

1. (a) reflected rays off concave mirror towards marked F (1)
 correct convex mirror and rays reflected (1)
 rays cross, and pass through hole (1)
 emerge from eye lens parallel (1)

- (b)
- | | | |
|--|---|----------------|
| collects more light, mirrors can be larger than lens
better resolution, larger diameters

no chromatic aberration, $\left\{ \begin{array}{l} \text{only occurs with lenses} \\ \text{none with mirror} \\ \text{no refraction} \end{array} \right\}$

no spherical aberration of paraboloidal | } | any two (1)(1) |
|--|---|----------------|

[6]

2. (a) (i) curved dish (to collect radiation) (*)
 reflected to a focus/image or receiver (*)
 collect electromagnetic radiation (*)
 (*) any two (1) (1) 2

- (b) $\left(\lambda = \frac{c}{f} \text{ gives} \right) \lambda_1 = \frac{3 \times 10^8}{7.5 \times 10^8} = 0.4 \text{ m}$ and $\lambda_2 = \frac{3 \times 10^8}{1.5 \times 10^{10}} = 0.02 \text{ m}$ (1)
 $\lambda_2 \approx$ dimensions of holes and signal reduced (1)
 lower frequency gives $\lambda >$ dimensions of holes, signal not affected (1) 3

- (c) $\lambda_{\text{rad}} \gg \lambda_{\text{op}}$ (1)
 explanation (e.g. use of $\theta = \frac{\lambda}{d}$) of $(\text{res. power})_{\text{radio}} < (\text{res. power})_{\text{opt}}$ (1) 2

[7]

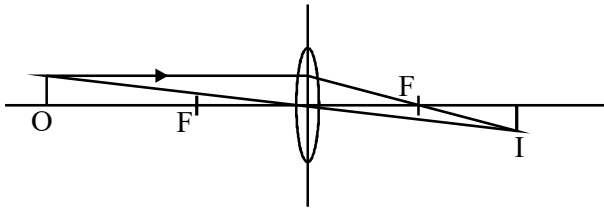
3. (a) (i) F_o, F_e shown coincident (1)
 objective and eyepiece correctly identified (1)

- (ii) $M = \frac{2.50}{0.020} (=125)$ (1)
 $\beta = 6.2(5) \times 10^{-3} \text{ rad}$ (1) 4

- (b) (i) convex mirror between objective and F_1 (1)
 (ii) two rays directed towards F_1 (1)
 rays cross after reflection (1)
 emerge parallel from lens (1)
 label F_2 (1)
 C shown correctly (1)
 if plane or concave mirror shown, mark as scheme to max 2/6 6
- (c) (i) (chromatic aberration -) different wavelengths (1)
 refracted different amounts [or different speeds in glass] (1)
 image with coloured edges [or different focus for different colours] (1)
- (ii) no refraction (by mirrors) [or telescopes use mirrors or no chrom abber by mirr] (1)
 some chromatic aberration in eyepiece lens (1) 5

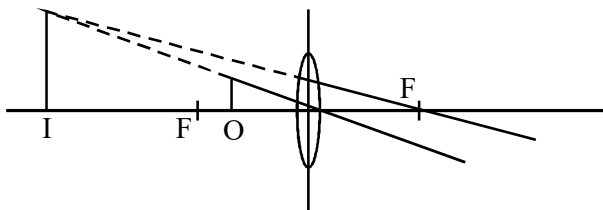
[15]

4. (a)



ray parallel to axis through F (1)
 ray through centre of lens
 to give image (1)

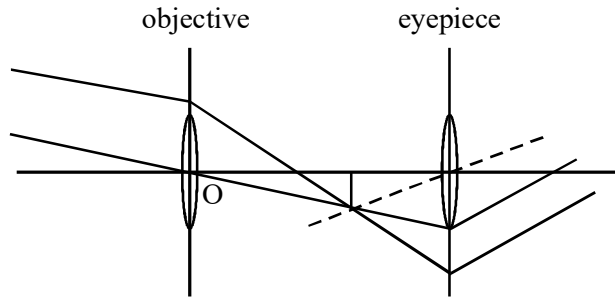
(b)



rays from object within focal distance
 emerge parallel to axis through F (1)
 rays through centre of lens
 to give virtual image (1)

[4]

5. (a) (i)



correct rays through objective (1)

first image at F_0 (1)

F_0 and F_e coincide (1)

correct construction line(s) (1)

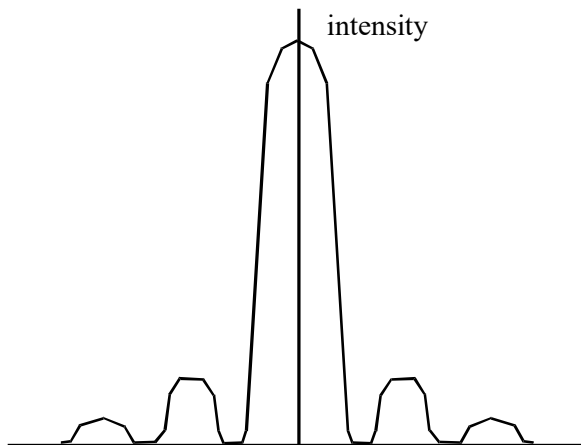
rays emerge parallel (1)

(ii) $\left(M = \frac{\alpha'}{\alpha} \text{ gives } \right) 24 = \frac{120}{a}$ (1)

$\alpha = 5 \text{ sec (of arc)}$ (1)

7

(b) (i)



central maximum (1)

decreasing maxima (1)

approximate equal spacing between
minima either side of central axis (1)

(ii) two intensity curves [or two Airy discs] (1)
central maximum of first coincides with
first minimum of second curve (1)

5

(c) (i) $\left(\theta = \frac{\lambda}{d} \text{ gives}\right) \theta = \frac{6.0 \times 10^{-7}}{15 \times 10^{-2}} = 4.0 \times 10^{-6} \text{ rad (1)}$

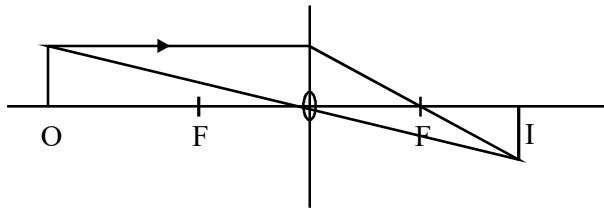
angular separation of Mizar $7.0 \times 10^{-5} \text{ rad}$, can be resolved (1)

(ii) resolving power controlled by diffraction effects [or by $\frac{\lambda}{d}$] (1)

hence increasing angular magnification does not increase resolution (1) 4

[16]

6. (a)



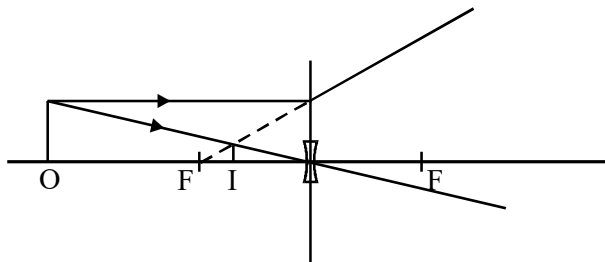
(object outside F)

ray parallel to axis through F (1)

ray through centre of lens to give image (1)

2

(b)



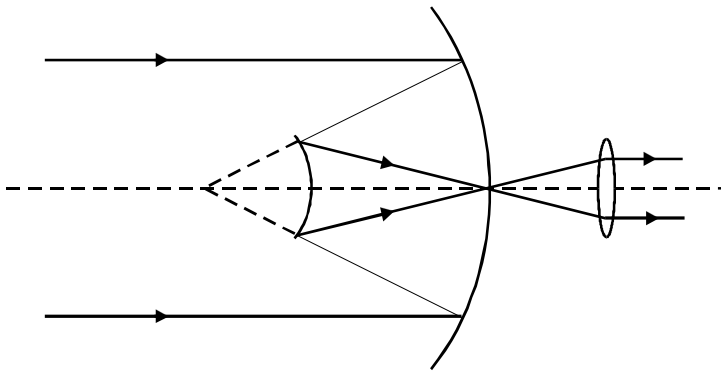
diverging ray appears to come from F (1)

ray through centre of lens to give image (1)

2

[4]

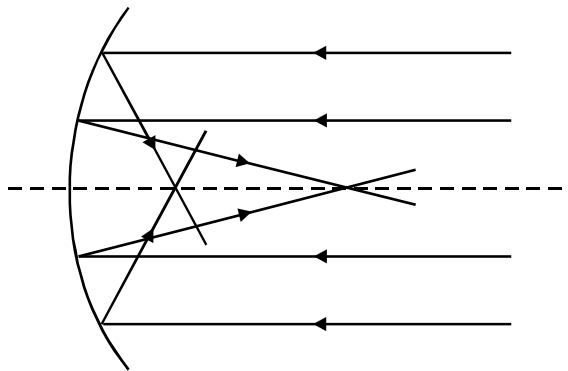
7. (a)



rays reflected at concave mirror (1)
 rays reflected at convex mirror (1)
 rays cross and emerge parallel from eye lens (1)

3

(b) (i)



rays close to axis and far from axis to different focal points (1)
 correct focal points (1)
 use of parabolic mirror (1)

(ii) light of different wavelength (1)
 refracted to different foci (1)
 no refraction with mirrors, no chromatic aberration with reflection (1)

6

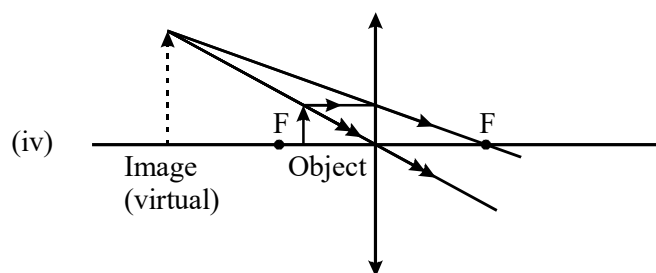
[9]

8. (i) (image is) virtual (1)

(ii) $f = \frac{1}{P} = \frac{1}{10} = 0.10 \text{ m}$ (1)

(iii) (use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ gives) $\frac{1}{0.1} = \frac{1}{u} - \text{(1)} \frac{1}{0.25} \text{(1)}$
 (allow C.E. for value of f from (ii))

$$\frac{1}{u} = 14 \text{ (1) (gives } u = 0.071 \text{ (m))}$$



ray parallel to axis through F and
 ray through centre of lens to form image (virtual) (1)
 image, object and principal foci labelled (1)

7

[7]

9. (a) (i) diagram to show:
 at least two bright rings (1)
 radius of central spot greater than thickness of secondary rings (1)

- (ii) two intensity or circular patterns (1)
 two objects can just be resolved when central maximum
 of one coincides with first minimum of other (1)

max 3

(b) $D = \frac{\lambda}{\theta} = \frac{5.7 \times 10^{-7}}{1.1 \times 10^{-5}} \text{ (1)}$
 $= 5.2 \times 10^{-2} \text{ m (1)}$

2

[5]

10. (a) diagram to show:
 both focal points coinciding and labelled, with $f_o > f_e$ (1)
 centre ray straight through objective, rays crossing at
 focal plane and proceeding to eyepiece (1)
 rays refracted at eyepiece and emerge parallel to
 construction line (1)

3

- (b) (i) ($f_o + f_e = 3.5$, and $f_o/f_e = 100$) estimate $f_o \approx 3.5 \text{ m}$ and $f_e \approx 0.035 \text{ m}$ (1)

(ii) (use of $M = \frac{\alpha'}{\alpha}$ gives) $\alpha = \frac{4.0 \times 10^{-3}}{100} = 4.0 \times 10^{-5}$ (rad) (1)
 (use of $\alpha = \frac{D}{r}$ gives) $D = 4.0 \times 10^{-5} \times 1.3 \times 10^9 = 5.2 \times 10^4$ km (1)
 (allow C.E. for value of α) 3

- (c) no chromatic aberration - mirrors do not refract light (1)
 no spherical aberration - use of parabolic mirror (1)
 no distortion - mirror can be supported more strongly (1)
 better resolving power or greater brightness - mirrors can be larger (1)
 more light gets through (image brighter) - lens absorbs more light (1)
 (any two) 2 [8]

11. (a) ratio of the number of photons falling on a device that produce a signal to the total number of photons falling on the device (1)
 > 70% (for CCD) (1) 2

- (b) silicon chip (1)
 divided into picture elements (pixels) (1)
 (light) photons incident (1)
 electrons released (1)
 charge or number released proportional/related to beam intensity/brightness (1)
 image produced identical to electron pattern (1)
 when exposure complete, charge processed to give image (1) max 5 [7]

12. (a) (i) 8.0 cm (1)
 (ii) diagram to show:
 ray parallel to axis through labelled F (1)
 ray through centre of lens to produce correct image (1) 3

- (b) (i) (use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ gives) $\frac{1}{0.12} = \frac{1}{0.08} + \frac{1}{v}$ (1)
 $\left(\frac{1}{v} = -4.2\right)$ and $v = -0.24$ m (1)
 (ii) magnified, upright, virtual (three correct (1) (1) two correct (1)) max3 [6]

13. (a) ray diagram to show:
 rays reflected at concave mirror (1)

- rays reflected at convex mirror (1)
 rays crossing in front of eyepiece (1) 3
- (b) different focal points for rays at different distances from axis (1)
 shortest focal length for paraxial rays (1) 2
- (c) light of different wavelengths refracted to different foci (1)
 diagram showing refraction with blue focal length closest to lens (1) max 2
- [7]**
- 14.** (i) real (1)
 inverted (1)
- (ii) diagram to show:
 ray parallel to axis through F with F labelled (1)
 ray through centre of lens to give (indicated) magnified image (1)
- (iii) (use of $P = \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ gives) $P = \frac{1}{0.17} + \frac{1}{1.62}$ (1)
 $= 6.5 \text{ D}$ (1) 6
- [6]**
- 15.** (a) diagram to show:
 correct curvature of mirrors (1)
 rays crossing in the hole in the objective mirror (1) 2
- (b) (i) $\theta \left(= \frac{\lambda}{d} \right) = \frac{2.0 \times 10^{-6}}{3.8}$ (1)
 $= 5.3 \times 10^{-7} \text{ rad}$ (1) $(5.26 \times 10^{-7} \text{ rad})$
- (ii) visible wavelengths shorter (than infra red) (1)
 \therefore smaller resolving angle (\therefore better resolving power) (1) 4
- (c) (i) water vapour (1) (or carbon dioxide)
- (ii) longer wavelengths absorbed (1)
 shifts peak of graph to shorter wavelengths (1)
 star appears hotter [or reference to appropriate equation] (1) max 3
- [9]**

16. (a) three parallel rays refracting through objective (1)
 rays pass through intermediate image at point labelled F_o , F_e with $f_o > f_e$ (1)
 rays leave eyepiece parallel to construction ray (which need not be shown) (1) 3
- (b) (i) separation ($= f_o + f_e$) = 0.10 + 0.50 = 0.60 m (1)
- (ii) (use of $m = \frac{f_o}{f_e}$ gives) $m = \frac{0.5}{0.1} = 5$ (1)
 $\alpha = m\alpha = 5 \times \frac{3500}{380000} = 0.46$ rad (1)
 [or $\alpha = \frac{3500}{380000}$
 $\alpha' = 5\alpha = 0.46$ rad]
- (iii) edges of the image will appear coloured (1) 4

[7]

17. (a) for **both** diagrams: one construction ray correct (1)
 principal foci correctly labelled (1) 4
 (real image) second construction ray to form real image (1)
 (virtual image) second construction ray to form virtual image (1)

(b) (i) $\left(\text{use of } P = \frac{1}{f} = 10, \text{ and use of } \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \text{ gives} \right) \frac{1}{u} = 10 - \frac{1}{0.25}$ (1)
 $u = 0.17$ m (1) (0.167 m)

(ii) $\frac{1}{u} = 10 + \frac{1}{0.25}$ (1)
 $u = 0.071(4)$ m (1) 4

[8]

18. (a) the central bright spot (1)
 of the diffraction pattern produced when light passes through a circular aperture (1)
 the minimum distance between two sources which can be resolved by a telescope found when centre of one Airy disc falls just outside the Airy disc for the other source (1)
 [or statement referring to maxima and minima]

3
QWC 1

- (b) (i) $\lambda \left(= \frac{c}{f} \right) = \frac{3.0 \times 10^8}{1.4 \times 10^9} = 0.21(4) \text{ m (1)}$
 precision needed = $\lambda/20 \approx 0.01 \text{ m (1)}$
- (ii) $\theta \left(= \frac{\lambda}{d} \right) = \frac{0.21}{305} = 6.9 \times 10^{-4} \text{ rad (1) } (6.88 \times 10^{-4} \text{ rad})$
 (use of $\lambda = 0.214$ gives $\theta = 7.02 \times 10^{-4} \text{ rad}$) 3

- (c) parallel rays furthest from axis of reflector brought to focus closer to reflector than rays close to axis (1) (allow correct diagram)
 use parabolic reflector (1) 2

[8]

19. (a) (i) (use of $\theta = \frac{\lambda}{d}$ gives) $\frac{\theta_{\text{reflector}}}{\theta_{\text{refractor}}} = \frac{d_{\text{refractor}}}{d_{\text{reflector}}} \text{ (1)}$
 $= \left(\frac{0.9}{1.52} \right) = 0.59(2) \text{ (1)}$

- (ii) use of, energy collected per sec \propto area $\propto d^2 \text{ (1)}$
 $\frac{P_{\text{refl}}}{P_{\text{refr}}} = \left(\frac{d_{\text{refl}}}{d_{\text{refr}}} \right)^2 = \left(\frac{1.52}{0.9} \right)^2 = 2.85 \text{ (1)}$ 3

- (b) (i) correct diagram showing four parallel co-axial rays, with outer rays brought to focus at a point closer to mirror than inner rays (1)
 (ii) (use of) parabolic mirror (1) 2

- (c) (i) correct diagram showing two mirrors, one concave, one convex (1)
 (ii) mirror blocks light so less light hits objective mirror (1)
 light diffracted passing secondary mirror affects image (1) 3

[8]

20. (a) silicon chip divided into picture elements (pixels) (1)
 incident photons release electrons (1)
 number liberated proportional to intensity (1)
 image identical to electron pattern (1)
 when exposure complete, charge processed to give image (1) 4

- (b) ratio of the number of photons falling on a device that produce a signal to the total number of photons falling on the device (1)
 $\geq 70\%$ (for CCD) (1) 2

[6]

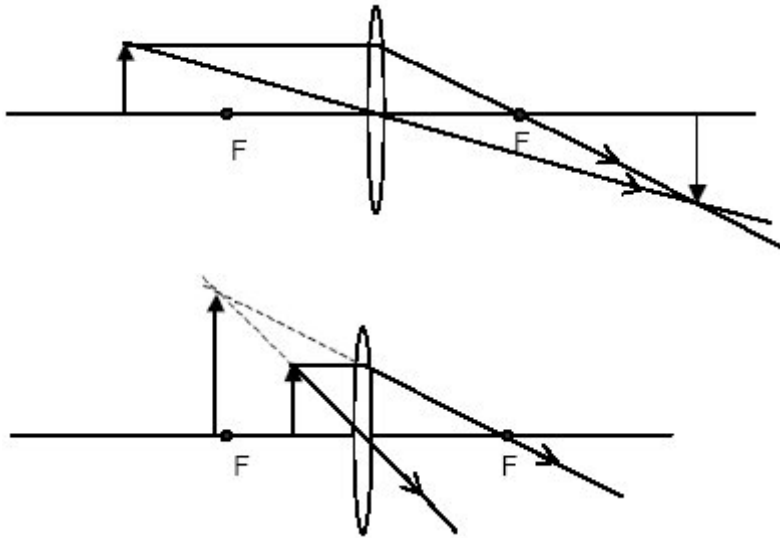
21. (a) for both diagrams:

rays from top of object passes straight through centre of lens (1)

principal foci correctly labelled (1)

ray parallel to principal axis passes through focal point to form virtual image (1)

ray parallel to principal axis passes through focal point to form real image (1)



4

(b) $P = 1/f = 1/u + 1/v$

$1/u = 1/0.1 + 1/0.25$ (1)

$u = 1/14 = 0.17\text{m}$

$= 0.07\text{m}$ (1)

2

[6]

22. 3 marks for any of the following 3 features

- compared with optical reflecting telescopes, radio telescopes:
- are much longer
- have a much lower resolving power
- are not as affected by the atmosphere and so their positioning is less critical
- have only one reflecting surface rather than two
- have a similar structure in that a concave reflecting surface reflects the em radiation to a detector at the focal point

3

explanations of resolving power

radio telescopes have a lower resolving power:

because the ratio of wavelength to telescope diameter is larger **(1)**

because radio wavelengths are very much larger than optical wavelengths (even though the diameters of radio telescopes are larger) **(1)**

explanations of collecting power:

collecting power depends on the area of the objective which is much larger for radio telescopes (depends on the square of the diameter) **(1)**

3

[6]