1 **(a** incident ray in (more) dense medium)
angle of incidence greater than critical angle/42°) any 3 B1 × 3
no light refracted)
reflected with $i = r$)

(b) reflection at Q only, no further reflections B2
(allow B1 only, if there is one further reflection at lower surface)
(give B0 for more than one further reflection) **[Total: 5]**

2 **(a** refracts/bends/changes direction NOT curves
Ignore converges/reflection)
downwards/inwards/towards F_1/focal point/normal)
speed change/reduces on entering glass OR change of n) any 3 B1 × 3
OR change of density)
idea of meets surface at an angle/one part of wave hits surface first)
splits into colours)

(b) all 3 rays through F_1 M1
all refractions correct
and either all at lens centre line or all at both surfaces A1

(ii) straight line through F_1 and F_2 B1

(c) X between vertical line through F_1 and vertical line through F_2 B1

(ii) virtual)
upright)
enlarged) any 3 B2
same side (of lens as object)) - 1 e.e.o.o.
further from lens (than object))

[Total: 9]

3 **(a (i)** reduced B1

(ii) reduced B1

(b) $n = \frac{\text{speed in air/vacuum}}{\text{speed in medium/glass}}$ in any form B1

2.0/2.03 x 10^8 m/s B1

(c) reflection shown M1
angle correct, by eye A1

[Total: 6]

4 **(a** medium A because angle in air is bigger OR angle in A is smaller OR refracts / bends away from normal / angle of refraction greater than angle of incidence / total internal reflection only occurs in denser medium B1

(b) air: light travels faster in less dense medium OR air: air is less dense / rarer B1

(c) 42°–43° B1

(d) total internal reflection B1

(e) $n = \sin i / \sin r$ OR $n = \sin r / \sin i$ OR $1.49 = \sin i / \sin 35$ C1
(allow 1.49 or refractive index instead of n in any of above)
58.719° to at least 2 s.f. Allow 58.71° A1

(f) n = *speed in air* / *speed in medium* in any arrangement
OR $1.49 = 3.0 \times 10^8$ / speed in medium A C1
2.01343×10^8 m/s to at least 2 s.f. A1 [8]

5 **(a** 2 cm (by eye) vertical object somewhere between F_2 and lens
(condone no O, if clear) B1

(b) any two standard rays correctly drawn (no extrapolation needed) B1
correct rays extrapolated back to intersect B1
virtual image drawn at candidate's intersection of extrapolated rays
(condone no I, if clear) B1

[4]

6 **(a)** (for all rays, ignore any arrows, -1 for each incorrect extra ray)
correct ray through F_1 ± 1mm on axis)
)
correct ray through F_2 ± 1mm on axis) any 2 B1, B1
)
ray through lens centre ± 1mm on axis)
image drawn between his intersection and axis B1

(b) virtual upright/erect magnified/enlarged further (from lens) any 3 B1 × 3

[6]