SECTION B

*Answer **all** questions*

Read through the following article carefully.

Freely adapted from:

Paragraph

The Physics of Optical Fibres
By Justino Luis Moreno

Basically, an optical fibre is just a piece of glass along which you send light. A similar procedure was first demonstrated not with glass but with water flowing from a spout in 1840 by scientists Daniel Colladon and Jacques Babinet. Babinet later published his work in an article entitled "On the reflections of a ray of light inside a parabolic liquid stream". This effect can be reproduced quite easily in a school lab using the apparatus shown in Figure 1. 1

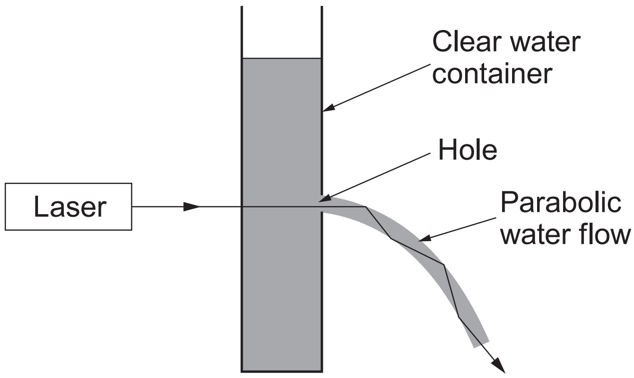

Figure 1

Although this set up is pleasing to the eye and is the basis of some water features, it isn't much use for international telecommunication! A standard optical fibre is shown in Figure 2 along with a ray of light entering it. 2

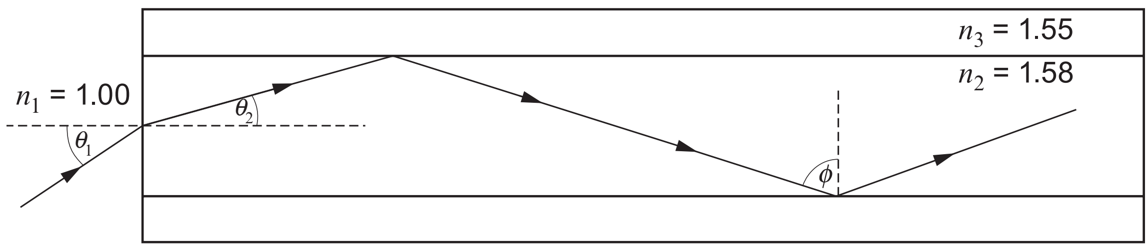

Figure 2

This ray of light is repeatedly reflected along the length of the optical fibre. If the entrance angle (θ_1) is small enough then an effect called total internal reflection (TIR) means that the light is completely reflected each time resulting in no light escaping as it travels along the optical fibre. The physicists in charge of designing these things can prove that the minimum value angle ϕ can have for TIR to take place is given by the equation: 3

$$\phi = \sin^{-1}\left(\frac{n_3}{n_2}\right)$$

Paragraph

This angle is around 80° for the optical fibre shown. The minimum angle for ϕ means that there
is a maximum angle for θ_1. This gives an acceptance cone where the input light gets propagated
without loss. A quick bit of geometry shows you that the exit angle is the same as the entry angle 4
so that when light exits it produces an almost perfect cone shaped beam with a circular cross-
section as can be seen in Figure 3.

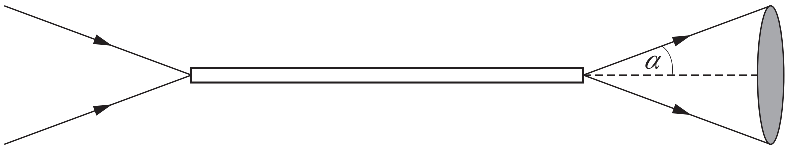

Figure 3

An important term in optical fibre technology is maximum bit rate. Since each pulse represents
a bit of data, this is the highest frequency of pulses that can be sent down an optical fibre before
the pulses start to overlap and become indistinguishable from each other. A monomode optical 5
fibre cable of length 80 km can comfortably have a maximum bit rate of $10\,\text{Gb}\,\text{s}^{-1}$. This means
that 10^{10} pulses can pass along its length every second without overlapping. A typical telephone
conversation requires around $10\,\text{kb}\,\text{s}^{-1}$ meaning that one monomode optical fibre cable can carry
a million telephone conversations simultaneously. High definition TV requires a much higher bit
rate and a $10\,\text{Gb}\,\text{s}^{-1}$ fibre will only handle around 2 000 high definition TV signals.

One of the most important factors that limit data transfer in optical fibres is multimode dispersion.
This, put simply, is to do with the entrance cone of light in Figure 3. There is a range of distances
that the pulses have to travel because there are a variety of angles at which they can travel along
the fibre. The pulses then become spread out and indistinct, ruining the digital signal. Multimode 6
dispersion is eliminated by using monomode optical fibre cables which have very thin cores. As
a rule, monomode fibres have a core diameter of around 8 μm. This means that the core is less
than 10 wavelengths thick so that the light stops behaving like rays. For monomode fibres there
is only one propagation direction – along the axis.

Another drawback of sending signals down long lengths of optical fibres is that some of the
light is either scattered or absorbed by the glass molecules themselves (an effect known as
attenuation). Although no light escapes the fibre due to TIR there are other losses involved and
these are usually summarised by using a decibel (dB) scale. This scale is defined by saying that 7
a 10 dB decrease (-10 dB) in power is when the power has dropped to 10% of its input value. A
loss of -20 dB then corresponds to a drop to 1% power and -30 dB is a drop to 0.1% power. The
following table shows the relationship between dB values and power ratio:

dB	Power ratio $\left(\frac{P}{P_0}\right)$
-5	0.316
-10	0.100
-15	0.032
-20	0.010

Table 1 8

The losses of optical fibres are usually quoted in the unit dB/km and some modern optical fibres
can have values as low as 0.01 dB/km. Hence, each km of cable loses 0.01 dB meaning that you
can use 1 000 km before your signal is down to 10% strength. Optical fibres have come a long
way since they were born in a fountain of light nearly 200 years ago. They stretch out (literally) to 9
all areas of the world bringing light, sound and broadband wherever they go. Technical advances
mean that data can be sent at a rate of 1.05×10^{15} pulses per second over a distance of 50 km
with only one monomode optical fibre. Nonetheless, the technology has its limitations of which
attenuation and multimode dispersion are but two.