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

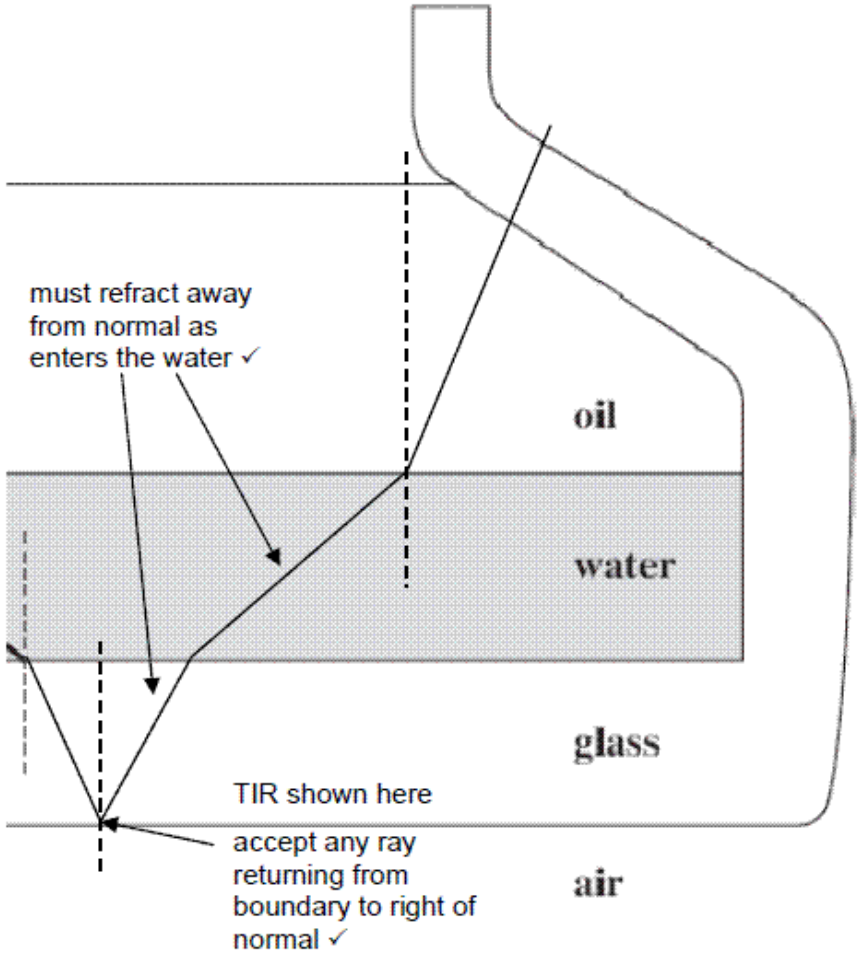
1

(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)

✓ ✓

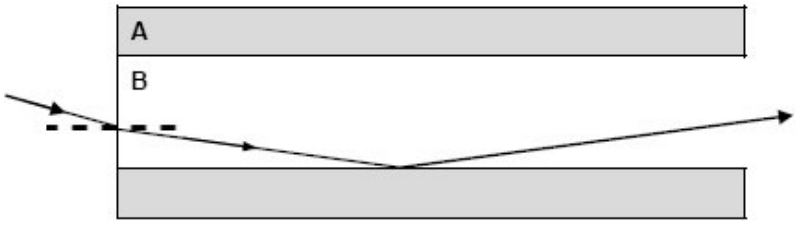
2

[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]

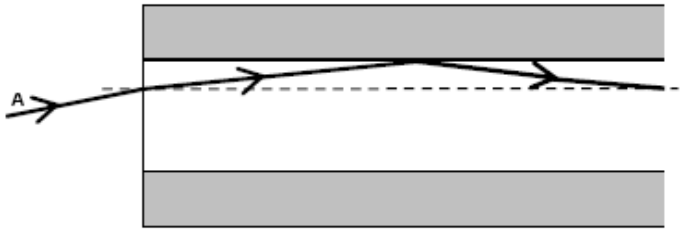
M6. (a) decrease ✓

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]