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Centre number

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Candidate number

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Surname

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Forename(s)

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A-level PHYSICS

Paper 3

Section B Electronics

Monday 3 June 2019

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	
3	
4	
5	
TOTAL	



J U N 1 9 7 4 0 8 3 B E 0 1

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Section BAnswer **all** questions in this section.**0 1**

Figure 1 shows the basic layout for a Johnson decade counter. The main input is the clock (CK). The main outputs are shown as Q_0 to Q_9 .

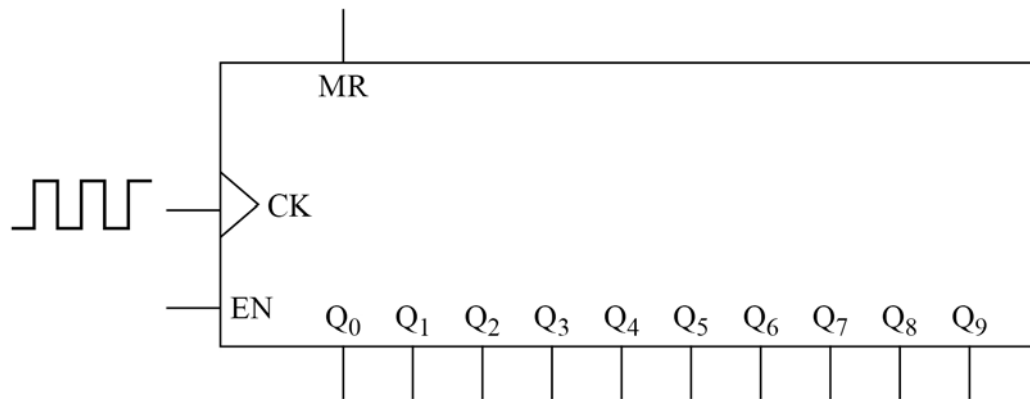
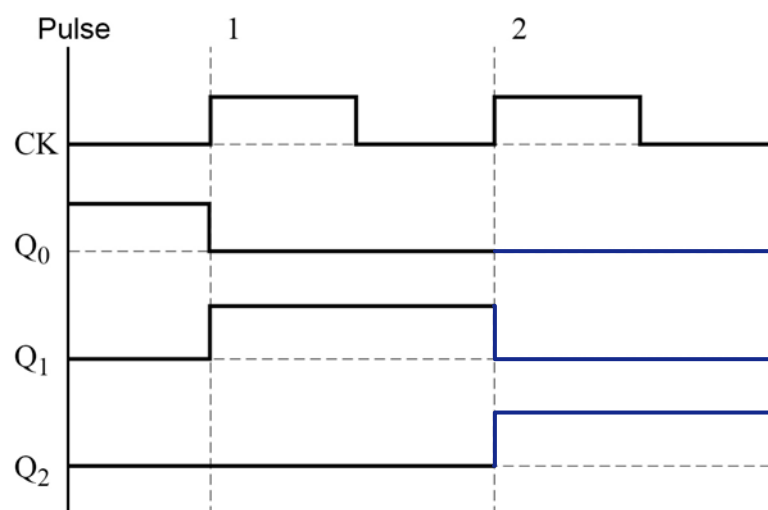
Figure 1**0 1 . 1**

Figure 2 shows part of the timing diagram for a Johnson decade counter. This timing diagram shows the output logic states against time. The counter is reset to make $Q_0 = 1$ and then the first two pulses are applied.

Complete **Figure 2** to show the logic states of Q_0 , Q_1 and Q_2 .

[2 marks]**Figure 2**

Question 1 continues on the next page

Turn over ►



0 1 . 2

A student sets up the counter to make the traffic light sequence:

red → **red + amber** → **green** → **amber**

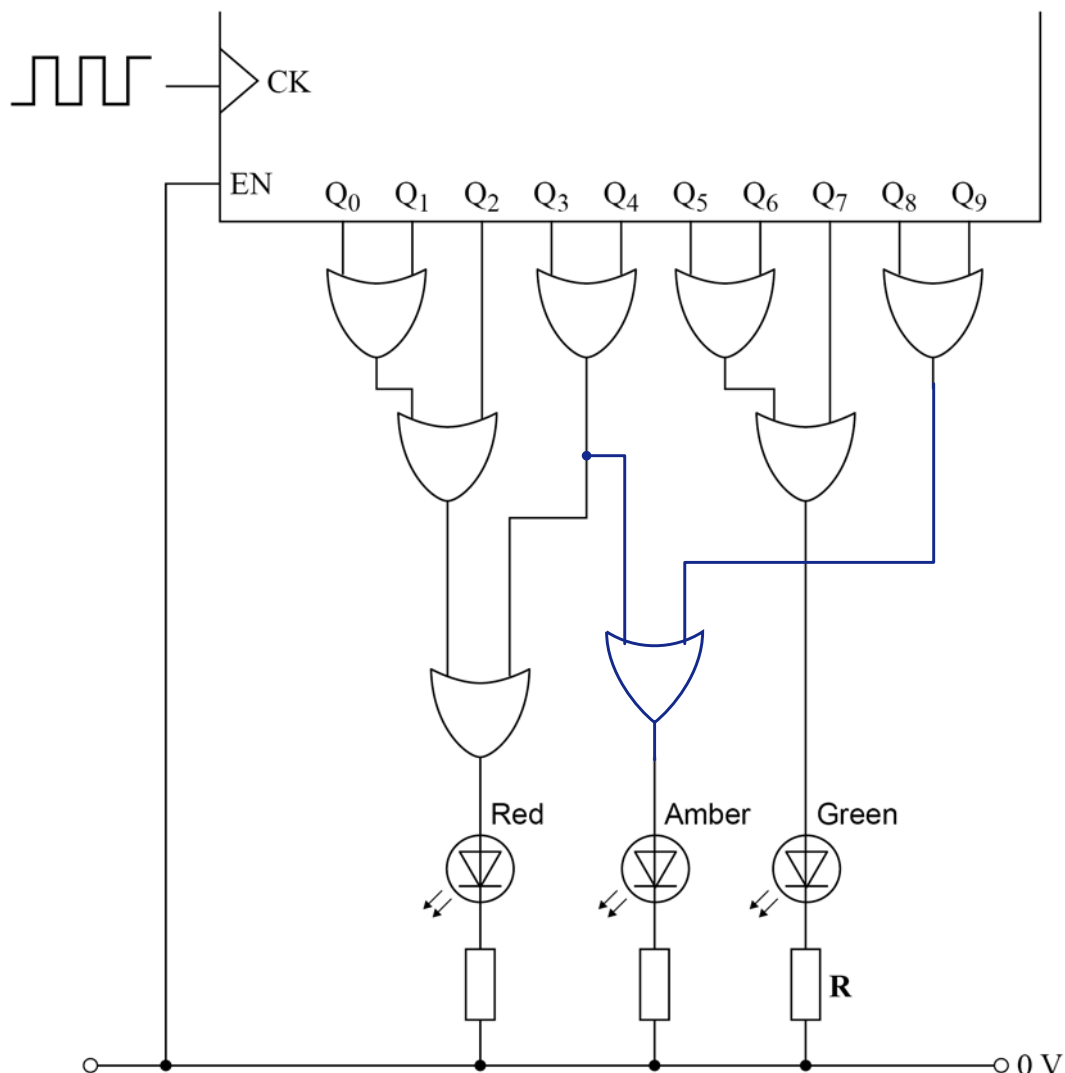
The sequence then repeats.

Figure 3 shows a partially completed diagram for producing this sequence.

Draw an OR gate and connections on **Figure 3** so that the LEDs go through the complete sequence.

[1 mark]

Figure 3



0 1 . 3

State **two** factors that determine the ON time for the green LED shown in **Figure 3**.
[2 marks]

1 *The frequency of the clock pulses (the period of each clock pulse).*

2 *The number of adjacent counter outputs that are OR'ed together to light the green LED.*

0 1 . 4

The potential difference across the green LED is 2.1 V when it is lit. The current through it should not exceed 9 mA.

All logic gate outputs are:

logic low = 0 V

logic high = 9 V.

The student suggests that a resistor of resistance 720 Ω and a tolerance of $\pm 5\%$ should be used for **R**.

Deduce whether the student's suggestion would be suitable.

[3 marks]

$$p.d. \text{ across } R: V_R = 9 - 2.1 = 6.9 \text{ V}$$

$$R = V_R / I = 6.9 / (9 \times 10^{-3}) = 767 \Omega \text{ (minimum value of } R)$$

$$720 \Omega \pm 5\%: \text{ range} = 684 \Omega \text{ to } 756 \Omega$$

Even the largest value, 756 Ω , is below the 767 Ω minimum: it gives 1

$$= 6.9 / 756 = 9.1 \text{ mA (684 } \Omega \text{ gives 10.1 mA).}$$

This exceeds the 9 mA limit, so the suggestion is not suitable.

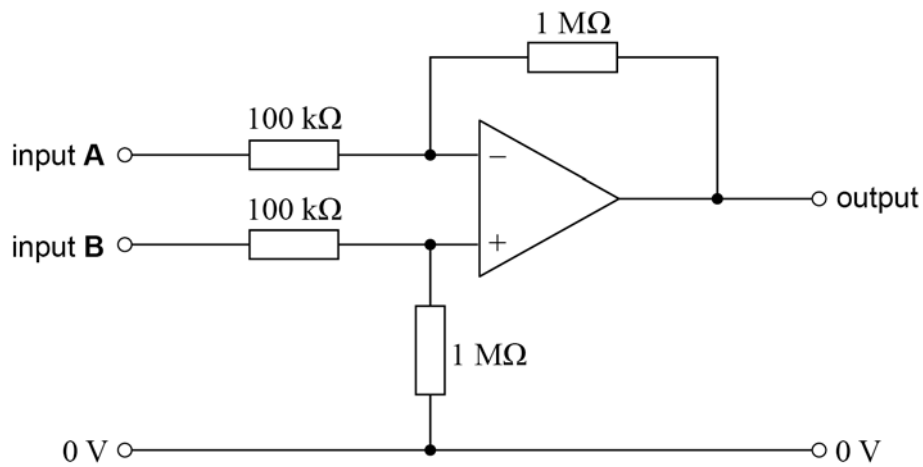
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0 2

Figure 4 shows an operational amplifier circuit used in an audio mixing desk.

Figure 4



The power supply for the amplifier is -12 V and $+12\text{ V}$ but this is not shown in **Figure 4**.

0 2

1

What is the operational amplifier configuration shown in **Figure 4**?
Tick (✓) **one** box.

[1 mark]

non-inverting amplifier

☐

comparator

☐

summing amplifier

☐

difference amplifier

☒


0 2 . 2

The circuit shown in **Figure 4** is tested by making the following connections:

- input **A** is connected to an audio signal of amplitude 150 mV
- input **B** is connected to 0 V.

Calculate the amplitude of the output voltage.

[2 marks]

$$V_{out} = (V_+ - V_-) \times R_f / R_{in}$$

$$V_{out} = (0 - 0.150) \times (1 \text{ M}\Omega / 100 \text{ k}\Omega) = -0.150 \times 10$$

$$V_{out} = -1.5 \text{ V}$$

output voltage = -1.5 V

Question 2 continues on the next page

Turn over ►



0 2 . 3

A microphone converts a sound wave into the voltage signal labelled **signal 1** in **Figure 5**. At the same time the microphone produces a second signal, labelled **signal 2**. **Signal 2** is the inversion of **signal 1**. These two signals travel along two separate wires in the same cable.

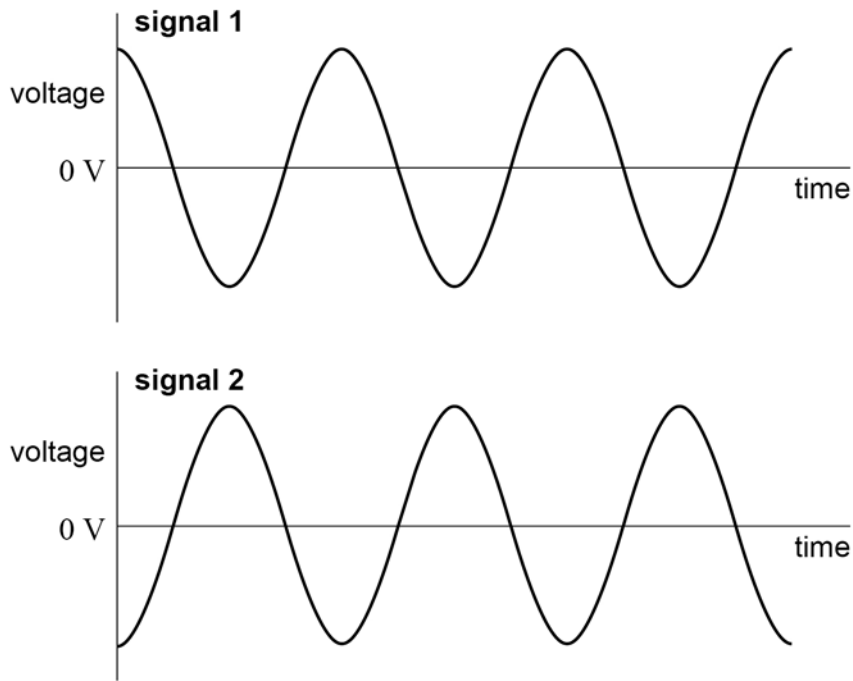
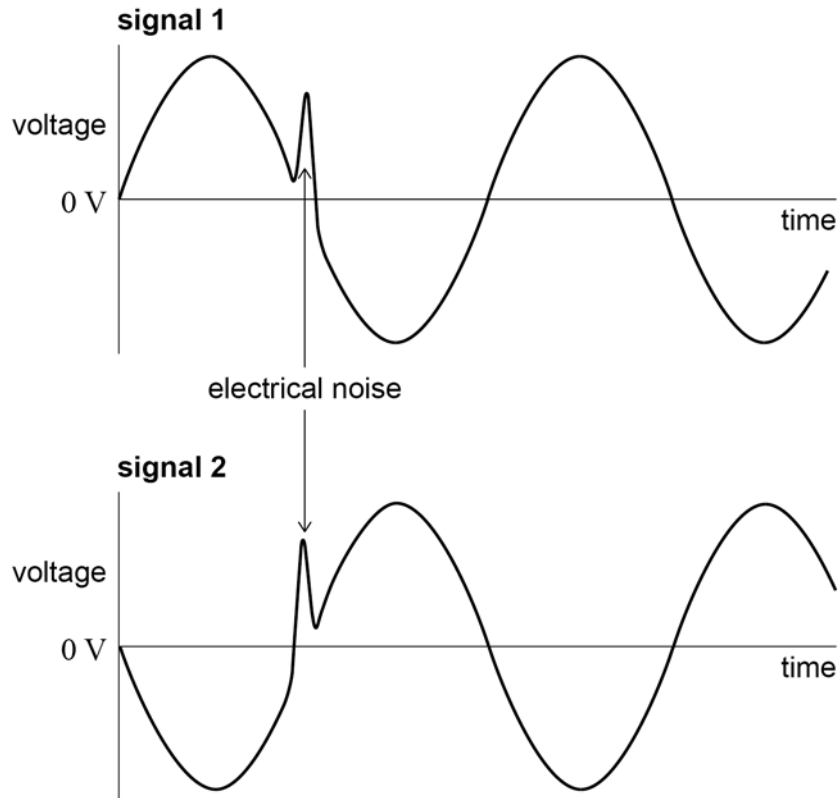
Figure 5

Figure 6 shows some electrical noise that has been picked up and added to the signals as they travel through the cable from the microphone to the operational amplifier circuit in **Figure 4**.

Figure 6



The connections made in question **02.2** are removed.

Signal 1 is connected to input **A** and **signal 2** is connected to input **B**.

Explain how the operational amplifier circuit affects the noise and strength of the output signal.

[3 marks]

It is a difference amplifier, so it subtracts signal 2 (at the + input) from signal 1 (at the - input), amplifying the difference by 10.

The noise is common to both signals (same size and same sign on both wires), so it is cancelled / eliminated when subtracted.

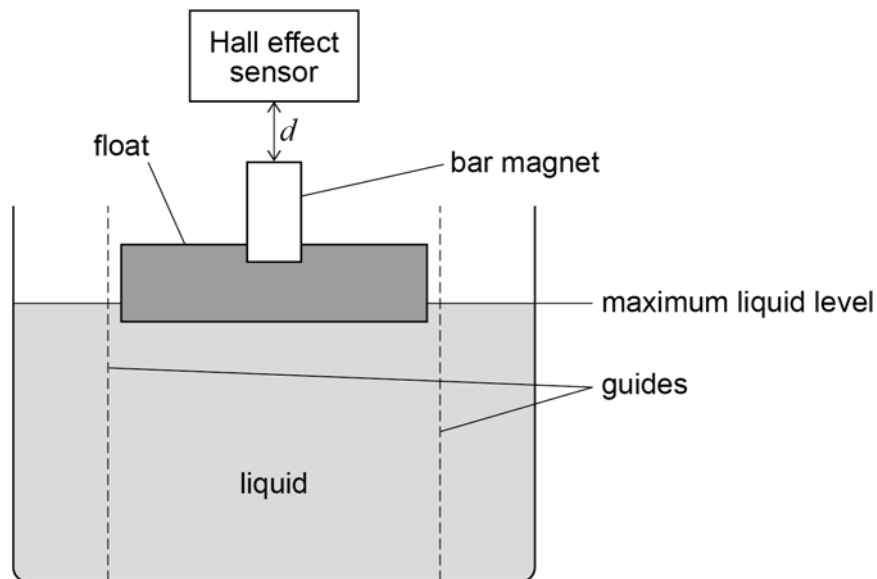
Signal 2 is the inverse of signal 1, so subtracting them adds (reinforces) the wanted signal, giving a stronger output.



0 3

Figure 7 shows a system to monitor a tank filling with liquid in which a magnet is mounted on a float.

Figure 7



The Hall effect sensor produces an output voltage V . V depends on the distance d between the sensor and the magnet.

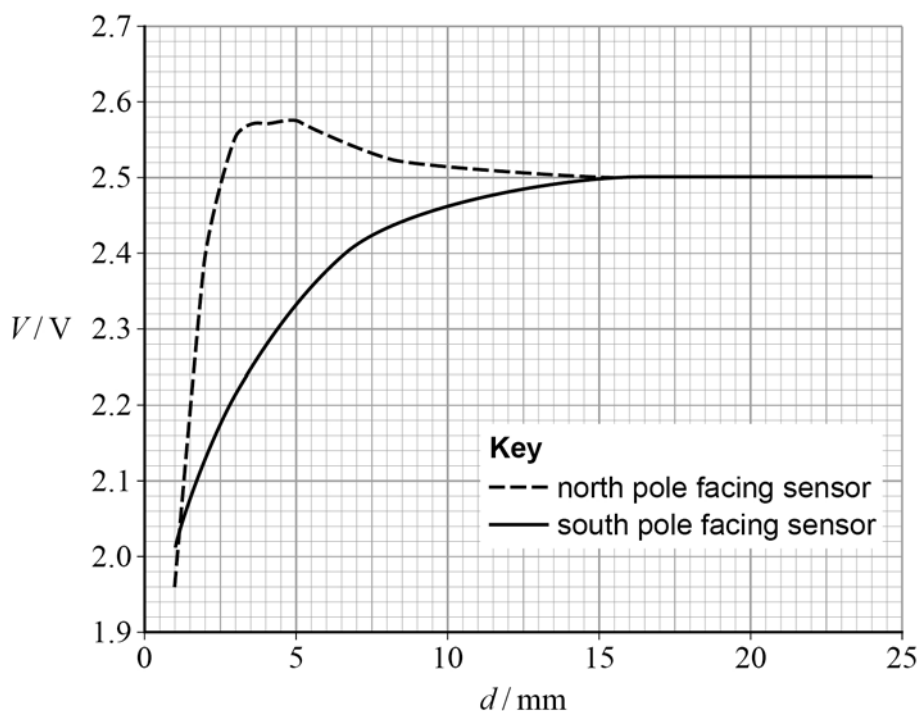
When V reaches a certain value, the flow of liquid to the tank is switched off.

The magnet may be arranged with either the north (N) or south (S) pole facing the sensor.



Figure 8 shows how the magnitude of V varies with d for the two possible arrangements of the magnet.

Figure 8



0 3 1

Compare the advantages of the two arrangements for monitoring the movement of the magnet towards the Hall effect sensor.

In your answer you should compare:

- the sensitivity of the system
- the range of d over which the system is useful.

You may ignore any effect from the Earth's magnetic field.

[3 marks]

North pole facing: higher sensitivity (larger gradient) but over a very short range of d (about 1 to 3 mm). The peak means one V can match more than one d , so the liquid level is ambiguous.

South pole facing: lower sensitivity (smaller gradient) but covers a larger range (about 1 to 15 mm), with no ambiguity: each d gives a unique V up to saturation.

Question 3 continues on the next page

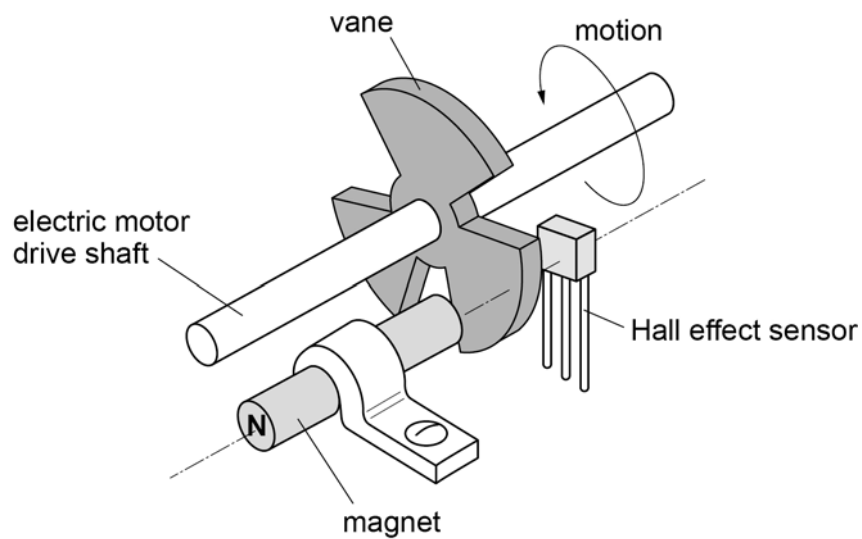
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0 3 . 2

Figure 9 shows a Hall effect sensor being used as a tachometer to monitor the rotational speed of the drive shaft of an electric motor.

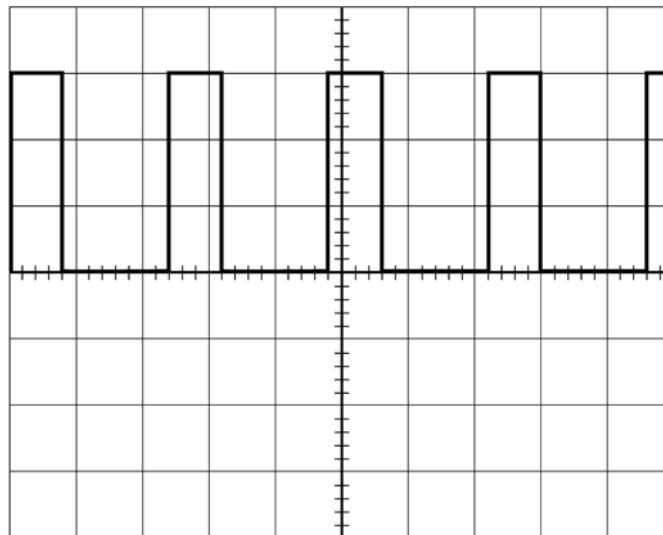
Figure 9



The output of the Hall effect sensor is connected to an oscilloscope. When the vane is between the magnet and the Hall effect sensor, the output of the Hall effect sensor is low.

The trace produced on the oscilloscope is shown in **Figure 10**.

Figure 10



The time-base on the oscilloscope is set to 5 ms / div.

Calculate the number of complete revolutions of the drive shaft in one second.

[3 marks]

One pulse every 2.4 div: $2.4 \times 5 \text{ ms} = 12 \text{ ms}$

The vane has 3 blades, so one revolution = 3 pulses

$T = 3 \times 12 \text{ ms} = 36 \text{ ms}$ ($7.2 \text{ div} \times 5 \text{ ms/div}$)

$f = 1 / T = 1 / 0.036 \text{ s} = 27.8 \text{ revolutions per second}$

Complete revolutions in 1 s = 27

number of complete revolutions = 27

6

Turn over for the next question

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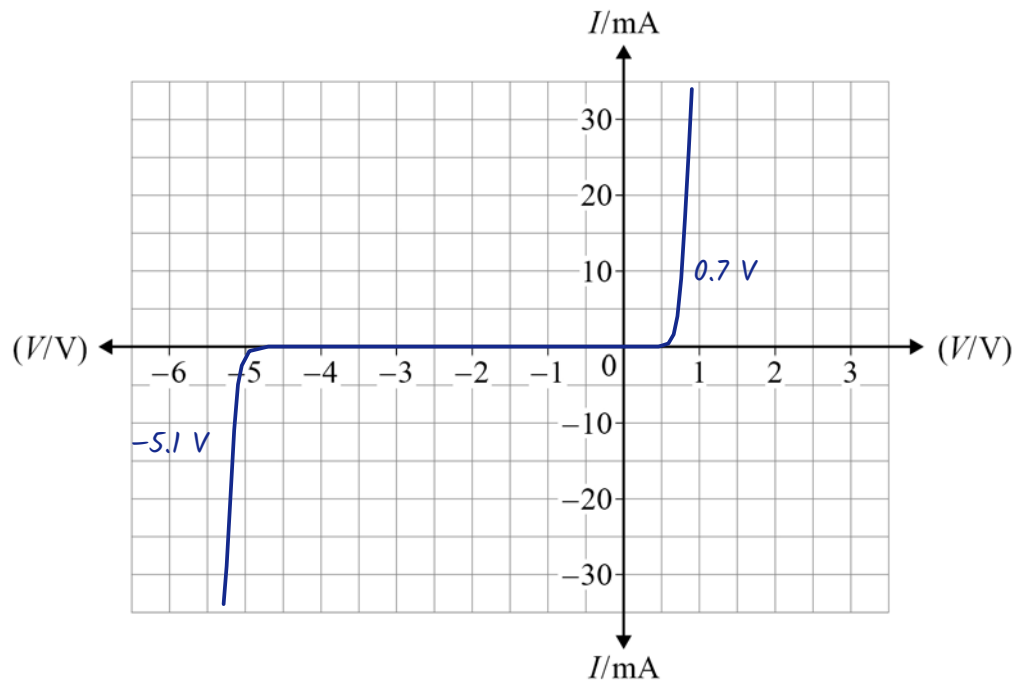


0 4

A silicon-based 5.1 V Zener diode requires a minimum operating current I of 5.0 mA to maintain its Zener voltage V_z .

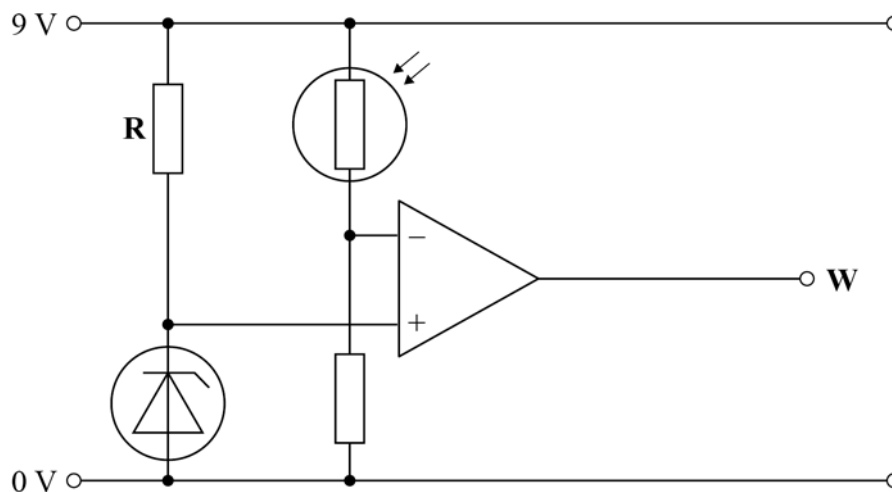
0 4 . 1

Draw on **Figure 11** the general I – V characteristic for this diode.

[2 marks]**Figure 11**

0 4 . 2

Figure 12 shows a circuit that uses a 5.1 V Zener diode. The circuit causes the output **W** of the operational amplifier to change at a particular light intensity.

Figure 12

State the function of the Zener diode in this circuit.

[1 mark]

It gives a stabilised 5.1 V reference voltage at the + input.

0 4 . 3

Deduce whether a 100 Ω , 0.13 W resistor is suitable for **R** in **Figure 12**.

[2 marks]

$$p.d. \text{ across } R = 9 - 5.1 = 3.9 \text{ V}$$

$$I = V / R = 3.9 / 100 = 0.039 \text{ A} = 39 \text{ mA}$$

$$P = I^2 R = (39 \times 10^{-3})^2 \times 100 = 0.152 \text{ W}$$

39 mA is larger than the 5.0 mA minimum needed for the Zener diode to work, so the resistance value is fine.

But 0.152 W is greater than the 0.13 W power rating, so the resistor is not suitable (it would overheat).

Question 4 continues on the next page

Turn over ►



0 4 . 4

The circuit in **Figure 12** is rebuilt and the position of **R** is swapped with the position of the Zener diode.

Explain how this affects the light intensity at which **W** changes.

[2 marks]

The reference voltage at the non-inverting input is now smaller (3.9 V not 5.1 V).

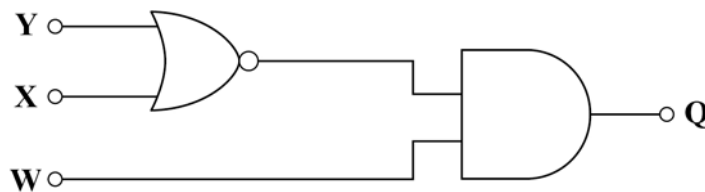
V₋ rises as light gets brighter, so it reaches the lower reference sooner:

W changes at a lower light intensity than before.

0 4 . 5

The output **W** from the operational amplifier shown in **Figure 12** becomes one of three inputs to the combinational logic circuit shown in **Figure 13**.

Figure 13



Write the Boolean algebra expression for the output **Q** in terms of **W**, **X** and **Y** based on the logic gates shown in **Figure 13**.

[1 mark]

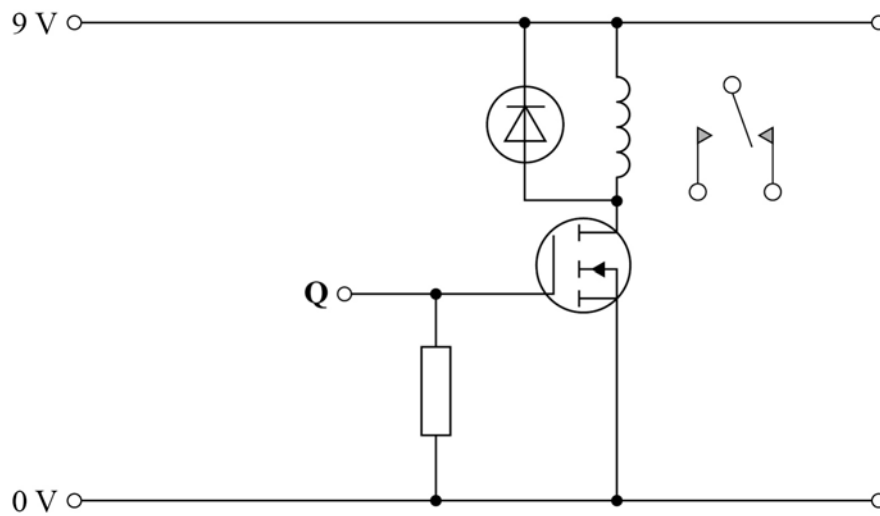
$$Q = \overline{(X + Y)} \cdot W$$



0 4 . 6

Output **Q** from **Figure 13** becomes the input to the final part of the circuit shown in **Figure 14**.

Figure 14



The circuit uses a MOSFET to activate a relay.

State **one** property that makes the MOSFET suitable for interfacing with logic gates.

[1 mark]

Very large input impedance (no loading of the logic gate output).

9

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0 5

A telephone company transmits 15 speech channels across a single transmission link. The analogue information is first subjected to pulse code modulation (PCM) before transmission using time division multiplexing (TDM). The transmission system incorporates regenerators which remove noise from the signal.

Explain the basic principles of:

- pulse code modulation (PCM)
- time division multiplexing (TDM)
- a regenerator.

[6 marks]

PCM: the analogue speech signal from each channel is sampled at regular intervals. The sampling frequency must be at least twice the highest frequency contained in the signal (e.g. 8 kHz for speech up to 4 kHz).

Each sample is then quantised: its voltage is given the nearest of a fixed number of levels, and that level is converted into an n -bit binary code (e.g. 8 bits gives 256 levels). The codes are sent as a serial stream of digital pulses.

The sampling rate and the number of bits per sample determine the bit rate, and the bit rate determines the bandwidth needed for transmission.

TDM: without TDM, each of the 15 speech channels would need its own cable / independent link, because their total bandwidth would exceed that of the link.

With TDM, the system allocates each channel a time slot in turn. A data block (one coded sample) from channel 1 is sent, then from channel 2, and so on up to channel 15, then the cycle repeats. The channels are multiplexed in sequence across the single link, and the full bandwidth of the link is available to each channel during its time slot.

At the receiver, a demultiplexer synchronised to the same timing separates the slots back into the 15 channels.



Regenerator: as the pulses travel along the link they are attenuated and distorted, and noise is added. A regenerator, placed at intervals along the link, uses a switching circuit (a Schmitt trigger) with two different switching thresholds.

The output only switches high when the input rises above the upper threshold and only switches low when it falls below the lower threshold, so noise between the thresholds has no effect. Clean, full-size pulses of the original shape are produced again, removing most of the noise before the signal is sent on.

Because the information is digital (just 1s and 0s), the regenerated signal is identical to the original code, so noise does not build up over long distances.

END OF QUESTIONS



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