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, $\begin{cases} \text{only occurs with lenses} \\ \text{none with mirror} \\ \text{no refraction} \end{cases}$ } any two **(1)(1)**

no spherical aberration of paraboloidal

[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) $\left(\lambda = \dfrac{c}{f} \; gives \right) \lambda_1 = \dfrac{3 \times 10^8}{7.5 \times 10^8} = 0.4 \text{ m and } \lambda_2 = \dfrac{3 \times 10^8}{1.5 \times 10^{10}} = 0.02\text{m}$ **(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 $\theta = \dfrac{\lambda}{d}$) of (res. power)$_{\text{radio}} <$ (res. power)$_{\text{opt}}$ **(1)**   2

[7]

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

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

(b) (i) <u>convex</u> 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 <u>wavelengths</u> **(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
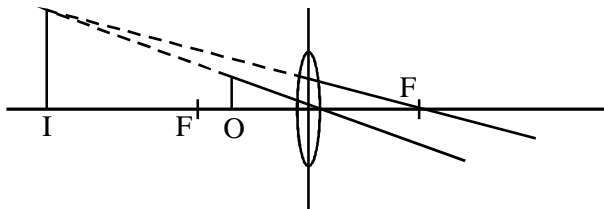
[15]

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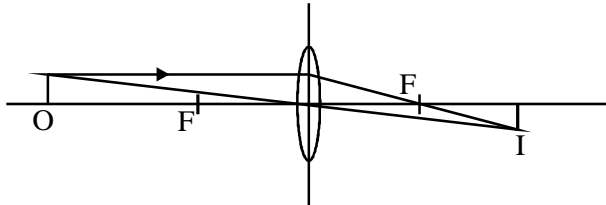
ray parallel to axis through *F* **(1)**
ray through centre of lens
to give image **(1)**

(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)
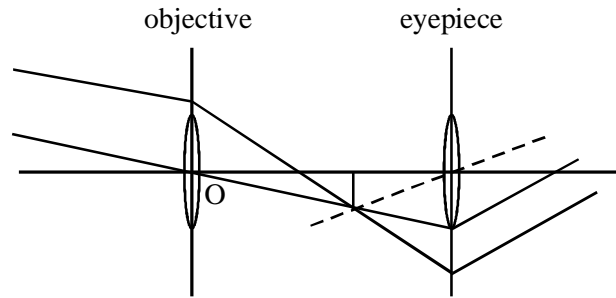
correct rays through objective **(1)**

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)
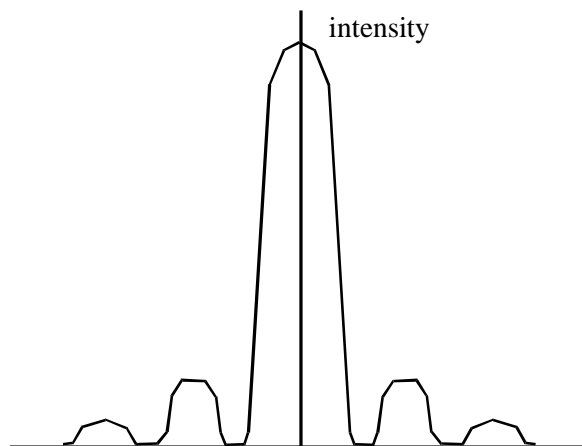
central maximum **(1)**

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

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

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

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

[16]

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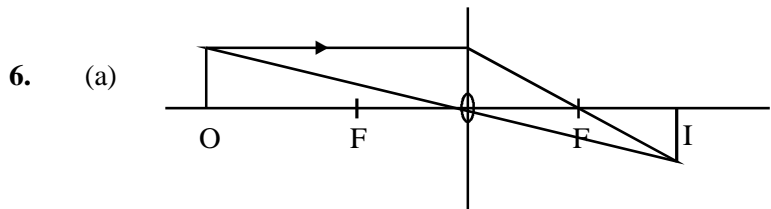
(object outside F)
ray parallel to axis through F **(1)**
ray through centre of lens to give image **(1)**   2

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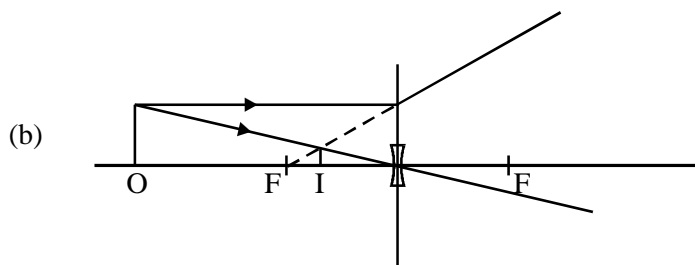
diverging ray appears to come from F **(1)**
ray through centre of lens to give image **(1)**   2

[4]

7. (a)
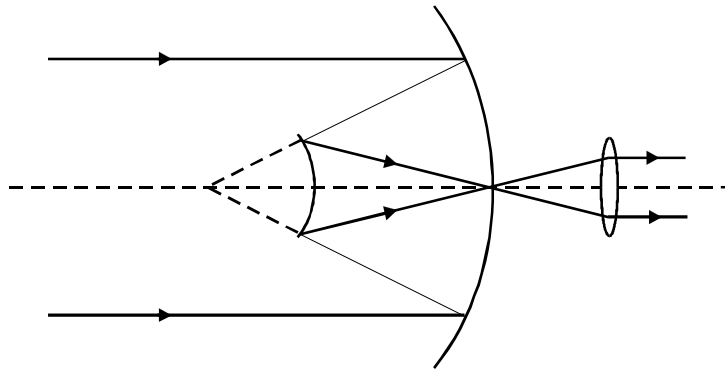
rays reflected at concave mirror **(1)**
rays reflected at convex mirror **(1)**
rays cross and emerge parallel from eye lens **(1)**   3

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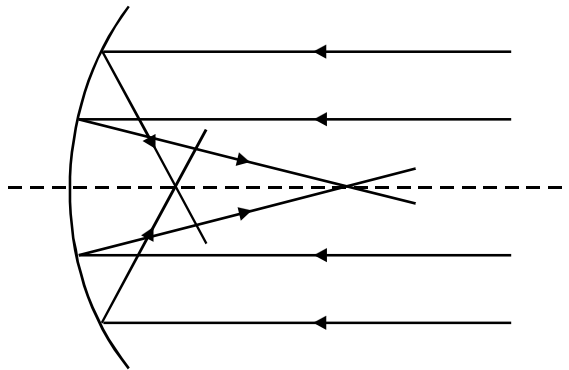
rays close to axis and far from axis to different focal points **(1)**
correct focal points **(1)**
use of parabolic mirror **(1)**

(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 $\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$ gives) $\dfrac{1}{0.1} = \dfrac{1}{u} - $ **(1)** $\dfrac{1}{0.25}$ **(1)**

(allow C.E. for value of f from (ii))

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

(iv)

Image (virtual)   Object

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)**
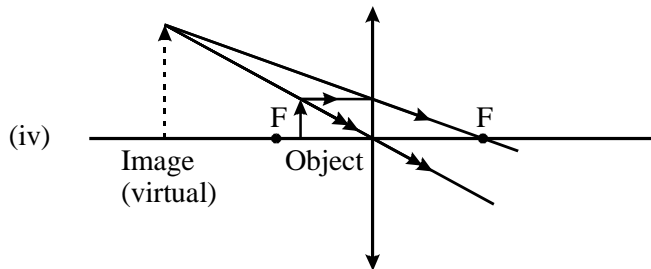two objects can just be resolved when central maximum
of one coincides with first minimum of other **(1)**   max 3

(b) $D = \dfrac{\lambda}{\theta} = \dfrac{5.7 \times 10^{-7}}{1.1 \times 10^{-5}}$ **(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 $M = \dfrac{\alpha'}{\alpha}$ gives) $\alpha = \dfrac{4.0 \times 10^{-3}}{100} = 4.0 \times 10^{-5}$ (rad) **(1)**

(use of $\alpha = \dfrac{D}{r}$ 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 $\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$ gives) $\dfrac{1}{0.12} = \dfrac{1}{0.08} + \dfrac{1}{v}$ **(1)**

$\left(\dfrac{1}{v} = -4.2 \right)$ and $v = -0.24$ m **(1)**

(ii)   magnified, upright, virtual (three correct **(1)** **(1)** two correct **(1)**)   max 3

[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 $P = \dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$ gives) $P = \dfrac{1}{0.17} + \dfrac{1}{1.62}$ **(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) $\theta\left(= \dfrac{\lambda}{d}\right) = \dfrac{2.0 \times 10^{-6}}{3.8}$ **(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 $m = \dfrac{f_o}{f_e}$ 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) $\left(\text{use of } P = \dfrac{1}{f} = 10, \text{and use of } \dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v} \text{ gives} \right) \dfrac{1}{u} = 10 - \dfrac{1}{0.25}$ **(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 $= \lambda/20 \approx 0.01$ m **(1)**

(ii) $\theta\left(=\dfrac{\lambda}{d}\right)=\dfrac{0.21}{305}=6.9\times10^{-4}$ rad **(1)** $(6.88\times10^{-4}$ rad)

(use of $\lambda = 0.214$ gives $\theta = 7.02\times10^{-4}$ 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 $\theta = \dfrac{\lambda}{d}\,\lambda$ 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 $\propto=$ area $\propto= d^2$ **(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)**
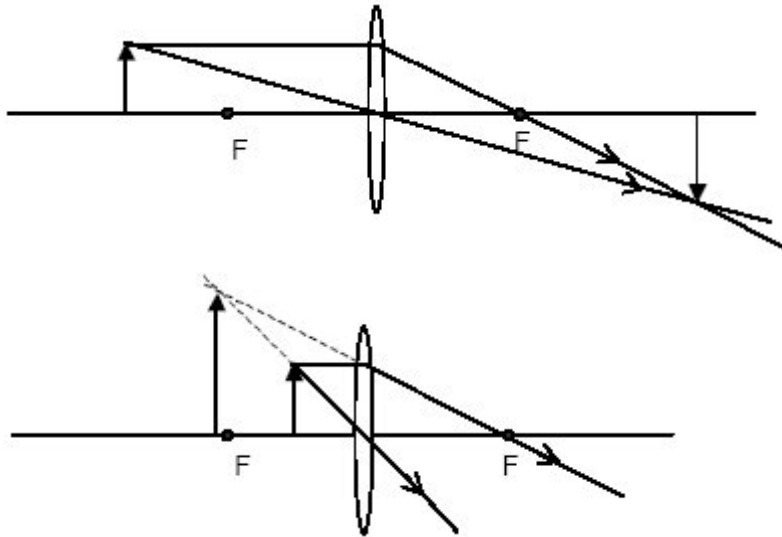$\geq 70\%$ (for   CCD) **(1)**   **2**

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]