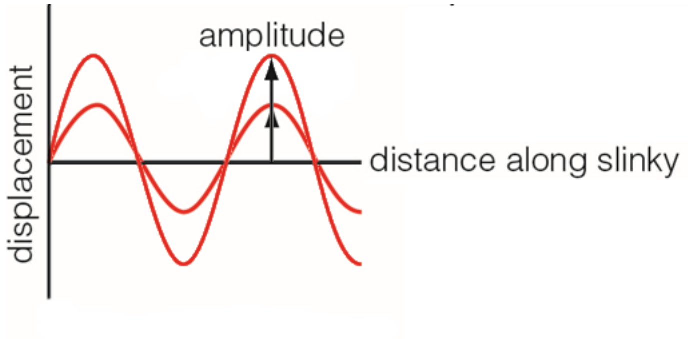
Page 70 Test yourself on prior knowledge

1



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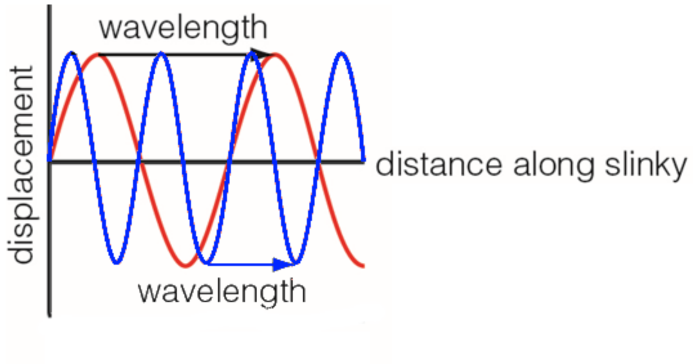


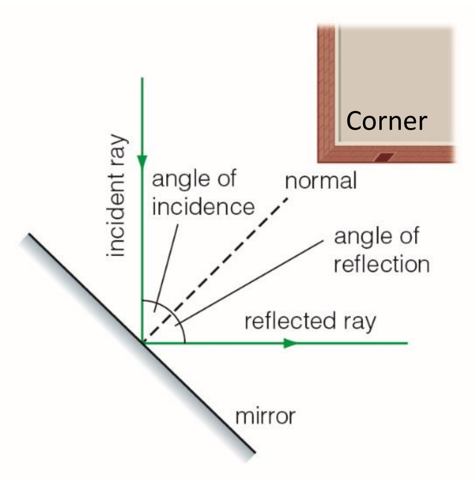
3 Similarity (examples): both involve a change of direction; both occur at a boundary.

Difference (examples): refraction involves a change of speed and reflection does not; reflected waves travel in the same material whereas on refraction waves travel into a different material, or the same material with different physical properties (e.g. water of different depths, solutions of different densities).

4 **a)** $v = f\lambda = 2\text{ m} \times 170\text{ Hz} = 340\text{ m s}^{-1}$

b) $\lambda = v/f = 1500\text{m s}^{-1} / 170\text{ Hz} = 8.8\text{ m}$

5



6 Similarities (examples): longitudinal and transverse waves both transfer energy/information without transferring material; both involve periodic oscillations (of a medium or field); both can be reflected, refracted, interfere and diffract.

Difference (example): the vibrations are perpendicular to direction of energy transfer in transverse wave and parallel to it in longitudinal waves; only transverse waves can be polarised.

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1 The knot moves vertically up from its equilibrium position to its maximum positive displacement (after 1/4 of a cycle), then down through the equilibrium position (after 1/2 a cycle) continuing down to its maximum negative displacement position (after 3/4 of a cycle) and back to the equilibrium position after one complete cycle.

2 a) $1/15000 = 6.67 \times 10^{-5}$ s

b) 0.03 s$/6.67 \times 10^{-5}$ s = 450 waves

3 a) $f = v/\lambda = 330$ m s^{-1}/3 m = 110 Hz

b) $\lambda = v/f = 1500$m s^{-1}/11 Hz = 13.6 m

4 a) 90° or $\pi/2$ radians

b) 270° or $3\pi/2$ radians

5 a) $\lambda/2$

b) $\lambda/6$

c) $\lambda/3$

6 a) Since T = 4s, each second represents ¼ cycle and therefore:

t = 1 s: displacement = 0 cm
t = 2 s: displacement = –3 cm
t = 3 s: displacement = 0 cm
t = 4 s: displacement = 3 cm

b) $y = A \sin(2\pi t/T) = 3\sin(2\pi \times 0.5/4) = 3\sin(\pi/4) = 2.12$ cm

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7 a) i) Lie the spring flat on the table, and move the end of the spring sideways, perpendicular to the length of the spring to show transverse waves.

ii) Lie the spring flat on the table, and move the end of the spring back and forth along the length of the spring to show longitudinal waves.

b) Transverse waves can be polarised but longitudinal waves cannot. To show light can be polarised (and is therefore a transverse wave) use polaroid filters. The intensity of light is reduced by a single filter and no light passes through crossed polaroids.

8 **a)** Microwaves are strongly absorbed by fat and water molecules making the molecules vibrate; this random vibrational energy is thermal energy in the food.

b) Information can be encoded into the microwaves by altering their amplitude or frequency. The micrrowaves can then travel through air, carrying information. (Microwaves which are used for communication are chosen so that they are not absorbed by the water in the atmosphere – they are of a different wavelength to the microwaves used in ovens.)

9 TV transmissions are usually carried by plane-polarised electromagnetic waves. The orientation of the aerial must match the wave's plane of polarisation (the direction in which the electrical field oscillates) for maximum intensity.

10 For example: in a polarising camera lens, and in sunglasses, the polarising filter is orientated to block horizontally polarised reflections from surfaces like water and snow so reducing glare (for safety in the case of sunglasses and allowing better photograph/to see into water in the case of cameras); in flat screen liquid crystal displays, polarising filters are used to allow selective transmission of light so allowing elements within the screen to be off or on.

11 **a)** **i)** $3\pi/2$ radians or 270°

ii) At these two points, the rock is moving in opposite directions (at the same speed).

b) The section of rock oscillates at right angles to the direction of wave progression. It moves down from its position of maximum displacement, through the equilibrium position, to a maximum negative displacement. It then moves upwards, back though the equilibrium position to the maximum positive displacement. The particle moves most rapidly when it moves through the equilibrium position, and is stationary at the two maximum displacements.

c) This means that the oscillations are only in one plane and tells us that the wave must be transverse, as only transverse waves are polarised.

d) **i)** $T = 1/f =$ 1/0.65 Hz = 1.54 s

ii) $\lambda = v/f = (4800 \text{ m s}^{-1})/(0.65 \text{ s}^{-1}) = 7400$ m or 7.4 km

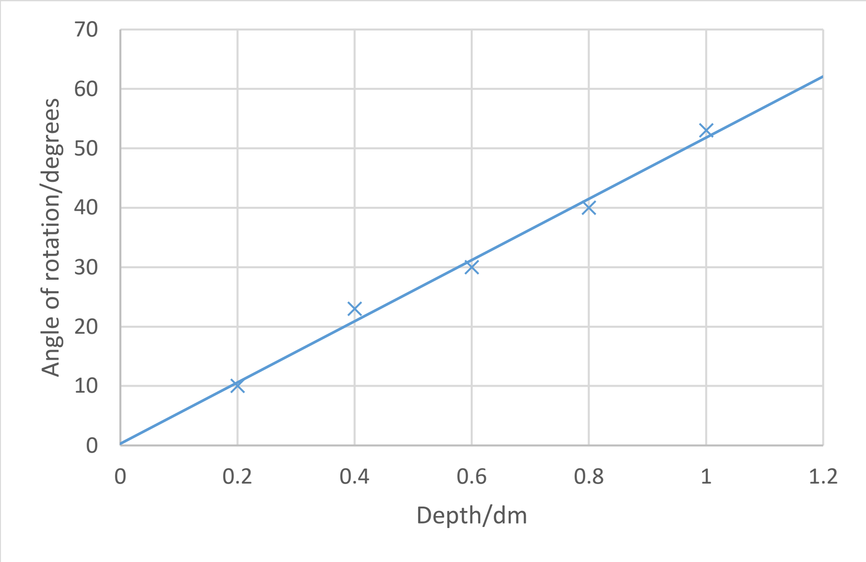
Page 82 Activity

Polarisation of glucose solution

1 Note that answers should be to the same number of decimal places as the readings.

Depth/cm	Mean angle of rotation/°
2	10
4	23
6	30
8	40
10	53

2 The results obey this relationship if a graph with the independent variable (depth) on the *x*-axis and the dependent variable (measured angle) on the *y*-axis is a straight line through the origin.



3 Specific angle of rotation is the gradient of the graph ≈ 52 °/dm
(Students who get an answer of e.g. 5.2 have not converted cm to dm.)

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12 a) $sin\, \theta_1 = {}_1n_2\, sin\, \theta_2 = 1.33\, sin\, 2\, 4 = 0.541$

θ_1 = 33°

b) Critical angle $= \sin^{-1}\frac{1}{1.33} = 49°$

13 a) $n_w \sin\theta_w = n_o \sin\theta_o$

So $\sin\theta_o = \frac{n_w \sin\theta_w}{n_o} = \frac{1.33 \sin 30}{1.52} = 0.4375$

So θ_o= 26°

b) $c_w = \frac{c}{n_w}$ and $c_o = \frac{c}{n_o}$

so $\frac{c_w}{c_o} = \frac{n_o}{n_w}$

and the ratio $c_w : c_o$ = 1.52 : 1.33 = 8 : 7

14 For red light, sin θ_r = sin 40°/1.509 = 0.4260
θ_r = 25.21°

For violet light, sin θ_v = sin 40°/1.521 = 0.4226
θ_v = 25.00 °

The difference in angle is 0.21°

15 a) Critical angle $= \sin^{-1}\frac{1}{2.4} = 25°$

b) This value is small so most of the light entering a diamond will totally internally reflected. To make a diamond sparkle, it is necessary for a jeweller to cut the diamond into a shape that concentrates light which has been totally internally reflected, directing it through visible surfaces (facets) in intense beams.

c) $\sin\theta_c = \frac{n_2}{n_1}$

$\sin\theta_c = \frac{1.33}{2.4}$ = 0.554

$\theta_c = 34°$

16 $n_w \sin\theta_w = n_g \sin\theta_g$ and $n_g \sin\theta_g = n_a \sin\theta_a$

$n_w \sin\theta_w = n_a \sin\theta_a$

$\sin\theta_a = 1.33 \times \sin 40°$

$\theta_a = 59°$

17 a) Transverse mechanical waves can only travel through a medium which 'springs back' – a taut rope for example. A liquid does not spring back like a rope. So only longitudinal pressure waves pass through the liquid outer core.

b) i) The waves bend towards the normal when they enter the outer core. This is like light entering glass from air. Waves bend towards the normal when they slow down.

ii) The waves are changing direction all the time that they travel deeper into the Earth; they are bending in the opposite direction to the example in (b) (i), so they must be speeding up.

c) $\frac{v_1}{v_2} = \frac{\sin\theta_1}{\sin\theta_2}$

$v_2 = \frac{\sin\theta_2}{\sin\theta_1} \times v_1$

$v_2 = \frac{\sin 23}{\sin 42} \times 12.5\ \mathrm{km\ s^{-1}} = 7.3\ \mathrm{km\ s^{-1}}$

d) ${}_1n_2 = \frac{\sin\theta_1}{\sin\theta_2}$

${}_1n_2 = \frac{\sin 23}{\sin 42} = 1.72 = \frac{1}{\sin\theta_c}$

$\theta_c = 36°$

This is shown in the diagram: waves travelling in the mantle that are incident on the outer core boundary at an angle of 90° are refracted into the core at this angle. Those travelling in the outer core are refracted into the mantle if they are incident on the boundary at less than this angle and only just pass through if the angle they make with the boundary is approximately equal to this angle.

e) $\lambda = \frac{v}{f} = \frac{12.5\ \mathrm{km\ s^{-1}}}{0.2\ \mathrm{Hz}} = 63\ \mathrm{km}$

f) Waves diffract around the edges of obstacles. Seismic waves have long wavelengths, which means they can be diffracted around the edge of the outer core and so reach the shadow zone.

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18 a) The light travels inside the core.
The cladding ensures light remains in the core; it controls the value of the critical angle and which wavelengths will travel through the fibre.

b) The material of the core should have low absorption; its refractive index should not vary much across the wavelengths of light that are to be used.
The cladding should have a lower refractive index than the core.

19 $\sin\theta_c = \frac{n_2}{n_1}$

$= \frac{1.52}{1.62}$

$= 0.938$

$\theta_c = 70°$

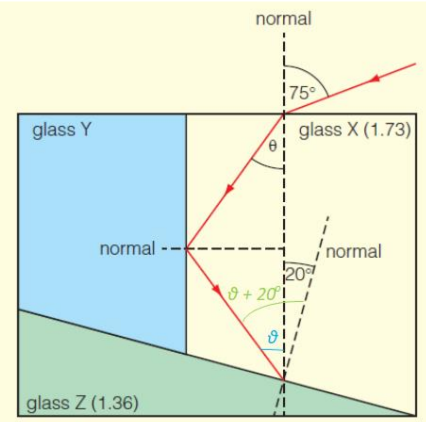
20 Modal dispersion and material dispersion both cause pulse broadening/spread out a sharp pulse.

Modal dispersion occurs because there is more than one path light can take through the optical fibre so parts of a signal travel different distances whereas material dispersion occurs because different frequencies of light have different refractive indices and travel through the fibre at different rates.

21 a) Reduce multipath dispersion by making the optic fibre core narrower (reduces the number of alternative routes through the fibre).

b) It is important to minimise pulse broadening to prevent individual pulses in a series from overlapping (this would make it hard to distinguish individual pulses).

22 a) The refractive index of the medium in which the light is travelling must be greater than that of the material on the other side of the boundary.
The light must strike the surface at an angle of incidence greater than the critical angle.



b) $v = \frac{c}{1.73} = \frac{3\times10^8}{1.73} = 1.73 \times 10^8\ \mathrm{m\ s^{-1}}$

c) $\sin\theta = \frac{\sin 75°}{1.73} = 0.558$
$\theta = 33.9°$

d) $\sin\theta_c = \frac{n_2}{n_1} = \frac{1.36}{1.73}$

$\theta_c = 52°$

e) The angle of incidence is $\theta + 20 = 54°$ (see diagram)

so the ray is totally internally reflected.

Pages 90-94 Practice questions

1 C

2 B

3 D

4 A

5 B

6 B

7 B

8 A

9 C

10 C

11 a) $T = 1/f$ = 1/50 Hz =0.02 s or 20 ms [1]

b) $2\pi/3$ [1]

c) $2\pi/3$ or 120 ° is one third of a cycle so the time difference is

$T/3 = 1/3 \times 20\text{ms} = 6.7$ ms [1]

12 a) wavelength = speed/frequency [1]

$\lambda = 3.33 \times 10^7 / 82 = 4.0 \times 10^5$ m [1]

b) TIf the distance between the dolphin and the submarine is s, the wave travels to the submarine and back to the dolphin, a distance of $2s$ [1]
distance = speed × time [1]
$2s = 1500 \times 100 \times 10^{-3} = 150$m
So the distance is 75 m [1]

c) Any 4 points from

- Radio waves travel much faster than sound waves underwater
- this means communications over long distances will be faster.
- Radio waves and sound waves travel different distances depending on how well they are absorbed in water (although a calculation is not possible, the answer may discuss how far a person can see and hear underwater)
- this will affect the distance over which communication is possible.
- The ultrasound frequency is much higher than the radio wave frequency.
- Radio waves can be polarised; sound waves cannot.

13 a) Total internal reflection [1]

b) The angle from which it is viewed. [1]

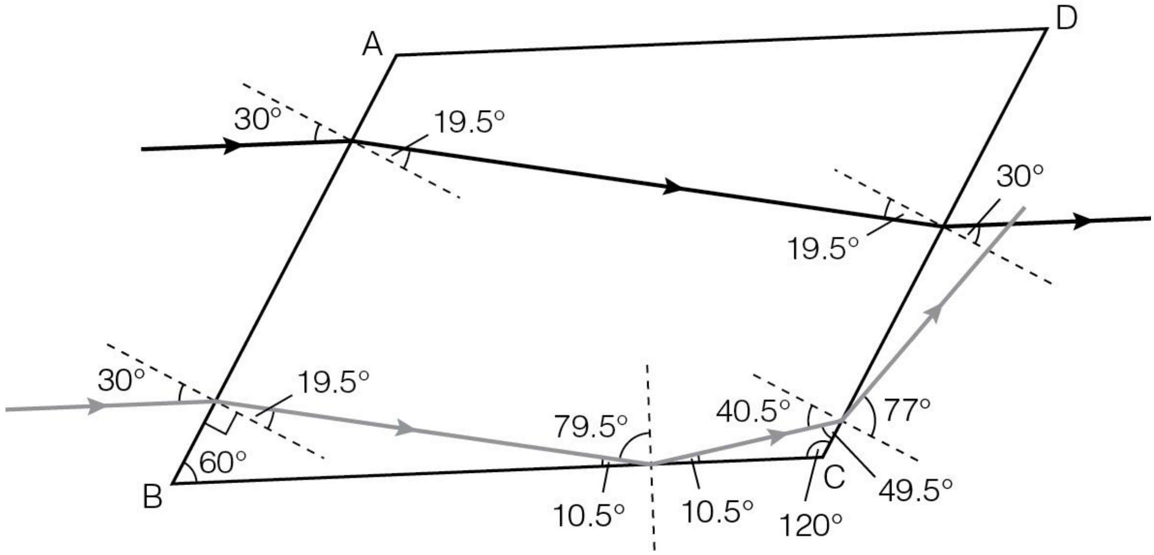
Any three from:

- When viewed along the normal to the large surface (or at an angle close to it)
- light reaching the viewer will have passed through the glass, so the glass looks transparent.
- As the person looking at the sculpture moves around so that light reaching their eyes is travelling closer to the plane of the surface
- light reaching the viewer will have been internally reflected before leaving the glass (because the glass is relatively thin and the sides are not parallel)
- and the sculpture appears opaque/the structure can be seen.

14 The light is refracted towards the normal on entering the prism through face *AB* (see diagram):
sin 30° = 1.5 sinθ_{glass}

θ_{glass} = 19.5°

If point of entry is such that this then hits the parallel face, *CD*, the angle of incidence is 19.5°and it will be refracted back out, again at an angle of 30° (by symmetry, no calculation required).



If, instead, the refracted beam hits *BC*, the angle of incidence will be
90 – (180 – (60 + 90 + 19.5)) = 79.5° (see diagram).

The critical angle for this glass is given by $\sin^{-1}\frac{1}{1.5} = 42°$

so the beam will be internally reflected.

If it then hits *CD*, the angle of incidence is
90 – (180 – (120 + 10.5)) = 40.5° (see diagram).

This is less than the critical angle, so it will be refracted back out:

1.5 sin 40.5 = sin θ_{air}

θ_{air} = 77°

15 a) total internal reflection [1]

b) sin $\theta_c = \frac{n_2}{n_1}$ [1]

sin $\theta_c = \frac{1.50}{1.60}$ = 0.9375 [1]

θ_c = 69.6° [1]

c) i) Pulse broadening is the spreading out of pulses travelling through an optical fibre, [1]
so each pulse lasts for a longer time when it is received than when it is transmitted [1].

ii) A multimode optical fibre is wider than a single mode optical fibre so there are more paths for rays to take [1]
and there is modal dispersion as well as material dispersion. [1]

iii) Pulse broadening means that adjacent pulses may overlap [1]
and so it limits the frequency of pulses in a signal (and therefore the bandwidth). [1]

d) Any 5 from: [5]

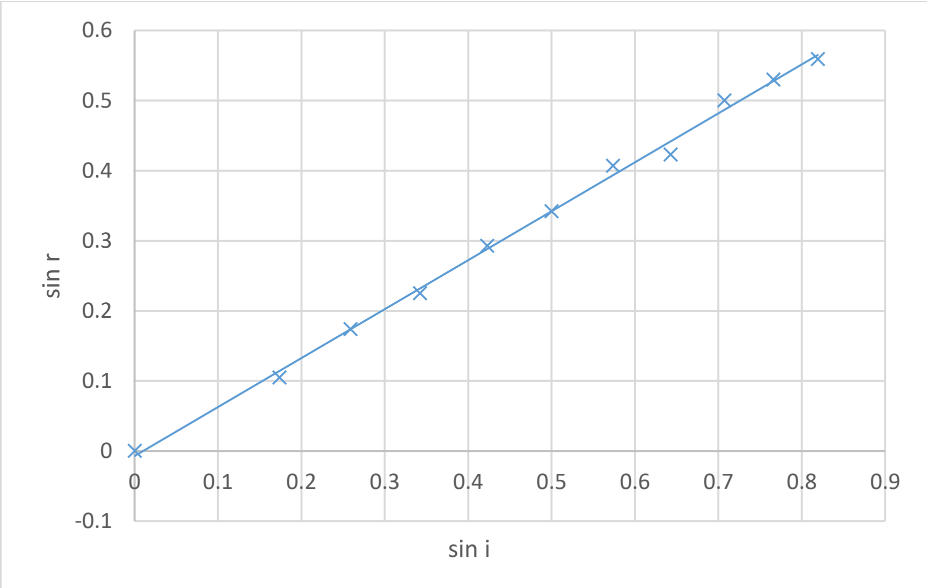
- The material for the core must be very pure
- to reduce scattering of light from imperfections;
- it must not absorb the frequencies of light used in the fibre
- so the signal can reach the end of the fibre;
- it must have a higher refractive index than the cladding
- so internal reflection occurs;
- the refractive index for each of the frequencies transmitted should be similar
- to reduce modal dispersion.

16 a) The number of decimal places in the raw data is determined by the measuring instrument used. In this instance, the accuracy of the instrument used to measure angle (protractor) remains constant across the range. [1]

b) The calculated data has more significant figures than the raw data which implies better accuracy than the instrument can provide. [1]

c) Values calculated and tabulated [1]
with sensible number of decimal places [1]
scales so graph fills paper and sensible divisions [1]
points plotted accurately [1]
line of best fit drawn [1]

Angle of incidence/°	Angle of refraction/°	sin *i*	sin *r*
0	0	0	0
10	6	0.17	0.10
15	10	0.26	0.17
20	13	0.34	0.22
25	17	0.42	0.29
30	20	0.50	0.34
35	24	0.57	0.41
40	25	0.64	0.42
45	30	0.71	0.50
50	32	0.77	0.53
55	34	0.82	0.56



d) From Snell's law: $n = \frac{\sin i}{\sin r} \Rightarrow \sin r = \frac{\sin i}{n}$
so gradient of graph = 1/n [1]

Choice of points on line to calculate gradient (wide spaced, not measured values) [1]

Gradient calculated to sensible number of d.p (should come out around 0.70) [1]

Refractive index consistent with gradient and sensible number of d.p. (1.4–1.5) [1]

e) The maximum uncertainty is half the maximum range of repeated readings [1]
i.e. 1.5 (half of 3 which is the range for the readings for 25 degrees) [1]

f) Any two of the following or similar sensible answers
one mark for problem, one mark for matching solution [4]

- the ray may not be bright enough to see clearly so use black out blinds
- hard to draw lines accurately/the ray spreads out so use pencil dots and a ruler to indicate the path of the ray
- protractors may be poor quality so draw the lines first before measuring and use a transparent protractor with sharp markings.

g) θ ranges from 20.5 – 19.5.
The values of sin θ range between 0.35 – 0.33 so the range of sin θ is 0.02.

The uncertainty is half the range, or 0.1.
The % uncertainty is uncertainty / average value × 100% = 0.01 /0.34 × 100% = 3.0%

17 a) $v = s / t$ [1]

$t = s / v = 550 \times 10^3 / 3 \times 10^8$ [1]

1.8×10^{-3} s [1]

b) Microwave radiation [1]
Any suitable reason e.g. can pass through the atmosphere; it can carry information; it can be sent as a narrow beam as it has a short wavelength and there is little diffraction. [1]

c) Our atmosphere absorbs gamma rays [1]
so they will not reach an earth-based satellite; [1]
the rays travel very long distances across the Universe without losing energy so the telescope does not have to be close to the source of gamma rays.

d) Long wavelengths can pass through air so no need to put above the atmosphere; [1]
the telescope is too heavy/large to launch into space [1]

Page 94 Stretch and challenge

18 a) $\theta_c = \sin^{-1}(n_{cl}/n_{co})$

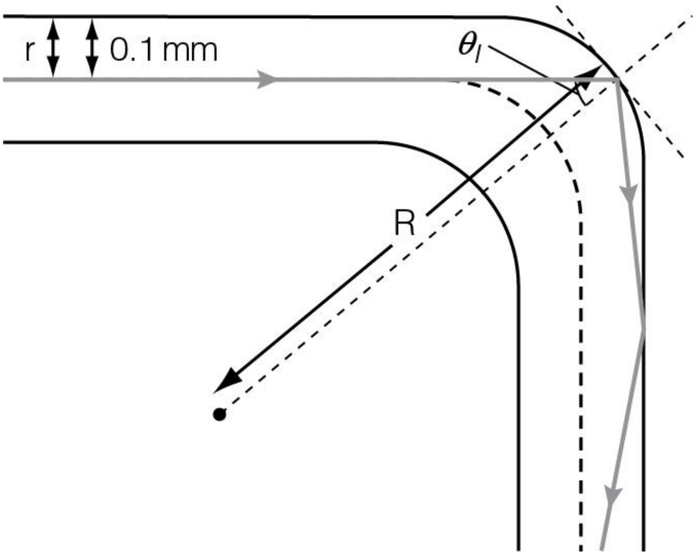
b) For light of wavelength 400 nm $\theta_{c400} = \sin^{-1}1.470/1.635 = \sin^{-1}0.8991 = 64.04°$

for light of wavelength 700 nm $\theta_{c700} = \sin^{-1}1.456/1.602 = \sin^{-1}0.9089 = 65.34°$

Difference in critical angle is 1.30°

c) All light remains inside the fibre when it is incident on the outer face at an angle greater than the critical angle for all wavelengths: $\theta_I > \theta_c$

d) If $\theta_I > \theta_{c700}$ then $\theta_I > \theta_{c400}$ since $\theta_{c700} > \theta_{c400}$
So, in this case, for light of all wavelengths to remain in the fibre $\theta_I > \theta_{c700}$



From the diagram, $\sin\theta_i = R/(R + r)$ where r is the radius of the fibre = 0.2 mm / 2 = 0.1 mm

Rearranging, $(R + r)\sin\theta_i = R$

So $R = r\sin\theta_i\ /(1 - \sin\theta_i)$

In the limiting case when $\theta_I = \theta_{c700}$

$R = 0.1 \times 0.9089\ /\ (1 - 0.9089)$

$R = 1.0$ mm

(This is the minimum value of R as curves of greater radius will more closely resemble a straight fibre.)

e) Fibres used in an endoscope must be able to bend through parts of the body. The cladding material increases the critical angle for light travelling in the core, so reducing the smallest value of coil radius.
(Alternative answer: cladding material can protect the core of the optic fibre when it is inside the body.)

19 a) Rearranging: $c^2\mu/l = k$

Substituting dimensions for μ, l and c gives dimensions for

$[k] = (LT^{-1})^2 \times ML^{-1} \times L^{-1} = MT^{-2}$

b) $\mu = 0.6$ kg / 3m = 0.2 kg m^{-1}
$k = 9$ N / 3 m = 3 Nm^{-1}

Using $c = \sqrt{(kl/\mu)}$

gives $c = \sqrt{(3 \times 3 / 0.2)} = 6.7$ ms^{-1}

c) The spring constant, k, does not change and μ is inversely proportional to l.
kl/μ is therefore proportional to l^2 which means c is proportional to l.

time = speed / distance

Doubling the length doubles both the speed of the wave and the distance it travels and so does not affect the time taken for the wave to travel along the spring.