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, only occurs with lenses / none with mirror / no refraction
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) $\left(\lambda = \frac{c}{f}\ gives\right) \lambda_1 = \frac{3\times10^8}{7.5\times10^8}$ =0.4 m and $\lambda_2 = \frac{3\times10^8}{1.5\times10^{10}}$ = 0.02m **(1)**
$\lambda 2 \approx$ dimensions of holes and signal reduced **(1)**
lower frequency gives $\lambda >$ dimensions of holes, signal not affected **(1)** 3

(c) $\lambda_{rad} >> \lambda_{op}$ **(1)**

explanation (e.g. use of $\theta = \frac{\lambda}{d}$) of (res. power)$_{radio}$ < (res. power)$_{opt}$ **(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)**
$\beta = 6.2(5) \times 10^{-3}$ rad **(1)** 4

(b) (i) convex mirror between objective and F_1 **(1)**

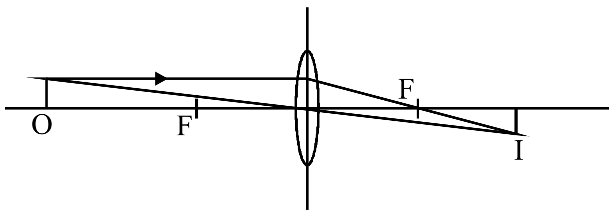
(ii) two rays directed towards F_1 **(1)**
rays cross after reflection **(1)**
emerge parallel from lens **(1)**
label F_2 **(1)**
C shown correctly **(1)**
if plane or concave mirror shown, mark as scheme to max 2/6 6

(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

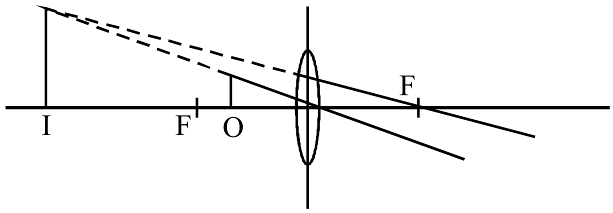
[15]

4. (a)



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

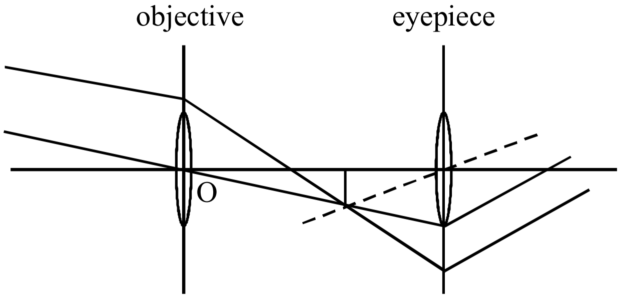
(b)



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)**

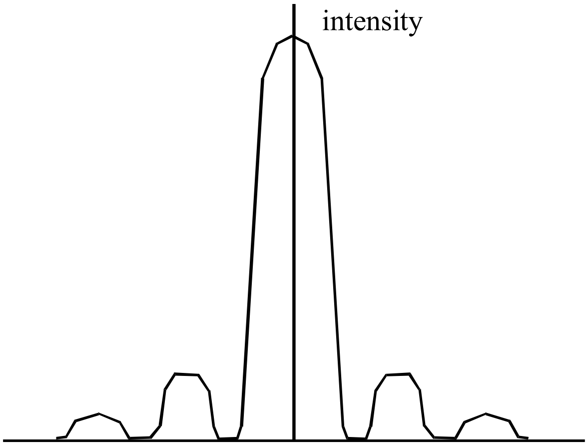
correct construction line(s) **(1)**

rays emerge parallel **(1)**

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

$\alpha = 5$ 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) $\left(\theta = \frac{\lambda}{d} \text{ gives}\right) \theta = \frac{6.0 \times 10^{-7}}{15 \times 10^{-2}} = 4.0 \times 10^{-6}$ rad **(1)**

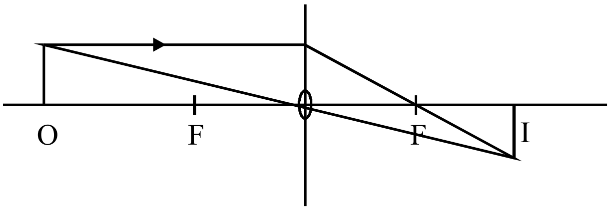
angular separation of Mizar 7.0×10^{-5} rad, can be resolved **(1)**

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

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

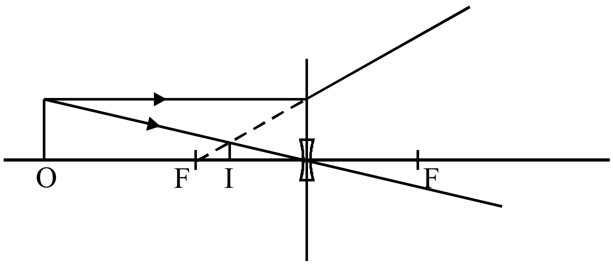
[16]

6. (a)



(object outside F)
ray parallel to axis through F **(1)**
ray through centre of lens to give image **(1)** 2

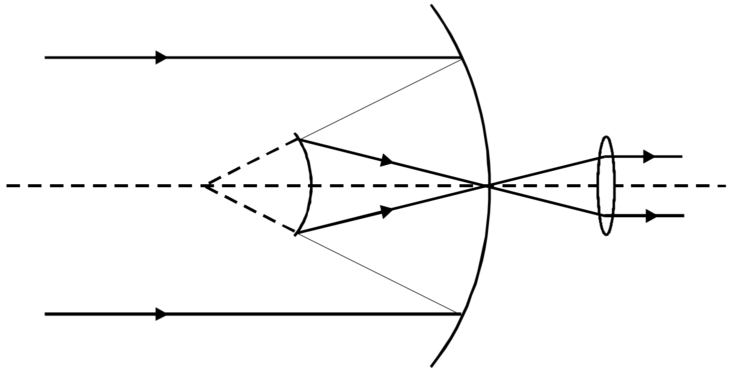
(b)



diverging ray appears to come from F **(1)**
ray through centre of lens to give image **(1)** 2

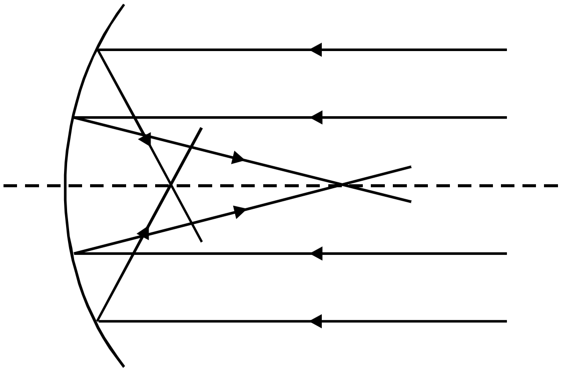
[4]

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]

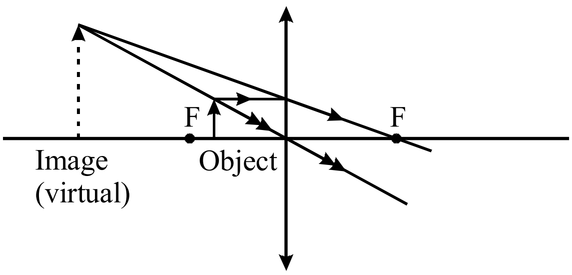
8. (i) (image is) virtual **(1)**

(ii) $f = \dfrac{1}{P} = \dfrac{1}{10} = 0.10$ m **(1)**

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

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

(iv)



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) $D = \frac{\lambda}{\theta} = \frac{5.7 \times 10^{-7}}{1.1 \times 10^{-5}}$ **(1)**

$= 5.2 \times 10^{-2}$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 $f_o \approx 3.5$ m and $f_e \approx 0.035$ m **(1)**

(ii) (use of $M = \frac{\alpha'}{\alpha}$ gives) $\alpha = \frac{4.0\times10^{-3}}{100} = 4.0\times10^{-5}$ (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)**
$= 6.5$ 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)**
$= 5.3 \times 10^{-7}$ rad **(1)** (5.26×10^{-7} 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 $m = \dfrac{f_o}{f_e}$ gives) $m = \dfrac{0.5}{0.1} = 5$ **(1)**

$\alpha = m\alpha = 5 \times \dfrac{3500}{380000} = 0.46$ rad **(1)**

[or $\alpha = \dfrac{3500}{380000}$

$\alpha' = 5\alpha = 0.46$ 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) $\left(\text{use of } P = \dfrac{1}{f} = 10, \text{and use of } \dfrac{1}{\text{f}} = \dfrac{1}{u} + \dfrac{1}{v} \text{ gives}\right) \dfrac{1}{u} = 10 - \dfrac{1}{0.25}$ **(1)**

$u = 0.17$ m **(1)** (0.167 m)

(ii) $\dfrac{1}{u} = 10 + \dfrac{1}{0.25}$ **(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) $\lambda\left(=\dfrac{c}{f}\right)=\dfrac{3.0\times10^{8}}{1.4\times10^{9}}$ = 0.21(4) m **(1)**

precision needed = λ/20 ≈ 0.01 m **(1)**

(ii) $\theta\left(=\dfrac{\lambda}{d}\right)=\dfrac{0.21}{305}$ = 6.9 × 10^{-4} rad **(1)** (6.88 × 10^{-4} rad)

(use of λ = 0.214 gives θ = 7.02 × 10^{-4} 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 $\theta=\dfrac{\lambda}{d}$ λ gives) $\dfrac{\theta_{reflector}}{\theta_{refractor}}=\dfrac{d_{refractor}}{d_{reflector}}$ **(1)**

$=\left(\dfrac{0.9}{1.52}\right)=0.59(2)$ **(1)**

(ii) use of, energy collected per sec ∝= area ∝= d^2 **(1)**

$\dfrac{P_{refl}}{P_{refr}}=\left(\dfrac{d_{refl}}{d_{refr}}\right)^2=\left(\dfrac{1.52}{0.9}\right)^2=2.85$ **(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)**
≥70%(for CCD) **(1)** 2

[6]

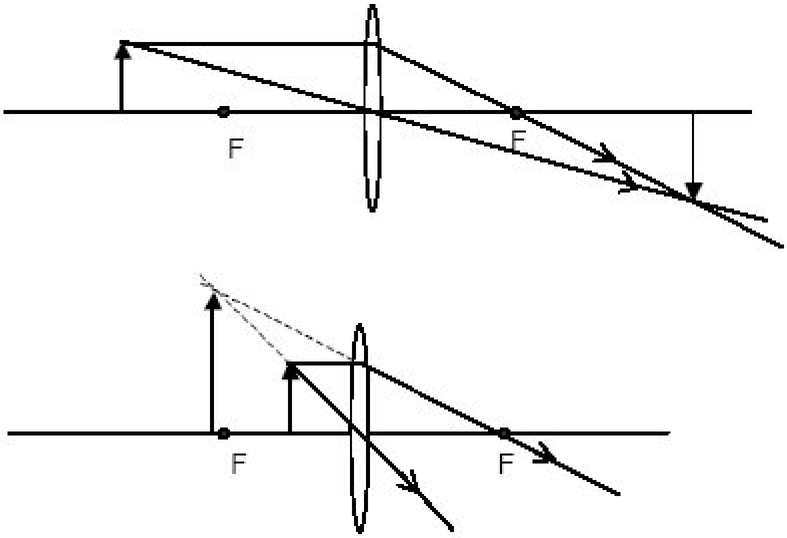
21. (a) for both diagrams:

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 = 0.17m

= 0.07m **(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]