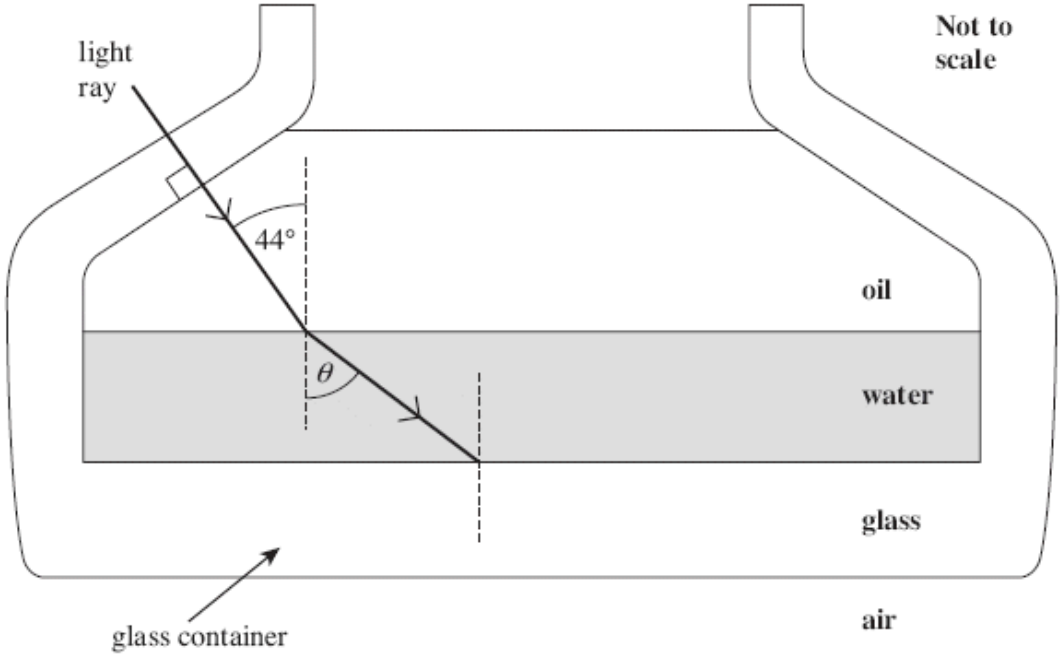
Q1. The figure below shows a layer of oil that is floating on water in a glass container. A ray of light in the oil is incident at an angle of 44° on the water surface and refracts.



The refractive indices of the materials are as follows.

refractive index of oil = 1.47
refractive index of water = 1.33
refractive index of the glass = 1.47

(a) Show that the angle of refraction θ in the figure above is about 50°.

(2)

(b) The oil and the glass have the same refractive index. On the figure above, draw the path of the light ray after it strikes the boundary between the water and the glass and enters the glass. Show the value of the angle of refraction in the glass.

(2)

(c) Explain why the total internal reflection will not occur when the ray travels from water to glass.

.....

.....

.....

(1)

(d) Calculate the critical angle for the boundary between the glass and air.

answer = ... degrees

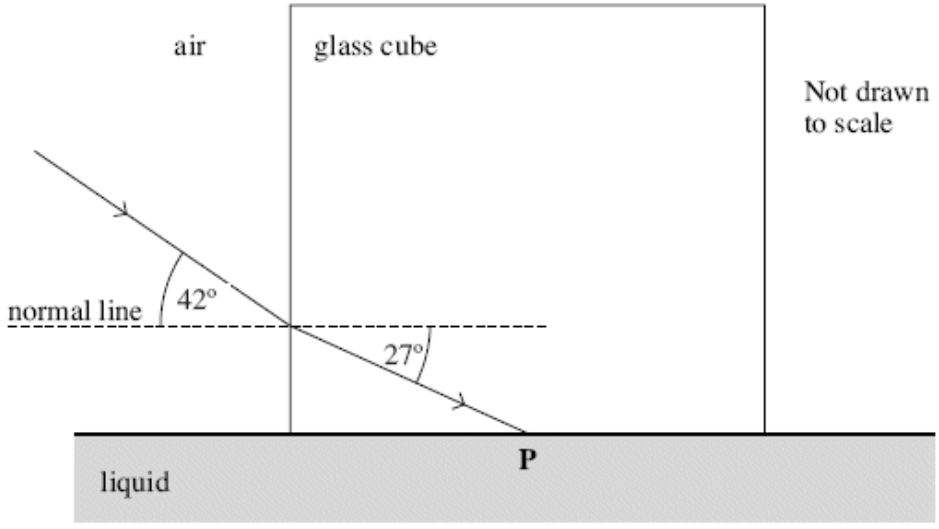
(2)

(e) On the figure above, complete the path of the ray after it strikes the boundary between the glass and air.

(2)

(Total 9 marks)

Q2. A glass cube is held in contact with a liquid and a light ray is directed at a vertical face of the cube. The angle of incidence at the vertical face is then decreased to 42° as shown in the figure below. At this point the angle of refraction is 27° and the ray is totally internally reflected at **P** for the first time.



(a) Complete the figure above to show the path of the ray beyond **P** until it returns to air.

(3)

(b) Show that the refractive index of the glass is about 1. 5.

(2)

(c) Calculate the critical angle for the glass-liquid boundary.

answer = ... degrees

(1)

(d) Calculate the refractive index of the liquid.

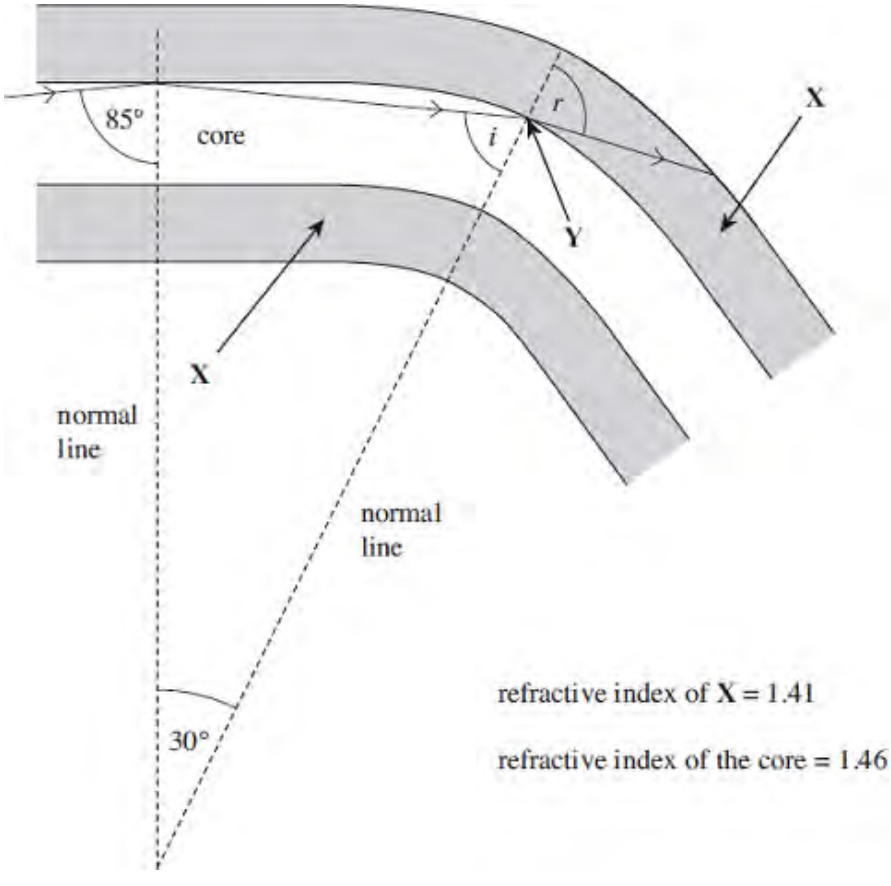
answer = ...

(2)

(Total 8 marks)

Q3. **Figure 1** shows a cross-section through an optical fibre used for communications.

Figure 1



(a) (i) Name the part of the fibre labelled **X**.

.....

(1)

(ii) Calculate the critical angle for the boundary between the core and **X**.

answer = ...degrees

(2)

(b) (i) The ray leaves the core at **Y**. At this point the fibre has been bent through an angle of 30° as shown in **Figure 1**.

Calculate the value of the angle *i*.

answer = ...degrees

(1)

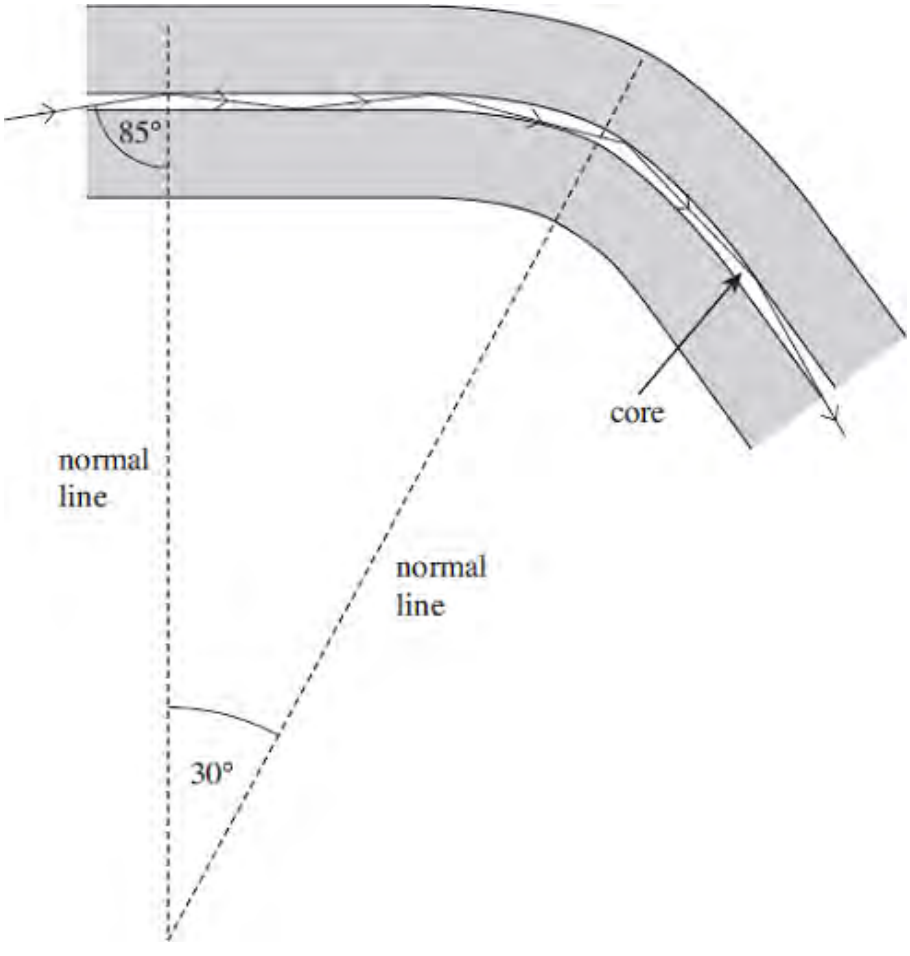
(ii) Calculate the angle *r*.

answer = ...degrees

(2)

(c) The core of another fibre is made with a smaller diameter than the first, as shown in **Figure 2**. The curvature is the same and the path of a ray of light is shown.

Figure 2



(c) State and explain **one** advantage associated with a smaller diameter core.

.....

.....

.....

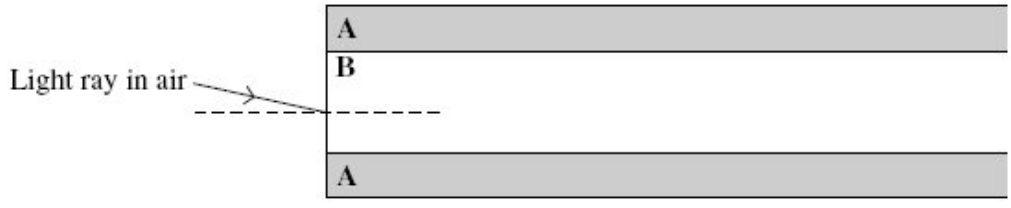
.....

.....

(2)

(Total 8 marks)

Q4. The diagram below shows a cross-section through a step index optical fibre.



(a) (i) Name the part **A** and **B** of the fibre

A	
B	

(1)

(ii) On the diagram above, draw the path of the ray of light through the fibre. Assume the light ray undergoes *total internal reflection* at the boundary between **A** and **B**.

(2)

(b) Calculate the critical angle for the boundary between **A** and **B**.
Give your answer to an appropriate number of significant figures.

The refractive index of part **A** = 1.46
The refractive index of part **B** = 1.48

answer = ... degrees

(2)

(c) State and explain **one** reason why part **B** of the optical fibre is made as narrow as possible.

.....

.....

.....

.....

(2)

(d) State **one** application of optical fibres and explain how this has benefited society.

Application

.....

.....

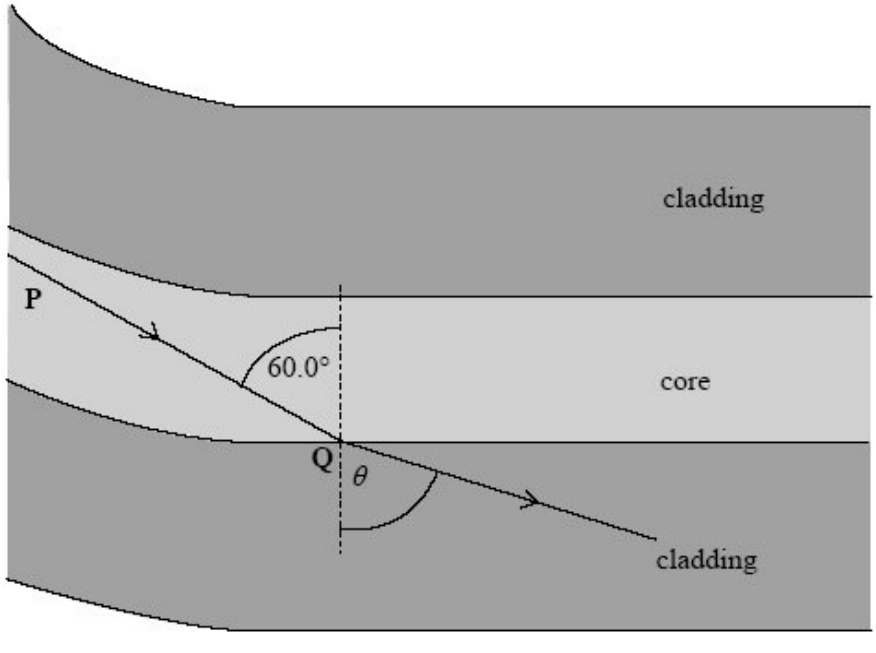
Benefit

.....

.....

(2)
(Total 9 marks)

Q5. An optical fibre used for communications has a core of refractive index 1.55 which is surrounded by cladding of refractive index 1.45.



(a) The diagram above shows a light ray **P** inside the core of the fibre. The light ray strikes the core-cladding boundary at **Q** at an angle of incidence of 60.0°.

(i) Calculate the critical angle of the core-cladding boundary.

answer ..... degrees

(3)

(ii) State why the light ray enters the cladding at **Q**.

.....

.....

(1)

(iii) Calculate the angle of refraction, θ, at **Q**.

answer ..... degrees

(3)

(b) Explain why optical fibres used for communications need to have cladding.

.....

.....

.....

.....

.....

.....

(2)

(Total 9 marks)

Q6. (a) The speed of light is given by

$$c = f\lambda$$

State how each of these quantities will change, if at all, when light travels from air to glass.

c .....

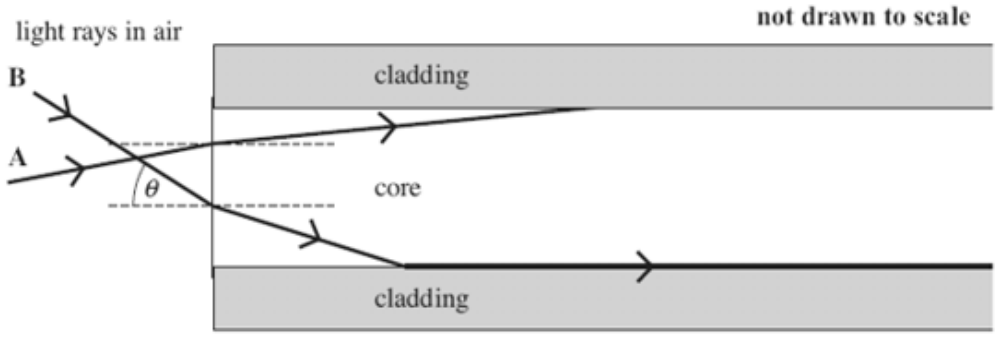
f .....

λ .....

(3)

Figure 1 shows a side view of a step index optical fibre.

Figure 1



(b) Ray **A** enters the end of the fibre and then undergoes total internal reflection.

On **Figure 1** complete the path of this ray along the fibre.

(2)

(c) (i) The speed of light in the core is 2.04×10^8 ms^{-1}. Show that the refractive index of the core is 1.47.

(2)

(ii) Show that the critical angle at the boundary between the core and the cladding is about 80°.

refractive index of the cladding = 1.45

(2)

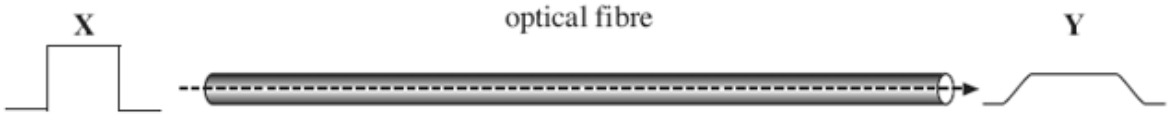
(d) Ray **B** enters the end of the fibre and refracts along the core-cladding boundary. Calculate the angle of incidence, θ, of this ray at the point of entry to the fibre.

answer = ... degrees

(3)

(e) **Figure 2** shows a pulse of monochromatic light (labelled **X**) that is transmitted a significant distance along the fibre. The shape of the pulse after travelling along the fibre is labelled **Y**. Explain why the pulse at **Y** has a lower amplitude and is longer than it is at **X**.

Figure 2



.....

.....

.....

.....

(2)
(Total 14 marks)

Q7. (a) State and explain **two** physical properties of the light produced by a laser which makes it different from the light produced by a filament lamp.

Property 1 .....

.....

.....

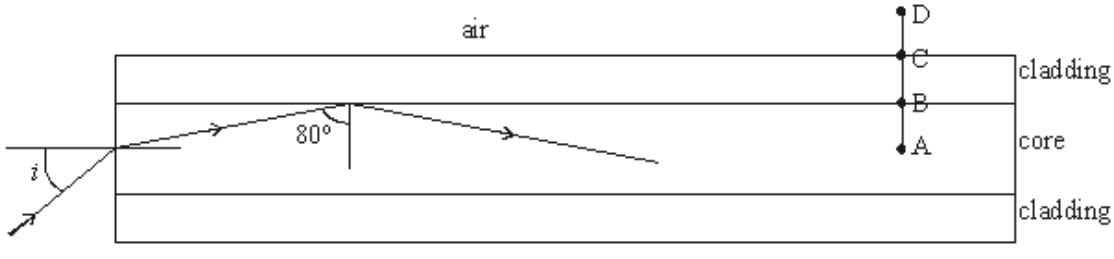
Property 2 .....

.....

.....

(4)

(b) The diagram below shows a cross-section through an optical fibre used for transmitting information. A laser beam, carrying digital data, is incident on the end of the core of the fibre at an angle of incidence *i*.
The core is made from glass of refractive index 1.5.



(i) Complete the graph below to show how the refractive index changes with radial distance along the line ABCD in the diagram, above.

(ii) Calculate the value of the angle of incidence, *i*, shown in the diagram.

Angle of incidence, *i* .....

(iii) Explain how the glass cladding around the optical fibre's core improves the security of data being transmitted through it and give a reason why this is important.

.....

.....

.....

(8)

(Total 12 marks)

M1. (a) $\sin\theta = \frac{1.47 \sin 44}{1.33}$ or $1.33 \sin\theta = 1.47 \sin 44$ or $\sin^{-1} 0.768$ **(1)**

$\theta = 50.15, 50.2, 50.35$ (°) **(1)**

answer seen to > 2 sf

2

(b) refracts towards normal **(1)** 44° shown **(1)**

2

(c) (TIR) only when ray travels from higher *n* to lower *n* **or** (water to glass) is lower *n* to higher *n* **(1)**

do not allow 'density', allow 'optical density', n or refractive index only

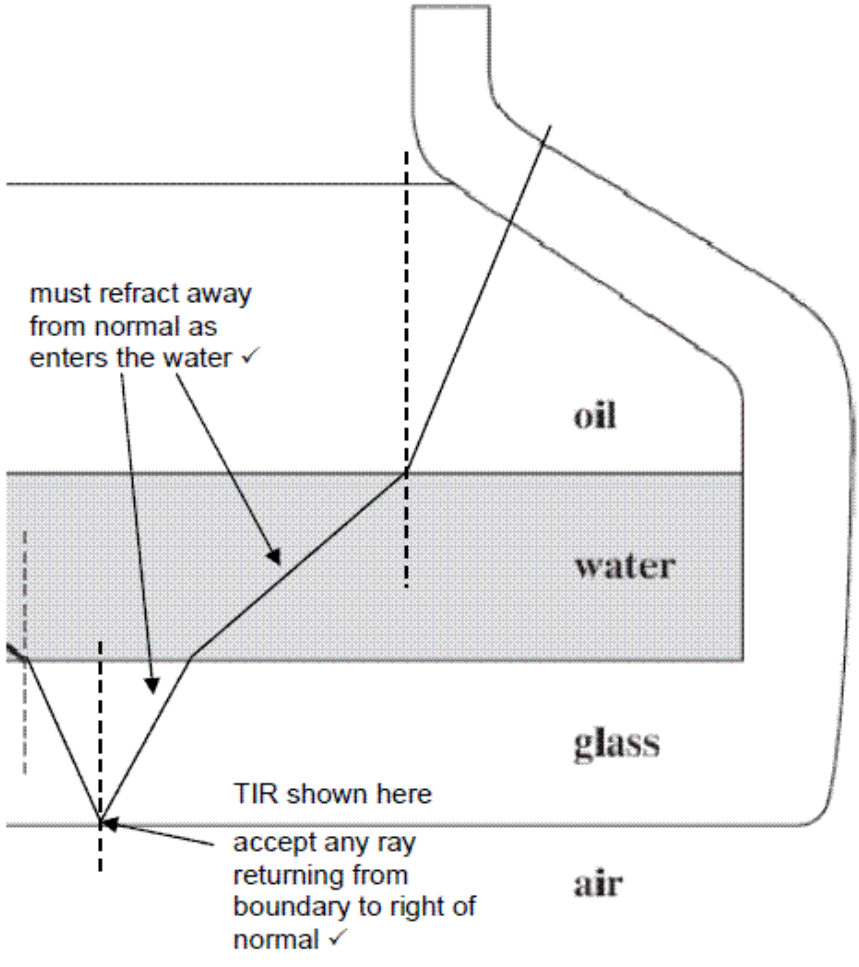
1

(d) $\sin\theta_c = \frac{1}{1.47}$ or $1.47 \sin\theta_c = (1 \times) \sin 90$ **(1)**

$\theta_c = 42.86$ (= 43.0(°)) **(1)**

2

(e)



2

[9]

M2. (a) reflects at correct angle by eye (use top of '27' and bottom of '42' as a guide) **or 27**° or **63**° correctly marked **(1)**

refracts away from normal at glass/air **(1)**

symmetrical by eye or refracted angle (42°) correctly marked and at least one normal line added **(1)**

3

(b) $(n_g) = \frac{\sin 42}{\sin 27}$ **(1)** DNA 42/27 = 1.56

= 1.47 (1.474) 3 sf shown **(1)**

2

(c) 63 (°) **(1)**

allow 62 to 62.99 ***with*** *reasoning, allow 'slightly less than 63' without reason given*

1

(d) $\left(\frac{n_l}{n_g} = \frac{\sin 63}{\sin 90}\right) n_l$ = 1.474 sin (c) **(1)** or use of n = 1.5

= 1.3(1) or 1.34 if n = 1.5 used **(1)**

2

[8]

M3. (a) (i) cladding ✓

1

(ii) $\sin \theta_c = 1.41/1.46$ ✓

$\theta_c = 75.0$ (°) (74.96) ✓

2

(b) (i) 65 (degrees) ✓

1

(ii) 1.46 sin 65 = 1.41 sin r **or** sin r = 0.93845 ✓ ecf bi

r = 70 ✓ (degrees) (69.79) ecf bi

2

(c) Two from:

- less light is lost
- better quality signal / less distortion
- increased probability of TIR
- Less change of angle between each reflection
- reflects more times (in a given length of fibre) keeping (incident) angle large(r than critical angle)
- (angle of incidence is) less likely to fall below the critical angle
- less refraction out of the core
- improved data transfer / information / data / signal carried quicker
- less multipath dispersion (smearing / overlap of pulses)

✓ ✓

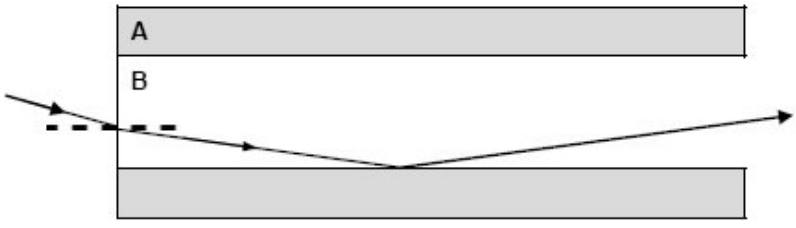
2

[8]

M4. (a) (i) A: **cladding** + B: **core (1)**

1

(ii)



refraction towards the normal line **(1)**

continuous lines + strikes boundary + TIR correct angles by eye + maximum 2 TIRs **(1)**

2

(b) $\left(\sin\theta_c = \frac{n_2}{n_1}\right)$ or = 0.9865 **(1)**

80.6 or 80.8 or 81 (°) only **(1)**

2

(c) to reduce **multipath** or **multimode dispersion (1)**

(which would cause) light travelling at different angles to arrive at different times/pulse broadening/merging of adjacent pulses/'smearing'/ poor resolution/lower transmission rate/lower bandwidth/less distance between regenerators **(1)**

or to prevent light/data/signal loss (from core or fibre) **(1)**

(which would cause) signal to get weaker/attenuation/crossover/data to be less secure **(1)**

2

(d) correct application **(1)** (endoscope, cytoscope, arthroscope etc, communications etc)

linked significant benefit stated eg improve medical diagnosis/improve transmission of data/high speed internet **(1)**

2

[9]

M5. (a) (i) (using $n_1 \sin \theta_1 = n_2 \sin \theta_2$ or $\sin \theta_c = n_2/n_1$ gives)

correct substitution in either equation (eg 1.55 sin c = 1.45 (sin 90) or sin c = 1.45/1.55) **(1)**

= 0.9355 (accept less sf) **(1)**
c = 69.3(°) **(1)** (accept 69.4°, 69° **or** 70°)

(ii) the angle (of incidence) is less than the **critical angle** or values quoted **(1)**

(iii) (using $n_1 \sin \theta_1 = n_2 \sin \theta_2$ gives)

1.55 sin 60 = 1.45 sin θ **(1)**

(sin θ = 1.55 sin 60/1.45 =) 0.9258 or 0.926 or 0.93 **(1)**

θ = 67.8° **(1)** (accept 68° **or** 68.4)

7

(b) any **two** from:

keeps signals secure **(1)**

maintains quality/reduces pulse broadening/smearing (owtte) **(1)**

it keeps (most) light rays in (the core due to total internal reflection at the cladding-core boundary) **(1)**

it prevents scratching **of the core (1)**

(keeps core away from adjacent fibre cores) so helps to prevent crossover of **information/signal/data** to **other** fibres **(1)**

cladding provides (tensile) strength for fibre/prevents breakage **(1)**

given that the core needs to be very thin **(1)**

max 2

[9]

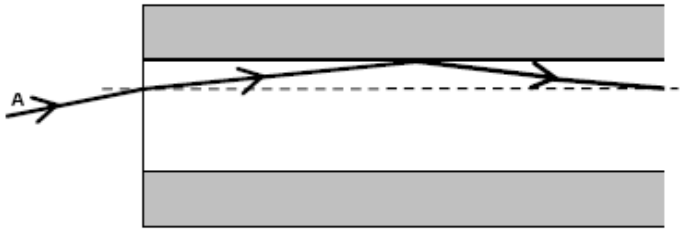
M6. (a) decrease ✓

constant ✓

decrease ✓

3

(b)



straight ray (ignore arrow) reflecting to the right ✓

reflected angle = incident angle ✓

(accept correct angle labels if reflected angle is outside tolerance)

2

(c) (i) ($n = \frac{c}{c_s}$) use of 3 ($\times 10^8$) ✓ = $\frac{300(\times 10^8)}{2.04(\times 10^8)}$ = 1.47 ✓ (1.4706)

(must see 3 sf or more)

2

(ii) $\sin \theta_c = \frac{1.45}{1.47(06)}$ or correct substitution in un-rearranged formula ✓

θ_c = 80.4 ✓ (80.401) (80.3 to 80.54) (≈ 80°) must see 3 sf or more

2

(d) angle of refraction = 180 – 90 – 80.4 = 9.6° ✓

$\sin\theta$ = 147(06) sin 9.6 ✓ = 0.25 ecf from first mark

θ = 14 (= 14.194°) ✓ ecf from first mark

range **13 to 15°** due to use of rounded values

3

(e) (reduced amplitude) due to absorption/energy loss
(within the fibre)/attenuation/scattering (by the medium)
/loss from fibre ✓

(pulse broadening caused by) multi-path (modal) dispersion
/different rays/modes propagating at different angles/non
a ial ray take longer time to travel ame di tance along fibre
as axial rays ✓

2

[14]

M7. (a) **property (of laser light)** **explanation**

monochromatic	waves of single frequency/wavelength
collimated	produces an approximately parallel beam
coherent	waves produced are in constant phase
polarised	vibrations in 1 plane only

two correct properties **(1)(1)**

each correct explanation **(1)(1)**
(if explanation contradicts property, no mark for explanation)

4

(b) (i) stepped graph: n = 1.5 A to B **(1)**

n lower and constant between 1.5 and 1.0 B to C **(1)**

n constant at 1.0: C to D **(1)**

(ii) $1.5 = \frac{\sin i}{\sin 10}$ **(1)** i = 15(.1)° **(1)**

(iii) light does not enter the cladding
so cannot pass across from one fibre to a neighbouring fibre **(1)**

fibres without cladding can allow light to pass between fibres when the surface of the fibre becomes scratched or moisture links two adjacent fibres optically **(1)**

personal data (such as bank account information) must be transmitted along fibres from which there is no danger of leakage of light resulting in a breach of security **(1)**

8

[12]