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Centre number

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Candidate number

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Surname

StemUp Model Solution

Forename(s)

Candidate signature

I declare this is my own work.

A-level PHYSICS

Paper 3

Section B Electronics

Friday 5 June 2020

Afternoon

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do **all** rough work in this book. Cross through any work you do not want to be marked.
- Show **all** your working.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 35.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

For Examiner's Use

Question	Mark
1	
2	
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4	
5	
TOTAL	



J U N 2 0 7 4 0 8 3 B E 0 1

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Section B

Answer **all** questions in this section.

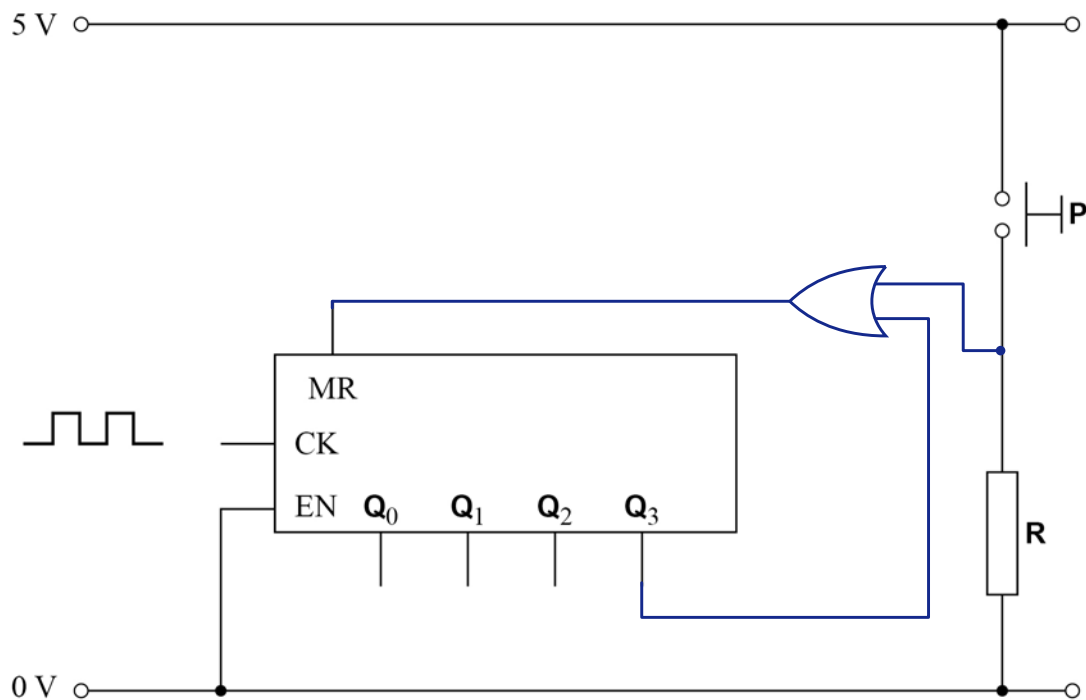
0 1

Figure 1 shows part of a circuit that includes a 4-bit binary counter. The main inputs and outputs of the counter are shown.

The counter generates a sequence of binary codes representing the decimal numbers 0 to 7

Output Q_0 is the least significant bit of the binary codes.

Figure 1



The counter resets when the master reset pin MR receives a logic 1

The circuit requires the counter to reset when either one of two conditions is met.

Condition 1 Manual reset using the switch **P** to reset the counter to 0

Condition 2 Automatic reset when an appropriate binary code is produced at the counter outputs. This will cause the counter to continually cycle through the decimal numbers 0 to 7

0 1 . 1

Complete **Figure 1** to show how both reset conditions can be met.

Do **not** show the power line connections to the integrated circuit.

[3 marks]

Question 1 continues on the next page

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0 1 . 2

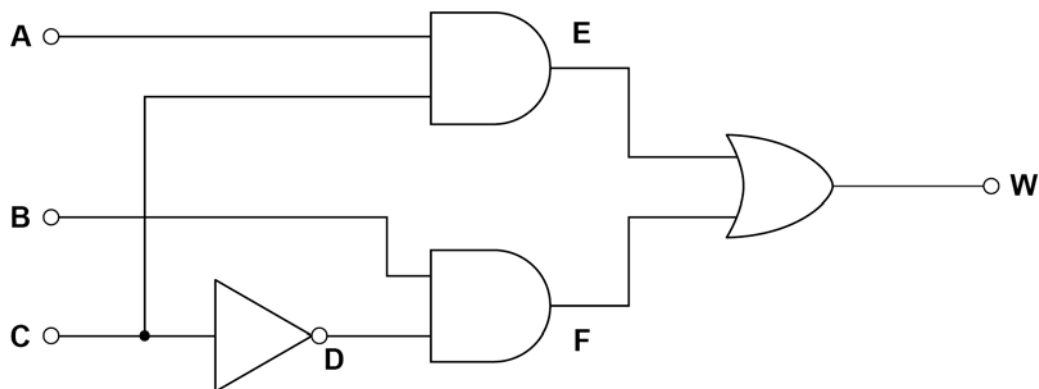
A logic system is designed to identify prime numbers.

The binary codes from the counter are now applied to the inputs **ABC** of the logic system shown in **Figure 2**.

Input **A** takes the least significant bit of the binary code from the counter.

Output **W** becomes logic state 1 when a prime number 2, 3, 5 or 7 is detected.
Otherwise output **W** is at logic 0

Figure 2



Write the Boolean algebra expression for output **W** in terms of the inputs **A**, **B** and **C**.
The expression must contain only the four logic gate operations shown in **Figure 2**.

[2 marks]

$$W = (A \cdot C) + (B \cdot \bar{C})$$



0 1 . 3 Complete **Table 1**, the truth table for the logic system in **Figure 2**.

[1 mark]

Table 1

Decimal number	C	B	A	D	E	F	W
0	0	0	0	1	0	0	0
1	0	0	1	1	0	0	0
2	0	1	0	1	0	1	1
3	0	1	1	1	0	0	1
4	1	0	0	0	0	0	0
5	1	0	1	0	1	0	1
6	1	1	0	0	0	0	0
7	1	1	1	0	1	0	1

0 1 . 4 The logic system in Question **01.2** is replaced with one that gives an output **S** using the same binary input codes **CBA**.

The Boolean algebra equation for output **S** is

$$S = \overline{A} \cdot (B + C)$$

Deduce which decimal numbers 0 to 7 will cause **S** to become logic 1

[1 mark]

S = 1 only when A = 0 and (B + C) = 1

i.e. even numbers that are not 0:

S is logic 1 for decimal numbers 2, 4 and 6

Question 1 continues on the next page

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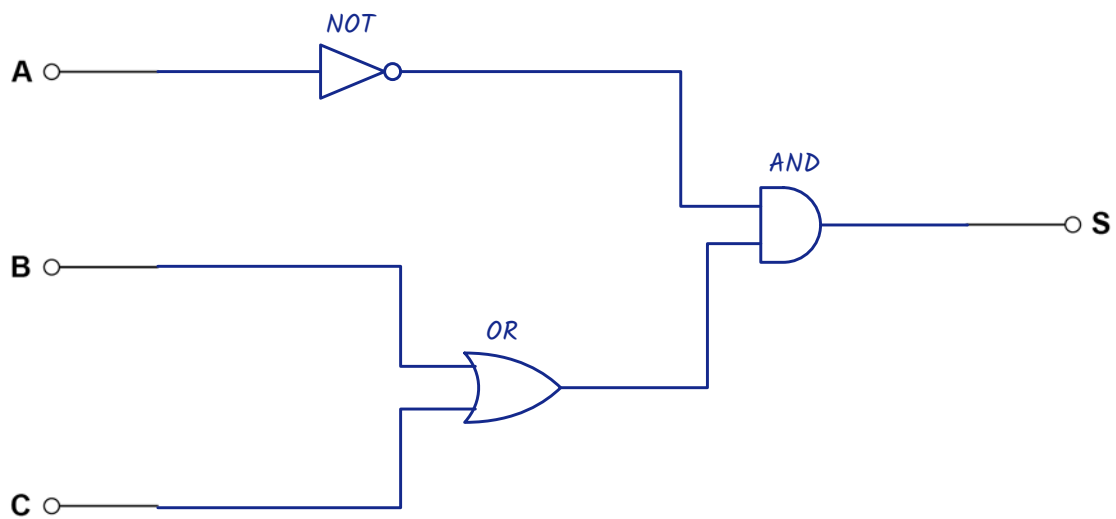


0 1 . 5 Complete **Figure 3** by drawing the logic system for **S**.

You must use only the logic gate operations given in $S = \bar{A} \cdot (B + C)$

[2 marks]

Figure 3



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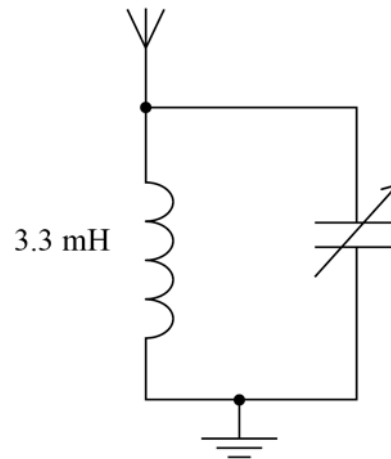


0 2

Figure 4 shows the filter circuit that forms the first stage in an amplitude modulated (AM) radio receiver.

The circuit contains a 3.3 mH inductor and a variable capacitor.

Figure 4



0 2. 1

The circuit is tuned to receive a radio station transmitting at a frequency of 1053 kHz.

Calculate the value of the capacitance needed to receive this station.

[1 mark]

$$f_0 = 1 / (2\pi\sqrt{LC}) \quad \text{so} \quad C = 1 / (4\pi^2 f_0^2 L)$$

$$C = 1 / (4\pi^2 \times (1053 \times 10^3)^2 \times 3.3 \times 10^{-3})$$

$$C = 6.92 \times 10^{-12} \text{ F} = 6.9 \text{ pF}$$

capacitance = 6.9 pF



0 2 . 2

The circuit is retuned to receive a different radio station by setting the variable capacitor to a value of 9.3 pF.

Table 2 shows the capacitance range of four variable capacitors **W**, **X**, **Y** and **Z**.

Comment on the suitability of these capacitors for this application and state your preference.

[2 marks]

Table 2

Capacitor	Range / pF
W	2–9
X	3–10
Y	4.5–20
Z	10–50

X and Y are suitable because 9.3 pF lies within their ranges; W (2 to 9 pF) and Z (10 to 50 pF) are out of range.

I prefer Y, because 9.3 pF falls near the centre of its range, so it can be tuned either side; 9.3 pF is near the top end of X's range.

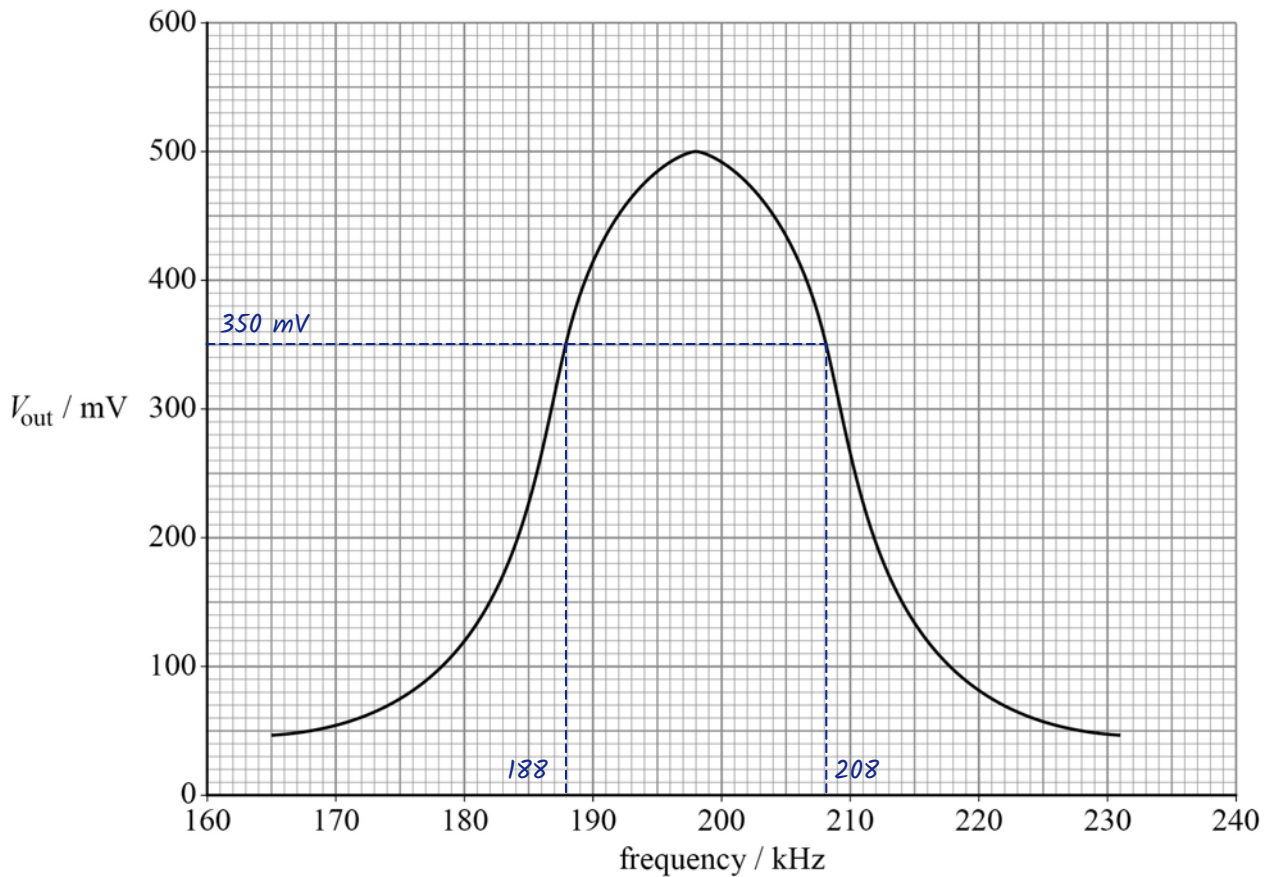
Question 2 continues on the next page

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0 2 . 3 Figure 5 shows part of the frequency response curve for a different filter circuit.

Figure 5



Determine the bandwidth of the filter circuit.

[2 marks]

$$V_{max} = 500 \text{ mV, so read at } 0.7 V_{max} = 0.7 \times 500 = 350 \text{ mV}$$

$$f_1 = 188 \text{ kHz and } f_2 = 208 \text{ kHz}$$

$$\text{bandwidth} = 208 - 188 = 20 \text{ kHz}$$

bandwidth = 20 kHz



0 2 . 4

Calculate the Q factor of the filter circuit in Question 02.3.

[1 mark]

$$Q = f_0 / f_B$$

$$f_0 = 198 \text{ kHz (resonant frequency at the peak)}$$

$$Q = 198 \text{ kHz} / 20 \text{ kHz} = 9.9$$

$$Q \text{ factor} = \underline{\quad 9.9 \quad}$$

0 2 . 5

The radio station is tuned using a different filter circuit with a very low Q factor.State and explain **one** effect of this change on the sound heard by a listener.

[1 mark]

A very low Q means a much larger bandwidth, so the listener hears

overlapping stations: nearby stations interfere with the wanted one.

7

Turn over for the next question

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0 3

Pulse code modulation (PCM) is used to encode live music as an uncompressed digital audio file.

Sampling of the analogue signal is carried out at 44.1 kHz.

A 16-bit system is used to encode each of the two channels that make up the stereo signal.

0 3 . 1

Explain why the sampling frequency used is suitable for this task.

[2 marks]

Music has an audio range (bandwidth) of about 20 kHz, i.e. frequencies up to 20 kHz.

By the Nyquist theorem the sampling frequency must be at least twice the maximum frequency (bandwidth): $2 \times 20 \text{ kHz} = 40 \text{ kHz}$. 44.1 kHz is greater than 40 kHz, so it is suitable.

0 3 . 2

Calculate the number of quantisation levels available on a 16-bit encoding system.

[1 mark]

$$\text{number of levels} = 2^n = 2^{16}$$

$$\text{number of quantisation levels} = 65\,536$$



- 0 3 . 3** A recorded piece of stereo music lasts for 3.5 minutes.

Calculate the size, in megabytes, of the digital file needed to store this recording.

[2 marks]

For one channel:

$$\text{bits} = 44.1 \times 10^3 \times 16 \times (3.5 \times 60) = 1.48 \times 10^8 \text{ bits} = 148.175 \text{ megabits}$$

$$\text{For stereo (2 channels): } 2 \times 148.175 = 296.35 \text{ megabits}$$

$$\text{file size} = 296.35 \div 8 = 37.04 \text{ megabytes} \approx 37 \text{ megabytes}$$

file size = 37 megabytes

- 0 3 . 4** The music file is used by a call centre to play as background music while a phone call is on hold. However, the telephone network is designed to use a bandwidth of 0.3 kHz – 3.4 kHz.

Compare the quality of the music heard by the telephone caller with that of the original file heard when played directly from a compact disc.

[2 marks]

The quality heard by the caller is lower: the telephone bandwidth (0.3 to 3.4 kHz, about 3 kHz) is much lower than the CD bandwidth (about 20 kHz).

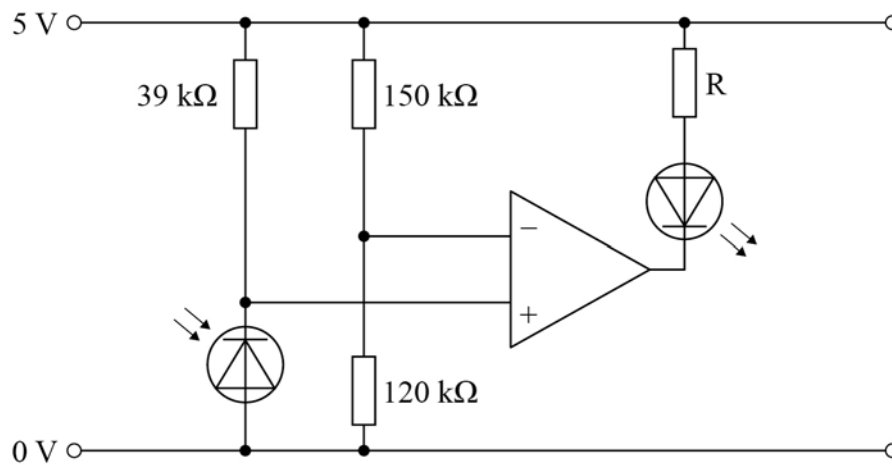
The low frequencies below 0.3 kHz and the high frequencies above 3.4 kHz are lost from the music, so it sounds thin and muffled.

Turn over ►



0 4

Figure 6 shows a circuit containing a photodiode and an ideal operational amplifier. This circuit is used to monitor the intensity of monochromatic radiation.

Figure 6

0 4 . 1

What is the configuration of the operational amplifier circuit shown in **Figure 6**? Tick (✓) **one** box.

[1 mark]

comparator



differential amplifier



inverting amplifier



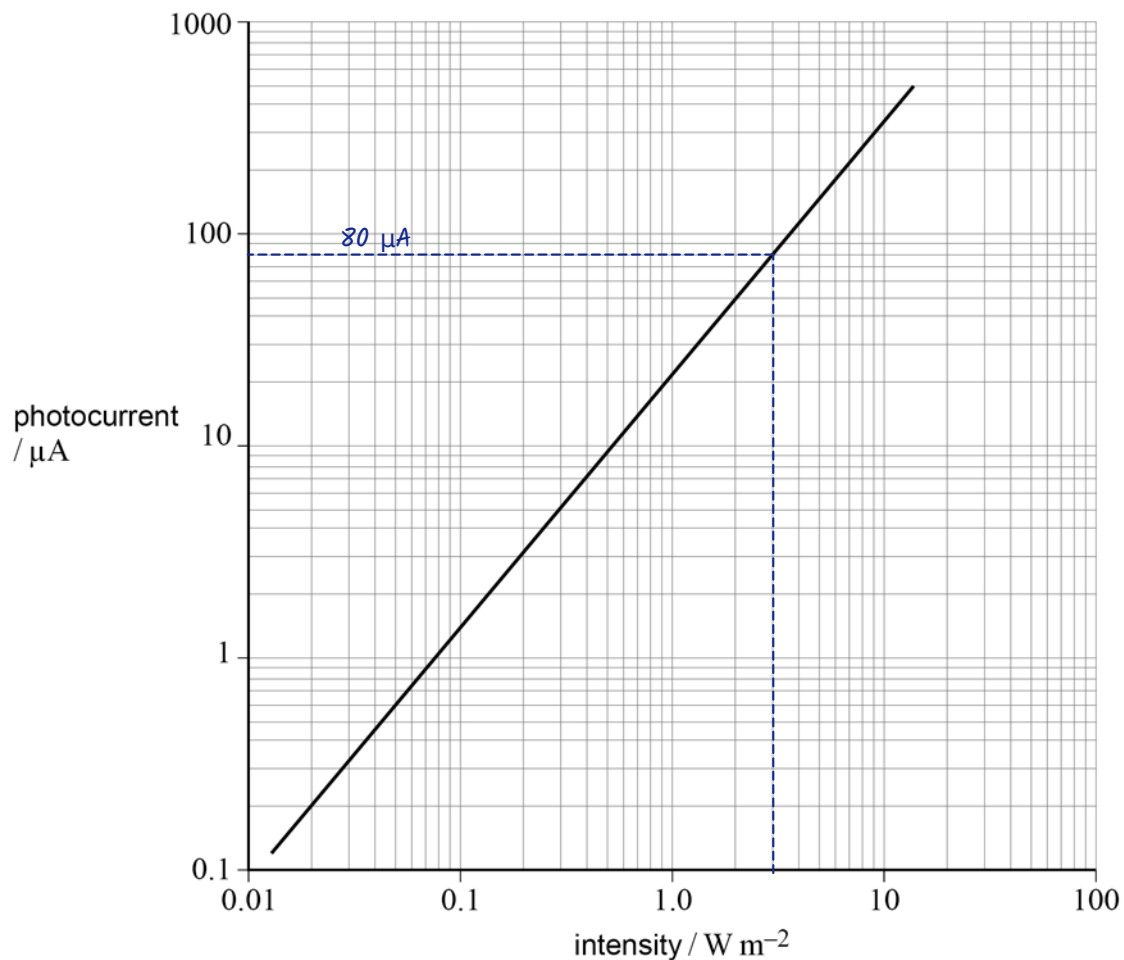
non-inverting amplifier



0 4 . 2

Figure 7 shows the variation of photocurrent with intensity for the monochromatic radiation incident on the photodiode.

Figure 7



Radiation of intensity 3.0 W m^{-2} is incident on the photodiode.

Show that the voltage at the non-inverting terminal (V_+) of the operational amplifier is 1.9 V.

[3 marks]

From Figure 7, at 3.0 W m^{-2} : photocurrent $I = 80 \mu\text{A}$

p.d. across the $39 \text{ k}\Omega$ resistor: $V_R = IR$

$$V_R = 80 \times 10^{-6} \times 39 \times 10^3 = 3.12 \text{ V}$$

$$V_+ = 5 - V_R = 5 - 3.12 = 1.88 \text{ V} \approx 1.9 \text{ V}$$

Question 4 continues on the next page

Turn over ►



0 4 . 3

The intensity of radiation incident on the photodiode remains at 3.0 W m^{-2} .

Deduce whether the light-emitting diode (LED) in **Figure 6** is on or off.

[2 marks]

Voltage at inverting pin from the potential divider:

$$V_- = 5 \times 120 / (150 + 120) = 2.2 \text{ V}$$

$$V_+ = 1.9 \text{ V}$$

V_- (2.2 V) is greater than V_+ (1.9 V), so the comparator output is low (about 0 V).

There is then a p.d. across the LED and R (from 5 V to the 0 V output), so current flows through it: the LED is on.



0 5

British embassies in Europe are to be connected to a new long-distance communication link. The link, in the form of a land-based cable, will support multiple simultaneous video conferencing as well as the transmission of sensitive government data.

The company installing the link has to consider the choice between using optic fibre or copper wire in the cables.

Compare the advantages and disadvantages of the two options for use in these cables.

State which option you would advise the company to use.

For both types of cable refer to their:

- physical properties
- ability to reject external interference
- signal-carrying properties.

[6 marks]

Physical properties: copper wire will corrode unless it is well protected, whereas glass optic fibre does not corrode, which suits a long land-based cable. Copper cable is heavier but is easier to join; optic fibre is lightweight, but sections are more difficult to join (they must be precisely aligned and spliced).

Ability to reject external interference: copper wire can pick up noise and cross talk from nearby cables and electrical equipment, because it carries electrical signals. Optic fibre carries light, so it is immune from electromagnetic noise and can be used in noisy environments.

Security matters for sensitive government data: copper can be tapped without breaking the cable, by picking up its signal. Optic fibre cannot be tapped unless the cable is physically broken into, which would be detected, so it is much more secure.

Signal-carrying properties: copper has high attenuation (signal degradation), so over a long distance many more repeaters or regenerators are needed. Optic fibre has low attenuation, although some

Question 5 continues on the next page

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pulse smearing (dispersion) is possible over long distances.

Copper has a relatively low bandwidth, so it has a low information-carrying capacity and fewer channels. Optic fibre has a much greater bandwidth, so it can carry many more channels and multiple types of signal at once, e.g. data plus talk, needed for multiple simultaneous video conferences.

Conclusion: although optic fibre is harder to join, I would advise the company to use optic fibre, because it does not corrode, is immune to interference, is secure against tapping for sensitive data, and has the low attenuation and high bandwidth needed for a long-distance link carrying multiple video conferences.

END OF QUESTIONS



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2 4



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