Marking Scheme

1.

Question			Marking details	Marks available AO1	AO2	AO3	Total	Maths	Prac
2	*(a)*		Use of Snell's law (1), e.g. $\sin 18.4^\circ = 1.65 \sin\theta_2$ Manipulation or Answer = 11.0° (1) accept $\sin^{-1}\left(\frac{\sin 18.4^\circ}{1.65}\right)$ but not just 10°	1	1		2	1	
	(b)		$\phi = 90 - \theta$ (79 or 80) (1) $n_2 \sin\theta_2 = n_3 \sin 90$ applied (1) or $n_2 \sin 79 = n_3 \sin\theta$ Answer = 73.2° (1) or no solution for θ Conclusion = Yes since ϕ greater than critical (1) [allow ecf on a calculated value of critical angle] or Yes refraction is impossible			4	4	3	
			Question 2 total	**1**	**1**	**4**	**6**	**4**	**0**

2.

Question			Marking details	Marks available AO1	AO2	AO3	Total	Maths	Prac
3	*(a)*		Refraction is a change in direction of the travel of waves (1) Waves travel more slowly in glass than in air (1) Therefore AB is greater than CD (1)	1 1	1		3		
	(b)		Measuring lengths AB = 2.9 cm and CD = 1.8 cm within 0.1 cm (1) Speed = $\frac{BD}{t}$ and $\frac{AC}{t}$ (can be implied) (**ecf**) (1) Speed = 1.9 [or 1.86] × 10^8 [m s^{-1}] (1)	1	1 1		3	2	
			Question 3 total	**3**	**3**	**0**	**6**	**2**	**0**

3.

Question			Marking details	Marks available AO1	AO2	AO3	Total	Maths	Prac
7	*(a)*	(i)	1.00 sin θ_{air} = 1.60 sin 30° or equivalent or by implication (1) θ_{air} = 53° (1) Beam bends sharply to the left at the surface (1)	1	1 1		3	2	
		(ii)	$\theta = \theta_C$ or by implication (1) $\sin\theta = \frac{1}{1.60}$ [=0.625] or equivalent (eg θ_C = 39°) (1) x =62.5 / 63 mm (1)	1 1	1		3	2	
	(b)		**Marking points** A1. Light [travelling at small angles to axis] hitting core/cladding boundary is totally internally reflected A2. [So] transmitted along fibre without loss B3. Light paths at different angles [to axis] are of different lengths [for given length of fibre] B4. [So] take [slightly] different times and [so] [each] pulse spread out [over time] on arrival at far end C5. Pulses may overlap (if in rapid sequence) C6. Spreading [accept mm dispersion] increases with length of fibre, [so] overlap more likely if fibre longer **5-6 marks** *Expect at least 4 points made from all of sections A, B and C* *There is a sustained line of reasoning which is coherent, relevant, substantiated and logically structured.* **3-4 marks** *Expect at least 3 points made from at least two sections from A, B or C* *There is a line of reasoning which is partially coherent, largely relevant, supported by some evidence and with some structure.*	6			6		
			1-2 marks *Any 2 points made* *There is a basic line of reasoning which is not coherent, largely irrelevant, supported by limited evidence and with very little structure.* **0 marks** *No attempt made or no response worthy of credit.*						
			Question 7 total	**9**	**3**	**0**	**12**	**4**	**0**

4.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
7.	*(a)*	(i)	$v_{plastic} = \frac{AC}{BD} \times c$ or equivalent or by implication (1) BD = 44 or 45 or 46 [mm]; AC = 31 or 32 or 33 [mm] (1) $v_{plastic}$ = (2.1 ± 0.1) × 10^8 [m s^{-1}] (1)		3		3	3	
		(ii)	n = 1.4 [± 0.1] ecf		1		1	1	
	(b)	(i)	A correct relevant time calculation e.g. for 120 m, 608 ns or for 120.9 m, 613 ns or by implication (1) Extra time by zig-zag route = 5 ns [4.6 n[s]] (1) **Therefore** overlap will occur, [as 4.6 ns > 4.0 ns] **no ecf** (1) [Allow 1 mark if n (refractive index) omitted leading to 3.0 ns delay and hence no overlap] **Alternative:** Extra distance for 4.0 ns extra time $\frac{3.00 \times 10^8 \times 4.0 \times 10^{-9}}{1.52}$ (1) = 0.79 [m] (1) **Therefore** overlap will occur [as 0.79 < 0.90 m] (1) [Allow 1 mark if n (refractive index) omitted leading to 1.2 m delay and hence no overlap]			3	3	2	
		(ii)	n_{clad} [sin 90°] = 1.520 sin 83° or equivalent (1) n_{clad} [sin 90°] = 1.51 (1)		2		2	2	
			Question 7 total	**0**	**6**	**3**	**9**	**8**	**0**

5.

Question			Marking details		Marks available				
				AO1	AO2	AO3	Total	Maths	Prac
6	*(a)*	(i)	Rearranging $\sin c = \frac{1.47 \sin 90}{1.52}$ (1) Critical angle = 75.3° (1)		2		2	2	
		(ii)	Substitution into Snell's law i.e. sin 15° = 1.52 sin θ_r (1) Refracted angle = 9.8° (1) A = 80.2° (90 - θ_r) (ecf on θ_r) (1)	1	1 1		3	2	
		(iii)	Angle A is greater than critical angle (ecf on A and critical angle) (1) So total internal reflection **and** light will travel down the fibre OR technician not correct (1)			2	2		
	(b)		Substituting values in speed = $\frac{\text{distance}}{\text{time}}$ (1) Speed of light in fibre = $\frac{c}{1.52}$ (1) Time = 7.6 × 10^{-5} s (1)	1	1 1		3	3	
	(c)	(i)	Monomode – parallel to axis/straight – Multimode zig zag paths	1			1		
		(ii)	No spreading of pulses OR only one path for data (1) Each pulse arrives at same time OR No overlapping of pulses (1) Allows faster rate of data transfer (1)	3			3		
			Question 6 total	**6**	**6**	**2**	**14**	**7**	**0**

6.

Question		Marking details	Marks available					
			AO1	AO2	AO3	Total	Maths	Prac
8	*(a)*	[Constant] velocity horizontal (1) Accelerating / force downwards [b.o.d. motion under gravity] (1) Projectile motion → 1 mark		2		2		
	(b)	$\phi = \sin^{-1}\left(\frac{1.55}{1.58}\right)$ (1) 78.82°, 78.8° or 79° etc. seen (not just 80) (1) 1.38 [rad] → 1st mark	1	1		2	2	
	(c)	Maximum angle for propagation with TIR (1) Rotational symmetry (about central axis) (1)		2		2		
	(d)	θ_2 = 90 - 80 = 10 degree or similar (11.2 degree etc.) (1) $n_1 \sin\theta_1 = n_2 \sin\theta_2$ used (1) Rearrangement $\theta_1 = \sin^{-1}\left(\frac{n_2}{n_1}\sin\theta_2\right)$ (1) Answer = 17.9° or 15.9° if 10° used (1)	1	1 1 1		4	3	
	(e)	Dispersion increases with length of fibre (1) [Maximum] bit rate and distance proportional [however stated, eg. Accept distance × 10 → bit-rate down by factor of 10] (1) Conclusion consistent with argument (1)			3	3		
	(f)	20 × 0.8 dB or 16 dB seen (1) Correct comparison with table e.g. 15 dB too much (0.03) (1) Correct conclusion: no, signal drops too much / distance too large (1) [NB Either distance for 6% = 15.3 km or 20 km → 2.5 % gives the first two marks].			3	3	2	
	(g)	Wavelength is decreased by factor n or $v=c/n$ (1) Wavelength is 820 nm (1) So thickness of around 8.2 μm is required (1) 13 μm student is wrong (1) [Allow Aled correct because 1.3 μm × 10 = 13 μm for 1 mark]			4	4	2	
		Question 8 total	**2**	**8**	**10**	**20**	**9**	**0**

7.

(a) $n_{clad}\sin 90^\circ = 1.540\sin 77^\circ$ **or** $n_{clad} = 1.540\sin 77^\circ$ [or by impl.] (1)

$n_{clad} = 1.50[1]$ [accept 1.5] (1)

(b) (i) $\text{speed} = \dfrac{3.00\times10^8}{1.54}$ (1)

$\text{time} = \dfrac{\text{distance}}{\text{speed}}$ (1) [transposed at any stage]

$= 1.027 \times 10^{-5}$ s (1) [omission of 1.54 loses just 1 mark]

(ii) I. $AB = \dfrac{AC}{\sin 77^\circ}$ **or** $AB = \dfrac{AC}{\cos 13^\circ}$ **or** equiv. (1)

II. Zigzag time $= 1.027 \times 10^{-5} \times 1.026$ s (1)

[**or** Extra time $= 1.027 \times 10^{-5} \times 0.026$ or by impl.]

Extra time $= 2.7 \times 10^{-7}$ s [e.c.f. on speed] (1)

(iii) Bit of data arrives spread out over a period of time [accept: data smeared or multimode dispersion] (1).

Data bits could overlap on arrival / can't distinguish (1)

8.

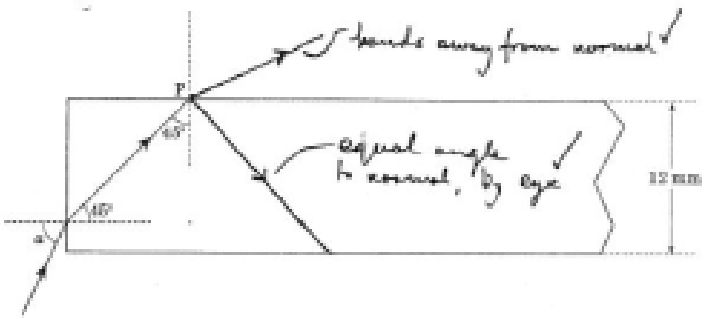
2	*(a)*	(i)	$v_{air} > v_{glass}$ (1), $f_{air} = f_{glass}$ **and** $\lambda_{air} > \lambda_{glass}$ (1)	2
		(ii)	Cycles [or oscillation] can't appear or disappear [at boundary] **or** equiv. / frequency determined by the source [**not** just f is constant]	1
	(b)	(i)	$[1.00]\sin 40^\circ = 1.52\sin\phi$ [where ϕ = angle of refraction] (1) $\phi = 25^\circ$ (1); $\theta = 90^\circ - 25^\circ$ (1) = [65°]	3
		(ii)	$\sin c = \dfrac{1}{1.52}$ [or equiv] $c = 41^\circ$ (1) $65^\circ > 41^\circ$ or remark (1)[free standing] **or**: $\sin^{-1}(1.52\sin 65^\circ)$ gives "error" (1), so refraction not possible (1)	2
		(iii)	I. Diagram: Reasonable path drawn [no gross departure from law of reflection] with emergent ray in correct quadrant (1)	1
			II. 2 sensible parallel paths inside block labelled (1) Emergent ray labelled as parallel to incident ray. (1)	2
	(c)		Any 2× (1) from: • minimises <u>multimode</u> dispersion [or equiv](✓) • cuts down range of path lengths (✓) • less pulse broadening **or** less likelihood of overlapping **or** more rapid data [allow: smearing and jumbling] sequence possible (✓) [not interfere or distorted]	2 **[13]**

9.

(a) Award 3 x (1) of:
- Refraction is change in direction of travel as waves change medium / air to glass (or equivalent).
- AB, CD are wavefronts (or peaks or crests).
- AB goes to CD.
- Waves travel more slowly in 2 than in 1.
- **Hence** BD < AC **Accept** wavelength less in medium 2.
- Direction of travel of waves is normal to wavefronts. [3]

(b) (i) [1.00] sin α = 1.33 sin 45° (1) or equivalent or by implication
α = 70° (1) [2]

(ii) I



[2]

No need for arrow heads. No penalty if reflected ray doesn't reach the bottom of the fibre.

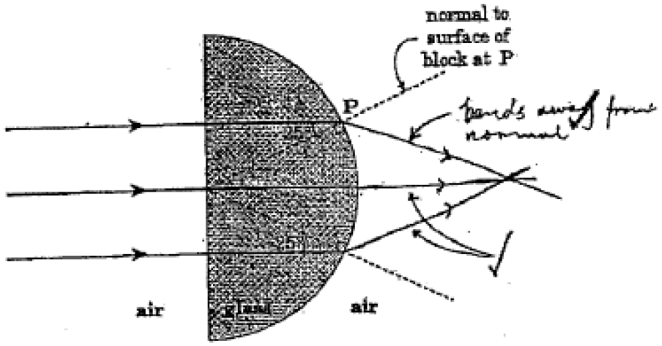
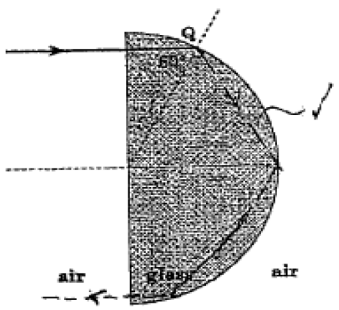
(ii) II 6 reflections needed [including that at P] (1)
Light travels 12 mm parallel to rod axis between successive reflections. (1) or by implication
Light has to travel 60 [mm] beyond P (1) Accept 72 [mm] [3]
Award 2 marks for 17 mm x 5 = 85 [mm]
Award 1 mark for 17 mm x 6 = 102 [mm]

(c) (i) c = 49° (1)
50° > 49° or 50° > c **AND** [2]
so refraction not possible / TIR / no power loss (1)

(ii) Total internal reflection [1]

10. *(a)*	(i)	$v_{air} > v_{glass}$ (1), $f_{air} = f_{glass}$ **and** $\lambda_{air} > \lambda_{glass}$ (1)	2
	(ii)	Cycles [or oscillation] can't appear or disappear [at boundary] **or** equiv. / frequency determined by the source [**not** just f is constant]	1
(b)	(i)	$[1.00]\sin 40^\circ = 1.52\sin\phi$ [where ϕ = angle of refraction] (1) $\phi = 25^\circ$ (1); $\theta = 90^\circ - 25^\circ$ (1) = [65°]	3
	(ii)	$\sin c = \frac{1}{1.52}$ [or equiv] $c = 41^\circ$ (1) $65^\circ > 41^\circ$ or remark (1)[free standing] **or**: $\sin^{-1}(1.52\sin 65^\circ)$ gives "error" (1), so refraction not possible (1)	2
	(iii)	I. Diagram: Reasonable path drawn [no gross departure from law of reflection] with emergent ray in correct quadrant (1)	1
		II. 2 sensible parallel paths inside block labelled (1) Emergent ray labelled as parallel to incident ray. (1)	2
(c)		Any 2× (1) from: • minimises <u>multimode</u> dispersion [or equiv](✓) • cuts down range of path lengths (✓) • less pulse broadening **or** less likelihood of overlapping **or** more rapid data [allow: smearing and jumbling] sequence possible (✓) [not interfere or distorted]	2
			[13]

11.

Question			Marking details	Marks Available
	(a)	(i)	(I)  	[2]
			(II) 1.58 sin25° = [1.00] sin *a* (1) or equivalent or by implication *a* = 42° (1)	[2]
		(ii)	(I) Either *c* = 39° (1) 60°>39° or equivalent (1) OR 1.58 sin 60° gives error (1) So refraction not possible or TIR [needs *attempt* to justify] (1)	[2]
			(II) TIR at Q and at least one more instance of TIR with subsequent **ecf** (1) As drawn with reflected ray at Q going off East of South, eventually emerging through diameter face ,with at least one more TIR event.(1)  	[2]
	(b)	(i)	Thinner	[1]
		(ii)	Monomode: parallel to axis (accept straight) Multimode: zig-zag paths as well (1) or some paths involve reflections	[1]
		(iii)	Only one route for data (1) [no zig-zag routes] Each pulse [data element etc] arrives [at other end of fibre] at same time (1) No overlapping of pulses (1) [even over long distances]	[3]
			Question 3 Total	**[13]**

12. *(a)*	(i)	medium 1: 2.0×10^8 [m s^{-1}] **and** medium 2: 2.5×10^8 [m s^{-1}]	1
	(ii)	Correct use of sin 30° seen clearly (1) Rest of argument, including use of $t = \frac{d}{v}$ [**ecf** on v and on value of sin 30°, if failure to reach the stated time is noted]. (1)	2
	(iii)	BD = 2.5×10^8 **ecf** $\times$ 2.5×10^{-11} [m] [= 6.25 mm] **or** by implication (1) θ_2 = 38.7° (or 39°) **ecf** on $v = 2.5 \times 10^8$ [m s^{-1}] (1)	2
	(iv)	1.50 sin 30° = 1.20 sin θ_2 (1) Therefore θ_2 = 38.7° (or 39°) **no ecf** (1)	2
(b)	(i)	Use of $v = 2.0 \times 10^8$ [m s^{-1}] (1) $t = \frac{1600}{2.0\text{x}10^8}$ [s] **ecf** on v (1)	2
	(ii)	Critical angle = 76° **or** by implication (1) n_{clad} [$\times$ sin 90°] = 1.500 sin 76° **ecf** on 76° **or** by implication (1) n_{clad} = 1.455 **or** 1.46 **do not accept** 1.45 **no ecf** (1)	3
	(iii)	$\frac{AC}{AB}$ = cos 14° **or** equivalent **or** by implication (1) Δt = 0.24 μs **ecf** on v (1)	2

13.

(a)	(i)	Smooth curve drawn through all the points	1
	(ii)	46° [or as appropriate from drawn line]	1
	(iii)	Reflected ray drawn with angle of reflection equal to θ_p by eye.	1
	(iv)	Any of:	

$\frac{\sin 14^\circ}{\sin 10^\circ}$ ✓	$\frac{\sin 28.5^\circ}{\sin 20^\circ}$	$\frac{\sin 44^\circ}{\sin 30^\circ}$	$\frac{\sin 64^\circ}{\sin 40^\circ}$	$\frac{\sin 82^\circ}{\sin 45^\circ}$
1.39 [±0.05]✓ or by implication	1.40[±0.05]	1.40[±0.05]	1.40[±0.05]	1.40[±0.05]

2

	(v)	I. Any 2 × (1) from • Straight ✓ • Through the origin ✓ • Gradient > 1 ✓	2
		II. [n is the] gradient	1
(b)	(i)	1.530 sin c = 1.520 [sin 90°] (1) [or by impl.] c = 83° (1)	2
	(ii)	θ = 7° [accept 6.5°] e.c.f. from (b)(i)	1
	(iii)	Smaller <u>differences</u> in distances travelled or times taken [by light travelling different paths] (1), so less blurring / smearing / overlap of data / pulses (1) [or data can be transmitted at a greater rate] Less multimode dispersion only award 2nd mark	2

14.

Question				Marking details	Marks Available
4	*(a)*	(i)		sin θ = 1.331 sin 40.36° **or** by implication (1) 60° (1) Accept 59.5 °	2
		(ii)		*Not* total + attempt at justification even if not worth next mark (1) **For the 2nd mark either:** Light got in at P or gets out at R, so can get out at **Q** [as angles in water the same] **or** 1.331 sin 40.36 reshown to be < 1 **or** $C = 49°$	2
		(iii)		$v_{violet} < v_{red}$ + attempt at justification even if not worth next mark e.g. violet bends more (1) **For the 2nd mark either:** Violet must have larger n therefore smaller v **or** bending caused by light travelling more slowly in water than in air, so violet must travel most slowly.	2
	(b)	(i)		Speed in glass = $\frac{360}{1.75 \times 10^{-6}}$ [= 2.06×10^8 m s^{-1}] **or** by implication (1) n = 1.46 (1) must be to 3 sig figs	2
		(ii)		$C = 75°$ **or** by implication (1) 1.46 sin 75° = n_{clad} [sin 90°] [Accept 1.5 for 1.46] **or** by implic (1) n_{clad} = 1.41 [1.45 if n_{core} taken as 1.50] (1) **Award 1 mark only for:** 1.46 sin 15° = n_{clad} [sin 90°]	3
		(iii)		Larger angles give longer propagation times. [Accept longer dists.](1) So each pulse spread out over time on arrival **or** each pulse is less spread out if the angles are restricted (1) So pulses might overlap (Accept pulses muddled) **or** overlap/muddling of pulses less likely if angles restricted. (1) **Award 1 mark only** for less multimode dispersion	3
				Question 4 Total	**[14]**