M1.(a)

	wavelength	**frequency**	**speed**
increases			
stays the same		✓	
decreases	✓		✓

middle column correct ✓
first and third column correct ✓

2

(b) (i) ($n_1 \sin\theta_2 = n_2 \sin\theta_2$)
(1.09)sin 65.0 = (1.00)sinθ_2 ✓ (giving $\theta_2 = 81°$)

α = 9(°) ✓ (8.93°)
no internal CE
allow 9.0°

2

(ii) 1.09sin65 = 1.70sin$x$
or sin$x$ = 0.58
or x = 35.5 (°) ✓ (allow 35° or 36°)
[beware an answer close to the correct value can come from n = 1 / sinC]

90 − 35.5 = 54.5(°) ✓ (allow 54° or 55°)
CE for 90° − their value

2

(c) (i) <u>total</u> internal reflection
TIR does not gain the mark

1

(ii) diagram showing core / cladding and light ray TIR at interface at least once with another TIR shown on the diagram or suggested in their

explanation ✓

labelling is not required and reflections do not have to be accurate provided they are shown on the correct side of the normal

light fibre consists of core and cladding with lower refractive index / optical density ✓

light (incident) at angle greater than the critical angle (results in TIR) ✓

3

[10]

M2.(a) Prevents (physical) damage to fibre / strengthen the fibre / protect the fibre

Allow named physical damage e.g. scratching

B1

Prevent crosstalk

1

(b) (Relative) refractive index = 1.03
or
Use of sin$c = n_2 / n_1$

Calculating the refractive indices and rounding before dividing gives 76.8

C1

76.0° or 76.8°

A1

2

[3]

M3.(a) Core is transmission medium for em waves to progress (by total internal reflection) ✓

Allow credit for points scored on a clear labelled diagram.

1

Cladding provides lower refractive index so that total internal reflection takes place ✓

1

And offers protection of boundary from scratching which could lead to light leaving the core. ✓

1

(b) Blue travels slower than red due to the greater refractive index

Red reaches end before blue, leading to material pulse broadening ✓

The first mark is for discussion of refractive index or for calculation of time difference.

1

Alternative calculations for first mark

Time for blue = $d / v = d / (c / n)$ = 1200 / (3×10^8 / 1.467) = 5.87×10^{-6} s

Time for red = $d / v = d / (c / n)$ = 1200 / (3×10^8 / 1.459) = 5.84×10^{-6} s

Time difference = $5.87 \times 10^{-6} - 5.84 \times 10^{-6} = 3(.2) \times 10^{-8}$ s ✓

The second mark is for the link to material pulse broadening

1

(c) Discussions to include:

Use of monochromatic source so speed of pulse constant

Use of shorter repeaters so that the pulse is reformed before significant pulse broadening has taken place.

Use of monomode fibre to reduce multipath dispersion ✓ ✓

Answer must make clear that candidate understands the distinction between modal and material broadening.

2

[7]

M4.B

[1]

M5.(a) (i) sin 60 = 1.47sin θ **OR** sin θ = sin 60 / 1.47 ✓

($\sin^{-1}$ 0.5891) = 36 (°) ✓ (36.0955°) (allow 36.2)

Allow 36.0

2

(ii) $\sin \theta_c = 1.33 / 1.47$ OR $\sin \theta_c = 0.9(048)$ ✓
$(\sin^{-1} 0.9048) = 65$ (°) ✓ (64.79)

Allow 64 for use of 0.9 and 66 for use of 0.91

2

(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
TIR ✓
angle of reflection = angle of incidence ✓

ignore the path of the ray beyond water / glass boundary

Approx. equal angles (continuation of the line must touch 'Figure 1' label)

2

(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 ✓

Allow 'ray doesn't bend towards normal' (at glass / water)
Allow optical density
Boundary in question must be clearly implied

4

[10]

M6.(a) $n_1 > n_2$ ✓

Allow correct reference to 'optical density'

(incident) angle > critical angle (allow θ_c not 'c')
OR critical angle must be exceeded ✓

Allow $n_A > n_B$
*Do not allow: 'angle **passes** the critical angle'*

2

(b)

$\left(n_s = \frac{c}{c_s} \right)$

$\left(c_A = \frac{c}{n_A} = \right) \quad \frac{3.00 \times 10^8}{1.80}$ ✓

For second mark, don't allow 1.6 × 10^8
Allow 1.66 × 10^8 or 1.70 × 10^8
Allow 1.6. × 10^8

(= 1.667 × 10^8) = 1.67 × 10^8 (ms^{-1}) ✓

2

(c) sin72 = 1.80sin θ ✓

($\sin\theta = \frac{\sin 72}{1.80} = \frac{0.9510565}{1.8} = 0.52836$)

Correct answer on its own gets both marks

θ = 31.895 = 31.9 correct answer >= 2sf seen ✓

Do not allow 31 for second mark
Allow 31.8 − 32

2

(d) 1.80 sin θ_c=1.40 **OR** $\sin\theta_c = \frac{1.40}{1.80}$
θ_c = 51.058 = 51.1 ° ✓ (accept 51)

Correct answer on its own gets both marks
Don't accept 50 by itself

2

OR = 0.778 ✓

(e) (i) 22 + their (c) (22 + 31.9 = 53.9) ✓
53.9 > (51.1) critical angle ✓

If c + 22 < d then TIR expected
If c + 22 > d then REFRACTION expected

OR
c + 22 $_\circ$) ✓ ecf from (c) and (d)
angle less than critical angle ✓

Allow max 1 for 'TIR because angle > critical angle' only if

their d > c + 22

2

(ii) TIR angle correct ✓
ecf from e(i) for refraction answer

Tolerance: horizontal line from normal on the right / horizontal line from top of lower arrow.
If ei not answered then ecf (d). If ei and d not answered then ecf c

1

[11]

M7.(a) (n =) $\frac{\sin 14.1}{\sin 9.54}$ **OR** 0.2436 / 0.1657 working must be seen

0.24 / 0.17 = 1.41 is not acceptable

AND (= 1.4699) = 1.47 ✓ given correctly to 3 or more significant figures

Watch for:14.1 / 9.54 = 1.478

1

(b) (i) ray goes along the boundary ✓

Deviation by no more than 1mm by the end of the diagram.

(partial) reflection shown ✓
(allow dotted or solid line. This mark can be awarded if TIR is shown)

Tolerance: 70° to 85° to normal or labelled e.g. θ and θ, etc

2

(ii) (90 − 9.54 =) 80.46 or 80.5 ✓( ) (allow 80)

Don't allow 81 degrees

1

(iii) *($n = n_c \sin \theta$)*

allow 80 or 81 degrees here

= 1.47 sin 80.46 ✓ ecf bii

=1.45 ✓ (1.4496)

Correct answer gains both marks

2

(c)

- protect the core (from scratches, stretching or breakage)
  comment on 'quality' of signal is not sufficient
- prevent 'crossover' of signal / ensure security of data / prevent loss of information / data / signal
  don't allow 'leakage' on its own.
- increase the critical angle / reduce pulse broadening / (modal)dispersion / rays with a small angle of incidence will be refracted out of the core
  Don't allow 'loss of light'
- increase rate of data transfer
  Allow 'leakage of signal', etc

max two correct (from separate bullet points) ✓ ✓

2

[8]