Access Tuition

A-Level Physics

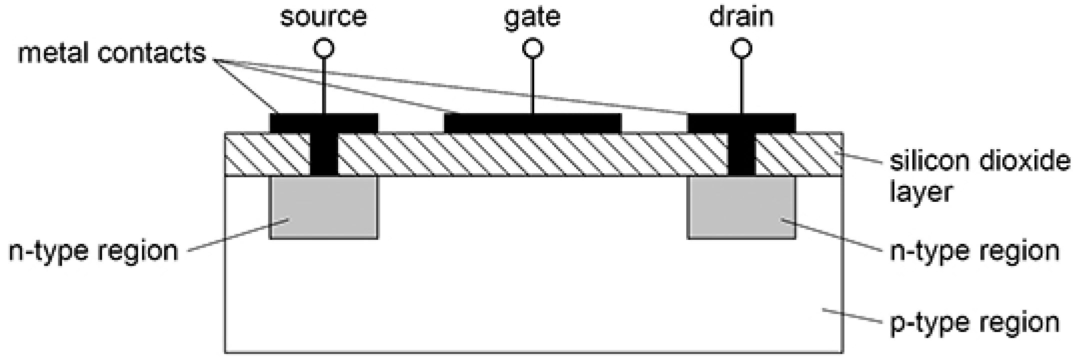
Discrete Semiconductor Devices

Question Paper

Time available: 73 minutes
Marks available: 42 marks

1. **Figure 1** shows a simplified structure of an N-channel enhancement mode MOSFET.

Figure 1



(a) State the name of the part shown in this MOSFET structure that causes the input resistance to be very large.

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(1)

(b) Which terminal of the MOSFET is connected directly to 0 V when it is used as a simple switch?

Tick (✓) **one** box.

drain ☐

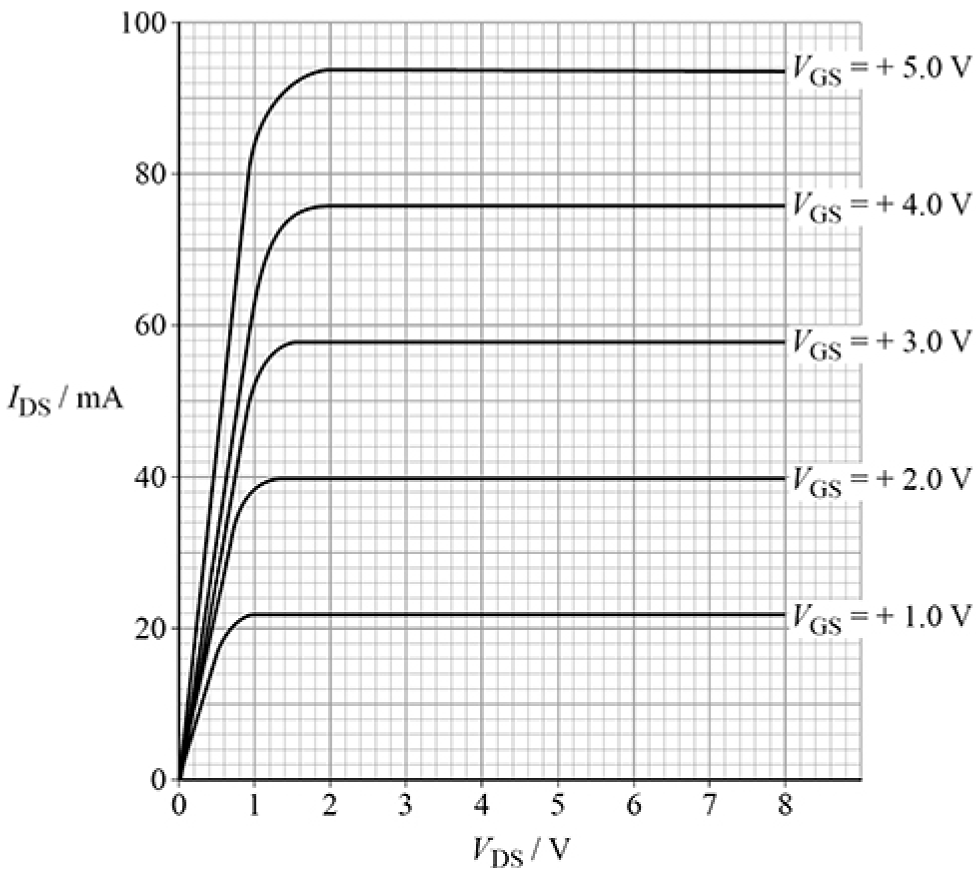
gate ☐

source ☐

(1)

Figure 2 shows how the drain–source current I_{DS} of the MOSFET varies with drain–source voltage V_{DS} for a range of gate–source voltages V_{GS}.

Figure 2



The MOSFET is used as a simple switch in a filament lamp circuit.
The circuit uses power rails of 12 V and 0 V.
The resistance of the lamp is 154 Ω when operating at its full power of 0.65 W.

(c) Deduce the minimum value of V_{GS} needed for the lamp to operate at full power.

V_{GS} = ________________ V

(2)

(d) **Figure 3** shows an individual MOSFET. The drain–source leakage current I_{DSS} for this MOSFET is about 10 nA.

Figure 4 shows a microchip where millions of MOSFETs are combined to enable complex processes to be carried out on one chip.

Figure 3

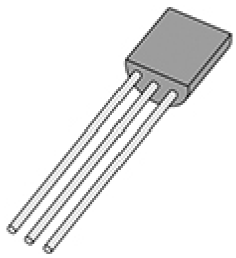
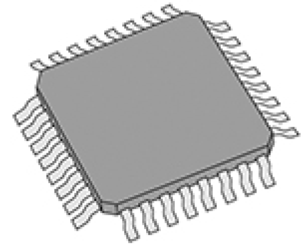


Figure 4



A mobile phone has a central processing unit (CPU) which uses a microchip similar to the one in **Figure 4**.

The table below shows the technical specification for the mobile phone.

Number of transistors in the CPU	8.5×10^9
Battery capacity	3110 mA h
Phone time available on stand-by from one full charge	≈ 12 hours

A fully charged battery with a capacity of 1 A h allows 3600 C of charge to flow through it before it is fully discharged.

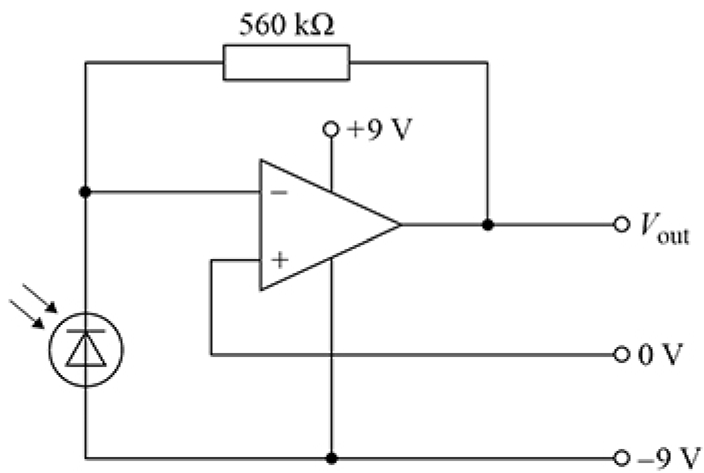
The I_{DSS} value for each MOSFET used in the mobile phone CPU must be different from that measured in the individual MOSFET shown in **Figure 3**.

Discuss, using the data provided, the reason for this difference.

(3)
(Total 7 marks)

2. **Figure 1** shows the circuit for an infrared detector using a photodiode and an operational amplifier. In this application the operational amplifier uses a feedback resistor to give a voltage signal when the current in the photodiode changes.

Figure 1



(a) State the mode in which the photodiode is being used in **Figure 1**.

(1)

(b) In the circuit shown in **Figure 1**, there is a current in the photodiode even when there is no light incident on it. This current is called the dark current.

In an optical communication system, the dark current needs to be very small in comparison to the photodiode current.

Explain why.

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(1)

The responsivity R_λ of a silicon photodiode is a measure of its sensitivity to light at a given wavelength λ.

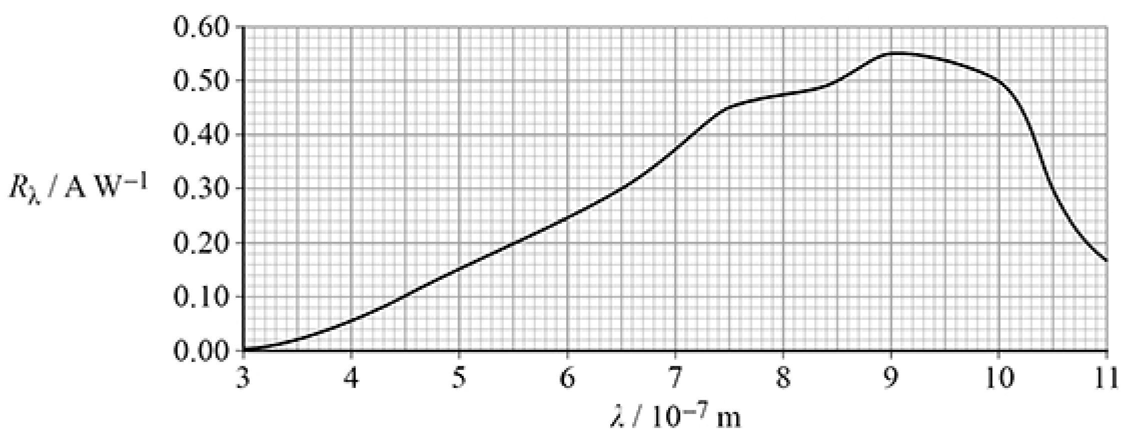
R_λ is defined as:

$$R_\lambda = \frac{I_p}{P}$$

where I_p is the current in the photodiode and P is the incident light power at the given wavelength.

Figure 2 shows the spectral response graph for this photodiode.

Figure 2



(c) Monochromatic radiation of wavelength 850 nm and power 4.0 μW is incident on the photodiode in **Figure 1**.

Calculate the output voltage of the detector circuit.

output voltage = _______________ V

(3)

(d) The output from the detector circuit in **Figure 1** needs to be amplified by a factor of +4

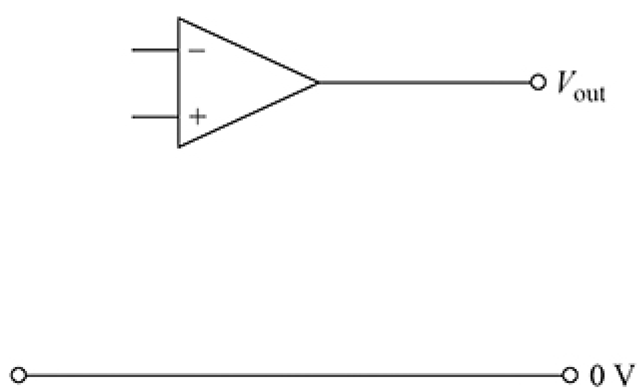
Complete **Figure 3** to show the amplifier circuit required.

In your completed circuit you should:

- label the input point as $\mathbf{V_{in}}$
- label your Figure with the values of resistance for any resistors used in your circuit. Any resistance values must lie within the range 1 kΩ to 100 kΩ.

Do **not** show the power supplies to the operational amplifier.

Figure 3

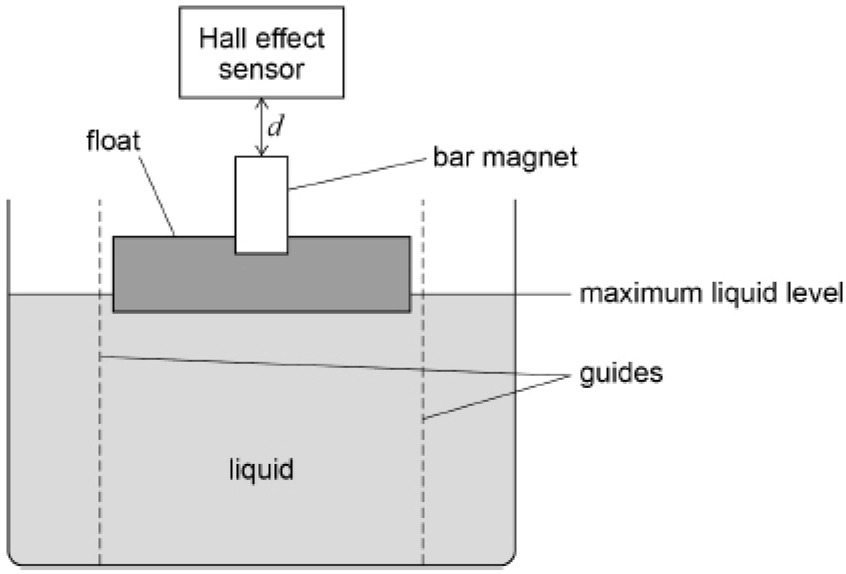


(3)

(Total 8 marks)

3. **Figure 1** shows a system to monitor a tank filling with liquid in which a magnet is mounted on a float.

Figure 1



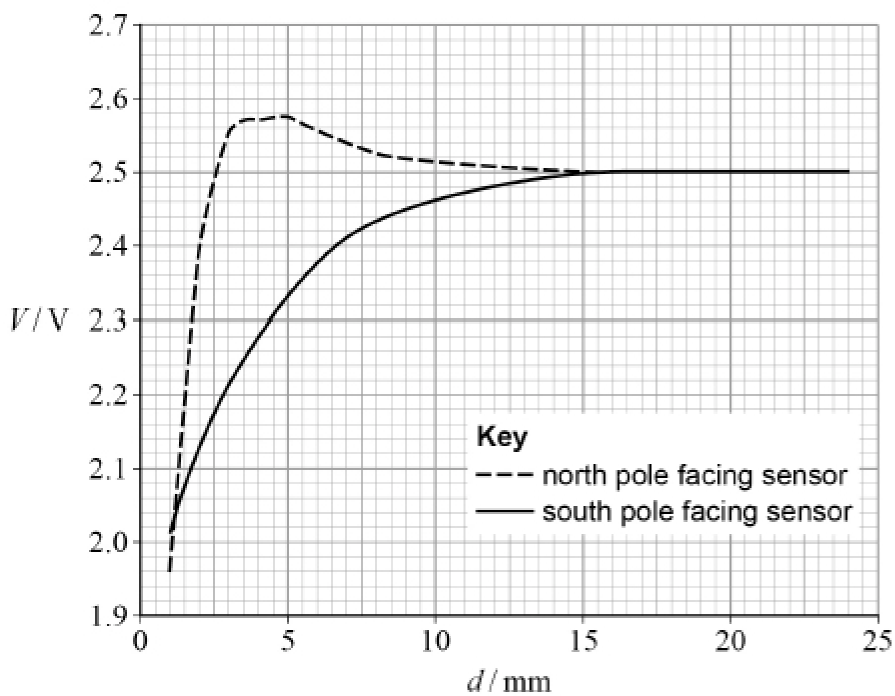
The Hall effect sensor produces an output voltage V. V depends on the distance d between the sensor and the magnet.

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

Figure 2



(a) 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.

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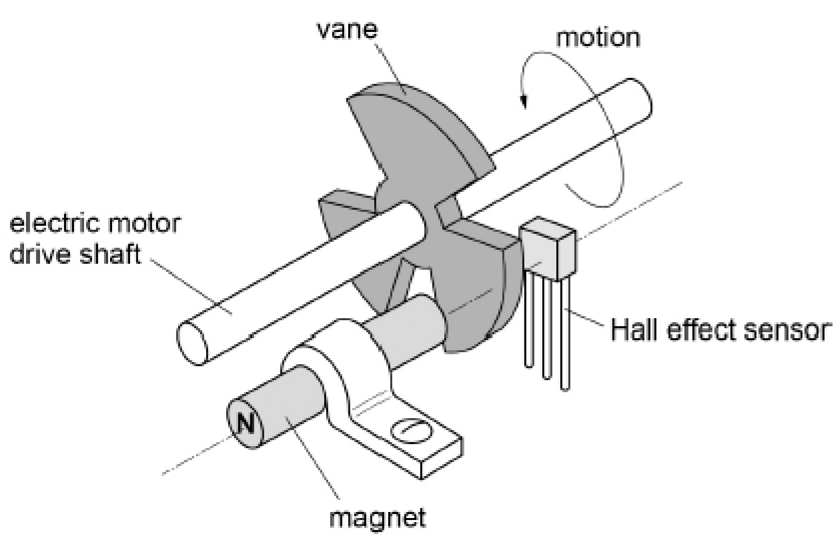
(3)

(b) **Figure 3** shows a Hall effect sensor being used as a tachometer to monitor the rotational speed of the drive shaft of an electric motor.

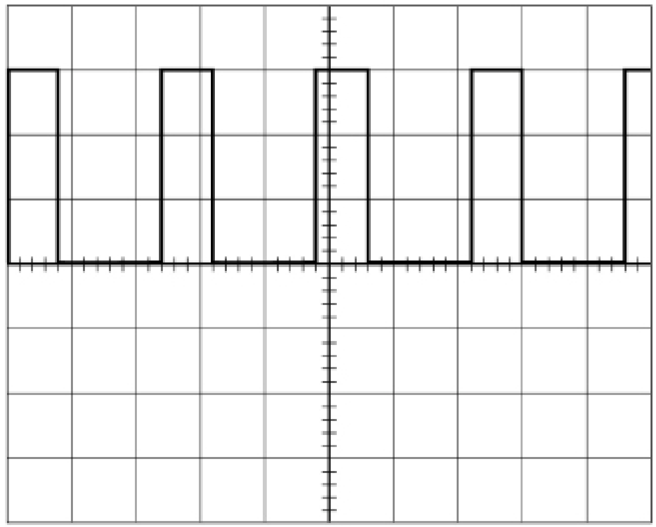
Figure 3



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 4**.

Figure 4



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.

number of complete revolutions = ____________________ V

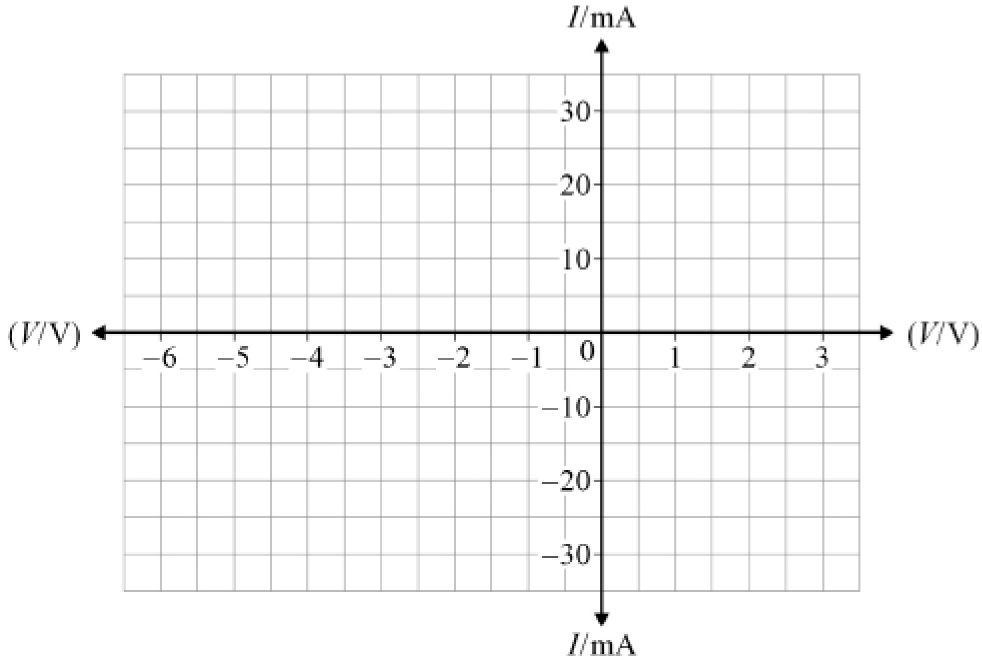
(3)

(Total 6 marks)

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.

(a) Draw on **Figure 1** the general $I-V$ characteristic for this diode.

Figure 1

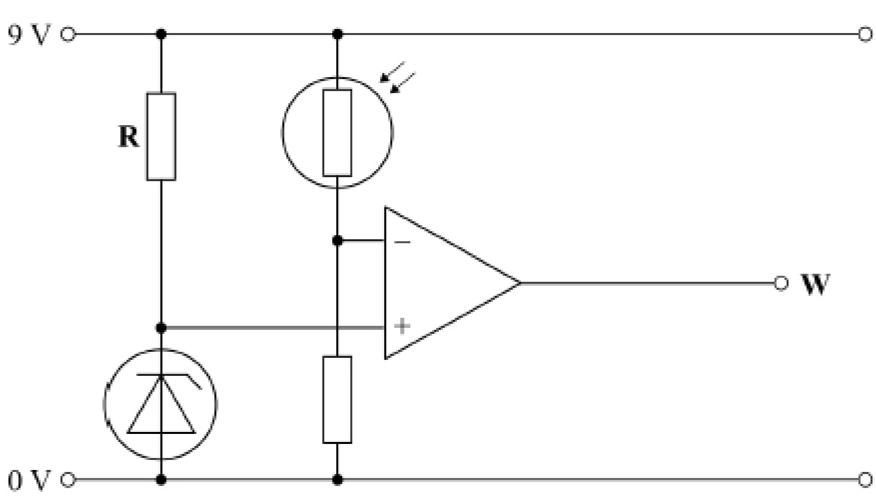


(2)

(b) **Figure 2** 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 2



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State the function of the Zener diode in this circuit.

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(1)

(c) Deduce whether a 100 Ω, 0.13 **W** resistor is suitable for **R** in **Figure 2**.

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(2)

(d) The circuit in **Figure 2** 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.

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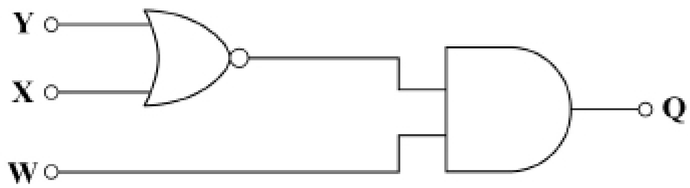
(2)

(e) The output **W** from the operational amplifier shown in **Figure 2** becomes one of three inputs to the combinational logic circuit shown in **Figure 3**.

Figure 3



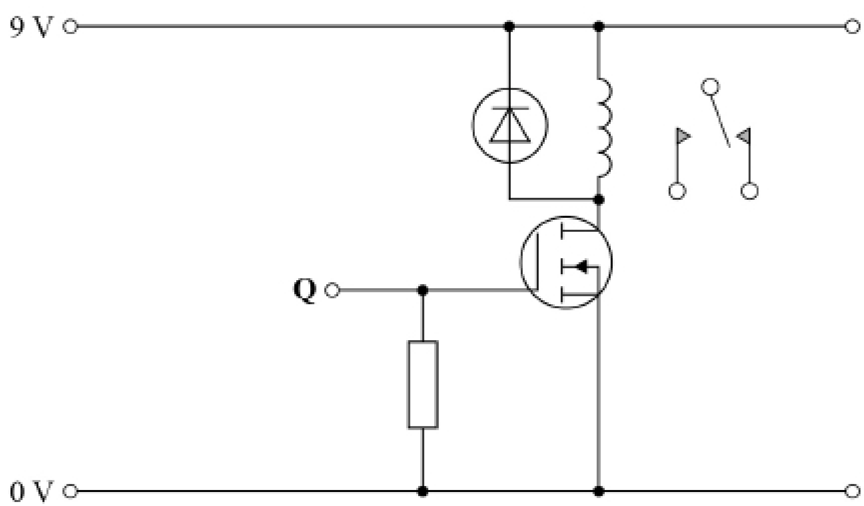
Write the Boolean algebra expression for the output **Q** in terms of **W**, **X** and **Y** based on the logic gates shown in **Figure 3**.

Q = ____________________

(1)

(f) Output **Q** from **Figure 3** becomes the input to the final part of the circuit shown in **Figure 4**.

Figure 4



The circuit uses a MOSFET to activate a relay.

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

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(1)

(Total 9 marks)

5. (a) **MOSFETs are commonly used in circuits where low power consumption is important to extend battery life.**

State and explain the property of MOSFET devices that makes them useful in these circuits.

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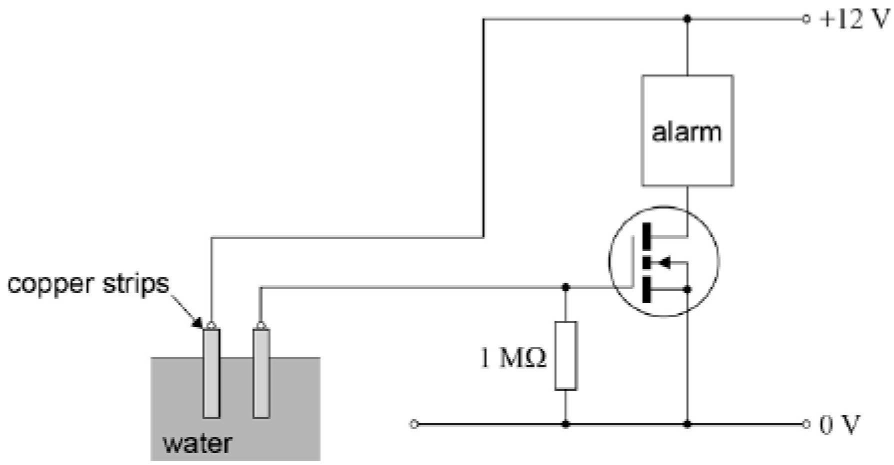
(2)

The figure below shows an N-channel enhancement mode MOSFET, being used as part of a circuit for the water level alarm in a garden pond.
When the gap between the copper strips is filled with water the MOSFET turns on and the alarm sounds.



(b) Explain the reason for the 1 MΩ resistor in this application.

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(2)

(c) The circuit is tested by immersing the copper strips in the water, and bringing them closer together until the alarm sounds.
V_{th} for the MOSFET in the figure above is 2.4 V.

Determine the resistance of the water between the copper strips when the alarm sounds.

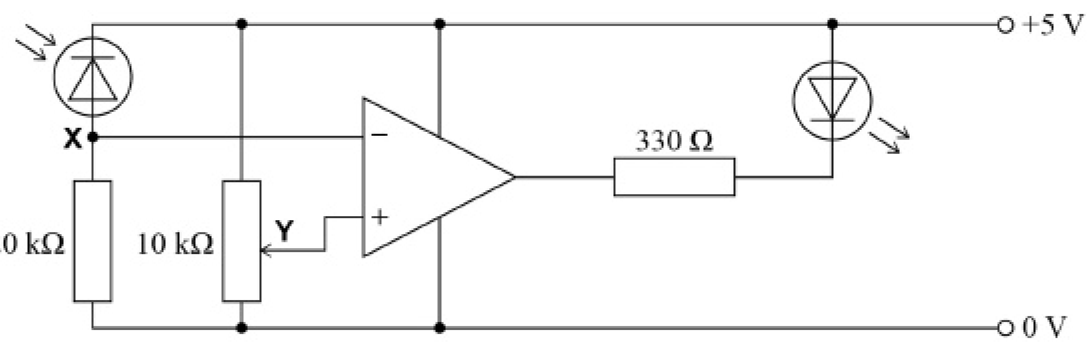
resistance = ____________________ MΩ

(2)

(Total 6 marks)

6. A photodiode forms part of a light meter used for checking light levels in an office. **Figure 1** shows the circuit diagram for the light meter.

Figure 1



(a) State the mode in which the photodiode is being used in **Figure 1**.

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(1)

(b) In which mode is the operational amplifier being used in **Figure 1**?

Tick (✓) the correct box.

Non-inverting amplifier ☐

Comparator ☐

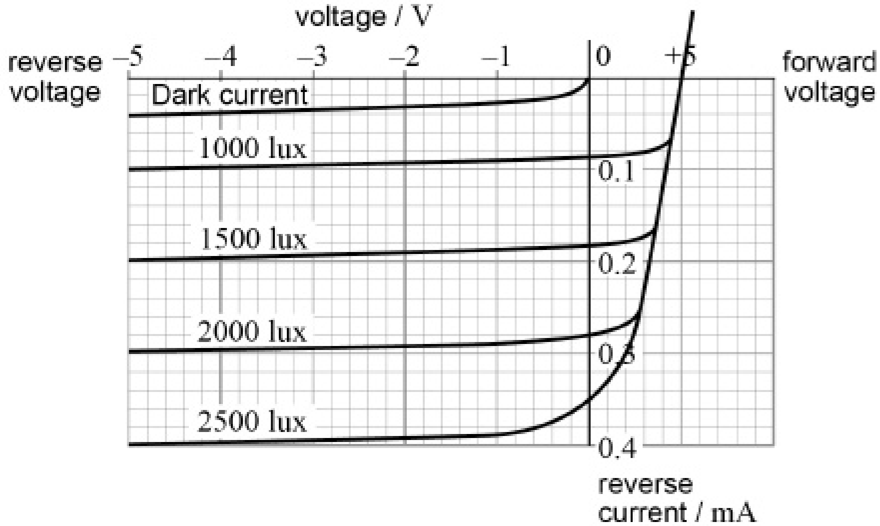
Summing amplifier ☐

Difference amplifier ☐

(1)

(c) **Figure 2** shows an extract from a data sheet of the characteristics for a photodiode under different light levels measured in lux.

Figure 2



For a particular lighting condition, the current through the photodiode in **Figure 1** was 0.10 mA.

Estimate, using the information in **Figure 2**, the light level needed to cause this reverse current through the photodiode.

light level = ____________________ lux

(1)

(d) Calculate the voltage at point **X** in the circuit shown in **Figure 1** for the light level in question (c).

voltage = ____________________ V

(1)

(e) The 10kΩ linear potential divider shown in **Figure 1** is set to give 1.75 V at point **Y**.

Assume that the operational amplifier has ideal characteristics.

Deduce whether the output LED would be switched ON or OFF when the current through the photodiode is 0.10 mA.

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(2)

(Total 6 marks)