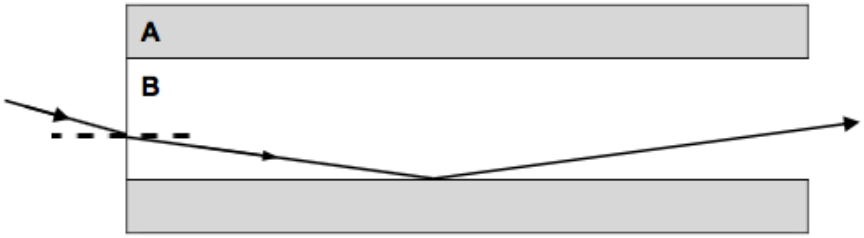
1)

(a)	reflects at correct angle by eye (use top of '27' and bottom of '42' as a guide) **or 27°** or **63°** correctly marked ✓ refracts away from normal at glass/air ✓ symmetrical by eye or refracted angle (42°) correctly marked and at least one normal line added ✓	**3**
(b)	$(n_g) = \frac{\sin 42}{\sin 27}$ ✓ DNA 42/27 = 1.56 = 1.47 (1.474) 3 sf shown ✓	**2**
(c)	63 (°) ✓ 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 (7 (c)) ✓ or use of n = 1.5 = 1.3(1) or 1.34 if n = 1.5 used ✓	**2**
	Total	**8**

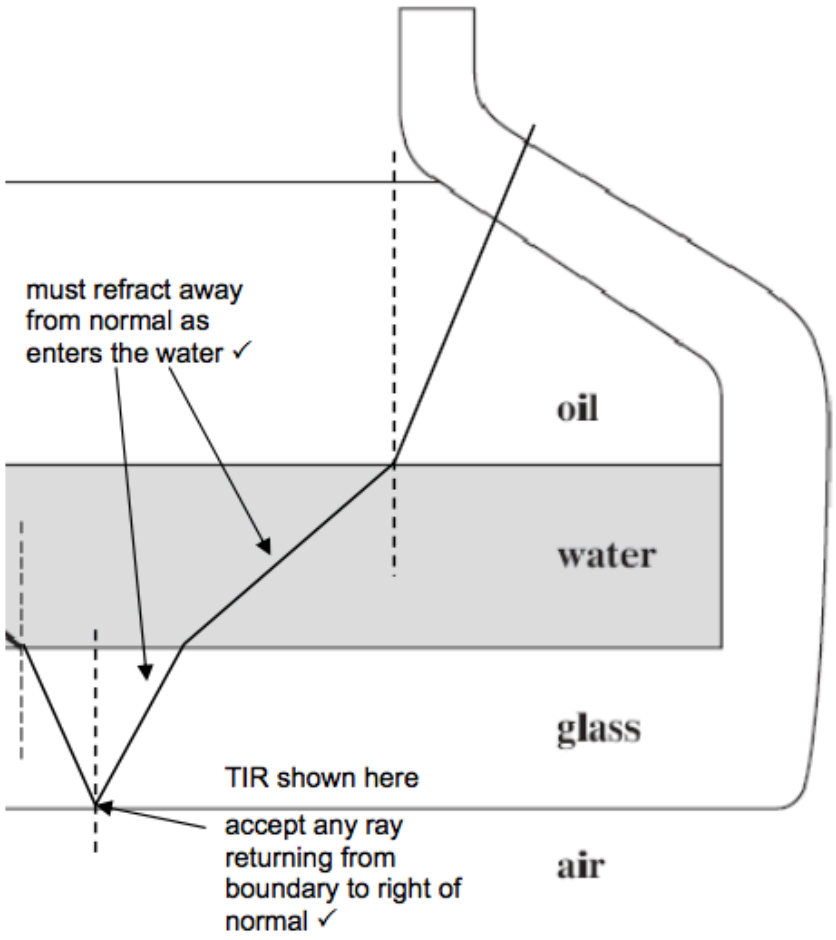
2)

(a)	(i)	(refractive index of water = 1/sin 49.0) = **1.33** (not 1.3 or 1.325) ✓	**4**
	(ii)	ray P shown in the air to right of vertical ✓ refracted away from the normal in the correct direction ✓ correct partial reflection shown ✓	
(b)	(i)	**critical angle** for water-air boundary = 49.0° or angle of (incidence of) Q is θ_c ✓ the angle of incidence (of R) exceeds the critical angle ✓	**6**
	(ii)	figure 6 shows that R undergoes TIR at water surface and strikes the glass side ✓ angle of incidence at glass side = 30° ✓ R enters the glass and refracts towards the normal ✓ because $n_g > n_w$ ✓ (or water is optically less dense than glass) (calculates angle = 26.2° gets last two marks)	
		Total	**10**

3)

(a)	(i)	A: **cladding** + B: **core** ✓	**1**
(a)	(ii)	 refraction towards the normal line ✓ continuous lines + strikes boundary + TIR correct angles by eye + maximum 2 TIRs ✓	**2**
(b)		$\left(sin\theta_c = \frac{n_2}{n_1}\right)$ or = 0.9865 ✓ 80.6 or 80.8 or 81 (°) only ✓	**2**
(c)		to reduce **multipath** or **multimode dispersion** ✓ (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 ✓ **or** to prevent light/data/signal loss (from core or fibre) ✓ (which would cause) signal to get weaker/attenuation/crossover/data to be less secure ✓	**2**
(d)		correct application ✓ (endoscope, cytoscope, arthroscope etc, communications etc) linked significant benefit stated eg improve medical diagnosis/improve transmission of data/high speed internet ✓	**2**
		Total	**9**

4)

(a)	$\sin\theta = \frac{1.47 \sin 44}{1.33}$ or $1.33 \sin\theta = 1.47 \sin 44$ or $\sin^{-1} 0.768$ ✓ θ = 50.15, 50.2, 50.35 (°) ✓ answer seen to > 2 sf	**2**
(b)	refracts towards normal ✓ 44° shown ✓	**2**
(c)	(TIR) only when ray travels from higher *n* to lower *n* **or** (water to glass) is lower *n* to higher *n* ✓ do not allow 'density', allow 'optical density', n or refractive index only	**1**
(d)	$\sin\theta_c = \frac{1}{1.47}$ or $1.47 \sin\theta_c = (1 \times) \sin 90$ ✓ θ_c = 42.86 (= 43.0(°)) ✓	**2**
(e)		**2**
	Total	**9**

5)

a	i	sin 56 = n_{glass} sin 30 ✓ (n_{glass} = sin56/sin30) (= 1.658) = 1.7 ✓	**2**
a	ii	sin θ_c = 1/1.658 ✓ ecf from ai θ_c = (37.09 or 37.04) = 37 (degrees) ✓ accept 36 (36.03 degrees) for use of 1.7	**2**
b		TIR from the upper side of the prism ecf from part aii **and** correct angle ✓ refraction out of the long edge of the prism away from the normal ✓	**2**
		Total	**6**

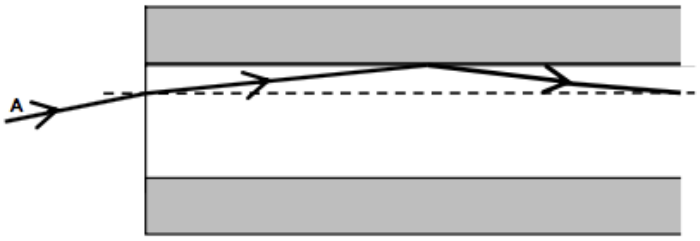
6)

a		$(n =) \frac{\sin 14.1}{\sin 9.54}$ **OR** 0.2436 / 0.1657 working must be seen **AND** (= 1.4699) = 1.47 ✓ given correctly to 3 or more significant figures	1	0.24/0.17 = 1.41 is not acceptable Watch for: 14.1 / 9.54 = 1.478
b	i	ray goes along the boundary ✓ (partial) reflection shown ✓ (allow dotted or solid line. This mark can be awarded if TIR is shown)	2	Deviation by no more than 1mm by the end of the diagram. Tolerance: 70° to 85° to normal or labelled e.g. θ and θ, etc
b	ii	(90 – 9.54 =) 80.46 or 80.5 ✓ (°) (allow 80°)	1	Don't allow 81 degrees
b	iii	$(n = n_c \sin\theta)$ = 1.47 sin 80.46° ✓ ecf bii =1.45 ✓ (1.4496)	2	allow 80 or 81 degrees here Correct answer gains both marks
c		• protect the core (from scratches, stretching or breakage) • prevent 'crossover' of signal / ensure security of data / prevent loss of information/data/signal • increase the critical angle / reduce pulse broadening/(modal)dispersion / rays with a small angle of incidence will be refracted out of the core • increase rate of data transfer max two correct (from separate bullet points) ✓✓	2	comment on 'quality' of signal' is not sufficient don't allow 'leakage' on its own. Don't allow 'loss of light' Allow 'leakage of signal', etc
		total	8	

7)

(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) ✓ = 0.9355 (accept less sf) ✓ c = 69.3(°) ✓ (accept 69.4°, 69° **or** 70°)	**7**
	(ii)	the angle (of incidence) is less than the **critical angle** or values quoted ✓	
	(iii)	(using $n_1 \sin \theta_1 = n_2 \sin \theta_2$ gives) 1.55 sin 60 = 1.45 sin θ ✓ (sin θ = 1.55 sin 60/1.45 =) 0.9258 or 0.926 or 0.93 ✓ θ = 67.8° ✓ (accept 68° **or** 68.4)	
(b)		any **two** from: keeps signals secure ✓ maintains quality/reduces pulse broadening/smearing (owtte) ✓ it keeps (most) light rays in (the core due to total internal reflection at the cladding-core boundary) ✓ it prevents scratching **of the core** ✓ (keeps core away from adjacent fibre cores) so helps to prevent crossover of **information/signal/data** to **other** fibres ✓ cladding provides (tensile) strength for fibre/prevents breakage ✓ given that the core needs to be very thin ✓	**max 2**
		Total	**9**

8)

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 (× 10^8) ✓ = $\frac{300\ (\times 10^8)}{2.04\ (\times 10^8)}$ = 1.47 ✓ (1.4706) (must see 3 sf or more)	**2**
c 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° ✓ sinθ = 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 axial rays take longer time to travel same distance along fibre as axial rays ✓	**2**
	Total	**14**

9)

a		$n_1 > n_2$ ✓ (incident) angle > critical angle (allow θ_c not 'c') **OR** critical angle must be exceeded ✓	2	Allow correct reference to 'optical density' Allow $n_A > n_B$ Do not allow: 'angle **passes** the critical angle'
b		($n_s = \frac{c}{c_s}$) ($c_A = \frac{c}{n_A}$ =) $\frac{3.00\times10^8}{1.80}$ ✓ (= 1.667×10^8) = 1.67×10^8 (ms^{-1}) ✓	2	For second mark, don't allow 1.6×10^8 Allow 1.66×10^8 or 1.70×10^8 Allow $1.\dot{6}\times10^8$
c		$\sin 72 = 1.80 \sin\theta$ ✓ ($\sin\theta = \frac{\sin 72}{1.80} = \frac{0.9510565}{1.8} = 0.52836$) θ = 31.895 = 31.9 correct answer >= 2sf seen ✓	2	Correct answer on its own gets both marks Do not allow 31 for second mark Allow 31.8 - 32
d		$1.80 \sin\theta_c = 1.40$ **OR** $\sin\theta_c = \frac{1.40}{1.80}$ θ_c = 51.058 = 51.1 ° ✓ (accept 51) **OR** = 0.778 ✓	2	Correct answer on its own gets both marks Don't accept 50 by itself
e	i	22 + their 5(c) (22+31.9 = 53.9) ✓ 53.9 > (51.1) critical angle ✓ **OR** 5c + 22 < their 5d (θ_c) ✓ ecf from (c) and (d) angle less than critical angle ✓	2	If 5c+22 **>** 5d then TIR expected If 5c+22 **<** 5d then REFRACTION expected Allow max 1 for 'TIR because angle > critical angle' only if their 5d >5c +22
e	ii	TIR angle correct ✓ ecf from e(i) for refraction answer	1	Tolerance: horizontal line from normal on the right/ horizontal line from top of lower arrow. If 5ei not answered then ecf 5(d). If 5ei and 5d not answered then ecf 5c

10)

a	i	sin 60 = 1.47sin θ **OR** sin θ = sin 60 / 1.47 ✓ ($\sin^{-1}$ 0.5891) = 36 (°) ✓ (36.0955°) (allow 36.2)	2		Allow 36.0
a	ii	$\sin \theta_c$ = 1.33/1.47 OR $\sin \theta_c$ = 0.9(048) ✓ ($\sin^{-1}$ 0.9048) = 65 (°) ✓ (64.79)	2		Allow 64 for use of 0.9 and 66 for use of 0.91
a	iii	Answer consistent with previous answers, e.g. If aii >ai: Ray refracts at the boundary AND goes to the right of the normal ✓ Angle of refraction > angle of incidence ✓ **this mark depends on the first** If aii < ai: TIR ✓ Angle of reflection = angle of incidence ✓ Ignore the path of the ray beyond water/glass boundary	2		Approx. equal angles (continuation of the line must touch 'Figure 4' label)
b		For Reason or Explanation: The angle of refraction should be > angle of incidence when entering the water ✓ water has a lower refractive index than glass \ light is faster in water than in glass ✓ TIR could not happen \ there is no critical angle, when ray travels from water to oil✓ TIR only occurs when ray travels from higher to lower refractive index \ water has a lower refractive index than oil ✓	4		Allow 'ray doesn't bend towards normal' (at glass/water) Allow optical density Boundary in question must be clearly implied
		total		10	