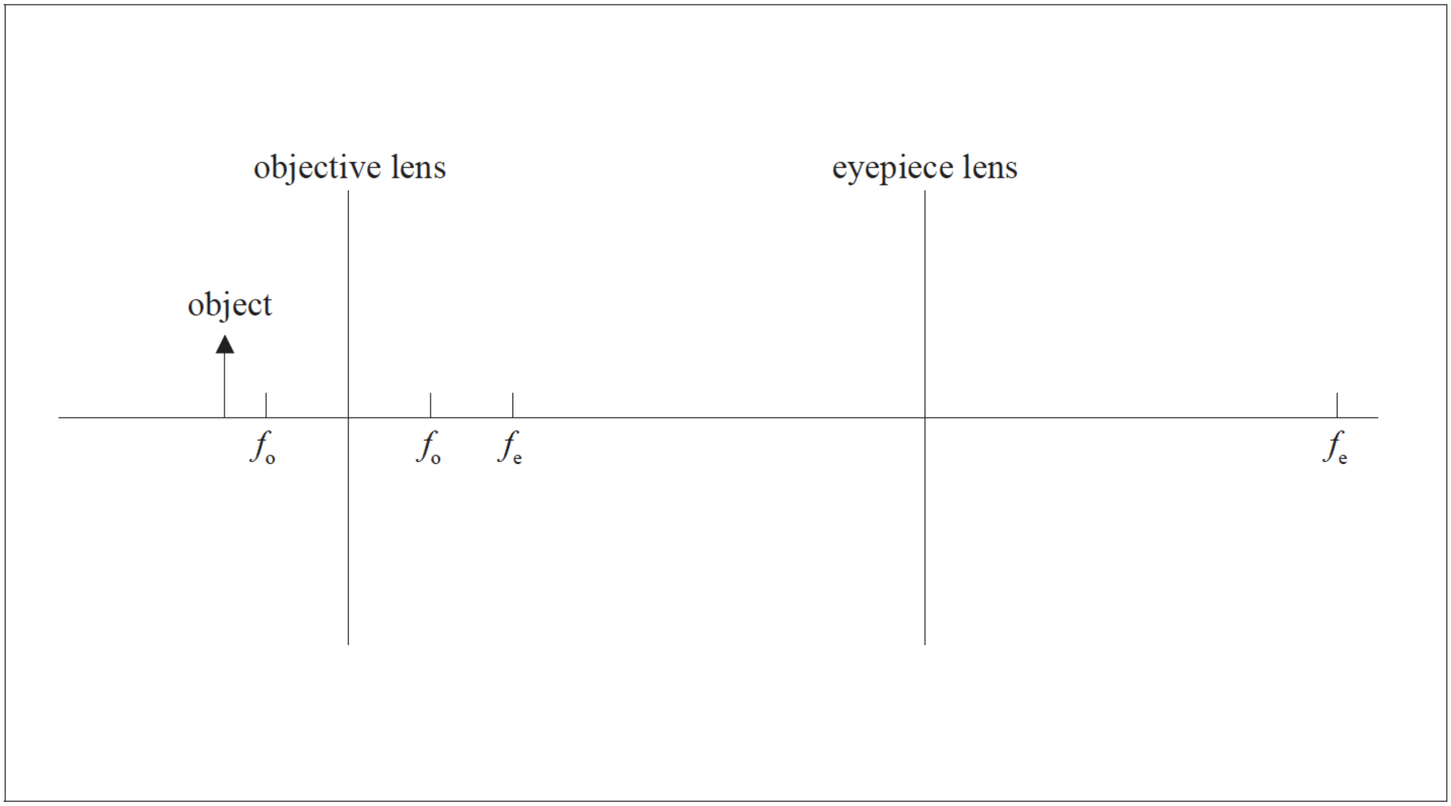
Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]

This question is about the compound microscope.

a. A convex lens used as a magnifying glass has a focal length of f_e. Derive an expression for the angular magnification when the image is at the near point D. [3]

b. The convex lens in (a) is used as the eyepiece of a compound microscope. [4]



An object is placed 1.5 cm from the objective lens. The focal length f_o of the objective lens is 1.0 cm.

(i) Draw rays on the diagram to show the formation of the intermediate image.

(ii) Calculate the distance of the intermediate image from the objective lens.

c. Lenses used in the compound microscope are subject to spherical aberration and chromatic aberration. [4]

Explain what is meant by

(i) spherical aberration.

(ii) chromatic aberration.

Markscheme

a. (angular magnification =linear magnification so) $M = \frac{D}{u}$;

$\frac{1}{u} + \frac{1}{D} = \frac{1}{f}$;

so $\frac{D}{u} = \frac{D}{f} + 1 = M$;

b. (i) ray through centre of objective lens and ray through f_o;

to show formation of intermediate image;

(ii) $\frac{1}{v} = \frac{1}{1} - \frac{1}{1.5}$;
v=3.0cm;
*Award **[2]** for a bald correct answer.*

c. (i) rays parallel to principal axis at edge of lens brought to different foci;

from those near to the centre of the lens;

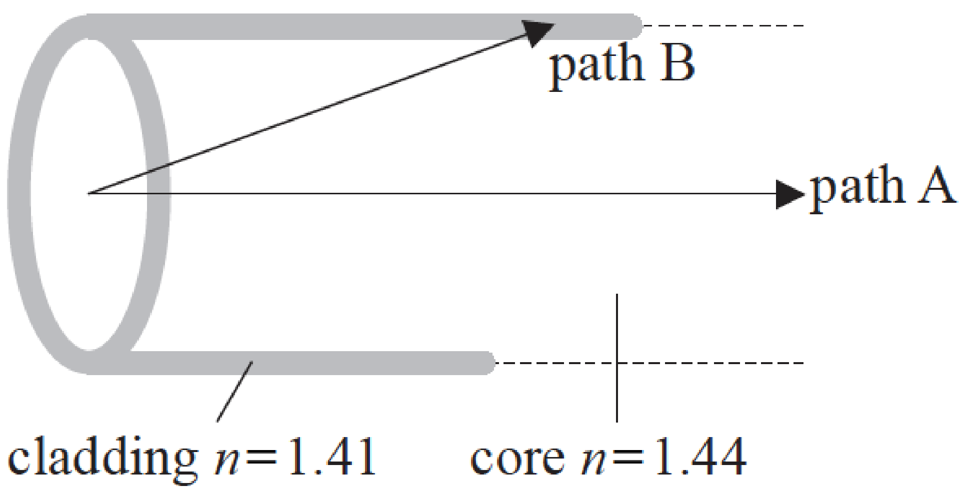
(ii) different colours have different refractive indices/speeds;
different colour refracted at different amounts / image formed for each colour;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

This question is about the digital transmission of information.

Digital information that is transmitted along optic fibres is often subject to dispersion due to light taking different paths along the fibre.



In a particular optic fibre of length 2.00×10^4 m, the refractive index of the cladding is 1.41 and that of the core is 1.44.

Two possible light paths are:

Path A: along the central axis of the fibre.
Path B: the path followed by light that is initially incident on the cladding at an angle just greater than the critical angle.

The speed of light in the core of the fibre is 2.10×10^8 ms^{-1}.

Show that the difference in transmission time between path B and path A is approximately 2.0 μs.

Markscheme

ratio of $n = \frac{1.41}{1.44}(= 0.979)$;

path difference between B and A$= 2.00 \times 10^4 - \frac{2.00\times10^4}{0.979} = 4.00 \times 10^2\ (\mathrm{m})$;

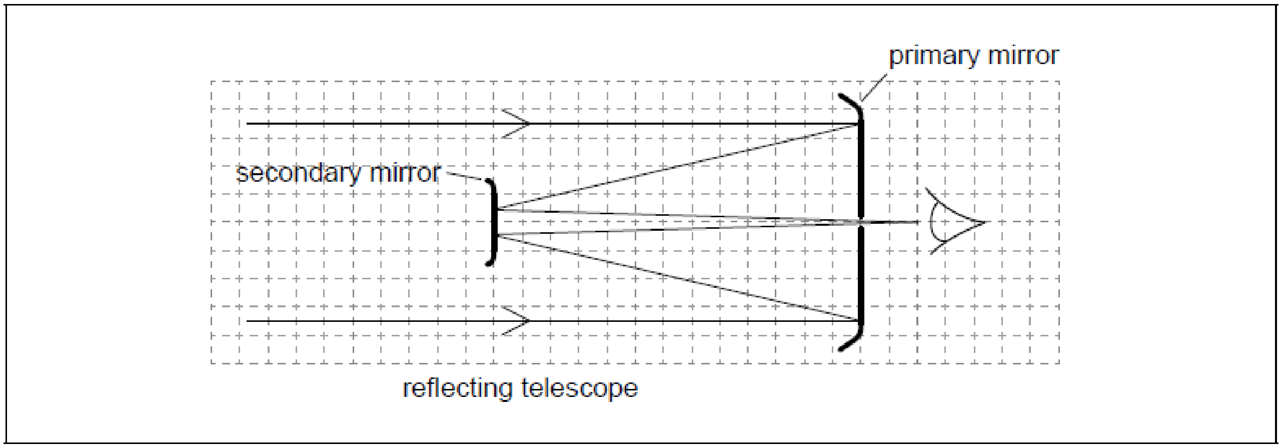
time difference$= \frac{4.00\times10^2}{2.10\times10^8}$;

$\approx 2.00\times10^{-6}$s

Examiners report

[N/A]

The diagram represents a simple optical astronomical reflecting telescope with the path of some light rays shown.



a. Identify, with the letter X, the position of the focus of the primary mirror. [1]

b. This arrangement using the secondary mirror is said to increase the focal length of the primary mirror. State why this is an advantage. [1]

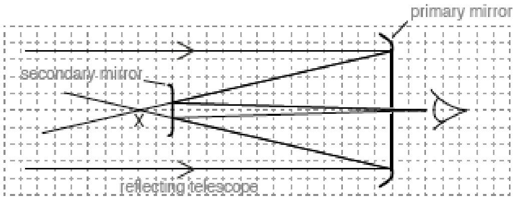
c. Distinguish between this mounting and the Newtonian mounting. [2]

d. A radio telescope also has a primary mirror. Identify **one** difference in the way radiation from this primary mirror is detected. [1]

Markscheme

a. where the extensions of the reflected rays from the primary mirror would meet, with construction lines

eg:



[1 mark]

b. greater magnification

[1 mark]

c. Newtonian mount has

plane/not curved «secondary» mirror

«secondary» mirror at angle/45° to axis

eyepiece at side/at 90° to axis

mount shown is Cassegrain

OWTTE

Accept these marking points in diagram form

[2 marks]

d. waves collected above mirror/dish

waves collected at the focus of the mirror/dish

waves detected by radio receiver/antenna

waves converted to electrical signals

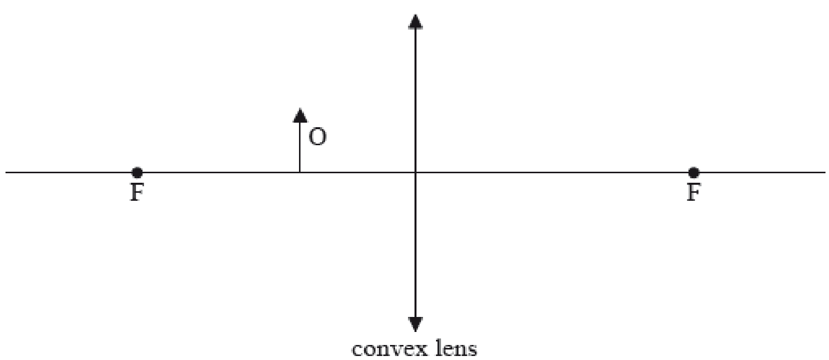
[1 mark]

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

This question is about a magnifying glass and a telescope.

A thin converging (convex) lens is used as a magnifying glass. Object O is placed between a focal point of the lens and the centre of the lens. The focal points of the lens are shown, labelled F.



The position of the lens in (a) is changed so that a virtual image of the object is formed at the near point of the eye. The eye is very close to the lens.

The lens in (a) has a focal length of 6.0 cm and is now used as the eyepiece of an astronomical telescope. The objective lens of the telescope has a focal length of 90 cm. The telescope is used in normal adjustment.

a. (i) Define the term *focal point*. [5]

(ii) On the diagram, construct rays to locate the position of the image of the object. Label the image I.

b. (i) Define the term *near point*. [2]

(ii) Outline the advantage of having the image positioned at the near point of the eye.

c. (i) State the separation of the objective lens and the eyepiece lens. [3]

(ii) Determine the angular magnification of the telescope.

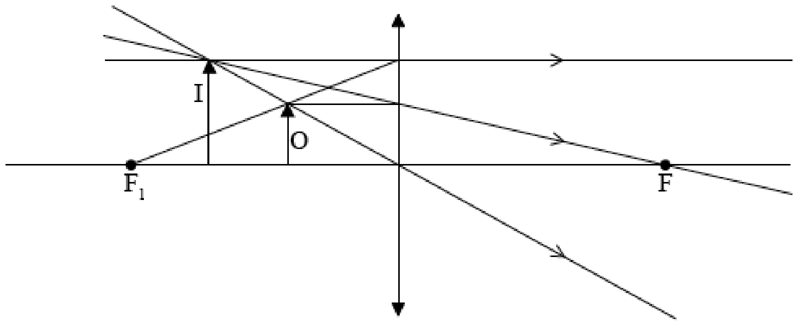
Markscheme

a. (i) the point on the principal axis;

through which rays parallel to the principal axis pass after going through the lens / from which rays are parallel to the principal axis after passing through the lens;

Allow marking points on a labelled diagram.

(ii)



any correct ray of the three shown in the diagram;

second ray correct;

image shown correctly, between O and F_1;

Accept rays without arrows and solid construction lines back to the image.

b. (i) closest point on which the eye can focus (comfortably); } *(allow closest distance)*

(ii) gives maximum angular magnification (without straining the eye);

c. (i) separation = 96 (cm);

(ii) $M = \left(\frac{f_o}{f_e} =\right) \frac{90}{6.0}$;

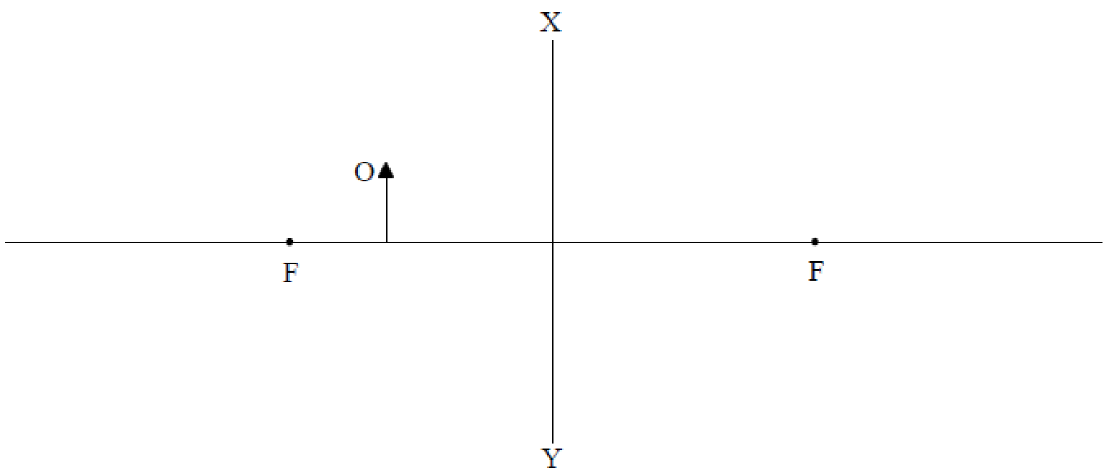
$M = 15$;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

This question is about a convex lens.

The diagram below, drawn to scale, shows a small object O placed in front of a thin convex (converging) lens. The focal points of the lens are shown, labelled F. The lens is represented by the straight line XY.



(i) Define the term *focal point*.

(ii) On the diagram above, construct the paths of two rays in order to locate the position of the image formed by the lens. Label the image I.

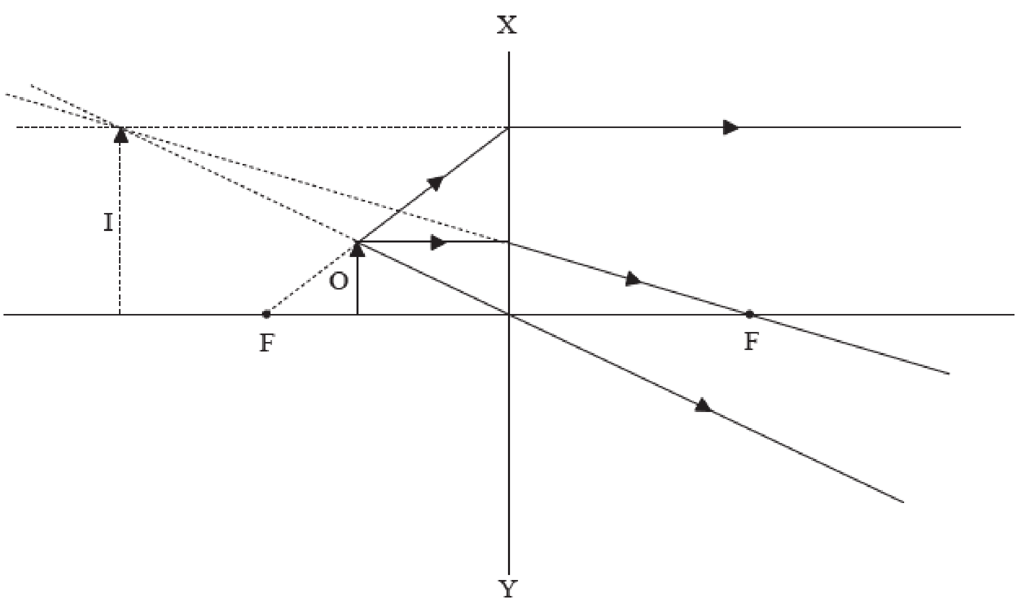
iii) Explain whether the image is real **or** virtual.

Markscheme

(i) the point on the principal axis;

through which parallel rays pass after going through the lens / from which rays are parallel after passing through the lens;

(ii)



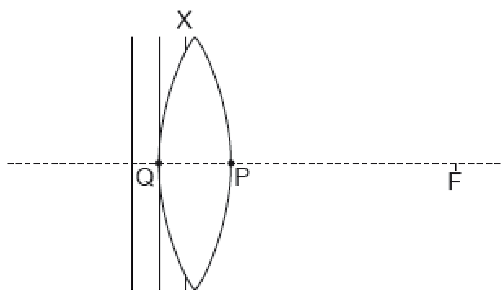
any two correct rays out of the three shown above;
image correctly located and labelled;

(iii) virtual because no rays pass through the image / image cannot be formed on a screen;
Mark is for explanation, not for statement of virtual.

Examiners report

[N/A]

The diagram shows planar wavefronts incident on a converging lens. The focal point of the lens is marked with the letter F.



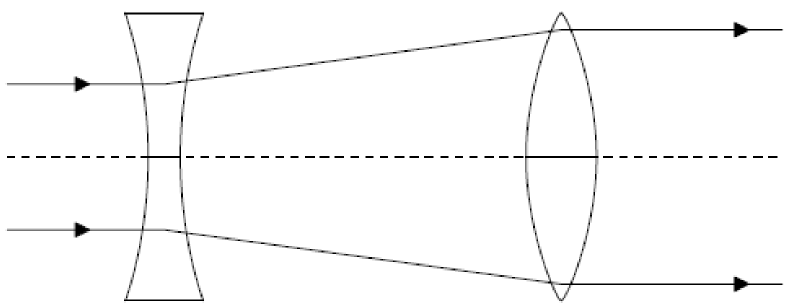
Wavefront X is incomplete. Point Q and point P lie on the surface of the lens and the principal axis.

a.i. On the diagram, sketch the part of wavefront X that is inside the lens. [1]

a.ii. On the diagram, sketch the wavefront in air that passes through point P. Label this wavefront Y. [1]

b. Explain your sketch in (a)(i). [2]

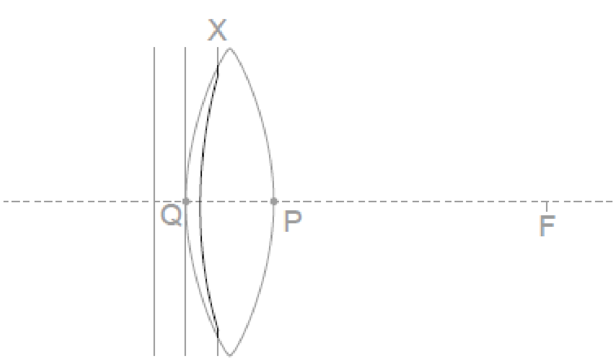
c. Two parallel rays are incident on a system consisting of a diverging lens of focal length 4.0 cm and a converging lens of focal length 12 cm. [2]



The rays emerge parallel from the converging lens. Determine the distance between the two lenses.

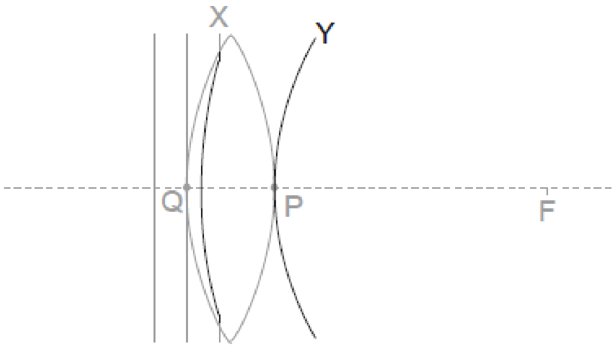
Markscheme

a.i. line of correct curvature as shown



[1 mark]

a.ii. line of approximately correct curvature as shown



Judged by eye.

Allow second wavefront Y, to have “passed” P as this is how this question is being interpreted by some.

Ignore any waves beyond Y.

[1 mark]

b. wave travels slower in glass than in air

OR

RI greater for glass

wavelength less in glass than air

hence wave from Q will cover a shorter distance «than in air» causing the curvature shown

OWTTE

[2 marks]

c. realization that the two lenses must have a common focal point

distance is 12 – 4.0 = 8.0 «cm»

Accept MP1 from a separate diagram or a sketch on the original diagram.

A valid reason from MP1 is expected.

*Award **[1 max]** for a bald answer of 12 – 4 = 8 «cm».*

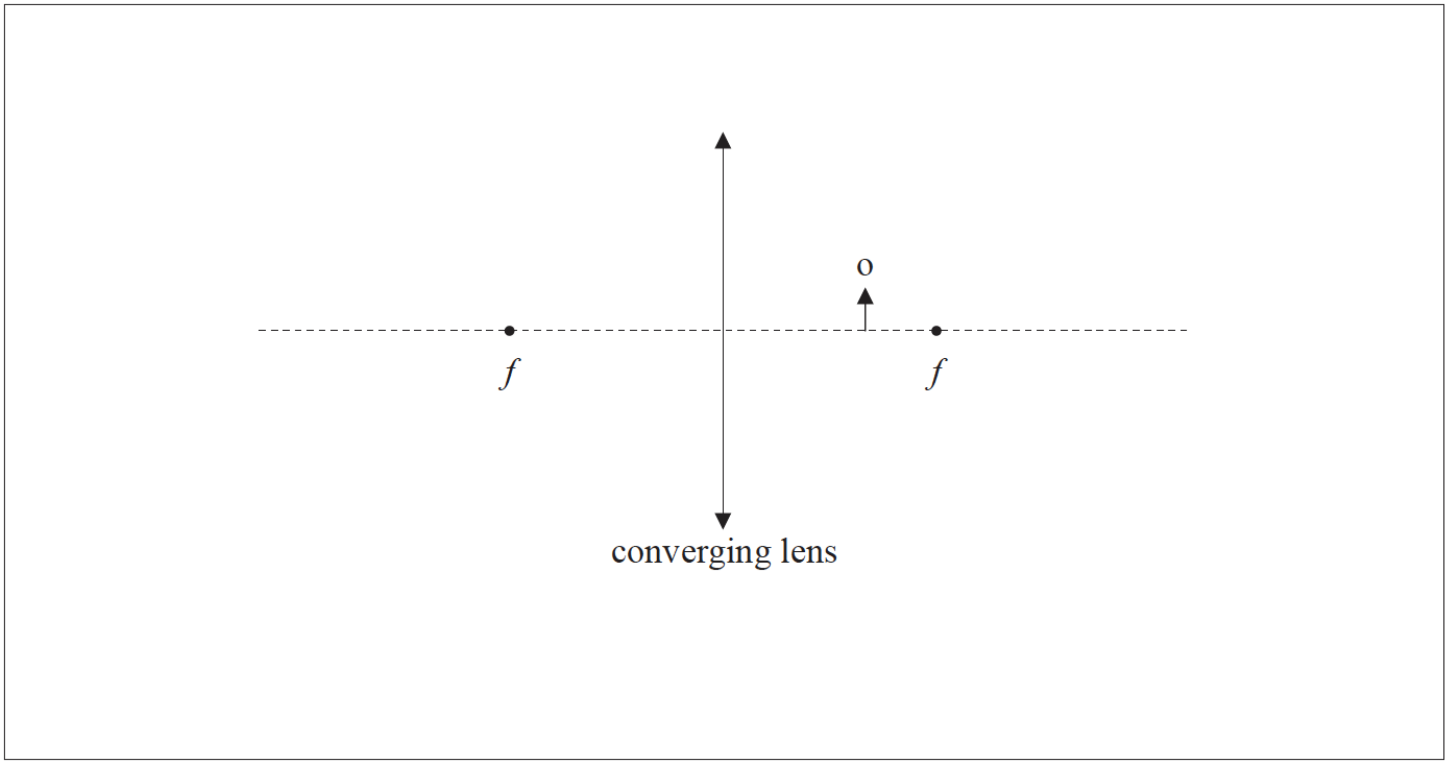
[2 marks]

Examiners report

a.i. [N/A]
a.ii. [N/A]
b. [N/A]
c. [N/A]

This question is about the simple magnifying glass and the compound microscope.

b. A converging lens is used as a magnifying glass. On the diagram draw rays to construct the image of the object, o. [3]



c. The lens has a focal length *f*. When the image is formed at the near point, the distance *u* of the object from the lens is given by [2]

$$u = \frac{fD}{D+f}$$

where *D* is the near point distance.

Deduce that the angular magnification *M* is given by

$$M = 1 + \frac{D}{f}$$

d. A compound microscope consists of an eyepiece lens of focal length 6.0 cm and an objective lens of focal length 2.8 cm. An object is placed 3.4 cm from the objective lens and the final image of the object is formed by the microscope at the near point. [5]

Determine the

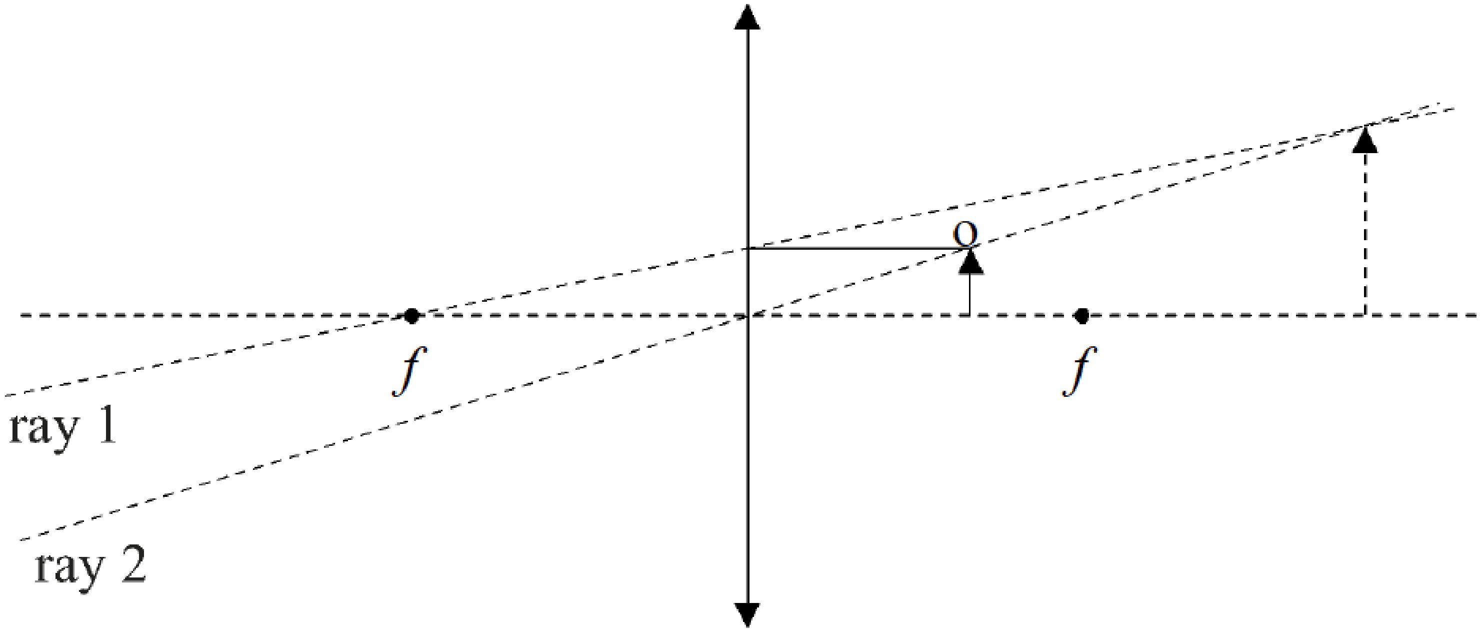
(i) angular magnification of the eyepiece. Take the near point distance to be 25 cm.

(ii) distance from the objective lens of the intermediate image formed by this lens.

(iii) overall magnification of the compound microscope.

Markscheme

b.



ray 1 correct;
ray 2 correct;
virtual rays converge/image shown;
Ignore arrows on any lines drawn.

c. $M = \left(\frac{\theta_i}{\theta_o} =\right) (-) \frac{v}{u}$;

$= \frac{D}{\frac{fD}{f+D}} = \frac{D(f+D)}{fD}$;

$\left(M = 1 + \frac{D}{f}\right)$

Check for correct manipulation.

d. (i) $M = \left(1 + \frac{25}{6} =\right) 5.2$;

(ii) $\frac{1}{v} = \frac{1}{2.8} - \frac{1}{3.4}$;
v=16 cm;
*Award **[2]** for a bald correct answer.*
*Award **[1]** for ECF giving v =1.5 cm.*

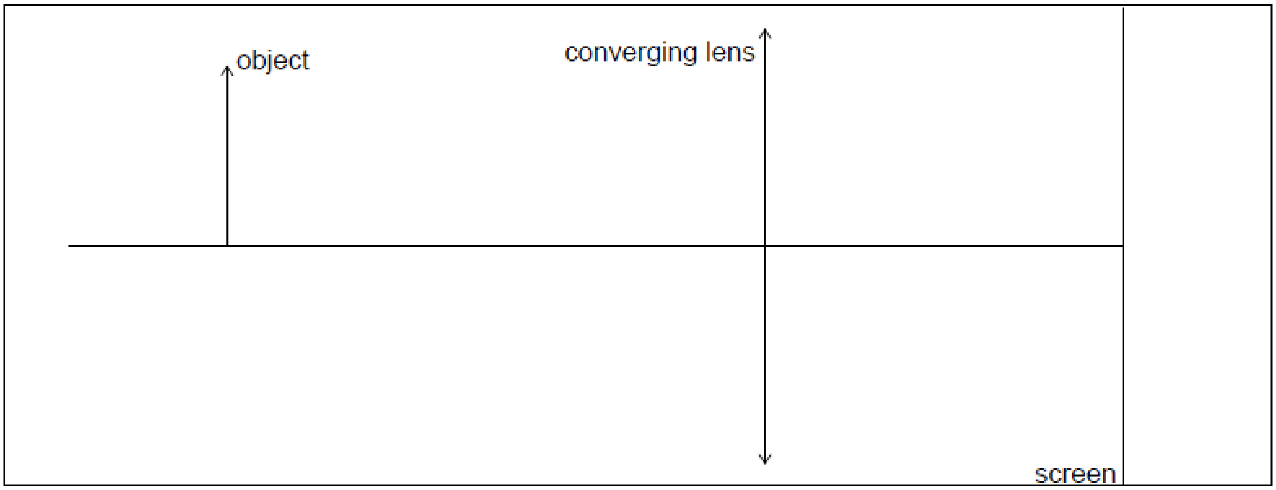
(iii) magnification of objective$= \left(\frac{16}{3.4} =\right) 4.7$;
overall magnification = (5.2×4.7 =)24;
*Award **[2]** for a bald correct answer.*
*Award **[2 max]** for ECF from (d)(i) and (d)(ii).*

Examiners report

b. [N/A]
c. [N/A]
d. [N/A]

A converging (convex) lens forms an image of an object on a screen.

diagram not to scale

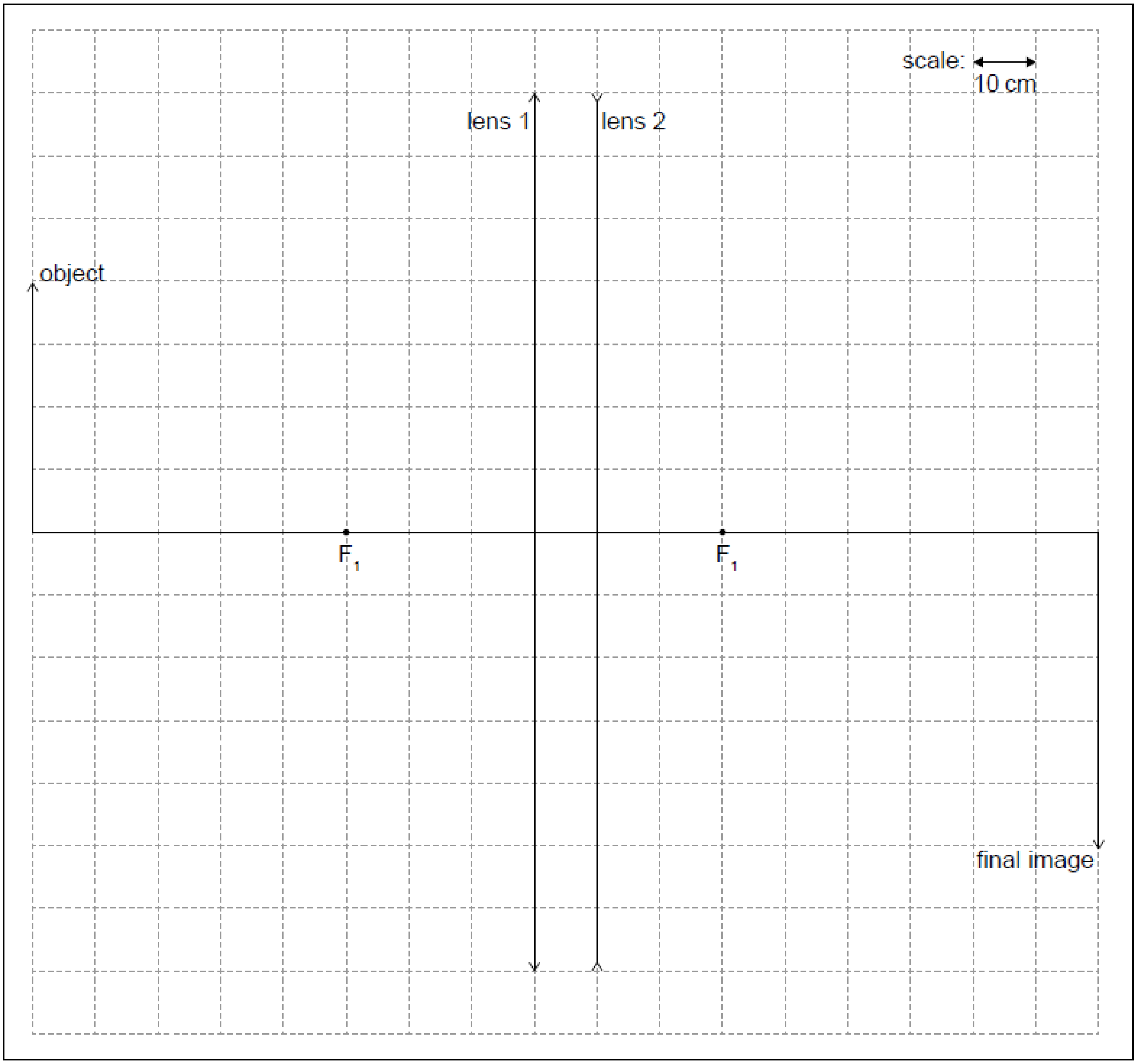


a.i. Identify whether the image is real or virtual. [1]

a.ii. The lens is 18 cm from the screen and the image is 0.40 times smaller than the object. Calculate the power of the lens, in cm^{-1}. [3]

a.iii Light passing through this lens is subject to chromatic aberration. Discuss the effect that chromatic aberration has on the image formed on the screen. [3]

b. A system consisting of a converging lens of focal length F_1 (lens 1) and a diverging lens (lens 2) are used to obtain the image of an object as shown on the scaled diagram. The focal length of lens 1 (F_1) is 30 cm. [3]



Determine, using the ray diagram, the focal length of the diverging lens.

Markscheme

a.i. image is real «as projected on a screen»

[1 mark]

a.ii. «$-\frac{18}{u}=-0.40$»

u = 45

$\frac{1}{45}+\frac{1}{18}=\frac{1}{f}$

OR

f = 13 «cm»

P = $\frac{1}{f}$ = «$\frac{1}{13}$» = 0.078 «cm^{-1}»

Accept answer 7.7«D».

[3 marks]

a.iii. refractive index depends on wavelength

light of different wavelengths have different focal points / refract differently

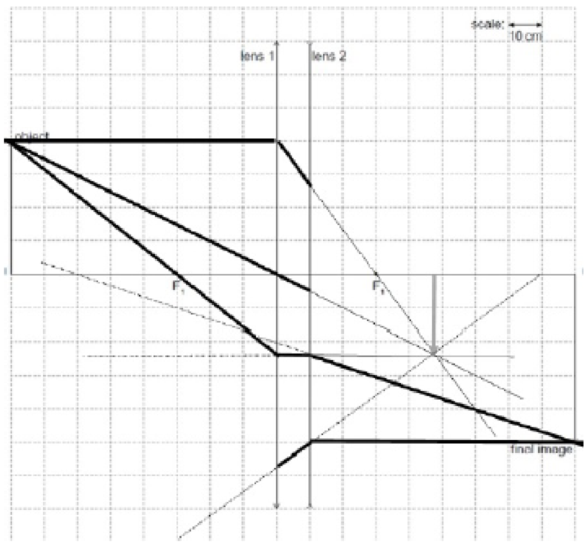
there will be coloured fringes around the image **/** image will be blurred

[3 marks]

b. any 2 correct rays to find image from lens 1

ray to locate F_2

focal length = «–»70 «cm»



Accept values in the range: 65 cm to 75 cm.

Accept correct MP3 from accepted range also if working is incorrect or unclear, award ***[1]****.*

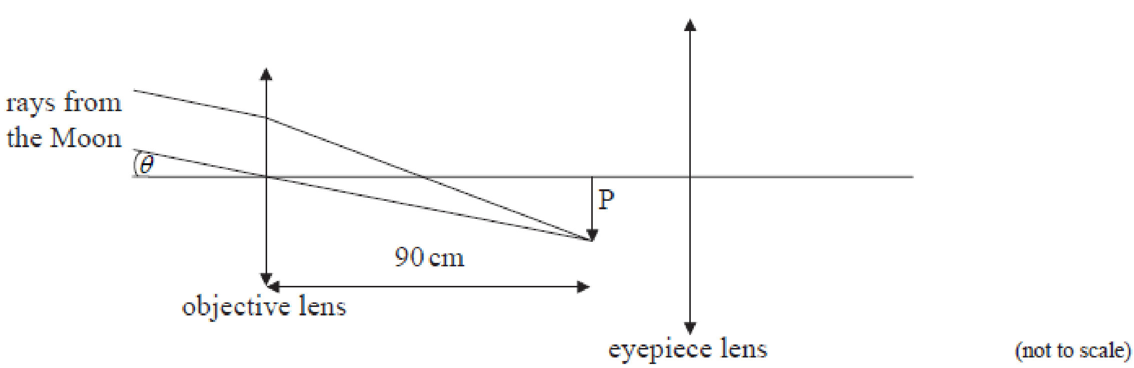
[3 marks]

Examiners report

a.i. [N/A]
a.ii. [N/A]
a.iii. [N/A]
b. [N/A]

This question is about an astronomical telescope.

A particular astronomical telescope is being used to observe the Moon. The ray diagram shows the position P of the intermediate image of the Moon formed by the objective lens.



The telescope is in normal adjustment.

a. On the diagram above, [4]

(i) label with the letter F the **two** focal points of the eyepiece lens.

(ii) draw rays to determine the location of the final image of the Moon.

b. The diameter of the Moon subtends an angle of 8.7×10^{-3} rad at the unaided eye. [4]

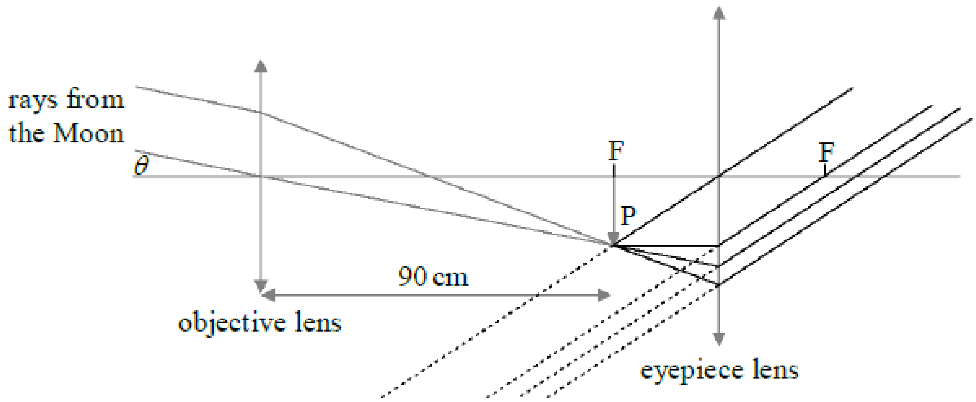
(i) Determine the diameter of the image of the Moon formed by the objective lens.

(ii) The focal length of the eyepiece is 30 cm. Calculate the angle that the final image of the Moon subtends at the eyepiece.

Markscheme

a. (i) F at P and second F at the same distance to the right of the eyepiece; *(judge by eye)*

(ii)



first construction line or ray; *(judge by eye)*
second construction line or ray;
extension of these to the left as parallel lines;

b. (i) $d=f_0 \tan\theta \approx f_0\theta$;

$d=90\times\tan(8.7\times10^{-3})=0.78\text{cm}$;

(ii) angular magnification is $M=\left(-\frac{f_0}{f_e}=\right)(-)\,3$;

hence $\theta' = -3\theta = (-)\,0.026\text{rad}$;

or

$\theta' = \frac{0.78}{30}$;
$\theta' = (-)\,0.026\text{rad}$;

Examiners report

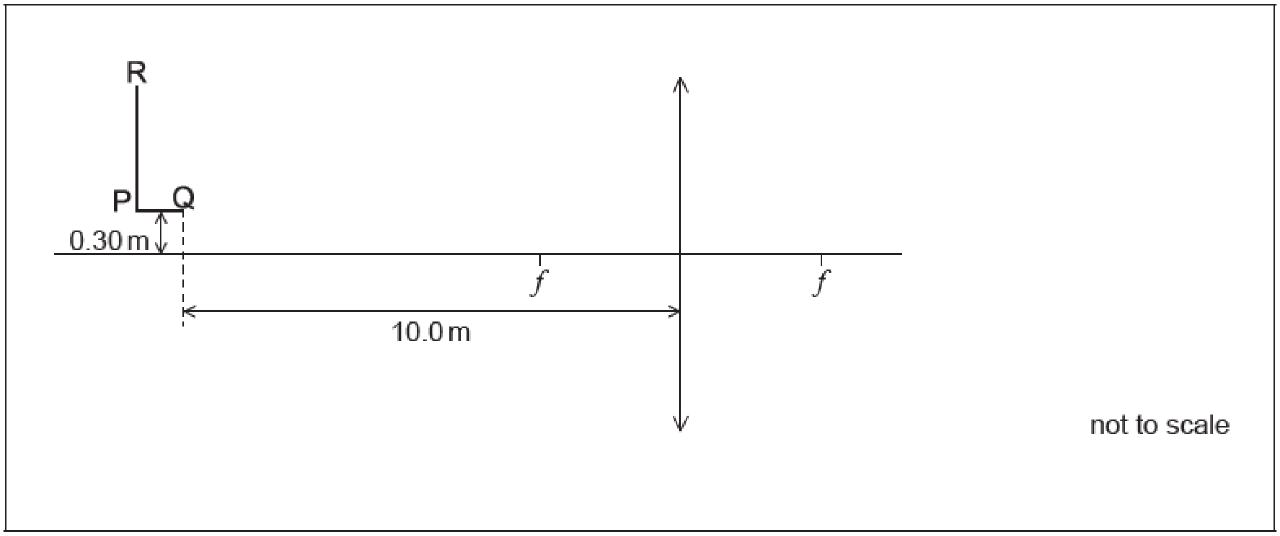
a.

b.

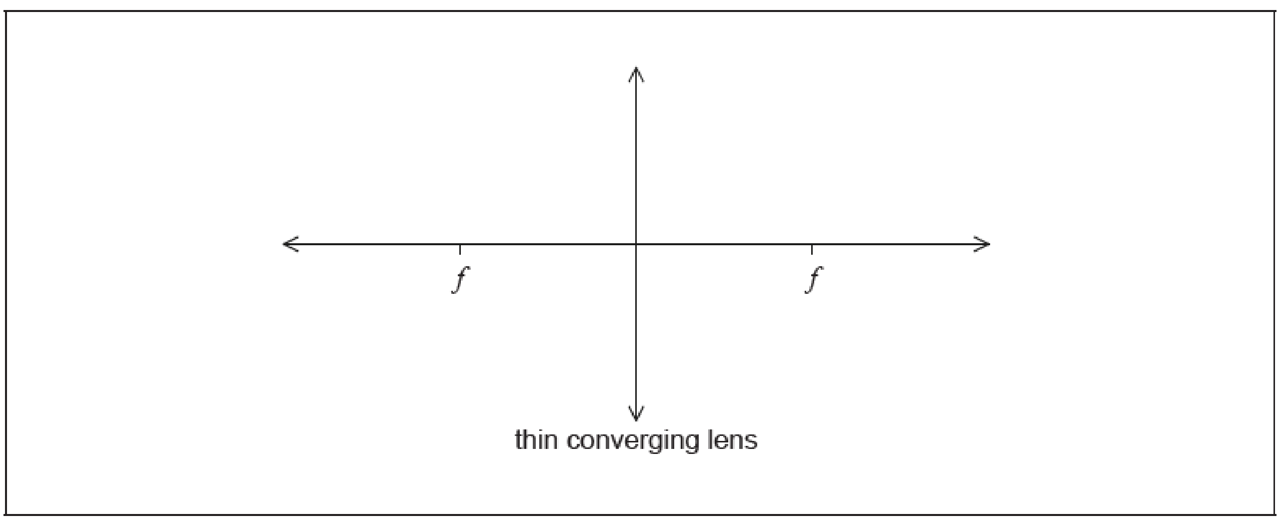
A magnifying glass is constructed from a thin converging lens.

A converging lens can also be used to produce an image of a distant object. The base of the object is positioned on the principal axis of the lens at a distance of 10.0 m from the centre of the lens. The lens has a focal length of 2.0 m.

The object is replaced with an L shape that is positioned 0.30 m vertically above the principal axis as shown. A screen is used to form a focused image of part of the L shape. Two points P and Q on the base of the L shape and R on its top, are indicated on the diagram. Point Q is 10.0 m away from the same lens as used in part (b).



a.i. Sketch a ray diagram to show how the magnifying glass produces an upright image. [2]



a.ii. State the maximum possible distance from an object to the lens in order for the lens to produce an upright image. [1]

b.i. Determine the position of the image. [2]

b.ii. State **three** characteristics of the image. [1]

c.i. On the diagram, draw **two** rays to locate the point Q′ on the image that corresponds to point Q on the L shape. [2]

c.ii. Calculate the vertical distance of point Q′ from the principal axis. [2]

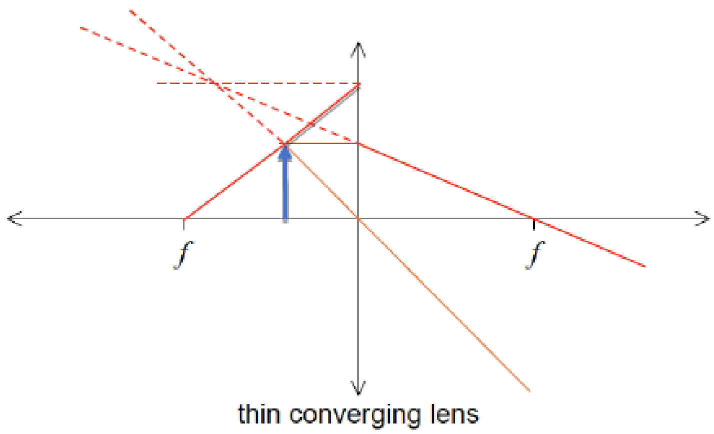
c.iii. A screen is positioned to form a focused image of point Q. State the direction, relative to Q, in which the screen needs to be moved to form a focused imaged of point R. [1]

c.iv. The screen is now correctly positioned to form a focused image of point R. However, the top of the L shape looks distorted. Identify and explain the reason for this distortion. [2]

Markscheme

a.i. with object placed between lens and focus

two rays correctly drawn



Backwards extrapolation of refracted rays can be dashes or solid lines

Do not penalize extrapolated rays which would meet beyond the edge of page

Image need not be shown

a.ii. «just less than» the focal length ***or*** *f*

b.i. $\frac{1}{10}+\frac{1}{v}=\frac{1}{2}$

v = 2.5 «m»

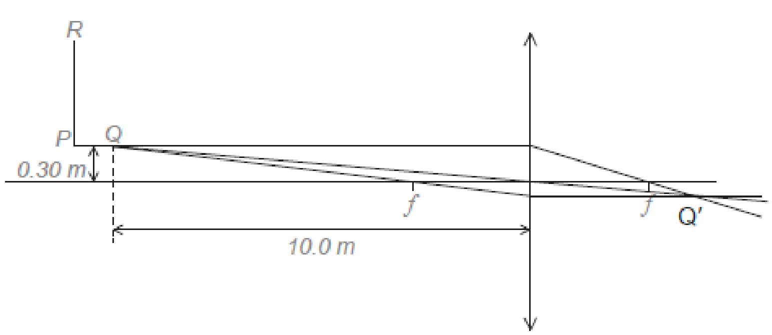
b.ii. real, smaller, inverted

All three required — OWTTE

c.i. two correct rays coming from Q

locating Q′ below the main axis ***AND*** beyond *f* to the right of lens ***AND*** at intercept of rays

Allow any ***two*** *of the three conventional rays.*



c.ii. $\frac{h}{h'}=\frac{-x}{x'}$

OR

2.5 ***or*** 10 × 0.3 «m»

«–» 0.075 «m»

c.iii towards Q

Accept move to the left

c.iv spherical aberration

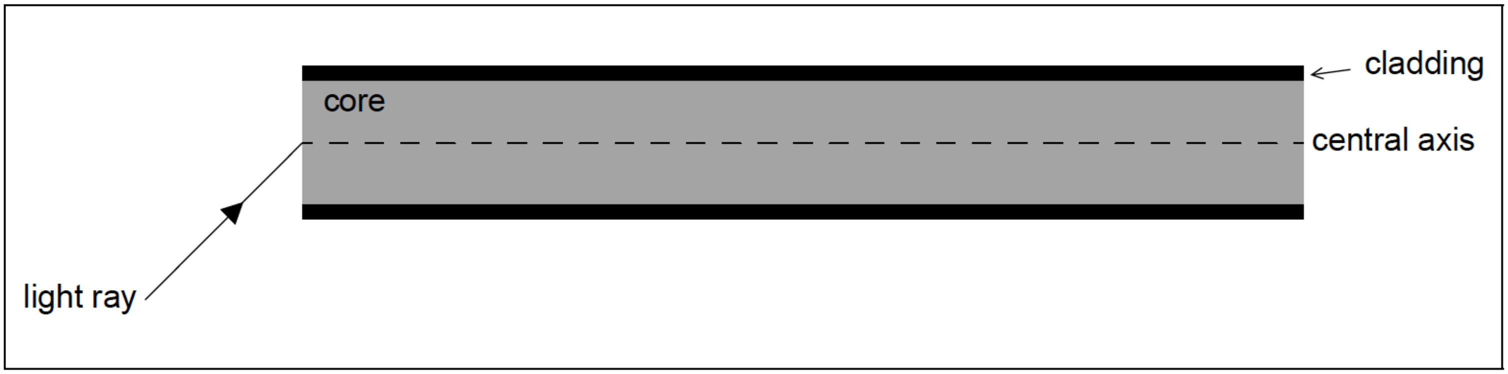
top of the shape «R» is far from axis so no paraxial rays

For MP2 accept rays far from the centre converge at different points

Examiners report

a.i. [N/A]
a.ii. [N/A]
b.i. [N/A]
b.ii. [N/A]
c.i. [N/A]
c.ii. [N/A]
c.iii. [N/A]
c.iv. [N/A]

A ray of monochromatic light enters a graded-index optic fibre.

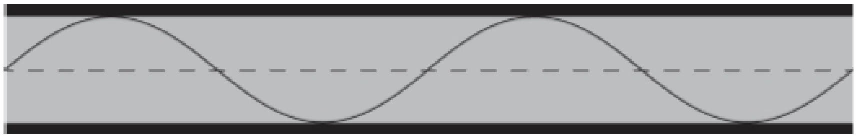


a. Draw the path of the ray as it travels through the graded-index optic fibre. [1]

b. Explain how the graded-index optic fibre reduces waveguide dispersion. [3]

Markscheme

a. curved, symmetrical path



Refraction on entry not required and ignored in diagram for simplicity.

b. waveguide dispersion means that rays not parallel to the central axis take longer to transmit

in a graded-index fibre rays away from the central axis travel at a higher speed ***OR*** rays are «refracted» closer to the central axis ***OR*** effective diameter of the fibre is reduced

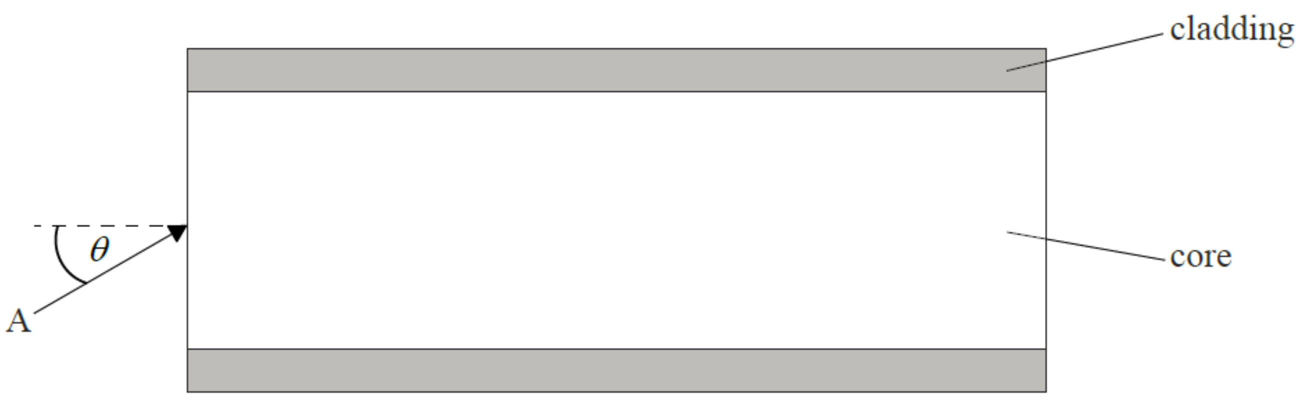
because refractive index is greater in the centre ***OR*** refractive index is less at the edge

Examiners report

a. [N/A]
b. [N/A]

This question is about an optic fibre.

Monochromatic light enters an optic fibre, from air, along direction A that is at an angle θ to the axis of the fibre.



The refractive index of the core is 1.62 and the refractive index of the cladding is 1.52. The critical angle at the core-cladding boundary is 70° .

a. Calculate the greatest angle of incidence θ that can be used with this fibre. [3]

b. Sketch the path of the light in the core on the diagram above. [2]

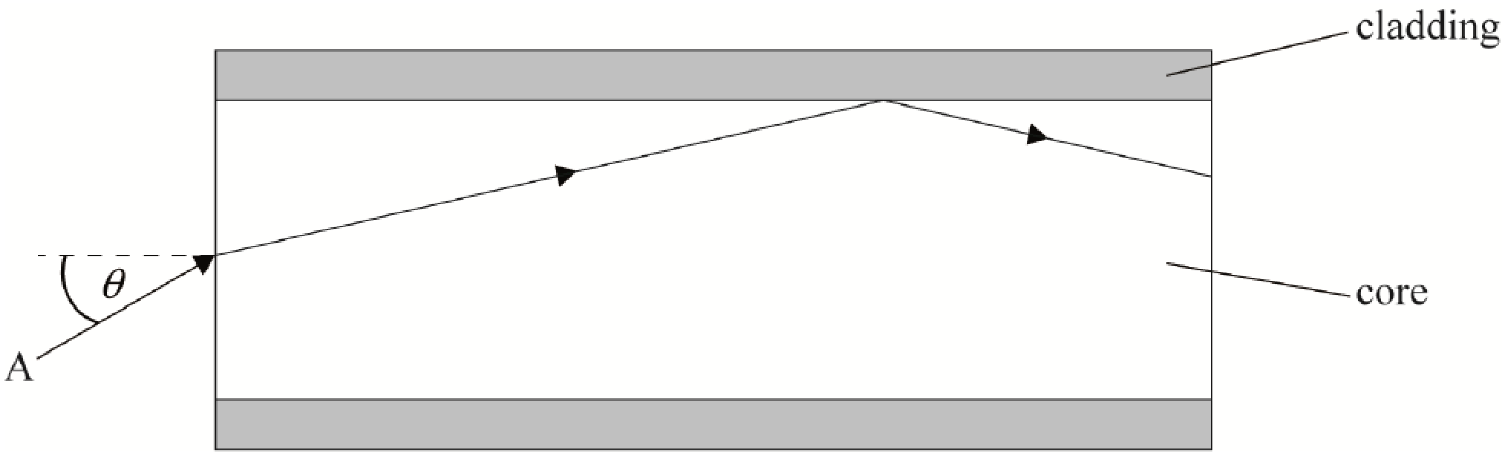
Markscheme

a. refracted angle inside core = 20°;

sin θ= sin 20° x 1.62;

34°;

b.



refraction angle on entering core sensible and smaller than incidence angle; equal angles of reflection at cladding; *(judge by eye)*

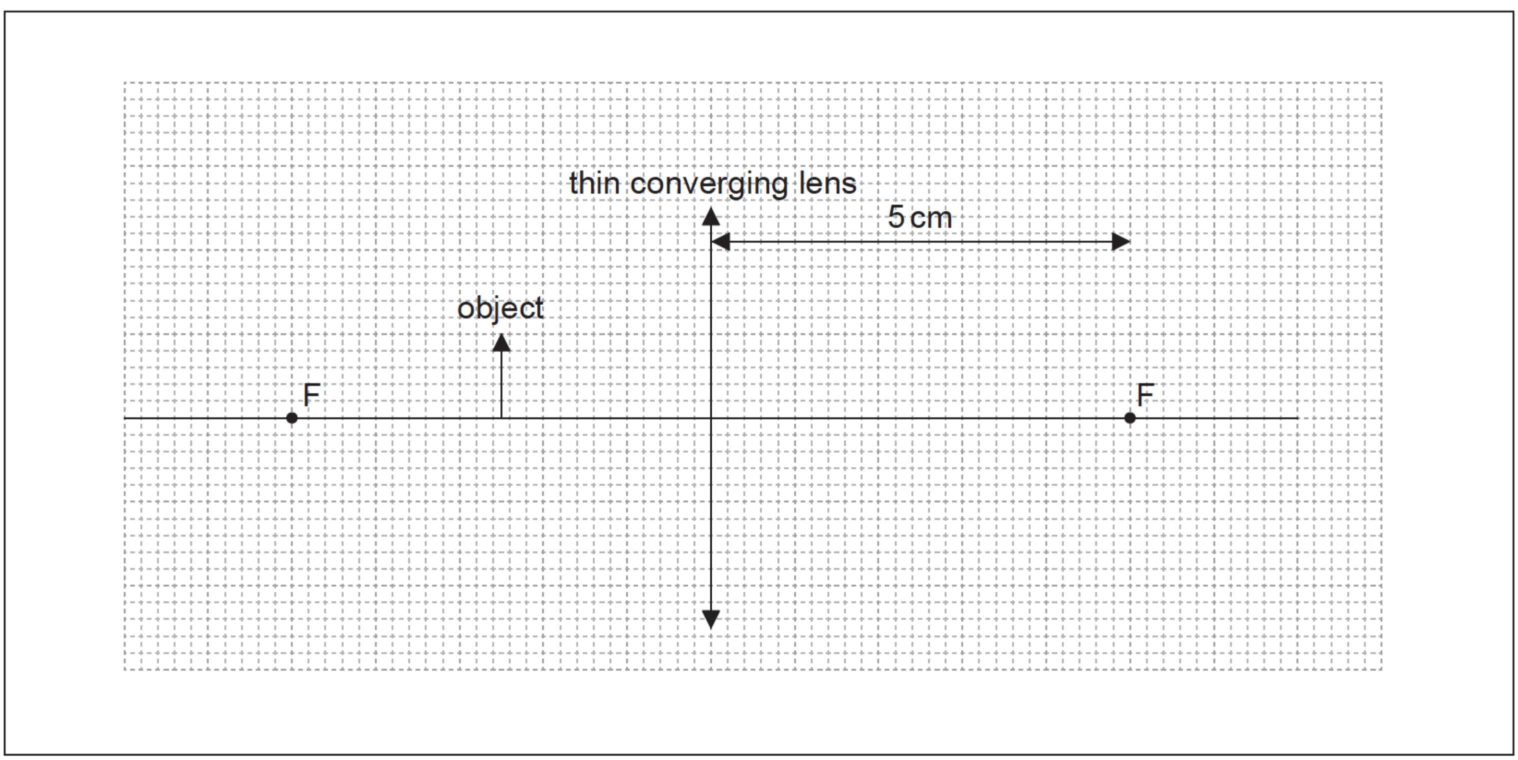
Examiners report

a. There were very few correct answers although this is fairly basic geometrical optics. Some attempted to use the equation $n_1 \sin\theta_1 = n_2 \sin\theta_2$ for refraction at the core/cladding boundary.

b. Very few answers showed refraction on entry, but many showed total internal reflection correctly.

This question is about a thin converging (convex) lens.

The diagram shows an object placed in front of a thin converging lens.



The focal points of the lens are labelled F.

a. (i) Using the diagram, determine the power of the lens. [7]

(ii) On the diagram, construct lines to show how the image of the object is formed by the lens.

(iii) State and explain whether the image is a real image **or** a virtual image.

b. Argus uses an astronomical telescope to observe a telecommunications tower. The height of the tower is 82 m and the distance from Argus to the tower is 4.0 km. The image formed by the telescope has an angular diameter of 0.10 rad and is formed at infinity. [3]

(i) Determine the angular magnification of the telescope.

(ii) The focal length of the eyepiece is 15 cm. Calculate the focal length of the objective lens.

Markscheme

a. (i) identifying focal length from diagram ***or*** *f*=5.0cm;

$\left(P=\frac{1}{f}=\frac{1}{5.0}\right)=0.20\left(\mathrm{cm}^{-1}\right)$ **or** 20 (D) **or** 20 $\left(m^{-1}\right)$;

*Award **[2]** for a bald correct answer.*

(ii) first ray from tip of object correctly refracted by lens;

a second ray from tip of object correctly refracted;

correct extrapolation back to tip of image;

Accept rays without arrows and solid construction lines back to the image.

(iii) image is virtual;
image cannot be formed on a screen / rays do not cross;

b. (i) $\theta_0=\left(\frac{82}{4\times10^3}=\right)2.05\times10^{-2}\,(\mathrm{rad})$;
$M=\left(\frac{0.1}{2.05\times10^{-2}}=\right)4.9$;

Allow ECF in second marking point for using incorrect angle.

*Award **[2]** for a bald correct answer.*

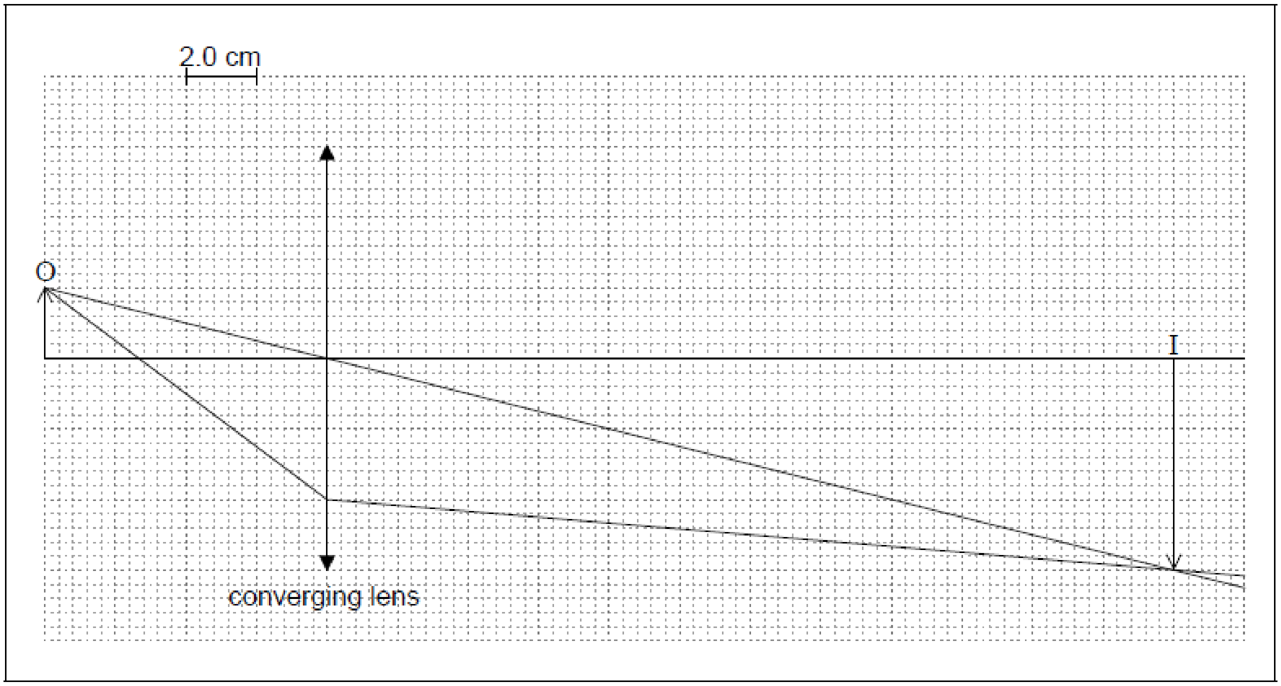
(ii) $(f_o=4.9\times15)=74\,(\mathrm{cm})$ ***or*** 73 (cm); *(allow ECF from (b)(i))*
Allow 75 (cm) due to rounding.

Examiners report

a. The magnifying glass ray diagram was almost always correct in (a). All candidates knew that the image was virtual, but often gave vague statements about what this means.

b. Part (b) was also done well with only a few candidates making POT errors when finding the angular magnification of the telescope.

A ray diagram for a converging lens is shown. The object is labelled O and the image is labelled I.

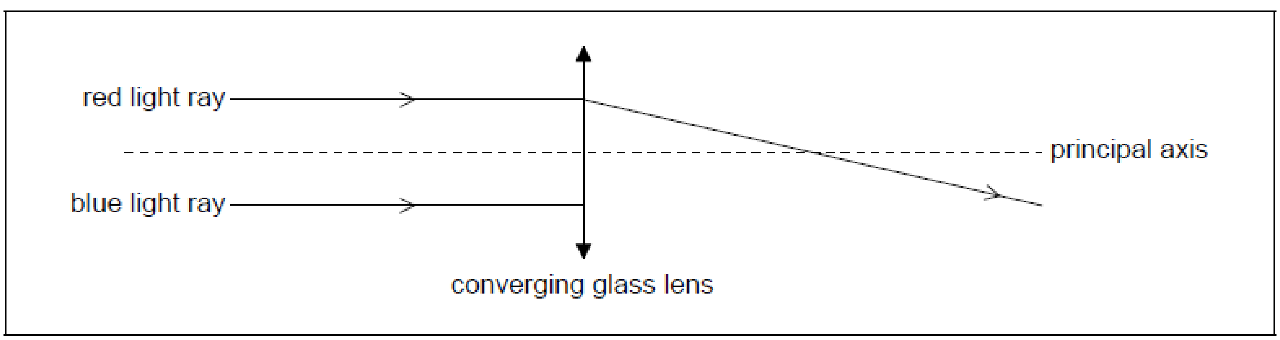


Using the ray diagram,

a.i. determine the focal length of the lens. [2]

a.ii. calculate the linear magnification. [1]

b. The diagram shows an incomplete ray diagram which consists of a red ray of light and a blue ray of light which are incident on a converging glass lens. In this glass lens the refractive index for blue light is greater than the refractive index for red light. [2]



Using the diagram, outline the phenomenon of chromatic aberration.

Markscheme

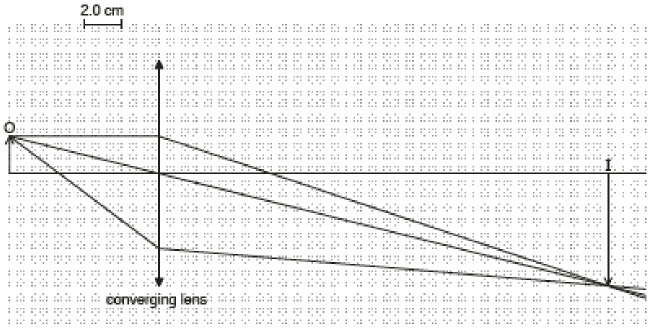
a.i. constructs ray parallel to principal axis and then to image position

OR

u = 8 cm and v = 24 cm and lens formula

6 «cm»

eg:



Allow answers in the range of 5.6 to 6.4 cm

[2 marks]

a.ii. m = «–»3.0

[1 mark]

b. completes diagram with blue focal point closer to lens

blue light/rays refracted/deviated more

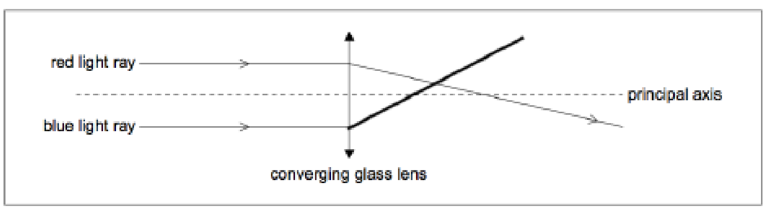
OR

speed of blue light is less than speed of red light

OR

different colors/wavelengths have different focal points/converge at different points

First marking point can be explained in words or seen on diagram



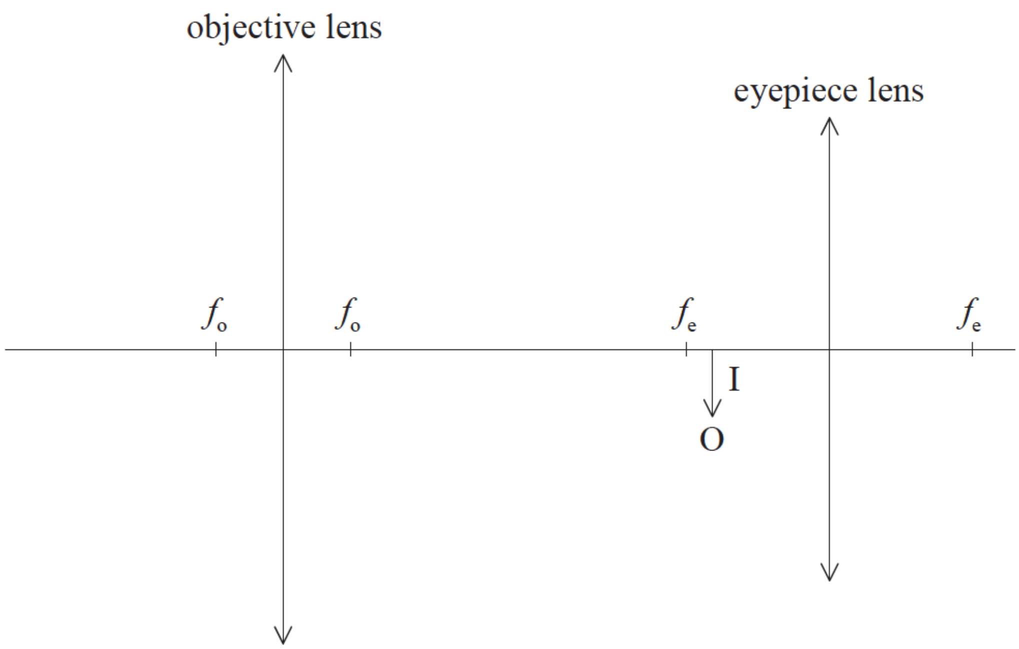
[2 marks]

Examiners report

a.i. [N/A]
a.ii. [N/A]
b. [N/A]

This question is about an optical microscope.

A compound microscope in normal adjustment consists of two lenses, an objective lens of focal length f_o and an eyepiece lens of focal length f_e. The diagram shows the position of the intermediate image I formed by the objective lens of the microscope.



a. Construct rays on the diagram to show how the final image is formed. [2]

b. The intermediate image forms 14.8 cm from the objective lens. The distance between the lenses is 18.1 cm. The focal length of the eyepiece lens is 3.8 cm. [5]

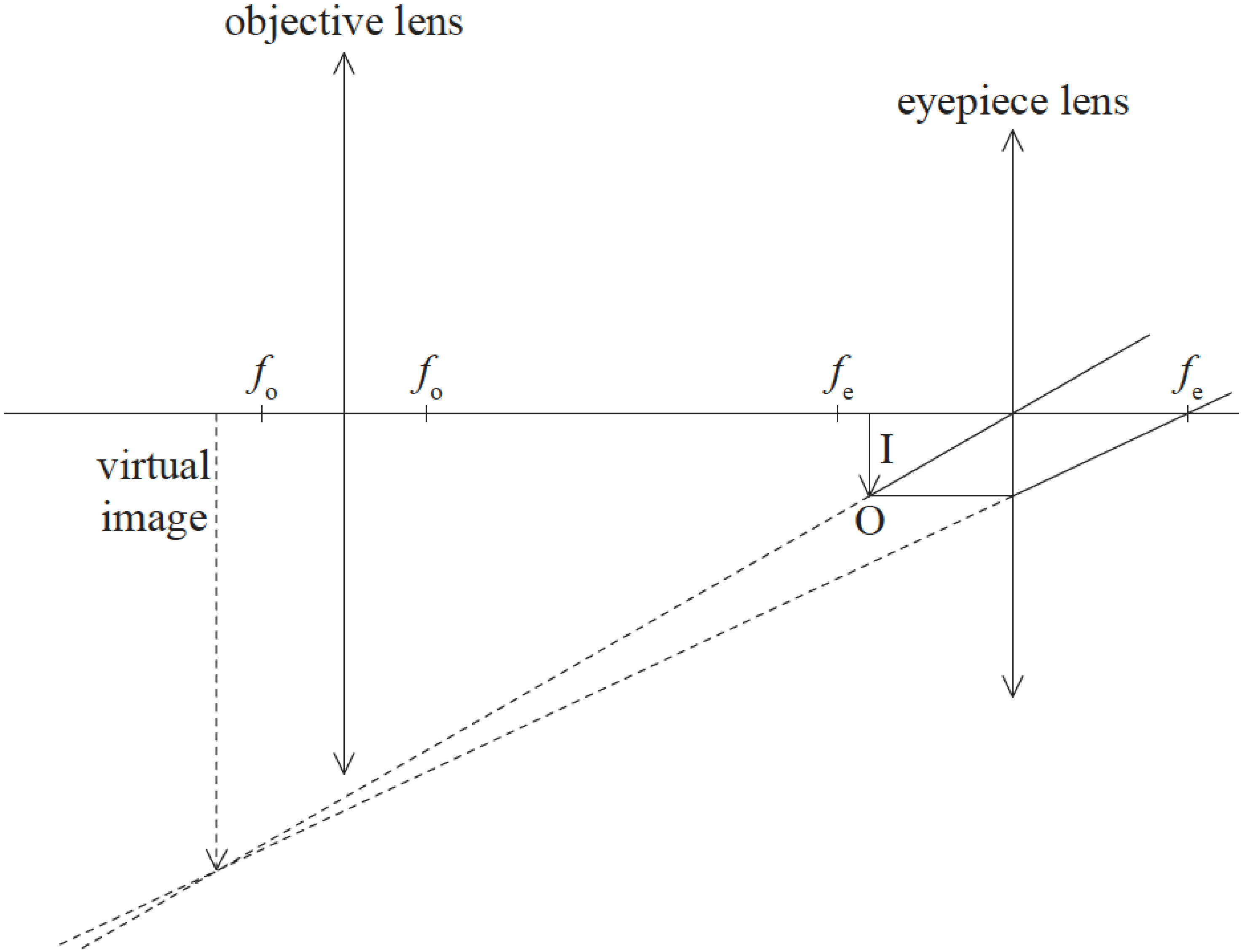
(i) Determine the distance of the final image from the eyepiece lens.

(ii) The angular magnification of the objective lens is ×6. Calculate the angular magnification of the microscope.

c. Outline how the effects of chromatic aberration in the microscope eyepiece can be reduced by illuminating the object with light that has a narrow range of wavelengths. [2]

Markscheme

a.



at least two rays from O correctly refracted at eyepiece;
completed extrapolation of these rays to form a virtual image;
Ignore rays refracted by the objective lens.
*Award **[1 max]** ECF in second marking point.*
Allow virtual image positions to be either side of objective lens.
*Award **[0]** for formation of a real image.*

b. (i) *u*=(18.1-14.8=)3.3 (cm);

$\frac{1}{v} = \frac{1}{3.8} - \frac{1}{3.3}$;

(–)25.1(cm);

*Award **[2 max]** ECF for wrong u value (eg. 14.8 (cm) giving an answer of v=5.1(cm).*

*Award **[1 max]** if positive sign appears in second term in right-hand side of equation.*

*Award **[3]** for a bald correct answer.*

(ii) $M_{eye} = \left(\frac{D}{f} + 1 = \frac{25.1}{3.8} + 1 = \frac{25.1}{3.3} =\right) 7.6$;
overall magnification=(6×7.6=)46;
*Award **[2]** ECF from (b)(i).*
*Award **[1 max]** ECF from first to second marking point.*
*Award **[2]** for a bald correct answer.*

c. each colour/wavelength has a different refractive index / *OWTTE*;

a range of wavelengths focuses different colours/wavelengths at different points/distances;

reducing the range of wavelengths reduces the range of image distances/reduces the coloured edging to images/reduces dispersion;

Examiners report

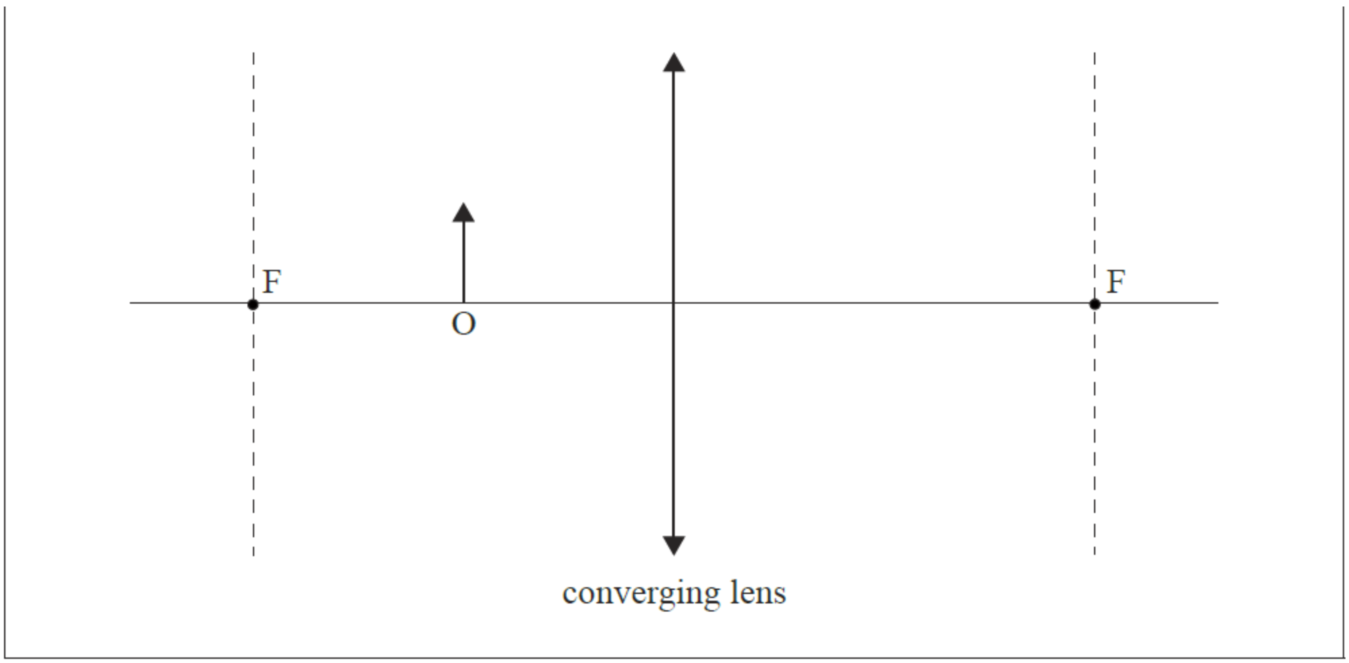
a. [N/A]
b. [N/A]
c. [N/A]

This question is about light and optical instruments.

A thin converging glass lens has focal length f=0.20m.

a. An object is placed 0.10 m in front of the lens. [4]

(i) On the diagram, construct rays to locate the image of the object, O. The focal points of the lens are labelled F.



(ii) Explain whether the image in (a)(i) is real or virtual.

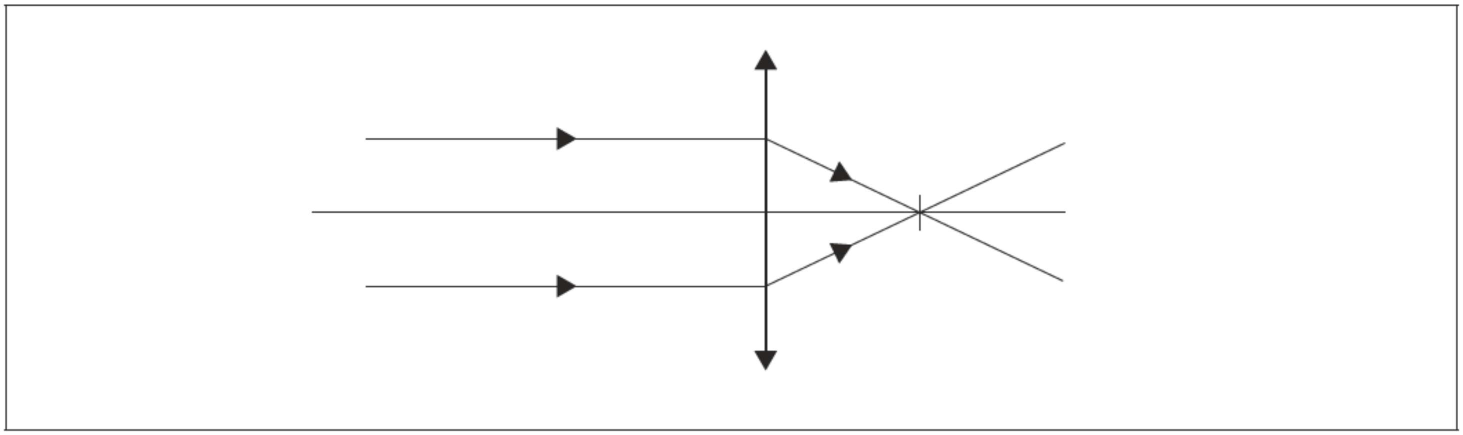
b. The object in (a) is now moved so that it is located 0.40 m from the lens. Calculate [4]

(i) the distance of the image from the lens.

(ii) the linear magnification.

d. The refractive index of the glass in the lens is greater for blue wavelengths than for red wavelengths. [1]

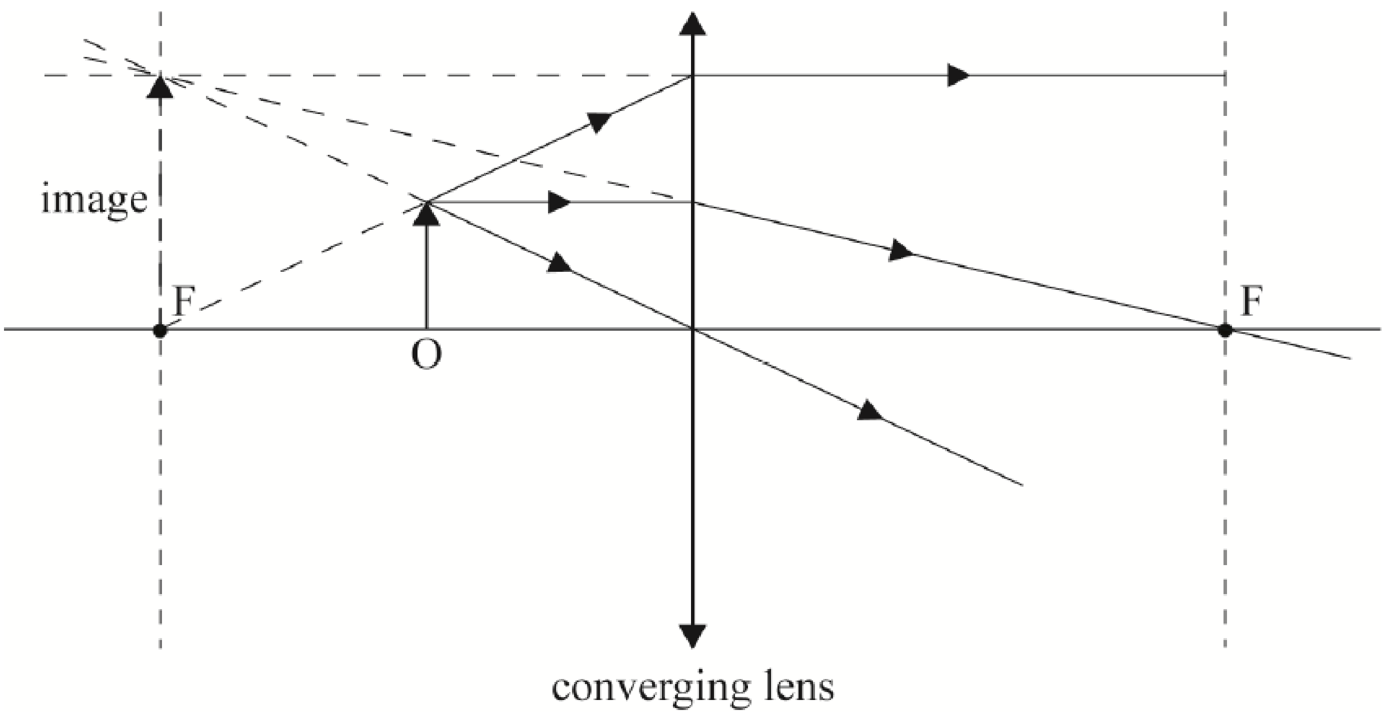
The diagram shows two rays of blue light incident on the lens.



On the diagram, sketch the paths of the rays if red light is used instead of blue light.

Markscheme

a. (i)



any correct ray out of the three shown above;
second ray correct;
image correctly located and labelled;

Accept rays without arrows and solid construction lines back to image.

(ii) virtual because no rays pass through the image / image cannot be formed on a screen;

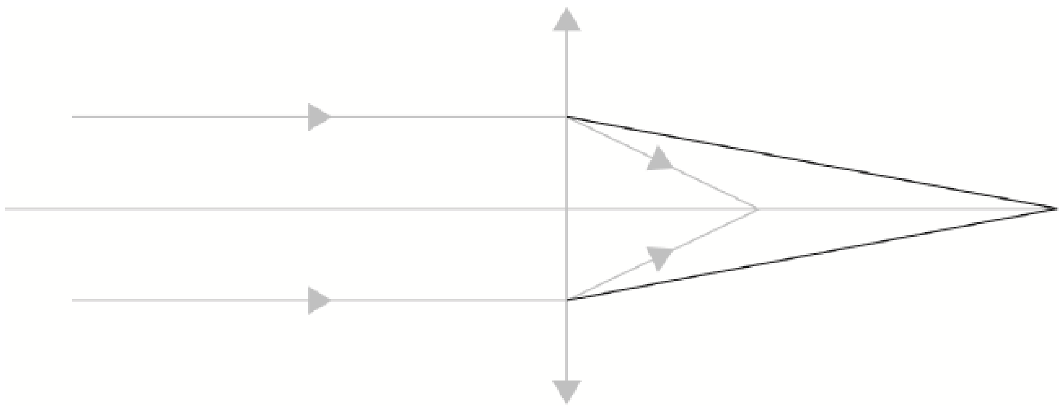
Mark is for explanation, not for statement that image is virtual.

b. (i) $\frac{1}{v} = \frac{1}{0.20} - \frac{1}{0.40} \left(= 2.5\text{m}^{-1}\right)$;

⇒v=0.40(m)

(ii) $m = -\frac{v}{u}$;
m=-1;

d.



the refracted rays converge on the principal axis farther from the lens than for blue;

Examiners report

a. (i) Rays were generally well done, but the image was sometimes not drawn at the intersection of the rays, and frequently the image was not labelled. There were very few correct answers to (ii), although this is a standard definition. Many candidates stated that the image is virtual because it is on the same side of the lens as the object. While this is true, it is not an explanation of why the image is virtual rather than real.

b. (i) and (ii) were very well done although some candidates omitted the negative sign in (b)(ii).

d. Was very well done, with only a few candidates put the focal point nearer the lens.

Both optical refracting telescopes and compound microscopes consist of two converging lenses.

a. Compare the focal lengths needed for the objective lens in an refracting telescope and in a compound microscope. [1]

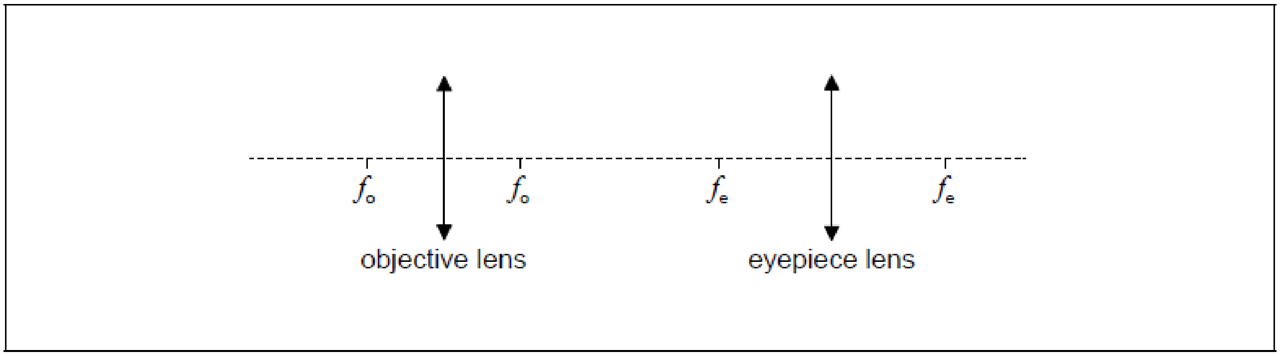
b. A student has four converging lenses of focal length 5, 20, 150 and 500 mm. Determine the maximum magnification that can be obtained with a refracting telescope using **two** of the lenses. [1]

c. There are optical telescopes which have diameters about 10 m. There are radio telescopes with single dishes of diameters at least 10 times greater. [2]

(i) Discuss why, for the same number of incident photons per unit area, radio telescopes need to be much larger than optical telescopes.

(ii) Outline how is it possible for radio telescopes to achieve diameters of the order of a thousand kilometres.

d. The diagram shows a schematic view of a compound microscope with the focal points f_o of the objective lens and the focal points f_e of the eyepiece lens marked on the axis. [1]



On the diagram, identify with an X, a suitable position for the image formed by the objective of the compound microscope.

e. Image 1 shows details on the petals of a flower under visible light. Image 2 shows the same flower under ultraviolet light. The magnification is the same, but the resolution is higher in Image 2. [1]

Image 1 Image 2

Explain why an ultraviolet microscope can increase the resolution of a compound microscope.

Markscheme

a. $f_{\text{OBJECTIVE}}$ for telescope $>$ $f_{\text{OBJECTIVE}}$ for microscope

OR

$f_{\text{OBJECTIVE}}$ for telescope$>$ f_{EYEPIECE} for telescope but $f_{\text{OBJECTIVE}}$ for microscope$<$ f_{EYEPIECE} for microscope

b. $\frac{500}{5}$

OR

100 times

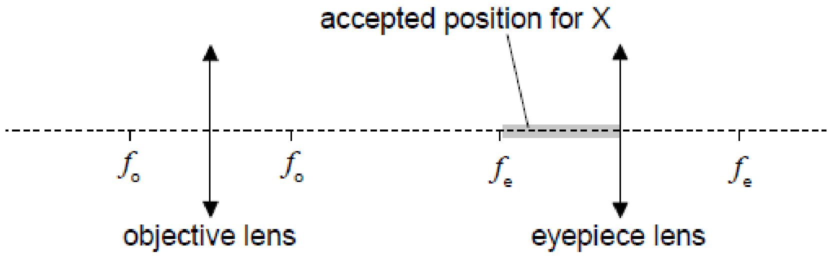
c. i

RF photons have smaller energy, so signal requires larger dish

RF waves have greater wavelength, good resolution requires larger dish
Must see both, reason and explanation.

ii
use of an array of dishes/many mutually connected antennas «so the effective diameter equals to the distance between the furthest antennas»

d. between f_e and eyepiece lens, on its left



Accept any clear indication of the image (eg: X, arrow, dot).
Accept positions which are slightly off axis.

e. resolution improves as wavelength decreases ***AND*** wavelength of UV is smaller

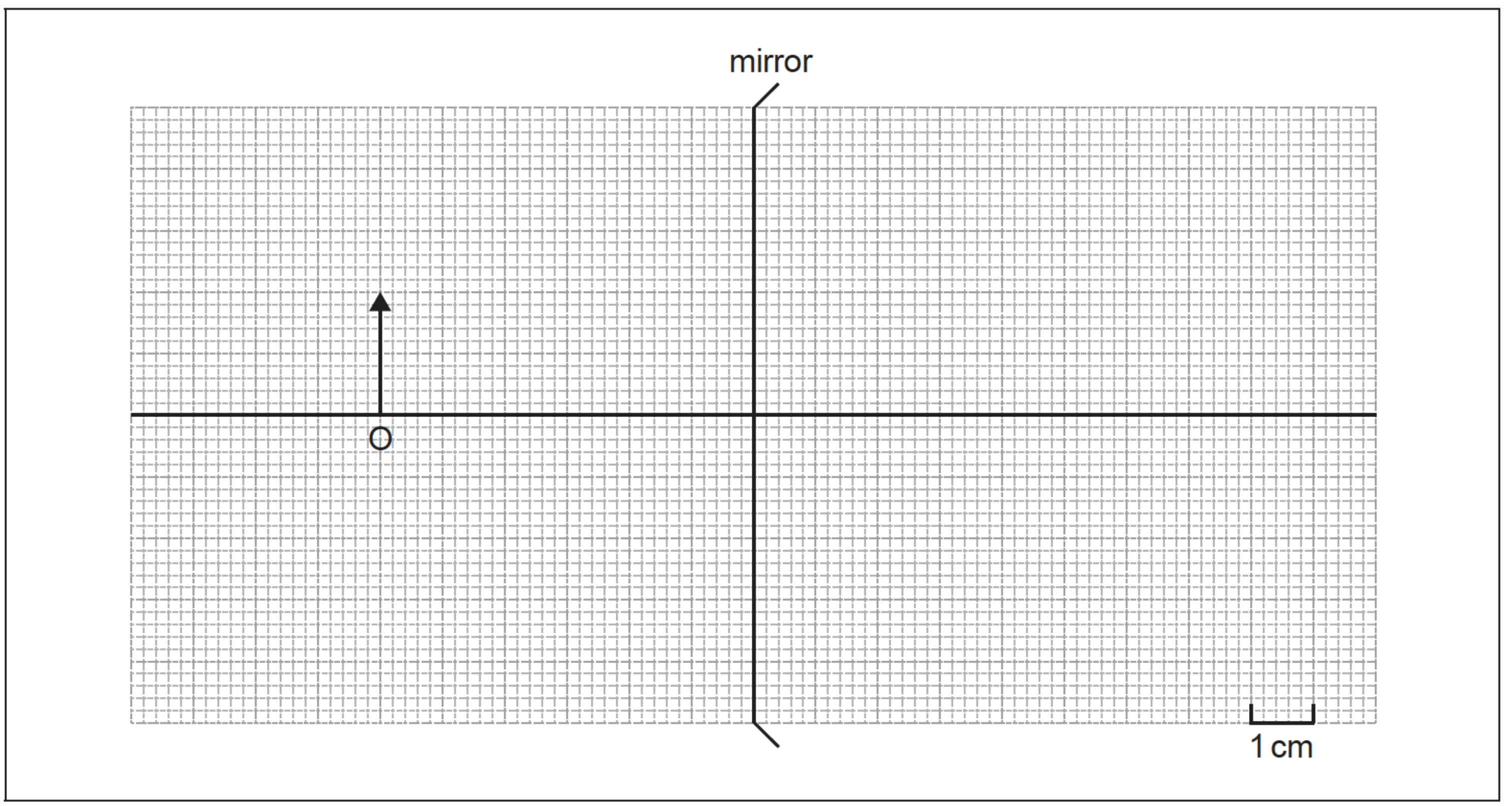
OR

gives resolution formula ***AND*** adds that λ is smaller for UV

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]

The diagram shows a diverging mirror.



Object O has a height of 2.0 cm and is 6.0 cm from the mirror surface. The focal length of the mirror is 4.0 cm and the radius of curvature is 8.0 cm.

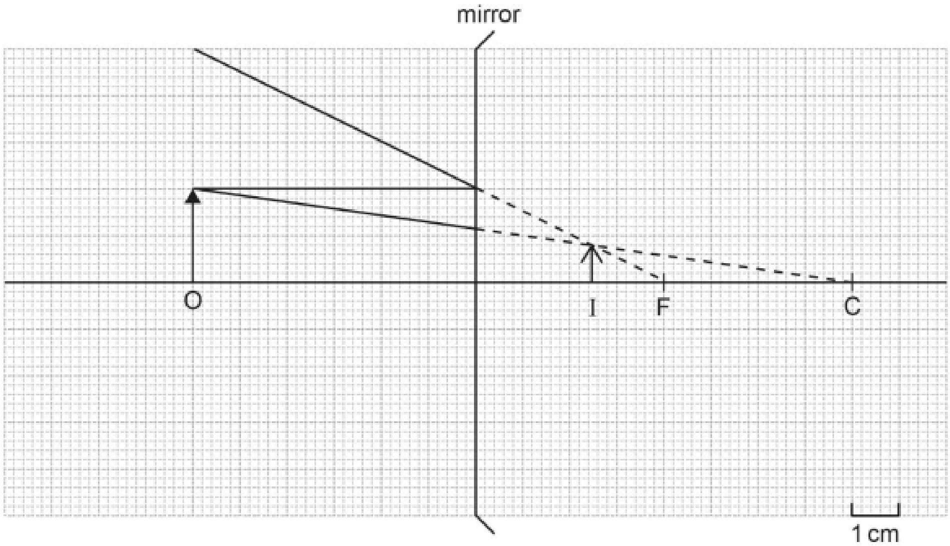
a. Construct a ray diagram for object O. Label the image I. [3]

b. Estimate the linear magnification of the image. [1]

c. Outline the advantage of parabolic mirrors over spherical mirrors. [3]

Markscheme

a.



one correct ray drawn
another correct ray
image located at intersection of rays, behind the mirror

Label I is required.

b. ≈ 0.4

c. image is in better focus/sharper ***OR*** parabolic do not suffer from spherical aberration

parabolic mirrors reflect parallel rays through one point

whereas spherical mirrors reflect parallel rays through different points

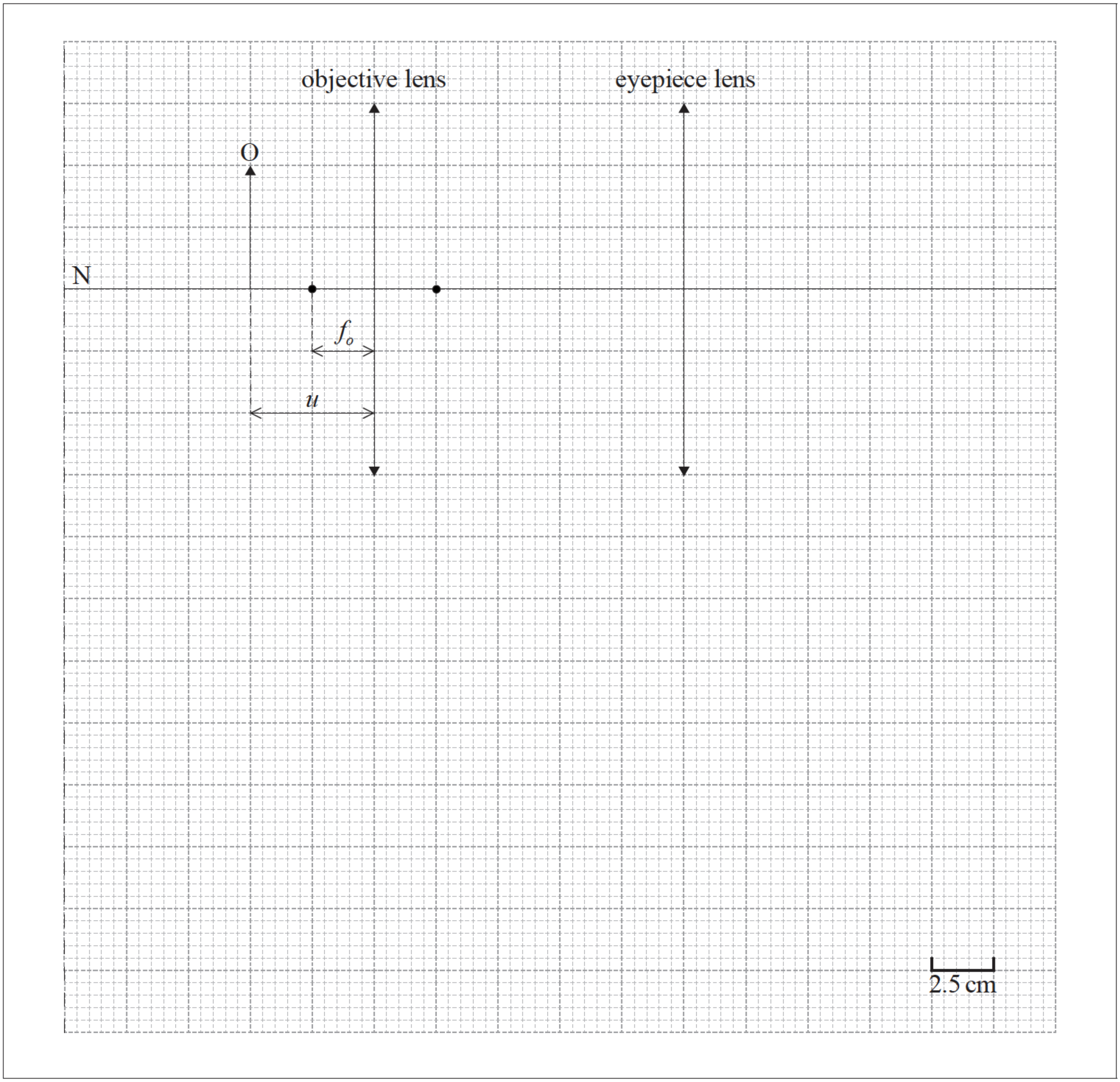
Award 3rd mark even if implied in the answer.

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

This question is about a compound microscope.

The diagram below shows two thin converging lenses in a compound microscope. The focal length of the objective lens is f_o. The object O is placed at a distance u from the objective lens.



a. (i) On the diagram above, construct a ray diagram to locate the position of the image formed by the objective lens. Label this image I. [3]

(ii) Outline whether the image I is real.

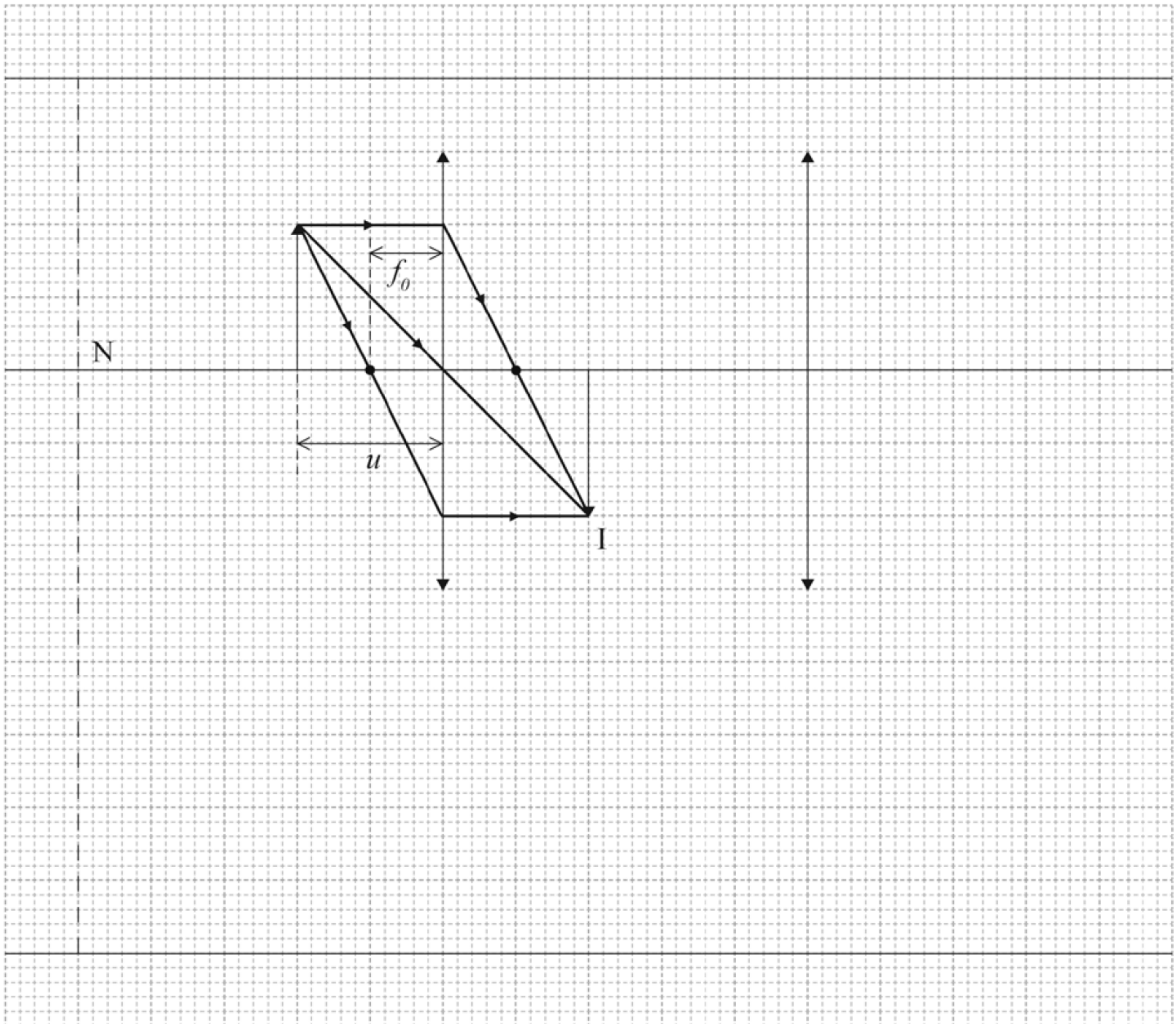
b. The compound microscope in (a) is in normal adjustment so that the final image is formed at the near point of an unaided eye. The position of the near point of the eye is located at N. [6]

(i) Define *near point*.
(ii) Deduce that the focal length of the eyepiece is around 10.7 cm.
(iii) Estimate the total linear magnification of the microscope.

Markscheme

a. (i) any two standard rays out of the three shown below;

converging to locate the image;

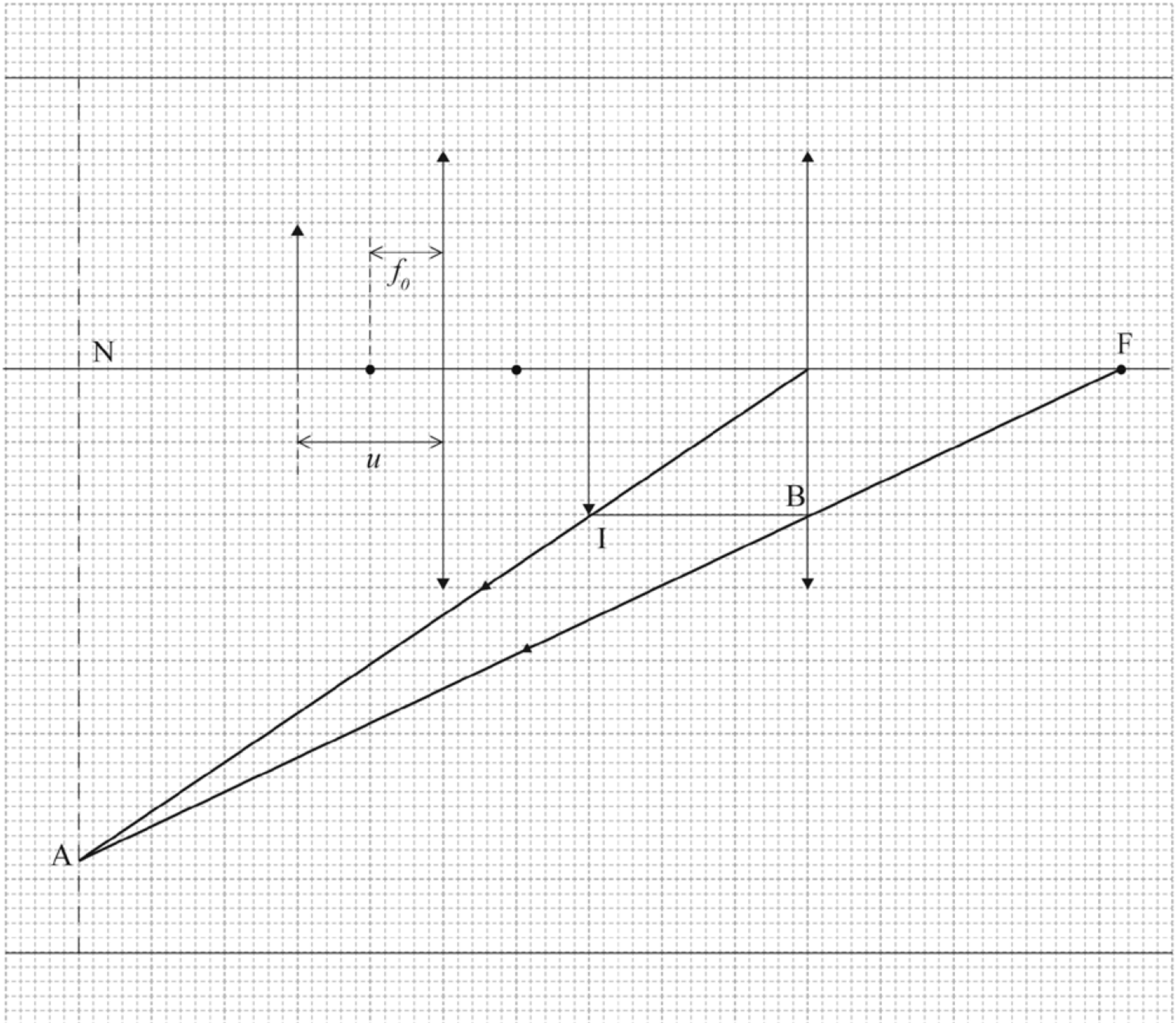


(ii) (image is real) because rays of light/energy pass through it;

b. (i) the closest distance the unaided human eye can focus (without undue strain);

Do not accept 25cm without explanations.

(ii) standard ray through the center of the eyepiece to locate point A;
standard ray through points A and B;
extrapolated to the principal axis to locate the focus F, 10.7cm from the eyepiece; } *(allow focal lengths between 9 cm and 12.5 cm if the two standard rays are clearly identified)*



or

v=-25cm;
u=+7.5cm;
$f = \left[\frac{1}{u} + \frac{1}{v}\right]^{-1} (= 10.7\text{cm});$

(iii) counting small squares, size of final image=33.3 and size of object=10;
$m = \frac{33.3}{10} = 3.3;$

or

$m_1 = 1$ and $M_2 = \left(\frac{25}{7.5} =\right) 3.3;$
$M = (m_1 \times M_2 =) \, 3.3;$

Examiners report

a. This question was relatively well answered. In (a), the majority of candidates proved that they are able to use standard rays to find the position of the image, although too many candidates were not able to outline clearly enough whether the image is real.

b. There were many correct answers to (b)(i), despite the general tendency for a lack of clarity in the answers to “define” questions. (b)(ii) and (iii) were well answered by the more able candidates. Generally the answers lacked clarity, explanation of formulas used and clarity of layout of working. More alternative solutions were accepted if clearly explained. Only a few construction based solutions was found, although this is by far the more understandable approach to the problem.