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AQA A LEVEL PHYSICS (7408): QUESTIONS BY TOPIC

Electricity (3.5)

A Level Physics (7408) · Section 3.5

97 questions · 409 marks · Mark schemes included

AQA A Level Physics (7408), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.
Click any row below to jump straight to that sub-topic or question.
On every question page, click ANSWER in the top-right corner to jump to its mark scheme.
Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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72.	**Q23**	*also 3.4 & 3.7*	7408/2 June 2023	1	**136**
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QUESTIONS

97 questions · 409 marks · 7 sub-topics

SUB-TOPIC 3.5.1.1

BASICS OF ELECTRICITY

Sub-topic 3.5.1.1 · 8 questions · 24 marks · lowest tariff first

2 6 A mobile phone operates at a constant power of 200 mW
It has a 3.7 V lithium-ion battery that has a charge capacity of 9400 C

What is the time taken for the battery to discharge completely?

[1 mark]

A 2 hours ⬭

B 48 hours ⬭

C 120 hours ⬭

D 140 hours ⬭

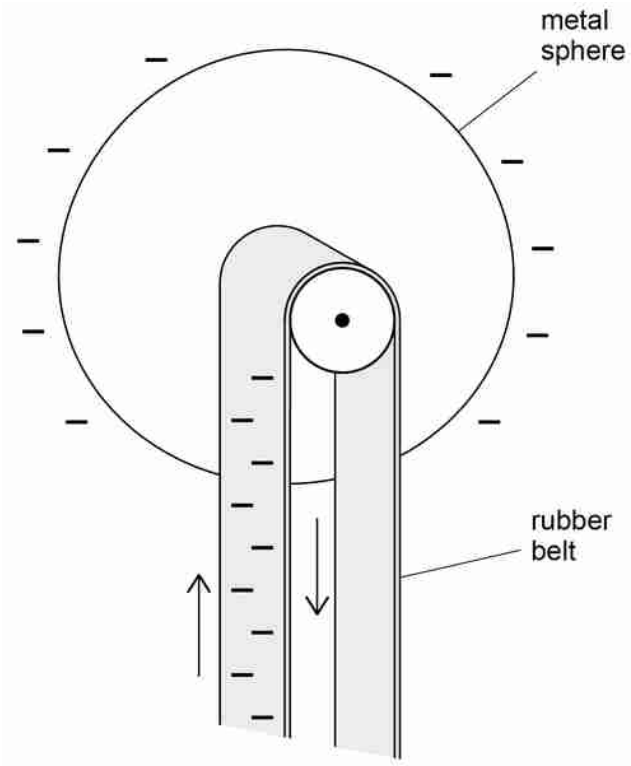
2 8 A voltmeter is used to measure potential difference for a component **X**.

Which row gives the position and ideal resistance for the voltmeter?

[1 mark]

	Position	Ideal resistance	
A	in series with **X**	infinite	⬭
B	in series with **X**	zero	⬭
C	in parallel with **X**	infinite	⬭
D	in parallel with **X**	zero	⬭

2 1 A rubber belt in an electrostatic machine has a width of $0.1\ \text{m}$ and moves with speed $0.4\ \text{m s}^{-1}$.
Each square metre of the belt carries a charge Q coulomb. The charge is removed and transferred to a metal sphere.



What is the charge collected by the sphere each second?

[1 mark]

A $0.016Q$ ⬭

B $0.04Q$ ⬭

C $0.25Q$ ⬭

D $4Q$ ⬭

2 9 The current in a metallic conductor is $1.5\ \text{mA}$.

How many electrons pass a point in the conductor in two minutes?

[1 mark]

A 1.1×10^{18} ⬭

B 1.9×10^{19} ⬭

C 1.4×10^{20} ⬭

D 2.0×10^{29} ⬭

2 9 A resistor dissipates 100 W when connected across a 25 V supply with negligible internal resistance.
The supply output is reduced to 20 V and the resistor is replaced so that the power dissipated is still 100 W.

What is the percentage decrease in resistance?

[1 mark]

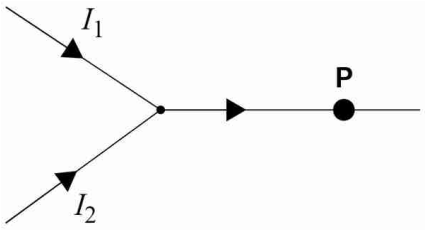
A 20 ⬭

B 36 ⬭

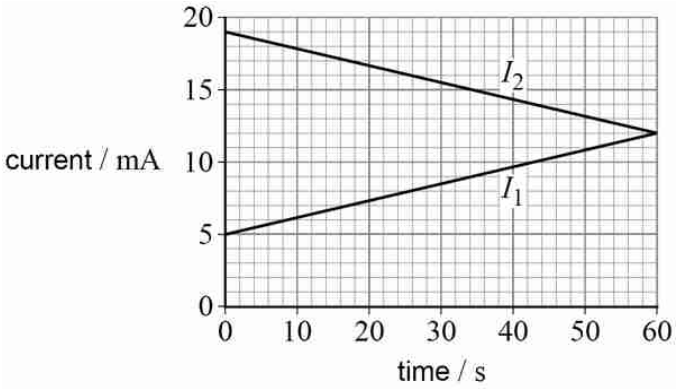
C 64 ⬭

D 80 ⬭

2 9 The diagram shows part of a circuit.



The graph shows how the two currents I_1 and I_2 vary with time.



What is the total charge that flows through point **P** in 60 s?

[1 mark]

A 1.44 C ⬭

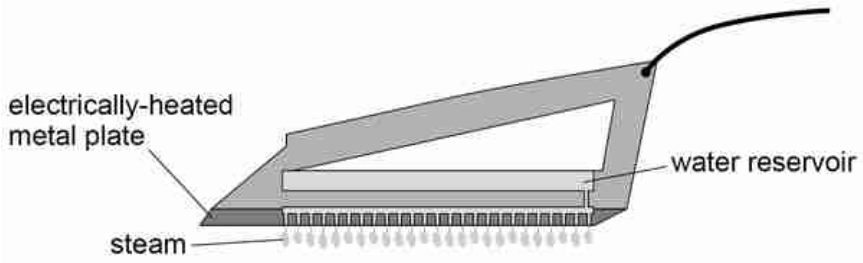
B 0.93 C ⬭

C 0.72 C ⬭

D 0.42 C ⬭

0 1 **Figure 1** shows an electric steam iron.

Figure 1



Water from a reservoir drips onto an electrically-heated metal plate. The water boils and steam escapes through holes in the metal plate.

The electrical power of the heater inside the iron is 2.1 kW.

Assume that all the energy from the heater is transferred to the metal plate.

0 1 . 1 The metal plate has a mass of 1.2 kg and is initially at a temperature of 20 °C. The heater is switched on. After a time t the metal plate reaches its working temperature of 125 °C.

Calculate t.

specific heat capacity of the metal = 450 J kg^{-1} K^{-1}

[2 marks]

t = _____ s

0 1 . 2 The metal plate is maintained at its working temperature.
Water at $20\ °C$ drips continuously onto the metal plate.
Steam at $100\ °C$ emerges continuously from the iron.

The maker claims that the iron can generate steam at a rate of $60\ g\ min^{-1}$.

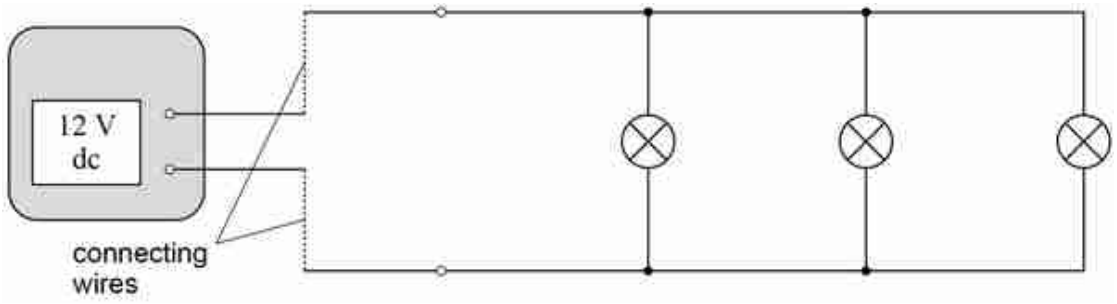
Determine whether this claim is true.

specific latent heat of vaporisation of water $= 2.3 \times 10^6\ J\ kg^{-1}$
specific heat capacity of water $= 4200\ J\ kg^{-1}\ K^{-1}$

[3 marks]

0 5 **Figure 9** shows some of the apparatus used in a demonstration of electrical power transmission using a dc power supply.

Figure 9



A power supply of emf 12 V and negligible internal resistance is connected to three identical 12 V, 1.5 W lamps in parallel.

0 5 . 1 Show that the resistance of one of the lamps when it is operating at 12 V is about 100 Ω.

[1 mark]

0 5 . 2 Initially the power supply is connected to the lamps using two short copper wires of negligible resistance.

Calculate the current in the power supply.

[2 marks]

current = _____ A

0 5 . 3 The two short copper wires are replaced with two long constantan wires.

Show that the resistance of each length of constantan wire is about $50\ \Omega$.

length of each constantan wire	$= 2.8\ \text{m}$
diameter of constantan wires	$= 0.19\ \text{mm}$
resistivity of constantan	$= 4.9 \times 10^{-7}\ \Omega\ \text{m}$

[3 marks]

0 5 . 4 The demonstration is intended to show that the lamps are significantly dimmer when connected using the long constantan wires than when using the short copper wires.

Discuss whether the demonstration achieves this.
Support your answer with suitable calculations.

[4 marks]

Question 5 continues on the next page

0 5 . 5 Scientists and engineers are investigating the use of superconductors in electrical transmission.

Discuss **one** advantage and **one** difficulty when using superconductors in electrical transmission over long distances.

[3 marks]

Advantage _____

_____

_____

_____

Difficulty _____

_____

_____

_____

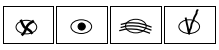
END OF SECTION A

Section B

Each of Questions **06** to **30** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.
For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD  WRONG METHODS 

If you want to change your answer you must cross out your original answer as shown. 

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown. 

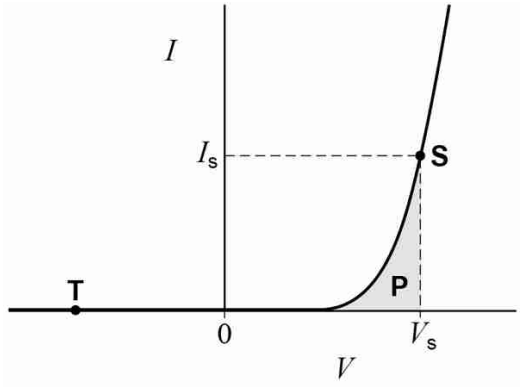
You may do your working in the blank space around each question but this will not be marked. Do **not** use additional sheets for this working.

SUB-TOPIC 3.5.1.2

CURRENT-VOLTAGE CHARACTERISTICS

Sub-topic 3.5.1.2 · 4 questions · 45 marks · lowest tariff first

1 6 The graph shows the I–V characteristic for a semiconductor diode.



Which is true for this graph?

[1 mark]

A The resistance of the diode decreases as V increases for $V > V_s$. ⬭

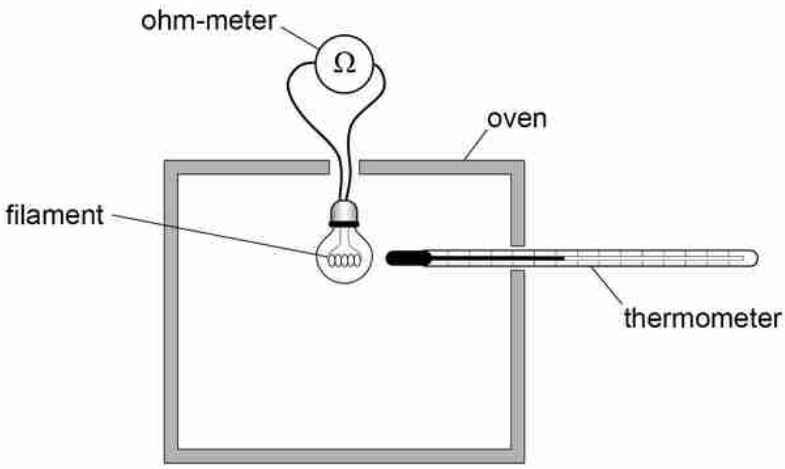
B The resistance at **S** is equal to $\frac{1}{\text{gradient}}$ ⬭

C The resistance at **T** is equal to zero. ⬭

D At $I = I_s$, the power dissipated in the diode is equal to area **P**. ⬭

0 3 **Figure 5** shows apparatus to investigate how the resistance R of a lamp filament varies with the absolute temperature T of the filament.

Figure 5



The lamp is inside an oven.

The oven temperature is increased to a steady value.
The filament is at the same temperature as the inside of the oven.

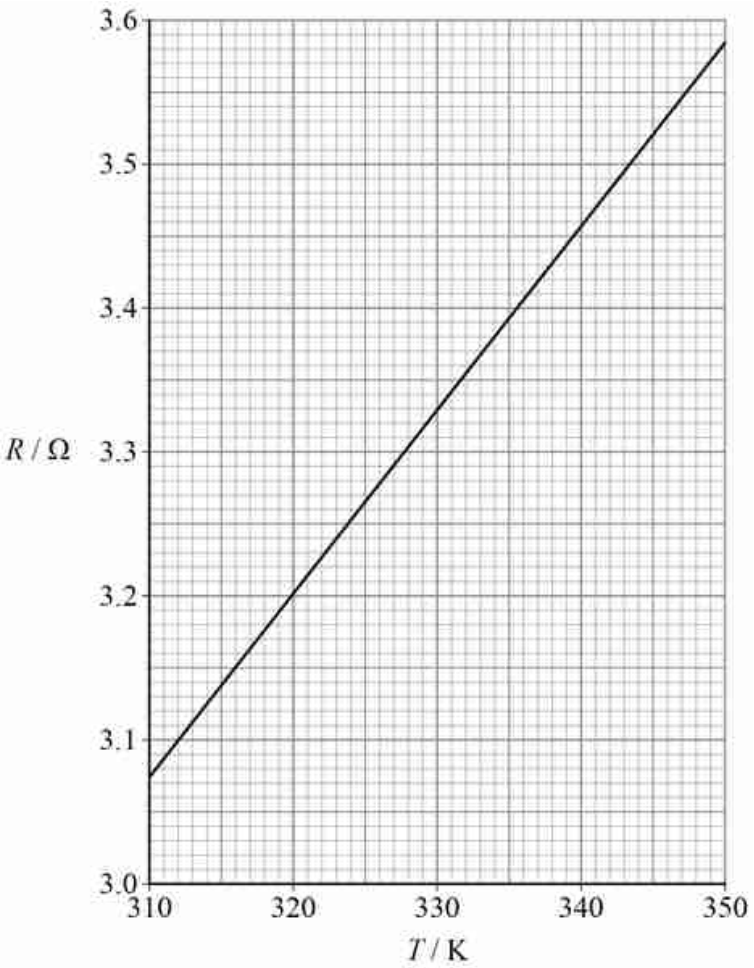
The temperature T in kelvin is determined using the thermometer.
An ohm-meter is connected to the filament to determine R at temperature T.

The oven temperature is increased to new steady values and further readings of T and R are recorded.

Question 3 continues on the next page

Figure 6 shows the variation of R with T.

Figure 6



It can be shown that:

$$\frac{R - R_0}{R_0} = \alpha(T - T_0)$$

where:

R_0 is the resistance of the filament at temperature T_0

α is a constant.

0 3 . 1 Determine α using the graph in **Figure 6**.
State an appropriate SI unit for your answer.

$R_0 = 2.83\ \Omega$ when $T_0 = 291\ \text{K}$

[3 marks]

$\alpha =$ _____ unit = _____

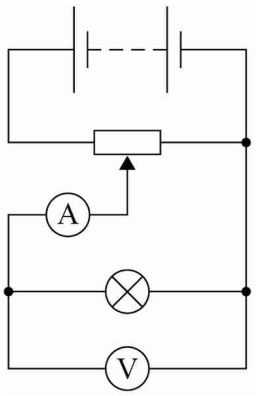
Question 3 continues on the next page

In a different investigation, a student investigates how the electrical power P transferred in the same filament lamp varies for values of T greater than $800\ \text{K}$.

The student assumes that α is constant for all values of T.

Figure 7 shows the circuit that the student uses.
The temperature of the filament is controlled by the energy supplied to it from the battery.

Figure 7



0 3 . 2 Explain how the ammeter and voltmeter readings are used to determine values of P and T.

[2 marks]

P

T

Question 3 continues on the next page

For a steady value of T, $P = P_1 + P_2$
where:
P_1 is the rate of heat transfer from the filament by radiation
P_2 is the rate of heat transfer from the filament by all other processes.

In **Figure 8**:
- the solid line shows how P varies with T
- the dashed line shows how P_2 varies with T.

Figure 8

0 3 . 3 Complete **Table 2**.

[3 marks]

Table 2

T / K	P / W	P_1 / W	P_2 / W
960	3.7	1.2	2.5
1100		2.0	3.0
1370			
1680	16.2	11.0	

Question 3 continues on the next page

0 3 . 4 It can be shown that $P_1 \propto T^n$ where n is an integer.

Determine n.

In your answer you should:
- use **Table 3** to organise the data you will plot
- plot a suitable graph on **Figure 9**.

[5 marks]

Table 3

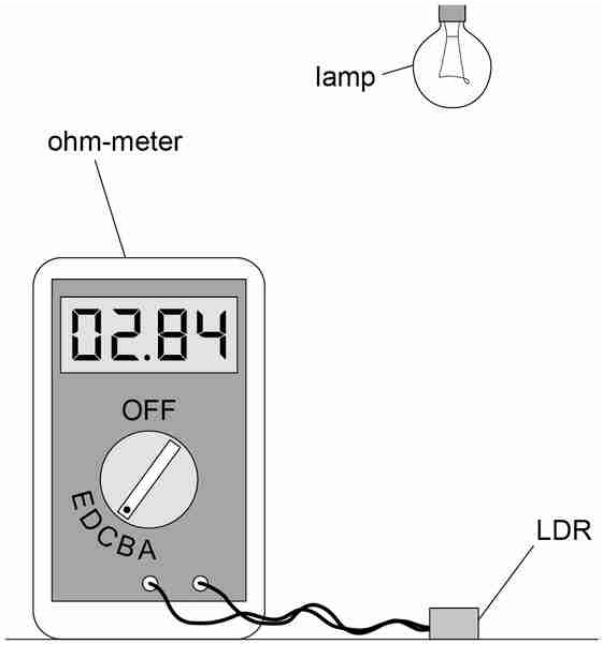
T / K	P_1 / W		
960	1.2		
1100	2.0		
1370			
1680	11.0		

$n =$ _____

Figure 9

0 2 **Figure 6** shows apparatus used to investigate how the resistance R of a light-dependent resistor (LDR) varies with illumination.

Figure 6



The ohm-meter

- **always** displays a four-digit reading of R
- can be set to the different ranges **A** to **E** shown in **Table 2**.

Table 2

Setting	Maximum reading displayed	Minimum (non-zero) reading displayed	Unit
range **A**	199.9	000.1	Ω
range **B**	1999	0001	Ω
range **C**	19.99	00.01	kΩ
range **D**	199.9	000.1	kΩ
range **E**	1.999	0.001	MΩ

0 2 . 1 Explain why the reading displayed in **Figure 6** shows that the ohm-meter is set to range **C**.

[1 mark]

0 2 . 2 The quantity E_V is a measure of the intensity of the light incident on the LDR.
The SI unit of E_V is the lux (lx).

The resistance R of the LDR is given by

$$\log(R / \Omega) = -0.772 \log(E_V / \text{lx}) + 5.09$$

Show that E_V for the arrangement shown in **Figure 6** is about 130 lx.

[2 marks]

Question 2 continues on the next page

R is recorded for different values of the vertical distance x between the lamp and the LDR.
E_V is calculated for each value of R.

Figure 7 shows how E_V varies with x.

Figure 7

It can be shown that $E_V \propto \frac{1}{x^2}$

0 2 . 3 Describe a method to show that **Figure 7** confirms this relationship.
You do not need to show any calculations.

[2 marks]

0 2 . 4 Deduce the value of x when $E_V = 130$ lx.

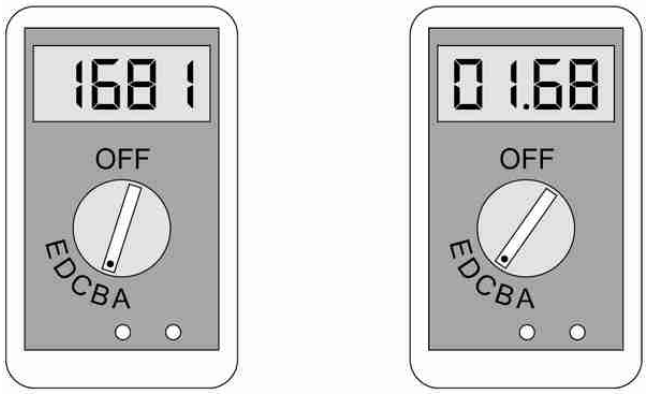
[2 marks]

$x =$ _____ mm

Question 2 continues on the next page

0 2 . 5 R is measured when $x = 450$ mm.
Figure 8 shows how the ohm-meter displays the values of R when set to range **B** and when set to range **C**.

Figure 8



The uncertainty of the reading on the ohm-meter is ±2% of the displayed reading plus ±2 in the least significant digit.

This means that:

- using range **B** the **maximum** value of R is $1.02 \times 1681 + 2 = 1717\ \Omega$
- using range **C** the **minimum** value of R is $0.98 \times 1.68 - 0.02 = 1.63\ \text{k}\Omega$.

Complete **Table 3**.
Go on to explain whether range **B** or range **C** should be used to measure R.

[2 marks]

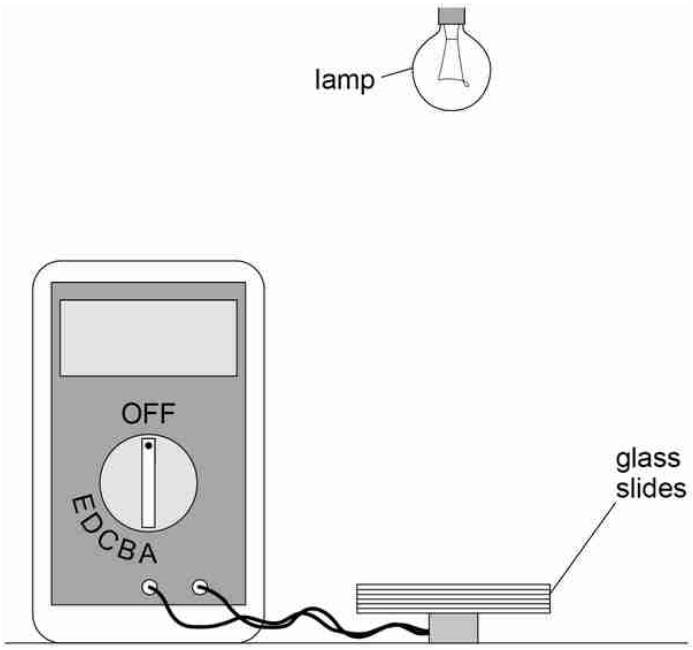
Table 3

Setting	Minimum R	Maximum R
range **B**	_____ Ω	1717 Ω
range **C**	1.63 kΩ	_____ kΩ

Question 2 continues on the next page

Figure 9 shows the LDR being used to investigate the transmission of light through glass slides.

Figure 9



The lamp and ohm-meter are switched on.
R is recorded with different numbers of slides placed on the LDR.
E_V is calculated for each value of R.

0 2 . 6 The positions of the lamp and the LDR are not changed during the experiment.

Identify **two** other control variables.

[2 marks]

1 _____

_____

2 _____

0 2 . 7 For the arrangement in **Figure 9** it can be shown that

$$E_V = 400\ e^{-\mu N}$$

where N is the number of slides
μ is a constant.

Explain how μ can be determined from a linear graph.

[2 marks]

0 2 . 8 In an experiment $\mu = 9.0 \times 10^{-2}$

Deduce the minimum number of slides needed to reduce E_V by 50%.

[2 marks]

number of slides = _____

0 2 **Figure 4** is a plot of current–voltage data for a filament lamp **L**.

Figure 4

The current I was measured as the voltage V across **L** was increased at a steady rate.
These data were obtained using a current sensor and a voltage sensor connected to a data logger.
The logger recorded data at a rate of $2.5\ \text{Hz}$.

0 2 . 1 Determine, in V s^{-1}, the rate of increase of V.

[2 marks]

rate of increase of V = _____ V s^{-1}

0 2 . 2 State **two** advantages of using data logging for this experiment.

[2 marks]

1 _____

_____

_____

2 _____

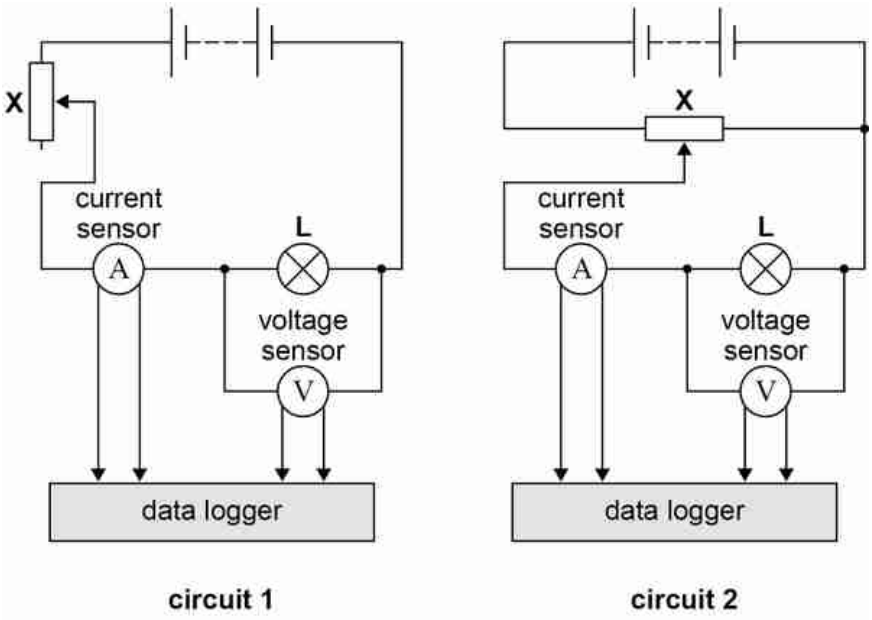
_____

_____

Question 2 continues on the next page

0 2 . 3 **Figure 5** shows two circuits that can be used to collect current–voltage data.

Figure 5



The dc supply has an emf of $12\ \text{V}$ and negligible internal resistance.
The current sensor and the voltage sensor behave as ideal meters.

In circuit **1**:

- **X** is used as a variable resistor with a maximum resistance of $14.9\ \Omega$
- when **X** is set to maximum resistance, the resistance of **L** is $2.3\ \Omega$.

In circuit **2**, **X** is used as a potential divider.

Discuss, with reference to circuit **1 and** circuit **2**, whether either circuit can produce all the data shown in **Figure 4**.
Support your answer with a calculation.

[4 marks]

Question 2 continues on the next page

Table 2 shows some values of V that are plotted on **Figure 4** and corresponding results for I and for the power P dissipated in **L**.

Table 2

V / V	I / A	P / W
3.30	1.07	3.53
5.17	1.32	
7.69	1.59	12.2
9.58		
11.47	1.94	22.3

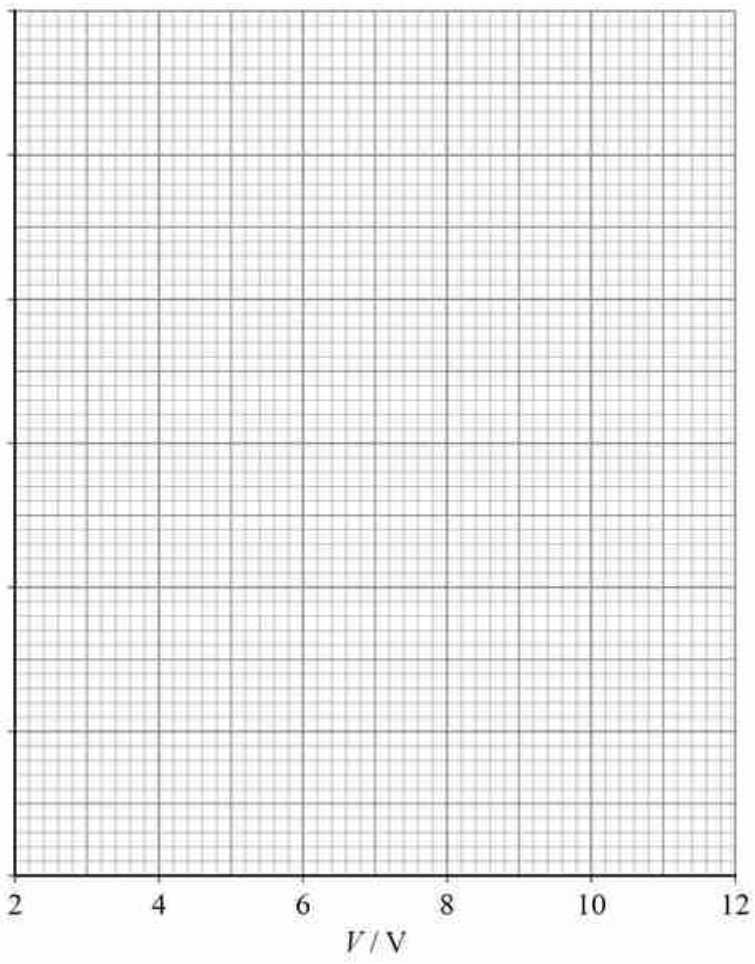
0 2 . 4 Complete **Table 2**.

[3 marks]

0 2 . 5 Plot on **Figure 6** a graph of P against V.
You should use only the data in your completed **Table 2**.

[3 marks]

Figure 6



Question 2 continues on the next page

0 2 . 6 **L** is connected to a $12\ \text{V}$ power supply of negligible internal resistance.
L then dissipates its rated power P_r.

A second lamp, identical to **L**, is now connected in series with **L**.

Determine the percentage of P_r that is dissipated in this circuit.

[2 marks]

percentage = _____ %

SUB-TOPIC 3.5.1.3

RESISTIVITY AND SUPERCONDUCTIVITY

Sub-topic 3.5.1.3 · 8 questions · 32 marks · lowest tariff first

2 7 The table shows the resistivity, length and cross-sectional area of wires P and Q.

	resistivity	length	cross-sectional area
wire P	ρ	L	A
wire Q	$\frac{\rho}{4}$	L	$\frac{A}{2}$

The resistance of wire P is R.

What is the total resistance of the wires when they are connected in parallel?

[1 mark]

A $\frac{R}{9}$ ⬭

B $\frac{R}{3}$ ⬭

C $\frac{2R}{3}$ ⬭

D $\frac{3R}{2}$ ⬭

0 8 A student carries out an experiment to determine the resistivity of a metal wire.
She determines the resistance from measurements of potential difference between the ends of the wire and the corresponding current. She measures the length of the wire with a ruler and the diameter of the wire using a micrometer. Each measurement is made with an uncertainty of 1%

Which measurement gives the largest uncertainty in the calculated value of the resistivity?
[1 mark]

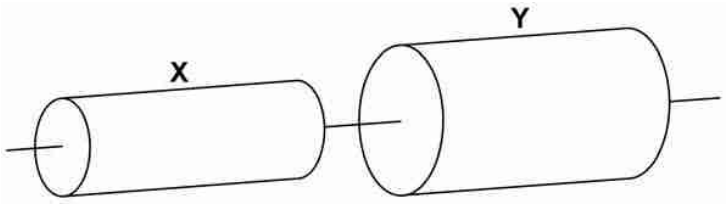
A current ⬭

B diameter ⬭

C length ⬭

D potential difference ⬭

2 7 The two resistors shown are both uniform cylinders of equal length made from the same conducting putty.



The diameter of **Y** is twice that of **X**. The resistance of **Y** is R.

What is the total resistance of the combination?

[1 mark]

A $\frac{4R}{5}$ ⬭

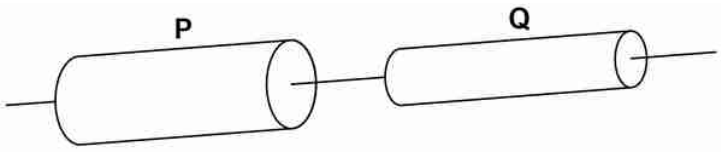
B $3R$ ⬭

C $4R$ ⬭

D $5R$ ⬭

2 5 Two cylindrical wires **P** and **Q** are of equal length and made of the same material. The diameter of **P** is greater than that of **Q**.

P and **Q** are connected in series and the ends of this arrangement are connected to a power supply.



Which two quantities are the same for **P** and **Q**?

[1 mark]

A	potential difference across wire	resistivity	⬭
B	resistivity	current	⬭
C	current	resistance	⬭
D	resistance	potential difference across wire	⬭

2 1 Which statement about a superconducting metal is correct?

[1 mark]

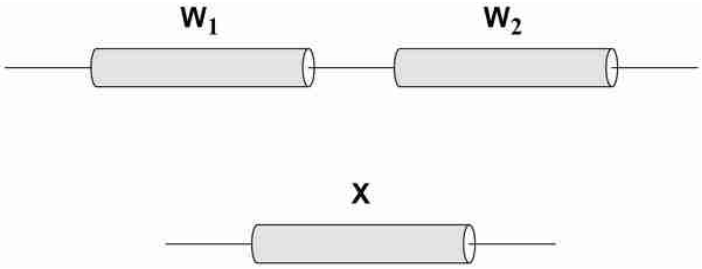
A Its resistivity is small but not zero. ⬭

B A current in it causes no heating effect. ⬭

C Its critical temperature is independent of the metal it is made from. ⬭

D Keeping it cold makes it too expensive to use. ⬭

2 6 Two thin metal rods $\mathbf{W_1}$ and $\mathbf{W_2}$, each of length L and diameter d, are connected in series.



The resistivity of $\mathbf{W_1}$ is ρ_1 and the resistivity of $\mathbf{W_2}$ is ρ_2.

A single metal rod **X**, also of length L and diameter d, has the same resistance as the series combination of $\mathbf{W_1}$ and $\mathbf{W_2}$.

What is the resistivity of **X**?

[1 mark]

A $\rho_1 + \rho_2$ ⬭

B $\frac{\rho_1 + \rho_2}{2}$ ⬭

C $\frac{\rho_1 + \rho_2}{\rho_1 \rho_2}$ ⬭

D $\frac{\rho_1 \rho_2}{\rho_1 + \rho_2}$ ⬭

0 3 Conductive putty can easily be formed into different shapes to investigate the effect of shape on electrical resistance.

0 3 . 1 A student uses vernier callipers to measure the diameter d of a uniform cylinder made of the putty.

Suggest **one** problem with using callipers to make this measurement.

[1 mark]

0 3 . 2 **Table 1** shows the calliper measurements made by a student.

Table 1

d_1 / mm	d_2 / mm	d_3 / mm	d_4 / mm	d_5 / mm
34.5	34.2	32.9	33.4	34.0

Show that the percentage uncertainty in d is about 2.4%.
Assume that all the data are valid.

[2 marks]

0 3 . 3 The length of the cylinder is 71 ± 2 mm.

Determine the uncertainty, in mm^3, in the volume of the cylinder.

[4 marks]

uncertainty = _____ mm^3

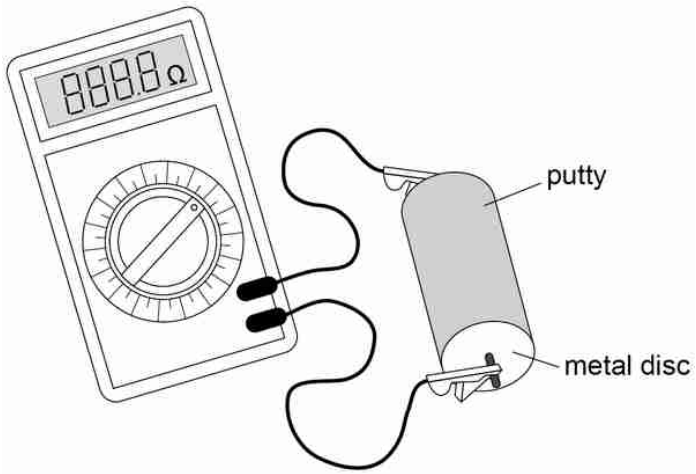
Question 3 continues on the next page

0 3 . 4 A student is given some putty to form into cylinders.

To find the resistance of a cylinder, metal discs are placed in contact with the ends of the cylinder and connected to a resistance meter.

Figure 7 shows the apparatus.

Figure 7



The student forms the putty into cylinders of different lengths, each of volume 5.83×10^{-5} m^3.
The length L and resistance R are measured for each cylinder.

It can be shown that $R = \dfrac{\rho L^2}{5.83 \times 10^{-5}}$ where ρ is the resistivity of the conductive putty.

The student plots the graph shown in **Figure 8**.

Determine ρ.
State an appropriate SI unit for your answer.

[4 marks]

$\rho =$ _____ unit = _____

Figure 8

0 1 This question is based on a method to determine the resistivity of a wire (required practical activity 5).

Figure 1 shows a micrometer screw gauge.

Figure 1

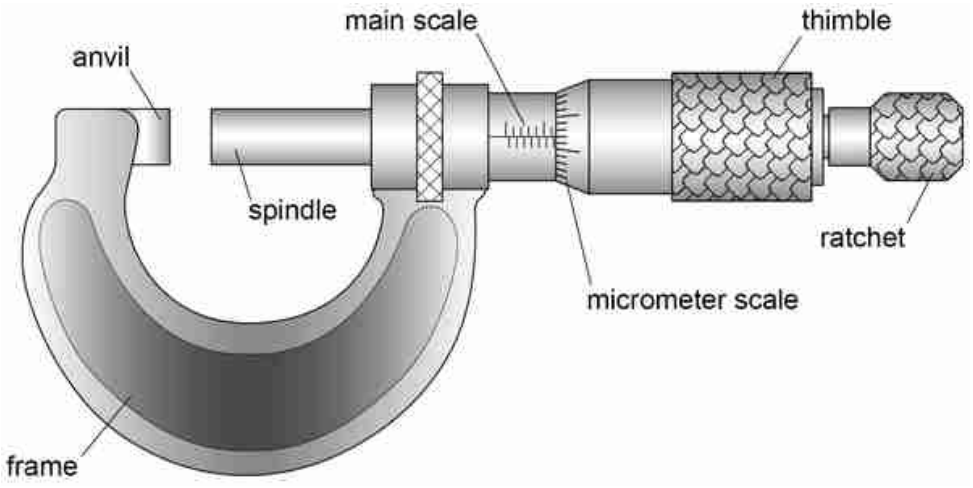


Figure 2 shows an enlarged view of the scales.

Figure 2

0 1 . 1 State, in mm, the resolution of the main scale.

[1 mark]

resolution = _____ mm

0 1 . 2 What is the reading on the micrometer?

Tick (✓) **one** box.

[1 mark]

6.22 mm ☐

6.72 mm ☐

6.78 mm ☐

8.22 mm ☐

0 1 . 3 A wire **X** is placed in the gap between the anvil and the spindle.

State and explain how this gap is closed just before taking a reading of the diameter of **X**.

[1 mark]

_____

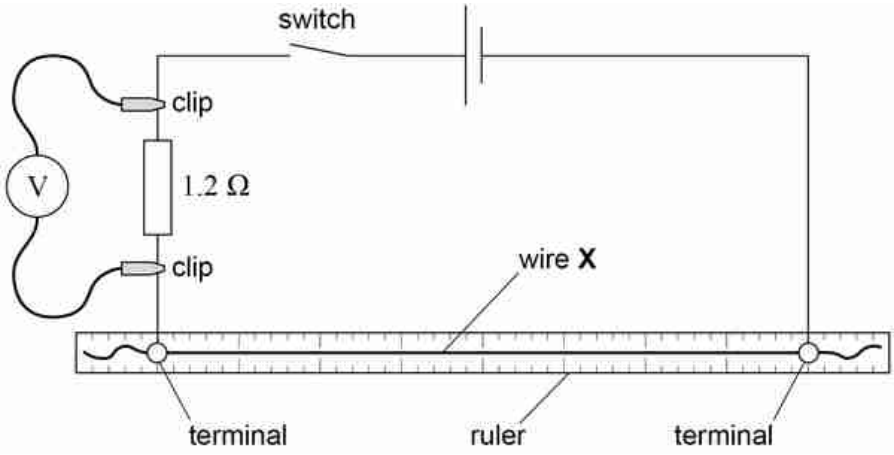
_____

_____

Question 1 continues on the next page

Figure 3 shows a circuit used to determine the resistance per metre of wire **X**.

Figure 3



Two terminals are used to mount **X** on a ruler.
Clips are used to connect a voltmeter across the $1.2\ \Omega$ resistor.
When the switch is closed, the voltmeter reading is $931\ \text{mV}$.

The switch is then opened and the voltmeter is connected to **X** as shown in **Figure 4**.

Figure 4

0 1 . 4 When the switch is closed, the voltmeter reading is $397\ \text{mV}$.

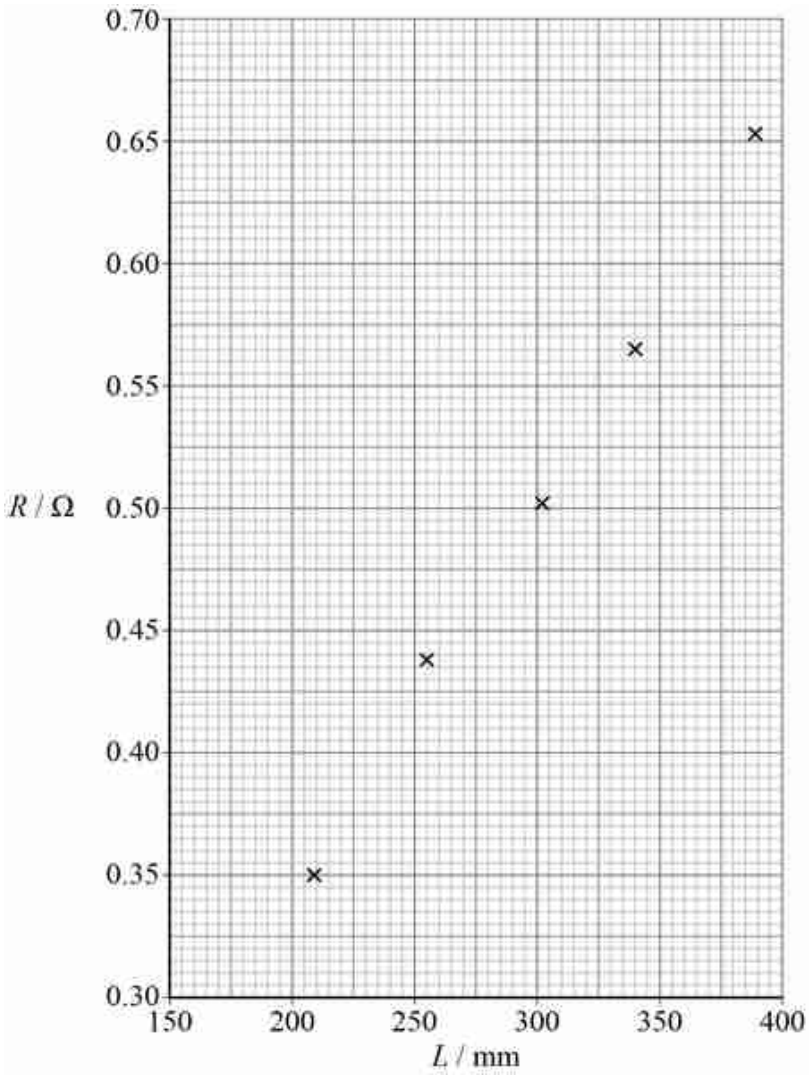
Show that, for the arrangement in **Figure 4**, the resistance R of the wire between the clips is about $0.5\ \Omega$.

[2 marks]

Question 1 continues on the next page

The length of wire between the clips is L.
Values of R are determined for different values of L.
Figure 5 shows these data.

Figure 5



0 1 . 5 Determine the resistance per metre of **X**.

[2 marks]

resistance per metre = _____ $\Omega\ m^{-1}$

0 1 . 6 **Table 1** shows the resistance per metre of various metal wires.
The diameter of **X** is one of the values of d shown in **Table 1**.

Table 1

	Resistance per metre of wire / $\Omega\ m^{-1}$			
d / mm	copper	tungsten	alumel	nichrome
0.38	0.151	0.504	3.15	9.73
0.93	0.0247	0.0824	0.515	1.59
1.63	0.00805	0.0268	0.168	0.518
2.08	0.00494	0.0165	0.103	0.318
3.66	0.00160	0.00532	0.0333	0.103

Identify the metal used for **X**.
Go on to determine the resistivity of the metal.
State an appropriate SI unit for your answer.

[4 marks]

metal used for **X** = _____

resistivity = _____ SI unit = _____

Question 1 continues on the next page

0 1 . 7 A student adds error bars for R and L to each point on **Figure 5**.

She estimates that

- each value of R has a percentage uncertainty of 6%
- each value of L has an absolute uncertainty of 5 mm.

Compare her error bars for the point at $L = 209$ mm with her error bars for the point at $L = 388$ mm.

[2 marks]

0 1 . 8 Outline how error bars are used to determine the uncertainty in the gradient of a linear graph.

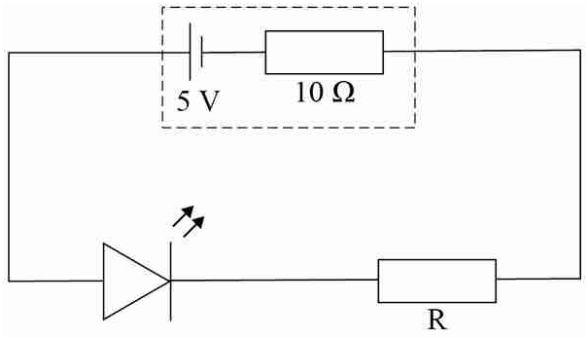
[2 marks]

SUB-TOPIC 3.5.1.4

CIRCUITS

Sub-topic 3.5.1.4 · 9 questions · 27 marks · lowest tariff first

2 5 In the circuit below, the potential difference across the light emitting diode (LED) is 1.8 V when it is emitting light.



The current in the circuit is 20 mA.

What is the value of the resistor R?

[1 mark]

A 80 Ω ⬭

B 90 Ω ⬭

C 150 Ω ⬭

D 160 Ω ⬭

2 6 The combined resistance of n identical resistors connected in parallel is R_n.

Which statement correctly describes the variation of R_n as n increases?

[1 mark]

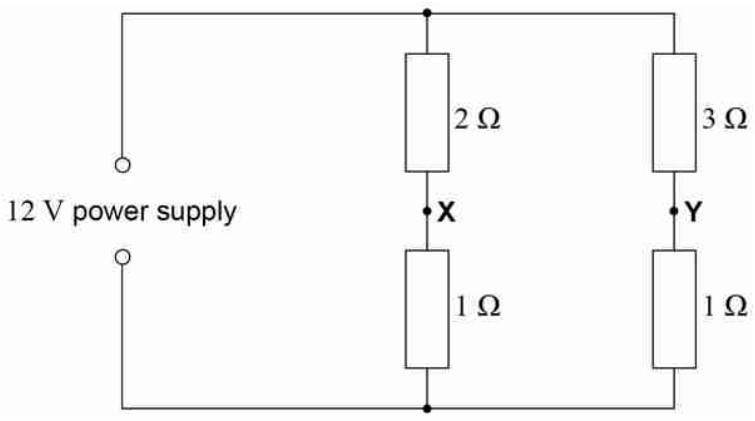
A R_n decreases linearly as n increases ⬭

B R_n decreases non-linearly as n increases ⬭

C R_n increases linearly as n increases ⬭

D R_n increases non-linearly as n increases ⬭

2 9 In this resistor network, the emf of the supply is 12 V and it has negligible internal resistance.



What is the reading on a voltmeter connected between points **X** and **Y**?

[1 mark]

A 0 V ⬭

B 1 V ⬭

C 3 V ⬭

D 4 V ⬭

2 4 A voltmeter has a resistance of $4.0\ \text{k}\Omega$ and reads $1.0\ \text{V}$ for every scale division on the meter.

A power supply of emf $20\ \text{V}$ and negligible internal resistance is connected across this voltmeter and a resistor in series. The voltmeter reads two divisions.

What is the value of the resistor?

[1 mark]

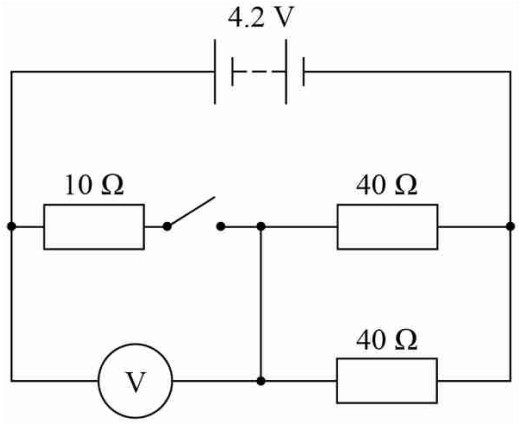
A $44\ \text{k}\Omega$ ⬭

B $36\ \text{k}\Omega$ ⬭

C $4.4\ \text{k}\Omega$ ⬭

D $3.6\ \text{k}\Omega$ ⬭

2 7 The battery in this circuit has an emf of 4.2 V and negligible internal resistance.

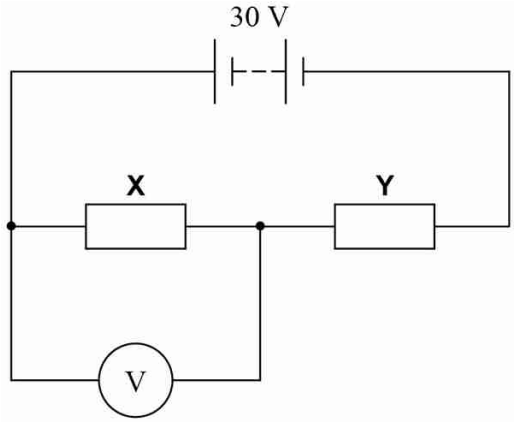


What are the readings on the voltmeter when the switch is open (off) and when the switch is closed (on)?

[1 mark]

	Open	Closed	
A	0 V	2.1 V	⬭
B	4.2 V	2.1 V	⬭
C	0 V	1.4 V	⬭
D	4.2 V	1.4 V	⬭

2 9 Two resistors **X** and **Y** are connected in series with a power supply of emf 30 V and negligible internal resistance.
The resistors are made from wire of the same material. The wires have the same length.
X uses wire of diameter d and **Y** uses wire of diameter $2d$.



What is the reading on the voltmeter?

[1 mark]

A 10 V ⬭

B 15 V ⬭

C 20 V ⬭

D 24 V ⬭

3 0 Which value of resistance **cannot** be made by combining three 10 Ω resistors?

[1 mark]

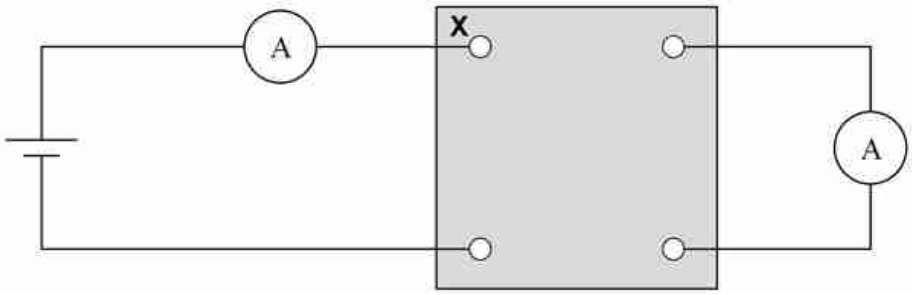
A 3.3 Ω ⬭

B 6.7 Ω ⬭

C 15 Ω ⬭

D 25 Ω ⬭

2 7 A box with four terminals is connected to a cell and two ammeters. The top left terminal is **X**.

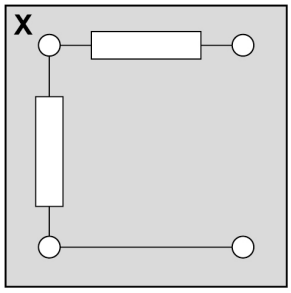


Each of the boxes **A** to **D** is connected into the circuit in turn. All the resistors have equal resistance.

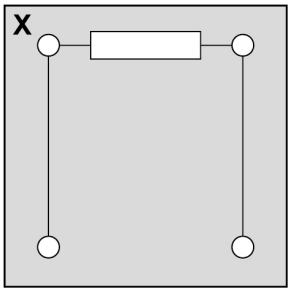
Which box gives the same reading on both ammeters?

[1 mark]

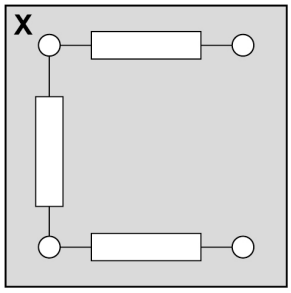
A



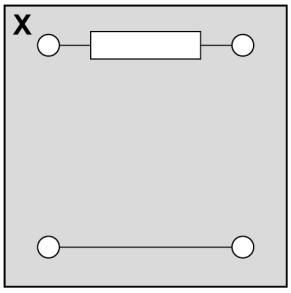
B



C



D



A ⬭

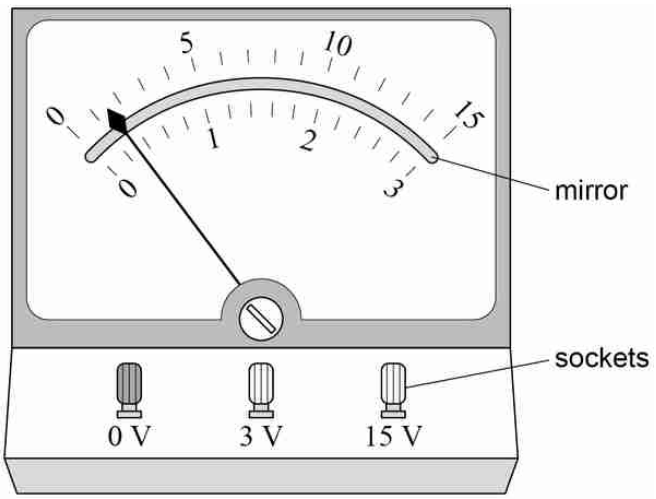
B ⬭

C ⬭

D ⬭

0 3 An analogue voltmeter has a resistance that is much less than that of a modern digital voltmeter.
Analogue meters can be damaged if the full-scale reading is exceeded.
Figure 6 shows a dual-range analogue voltmeter with a zero error.

Figure 6



0 3 . 1 The voltmeter is set to the **more sensitive** range and then used in a circuit.

What is the potential difference (pd) between the terminals of the voltmeter when a full-scale reading is indicated?

Tick (✓) **one** box.

[1 mark]

2.7 V ☐

3.3 V ☐

13.5 V ☐

16.5 V ☐

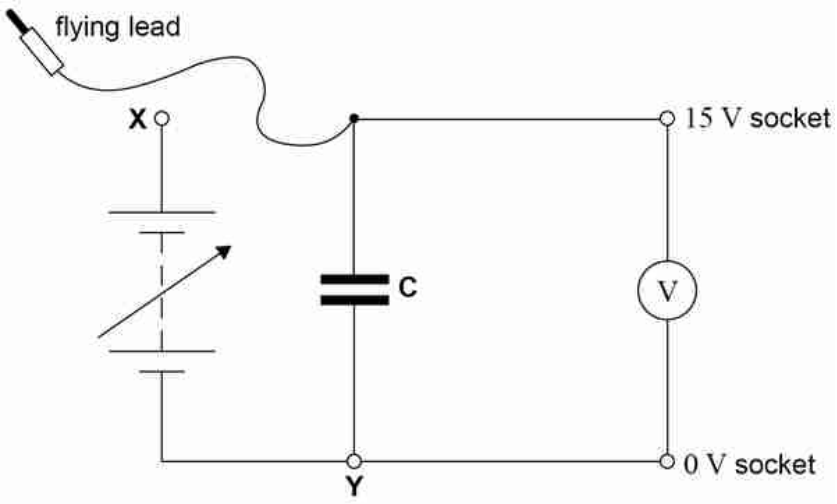
0 3 . 2 Explain the use of the mirror when reading the meter.

[2 marks]

Question 3 continues on the next page

A student corrects the zero error on the meter and then assembles the circuit shown in **Figure 7**.
The capacitance of the capacitor **C** is not known.

Figure 7



The output pd of the power supply is set to zero.
The student connects the flying lead to socket **X** and adjusts the output pd until the voltmeter reading is full scale (15 V).
She disconnects the flying lead from socket **X** so that **C** discharges through the voltmeter.

She measures the time $T_{½}$ for the voltmeter reading V to fall from 10 V to 5 V.

She repeats this process several times.

Table 1 shows the student's results, **none** of which is anomalous.

Table 1

$T_{½}$ / s	12.00	11.94	12.06	12.04	12.16

0 3 . 3 Determine the percentage uncertainty in $T_{½}$.

[2 marks]

percentage uncertainty = _____ %

0 3 . 4 Show that the time constant for the discharge circuit is about 17 s.

[1 mark]

Question 3 continues on the next page

0 3 . 5 The student thinks that the time constant of the circuit in **Figure 7** is directly proportional to the range of the meter.
To test her theory, she repeats the experiment with the voltmeter set to the $3\ \text{V}$ range.
She expects $T_{½}$ to be about $2.5\ \text{s}$.

Explain:

- what the student should do, before connecting capacitor **C** to the $0\ \text{V}$ and $3\ \text{V}$ sockets, to avoid exceeding the full-scale reading on the voltmeter
- how she should develop her procedure to get an accurate result for the time constant
- how she should use her result to check whether her theory is correct.

[4 marks]

The student wants to find the resistance of the voltmeter when it is set to the 15 V range.
She replaces **C** with an 820 μF capacitor and charges it to 15 V.
She discharges the capacitor through the voltmeter, starting a stopwatch when V is 14 V.
She records the stopwatch reading t at other values of V as the capacitor discharges.

Table 2 shows her results.

Table 2

V / V	14	11	8	6	4	3	2
t / s	0.0	3.1	7.2	11.0	16.2	19.9	25.2

0 3 . 6 Suggest **two** reasons why the student selected the values of V shown in **Table 2**.
Explain each of your answers.

[4 marks]

1

2

Question 3 continues on the next page

Figure 8 shows a graph of the experimental data.

Figure 8

0 3 . 7 Show, using **Figure 8**, that the resistance of the voltmeter is about $16\ \text{k}\Omega$.

[3 marks]

0 3 . 8 Determine the current in the voltmeter at $t = 10\ \text{s}$.

[2 marks]

current = _____ A

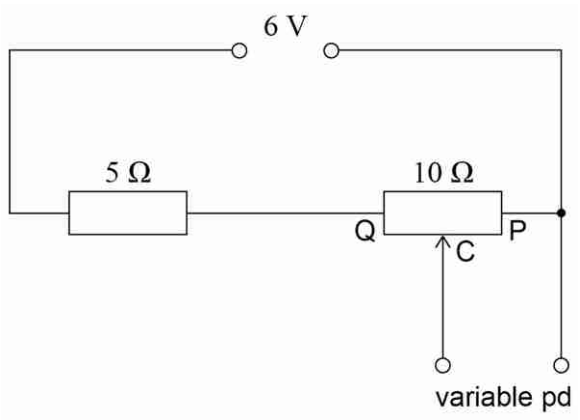
END OF QUESTIONS

SUB-TOPIC 3.5.1.5

POTENTIAL DIVIDERS

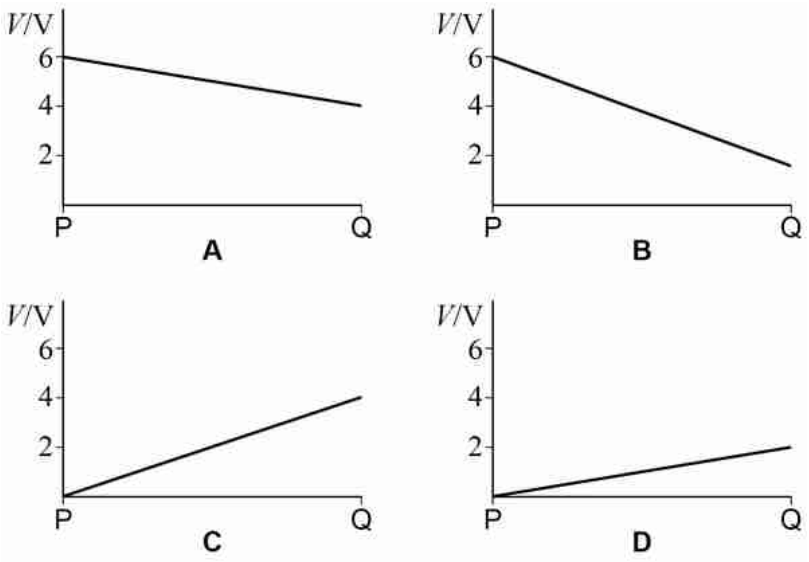
Sub-topic 3.5.1.5 · 6 questions · 31 marks · lowest tariff first

2 8 The circuit shown is used to supply a variable potential difference (pd) to another circuit.



Which graph shows how the pd supplied V varies as the moving contact C is moved from position P to position Q?

[1 mark]



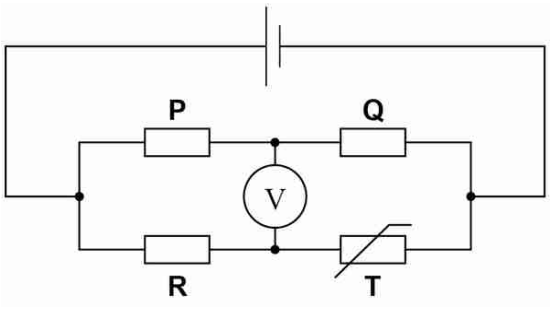
A ⬭

B ⬭

C ⬭

D ⬭

2 6 In the circuit below, the initial voltmeter reading is zero.



The temperature of the negative temperature coefficient thermistor **T** is then increased.

Which change to the circuit could restore the voltmeter reading to zero?

[1 mark]

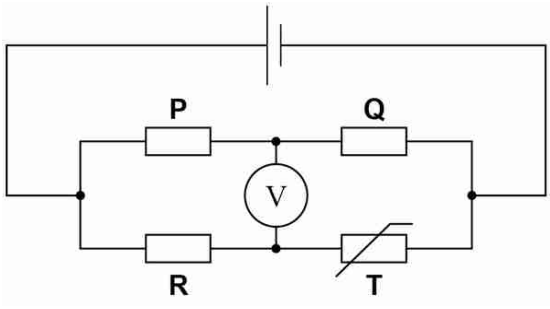
A Decreasing the resistance of **R**. ⬭

B Increasing the resistance of **R**. ⬭

C Decreasing the resistance of **P**. ⬭

D Increasing the resistance of **Q**. ⬭

2 7 In the circuit below, the voltmeter reading is zero.



When the temperature of the thermistor **T** is increased, the voltmeter reading changes.

Which change to the circuit will restore the voltmeter to zero?

[1 mark]

A a reduction in the emf of the cell ⬭

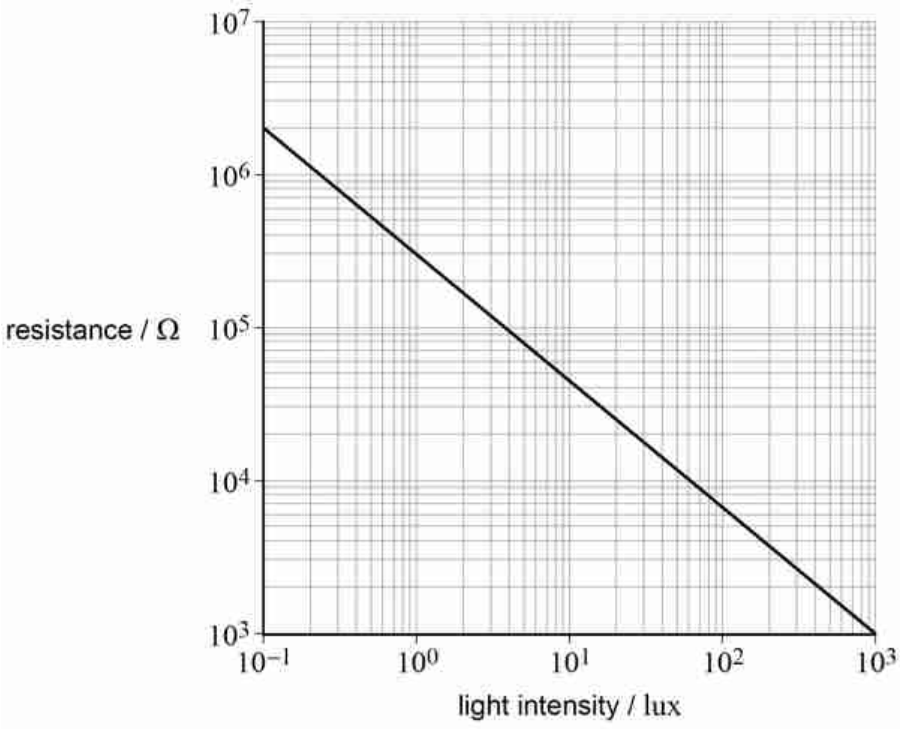
B a reduction in the resistance of **P** ⬭

C an increase in the resistance of **Q** ⬭

D a reduction in the resistance of **R** ⬭

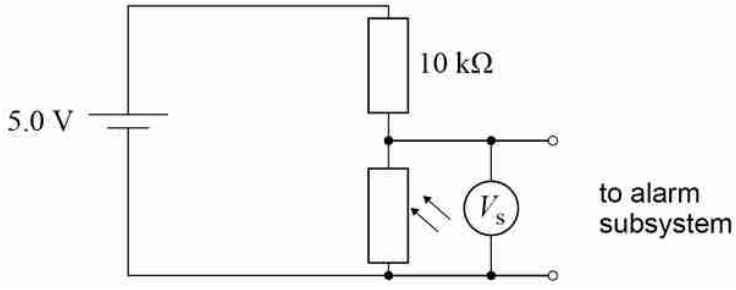
0 6 **Figure 11** shows how the resistance of an LDR varies with light intensity.

Figure 11



The LDR is used as part of an alarm system in a dim room. **Figure 12** shows one proposal for a sensor circuit for this system.

Figure 12



The power supply to the sensor has an emf of 5.0 V and a negligible internal resistance. A negligible current is drawn from the sensor circuit by the alarm subsystem.

A light beam illuminates the LDR. When the light beam is broken the LDR is not illuminated by the light beam. This causes the alarm to sound.

Table 3 shows how the light intensity at the LDR changes.

Table 3

	Light intensity / lux
LDR illuminated by light beam	4.0
LDR **not** illuminated by light beam	1.0

0 6 . 1 Show that the current in the sensor circuit when the LDR is **not** illuminated by the light beam is approximately 16 μA.

[2 marks]

0 6 . 2 The alarm sounds when the potential difference V_S across the LDR changes by more than 25% of the power supply emf.

Discuss whether the circuit shown in **Figure 12** is suitable.
Support your answer with a calculation.

[3 marks]

END OF SECTION A

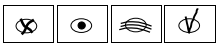
Section B

Each of Questions **07** to **31** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.
For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD 

WRONG METHODS 

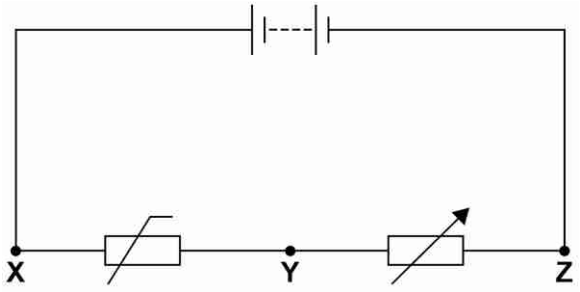
If you want to change your answer you must cross out your original answer as shown. 

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown. 

You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

0 6 The circuit in **Figure 5** is used as part of a temperature sensor.
The battery has an emf of 6.5 V and negligible internal resistance.

Figure 5



The initial temperature of the thermistor is 22 °C.
At this temperature the resistance of the thermistor is 350 Ω and the circuit current is 12 mA.

0 6 . 1 Calculate the resistance of the variable resistor.

[2 marks]

resistance = _____ Ω

Question 6 continues on the next page

0 6 . 2 The resistance R of the thermistor at temperature θ in K is given by:

$$R = R_0 e^{B\left(\frac{1}{\theta} - \frac{1}{\theta_0}\right)}$$

where R_0 is the resistance at the initial temperature θ_0 in K, and B is a constant.

The temperature of the thermistor is increased to 318 K.
The variable resistor is adjusted so that the circuit current is again 12 mA.
The potential difference across the thermistor is now 3.2 V.

Determine B.
State an appropriate unit for your answer.

[5 marks]

$B =$ _____ unit = _____

0 6 . 3 Explain why the current in the thermistor needs to be controlled.

[2 marks]

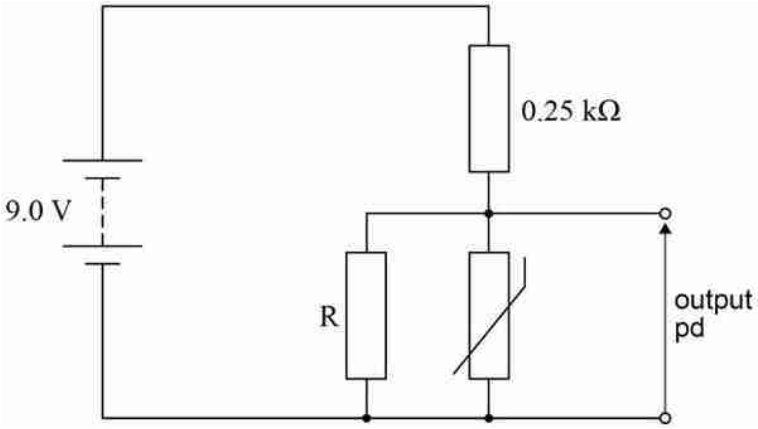
0 6 . 4 Explain how ammeters and voltmeters can be used in the circuit in **Figure 5** to demonstrate the conservation of charge and the conservation of energy.

Refer to points **X**, **Y** and **Z** in your answer.

[2 marks]

0 4 **Figure 7** shows a circuit designed by a student to monitor temperature changes.

Figure 7



The supply has negligible internal resistance and the thermistor has a resistance of 750 Ω at room temperature. The student wants the output potential difference (pd) at room temperature to be 5.0 V

0 4 . 1 The 0.25 kΩ resistor is made of 50 turns of wire that is wound around a non-conducting cylinder of diameter 8.0 mm

Resistivity of the wire = 4.2×10^{-7} Ω m

Determine the area of cross-section of the wire that has been used for the resistor.

[3 marks]

area of cross-section = _____ m^2

0 4 . 2 The student selects a resistor rated at $0.36\ \text{W}$ for the $0.25\ \text{k}\Omega$ resistor in **Figure 7**.

Determine whether this resistor is suitable.

[2 marks]

0 4 . 3 Determine the value of R that the student should select.

Give your answer to an appropriate number of significant figures.

[5 marks]

value of R = _____ Ω

Question 4 continues on the next page

0 4 . 4 State and explain the effect on the output pd of increasing the temperature of the thermistor.

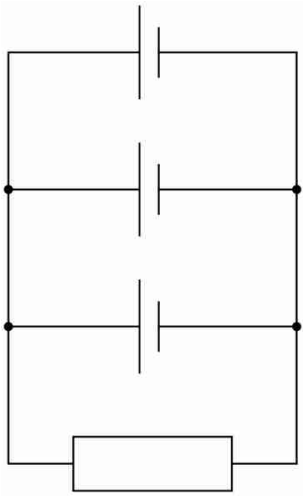
[2 marks]

SUB-TOPIC 3.5.1.6

EMF AND INTERNAL RESISTANCE

Sub-topic 3.5.1.6 · 10 questions · 59 marks · lowest tariff first

2 8 A resistor of resistance R and three identical cells of emf E and internal resistance r are connected as shown.



What is the current in the resistor?

[1 mark]

A $\frac{3E}{(3R+r)}$ ⬭

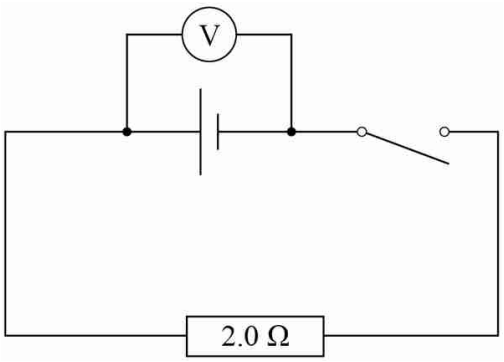
B $\frac{9E}{(3R+r)}$ ⬭

C $\frac{E}{R}$ ⬭

D $\frac{3E}{R}$ ⬭

2 9 In the circuit, the reading of the voltmeter is V.

When the switch is closed the reading becomes $\frac{V}{3}$.



What is the internal resistance of the cell?

[1 mark]

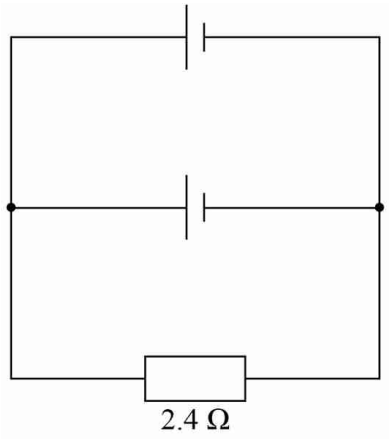
A 0.33 Ω ⬭

B 0.67 Ω ⬭

C 4.0 Ω ⬭

D 6.0 Ω ⬭

2 8 Two identical batteries each of emf $1.5\ \text{V}$ and internal resistance $1.6\ \Omega$ are connected in parallel. A $2.4\ \Omega$ resistor is connected in parallel with this combination.



What is the current in the $2.4\ \Omega$ resistor?

[1 mark]

A $0.38\ \text{A}$ ⬭

B $0.47\ \text{A}$ ⬭

C $0.75\ \text{A}$ ⬭

D $0.94\ \text{A}$ ⬭

2 7 A 12 Ω resistor is connected across the terminals of a battery of emf 2.0 V and internal resistance 4.0 Ω.

What is the pd across the resistor?

[1 mark]

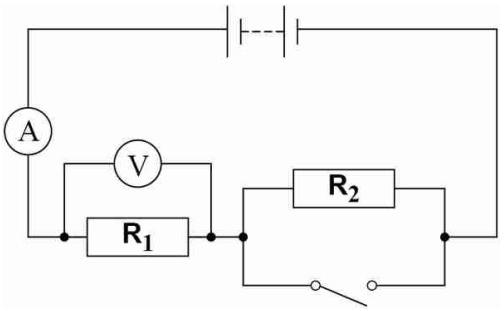
A 0.25 V ⬭

B 0.75 V ⬭

C 1.30 V ⬭

D 1.50 V ⬭

2 8 In a circuit, the resistance of resistor $\mathbf{R_1}$ is double the resistance of resistor $\mathbf{R_2}$.
The internal resistance of the battery is negligible.



When the switch is open, the voltmeter reads 12 V and the ammeter reads 12 mA.

What are the readings on the voltmeter and ammeter when the switch is closed?

[1 mark]

	Voltmeter reading / V	Ammeter reading / mA	
A	4	12	⬭
B	18	12	⬭
C	18	18	⬭
D	24	24	⬭

0 5 This question is about the batteries used to store energy in electric vehicles.
Each battery is a series of modules. Each module is an array of identical cells.

Table 2 shows the properties of one of these cells.

Table 2

emf	3.66 V
internal resistance	30.0 mΩ
maximum current	6.77 A

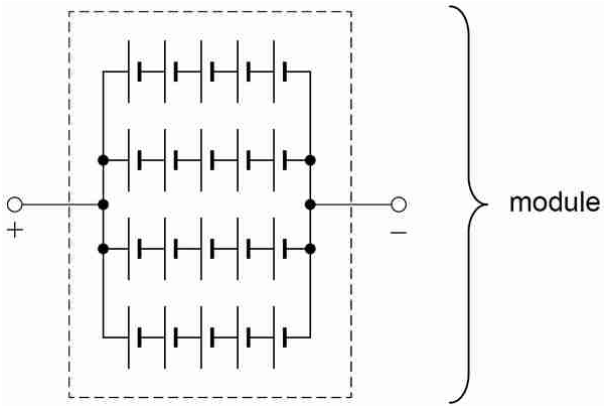
0 5 . 1 Calculate the terminal potential difference of the cell at its maximum current.

[1 mark]

terminal potential difference = _____ V

0 5 . 2 **Figure 6** shows an array of 20 of these cells connected to form a module.

Figure 6



Calculate the internal resistance of the module shown in **Figure 6**.

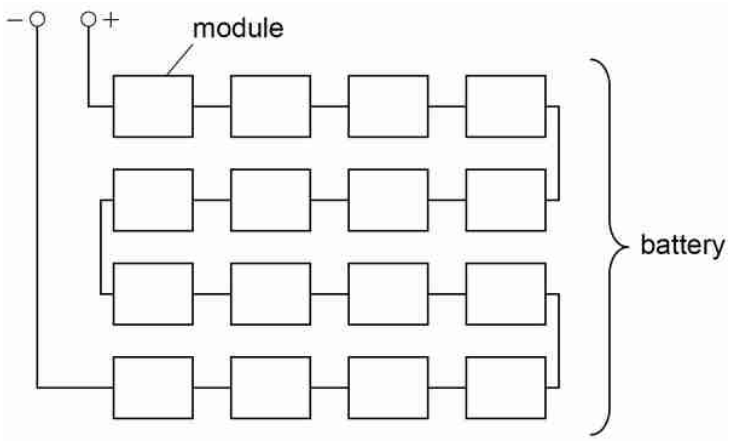
[2 marks]

internal resistance = _____ Ω

0 5 . 3 **Figure 7** shows the battery for an electric vehicle.
This battery has an emf of 352 V and gives a maximum current of 500 A.

The battery consists of a series of identical modules.
These modules are **different** from the module shown in **Figure 6**.

Figure 7



The individual cells used in each module have the properties shown in **Table 2**.

Deduce the number of cells in each module.

[3 marks]

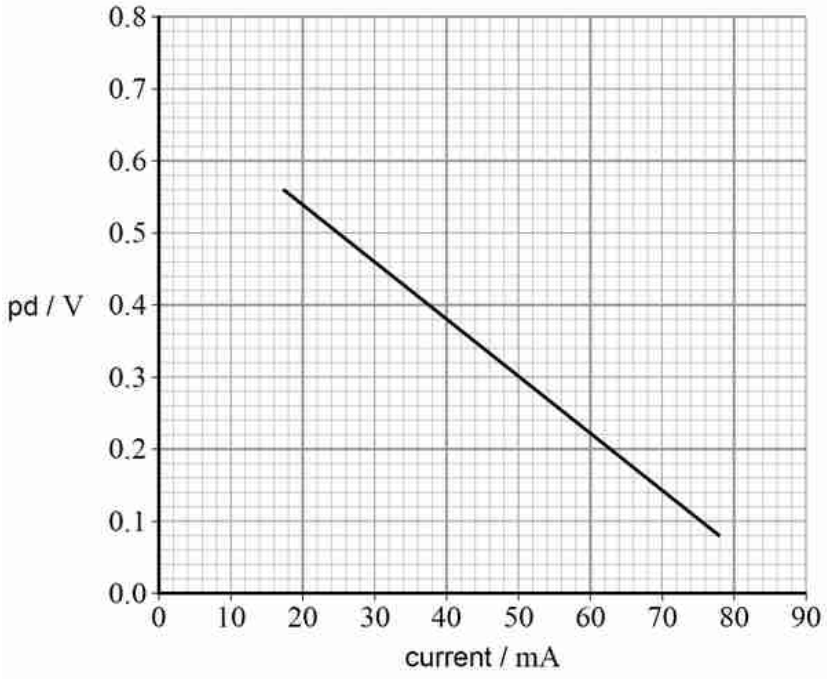
number of cells = _____

0 4 An engineer wants to use solar cells to provide energy for a filament lamp in a road sign.

The engineer first investigates the emf and internal resistance of a solar cell under typical operating conditions.

The engineer determines how the potential difference across the solar cell varies with current. The results are shown in the graph in **Figure 4**.

Figure 4



The engineer uses the graph to deduce that when operating in typical conditions a single solar cell produces an emf of $0.70\ \text{V}$ and has an internal resistance of $8.0\ \Omega$.

0 4 . 1 Explain how the engineer uses the graph to obtain the values for the emf and internal resistance of the solar cell.

[2 marks]

Question 4 continues on the next page

To operate effectively the lamp in the road sign needs a minimum current of $75\ \text{mA}$. At this current the resistance of the filament lamp is $6.0\ \Omega$.

The engineer proposes to try the two circuits shown in **Figure 5** and **Figure 6**.

Figure 5

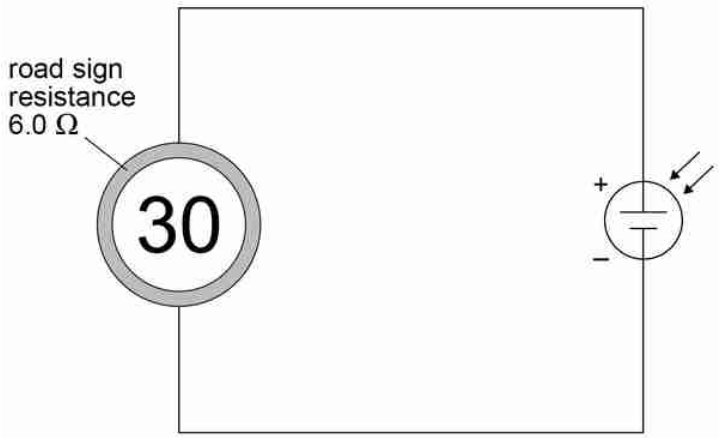


Figure 6

0 4 . 2 Deduce, using calculations, whether the circuits in **Figure 5** and **Figure 6** are suitable for this application.

[4 marks]

0 4 . 3 Solar cells convert solar energy to useful electrical energy in the road sign with an efficiency of 4.0%.
The solar-cell supply used by the engineer has a total surface area of $32\ \text{cm}^2$.

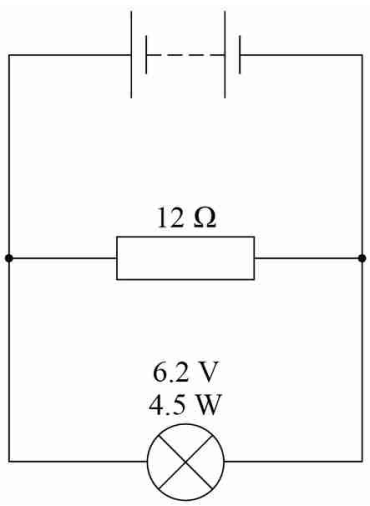
Calculate the minimum intensity, in W m^{-2}, of the sunlight needed to provide the minimum current of $75\ \text{mA}$ to the road sign when it has a resistance of $6.0\ \Omega$.

[3 marks]

intensity = _____ W m^{-2}

0 4 A student assembles the circuit in **Figure 6**.

Figure 6



The battery has an internal resistance of 2.5 Ω.

0 4 . 1 Show that the resistance of the 6.2 V, 4.5 W lamp at its working potential difference (pd) is about 9 Ω.

[1 mark]

0 4 . 2 The terminal pd across the battery is 6.2 V.

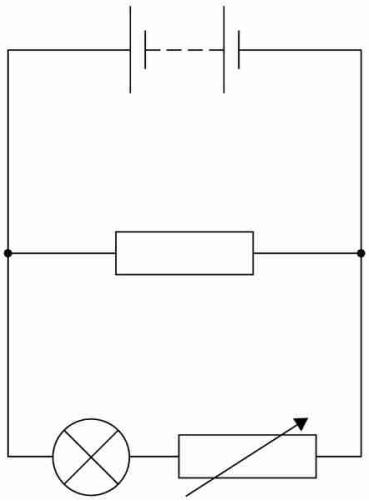
Calculate the emf of the battery.

[3 marks]

emf = _____ V

The student makes a variable resistor to control the brightness of the lamp.
Figure 7 shows her circuit.

Figure 7



0 4 . 3 She uses a resistance wire with a diameter of $0.19\ \text{mm}$ to make the variable resistor.
A $5.0\ \text{m}$ length of this wire has a resistance of $9.0\ \Omega$.

Calculate the resistivity of the wire.

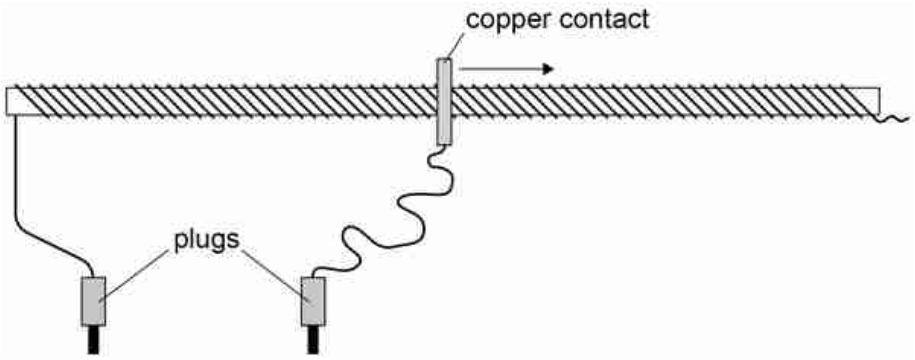
[3 marks]

resistivity = _____ $\Omega\ \text{m}$

Question 4 continues on the next page

0 4 . 4 **Figure 8** shows the 5.0 m length of wire wrapped around a tube to make the variable resistor.

Figure 8



Two plugs connect the variable resistor into the circuit. A moveable copper contact is used to vary the length of wire in series with the lamp.
When the contact is placed on the tube at one particular position, the lamp is dim.
The contact is then moved slowly to the right as shown in **Figure 8**.

Explain, without calculation, what happens to the brightness of the lamp as the contact is moved.

[2 marks]

0 4 . 5 The student now makes a different circuit by connecting the variable resistor **in parallel** with the lamp.

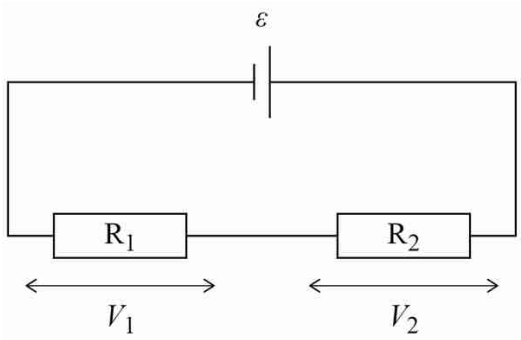
The contact is returned to its original position on the tube as shown in **Figure 8** and the lamp is dim. The contact is again slowly moved to the right.

Explain, without calculation, what happens to the brightness of the lamp as the contact is moved.

[2 marks]

0 3 . 1 In **Figure 2** the cell has emf ε and internal resistance r.

Figure 2



The current in the circuit is I.

The potential difference (pd) across R_1 is V_1 and the pd across R_2 is V_2.

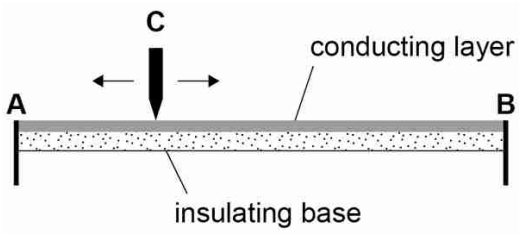
Explain how the law of conservation of energy applies in this circuit.
You should consider the movement of one coulomb of charge around the circuit.

[2 marks]

Question 3 continues on the next page

Figure 3 shows a variable resistor made with a thin conducting layer on an insulating base.

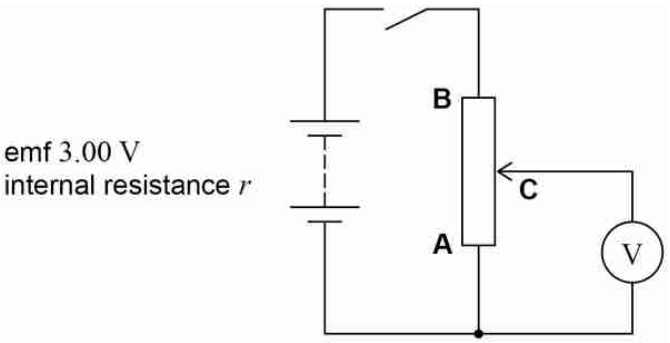
Figure 3



The conducting layer has constant width and thickness and has connections at the ends **A** and **B**.
C is a sliding contact that can move along the surface of the conducting layer between **A** and **B**.

Figure 4 shows a circuit that uses the variable resistor as a potential divider.

Figure 4



The variable resistor is connected to a battery of emf $3.00\ \text{V}$ and internal resistance r.
The resistance of the conducting layer between **A** and **B** is $125\ \Omega$.

0 3 . 2 The sliding contact **C** is moved to end **B** of the variable resistor. The switch is closed. The digital voltmeter reads $2.89\ \text{V}$.

Show that r is approximately $4.8\ \Omega$.

[3 marks]

0 3 . 3 **C** is set at $\frac{1}{5}$ of the distance between **A** and **B**. The thickness of the conducting layer is uniform so the resistance between **A** and **C** is $25.0\ \Omega$.

Determine the voltmeter reading at this setting.

[2 marks]

voltmeter reading = _____ V

Question 3 continues on the next page

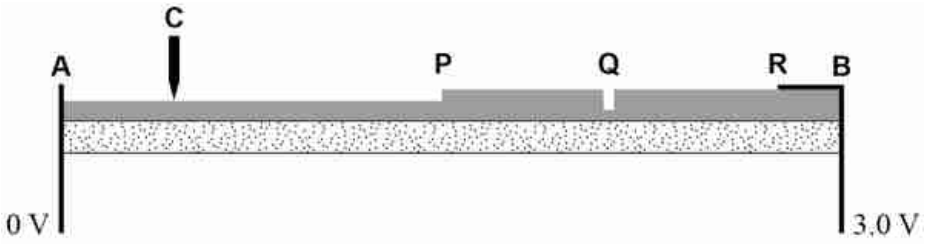
0 3 . 4 **Figure 5** shows a variable resistor similar to the one shown in **Figure 3** but with the following three manufacturing faults:

- at **P** the conducting layer changes in thickness so that **AP** is thinner than **PB**
- at **Q** there is a scratch into the surface of the conducting layer and across its full width
- from **R** to **B** the conducting connector is laid over the conducting layer.

The width of the conducting layer is constant.

A pd of 3.0 V is applied across **A** and **B**.
C is moved from **A** to **B**.

Figure 5



Sketch, on the axes in **Figure 6**, a graph to show how the pd between **A** and **C** varies as **C** is moved from **A** to **B**.

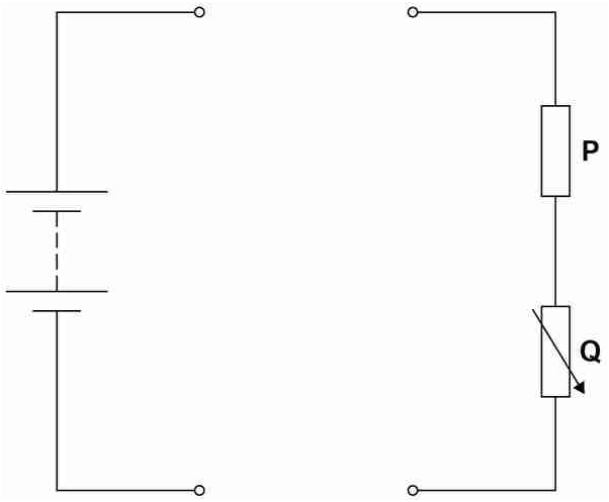
[4 marks]

Figure 6

0 3 **Figure 10** shows a partly-completed circuit used to investigate the emf ε and the internal resistance r of a power supply.

The resistance of **P** and the maximum resistance of **Q** are unknown.

Figure 10



0 3 . 1 Complete **Figure 10** to show a circuit including a voltmeter and an ammeter that is suitable for the investigation.

[1 mark]

0 3 . 2 Describe

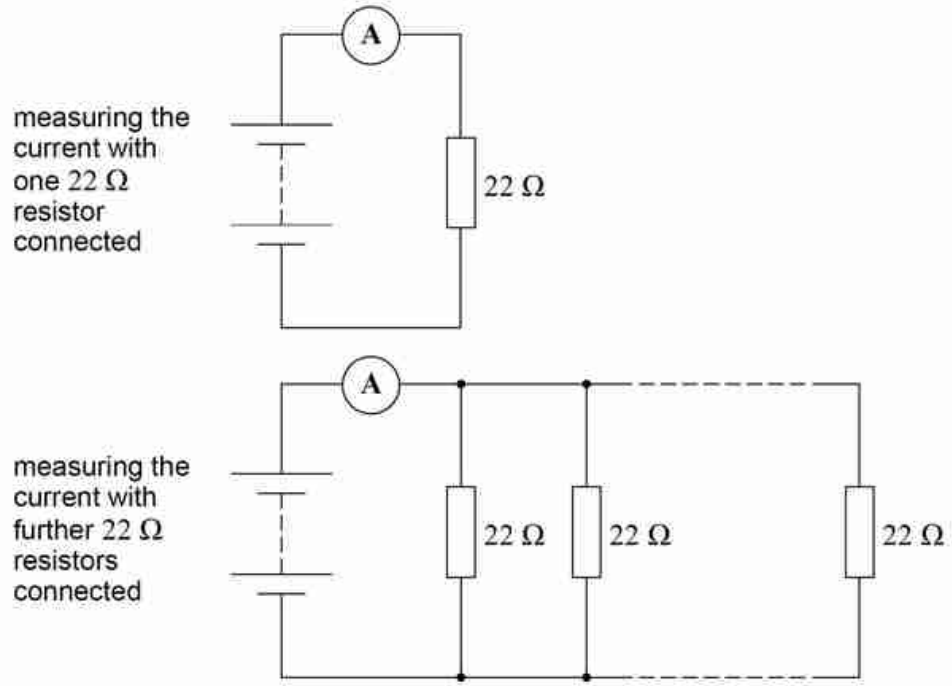
- a procedure to obtain valid experimental data using your circuit
- how these data are processed to obtain ε and r by a graphical method.

[4 marks]

Question 3 continues on the next page

Figure 11 shows a different experiment carried out to confirm the results for ε and r.

Figure 11



Initially the power supply is connected in series with an ammeter and a $22\ \Omega$ resistor. The current I in the circuit is measured.

The number n of $22\ \Omega$ resistors in the circuit is increased as shown in **Figure 11**. The current I is measured after each resistor is added.

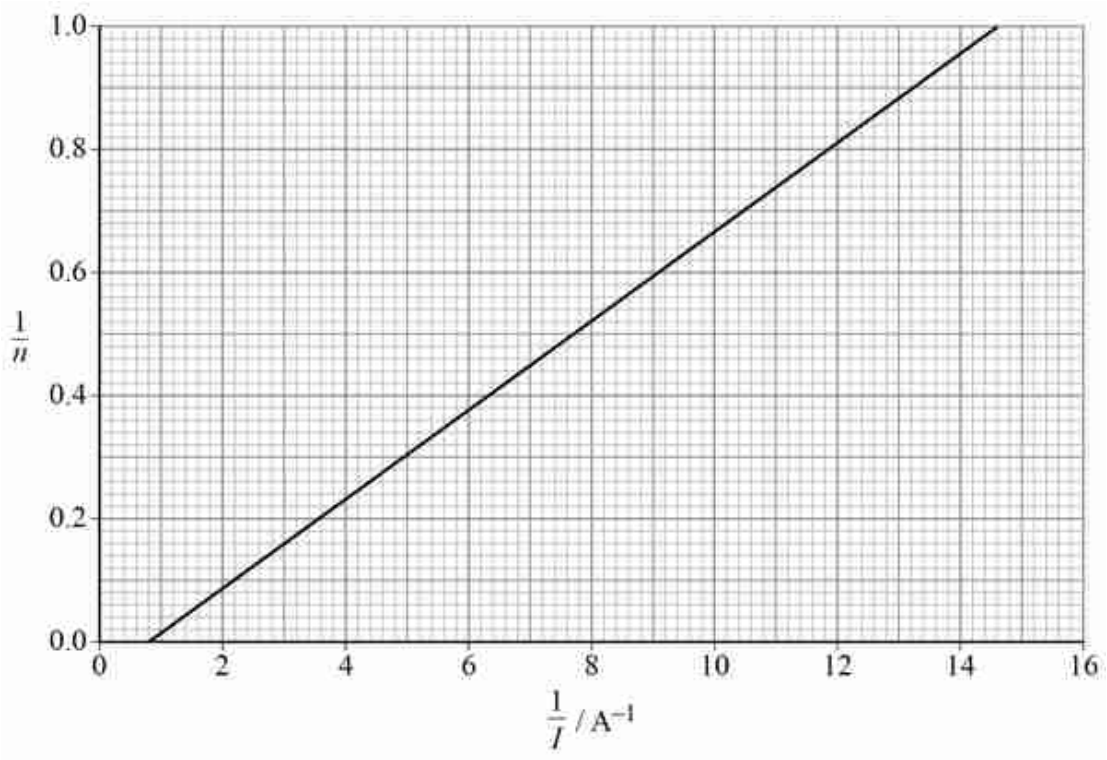
It can be shown that

$$\frac{22}{n} = \frac{\varepsilon}{I} - r$$

Figure 12 on page 22 shows a graph of the experimental data.

Question 3 continues on the next page

Figure 12

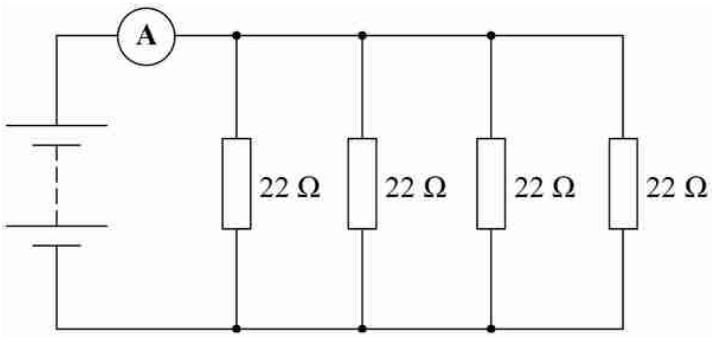


0 3 . 3 Show that ε is about 1.6 V.

[2 marks]

0 3 . 4 **Figure 13** shows the circuit when four resistors are connected.

Figure 13



Show, using **Figure 12**, that the current in the power supply is about 0.25 A.

[1 mark]

0 3 . 5 Deduce, for the circuit shown in **Figure 13**,

- the potential difference (pd) across the power supply
- r.

[4 marks]

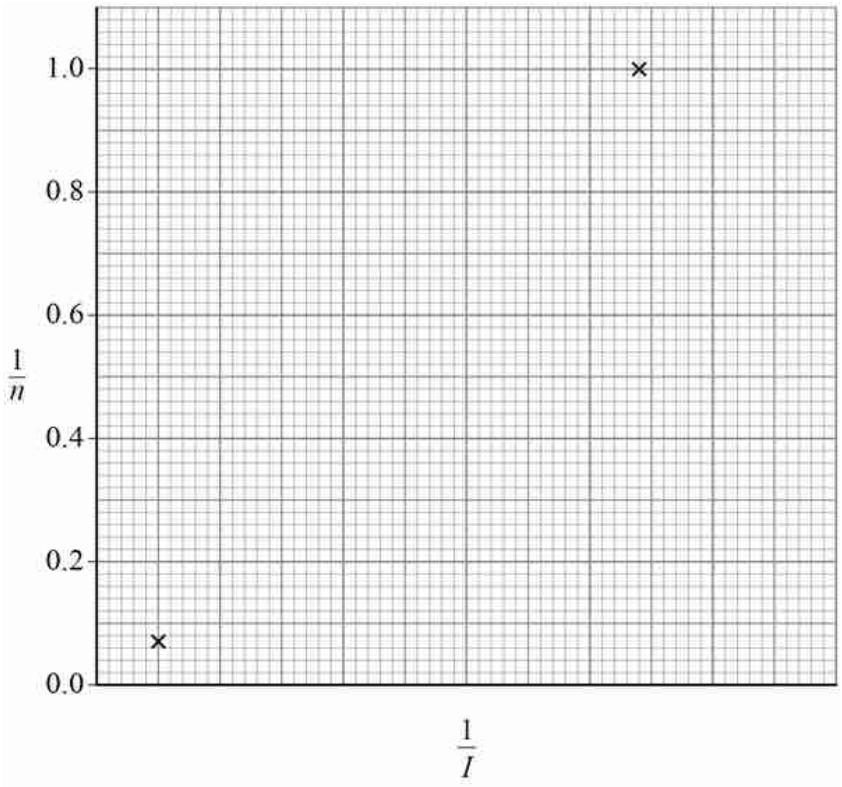
pd = _____ V

r = _____ Ω

Question 3 continues on the next page

0 3 . 6 **Figure 14** shows the plots for $n = 1$ and $n = 14$

Figure 14



Three additional data sets for values of n between $n = 1$ and $n = 14$ are needed to complete the graph in **Figure 14**.

Suggest which additional values of n should be used.
Justify your answer.

[3 marks]

0 3 . 7 The experiment is repeated using a set of resistors of resistance $27\ \Omega$.

The relationship between n and I is now

$$\frac{27}{n} = \frac{\varepsilon}{I} - r$$

Show on **Figure 14** the effect on the plots for $n = 1$ and $n = 14$
You do **not** need to do a calculation.

[2 marks]

END OF QUESTIONS

SUB-TOPIC 3.5.S

SYNOPTIC AND CROSS-TOPIC QUESTIONS

Sub-topic 3.5.S · 52 questions · 191 marks · lowest tariff first

2 2 A coil with 20 circular turns each of diameter $60\ \text{mm}$ is placed in a uniform magnetic field of flux density $90\ \text{mT}$.

Initially the plane of the coil is perpendicular to the magnetic field lines as shown in **Figure X**.

Figure X

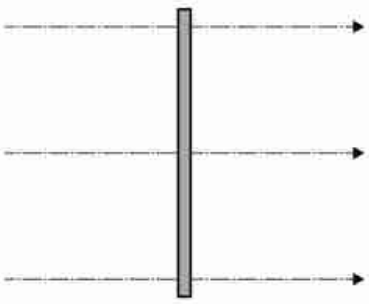
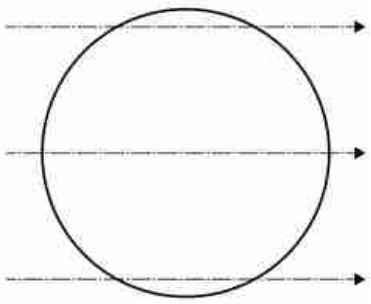


Figure Y



The coil is rotated about a vertical axis by $90°$ in a time of $0.20\ \text{s}$ so that its plane becomes parallel to the field lines as shown in **Figure Y**.
Assume that the rate of change of flux linkage remains constant.

What is the emf induced in the coil?

[1 mark]

A zero ⬭

B $1.3\ \text{mV}$ ⬭

C $25\ \text{mV}$ ⬭

D $100\ \text{mV}$ ⬭

2 3 The mean power dissipated in a resistor is $47.5\ \mu W$ when the root mean square (rms) voltage across the resistor is $150\ mV$.

What is the peak current in the resistor?

[1 mark]

A $2.3 \times 10^{-4}\ A$ ⬭

B $4.5 \times 10^{-4}\ A$ ⬭

C $2.3 \times 10^{3}\ A$ ⬭

D $4.5 \times 10^{3}\ A$ ⬭

2 5 A mains transformer has a primary coil of 2500 turns and a secondary coil of 130 turns.
The primary coil is connected to a mains supply where V_{rms} is 230 V.
The secondary coil is connected to a lamp of resistance $6.0\ \Omega$.
The transformer is 100% efficient.

What is the peak power dissipated in the lamp?

[1 mark]

A 12 W ⬭

B 24 W ⬭

C 48 W ⬭

D 96 W ⬭

2 6 The Rutherford scattering experiment led to

[1 mark]

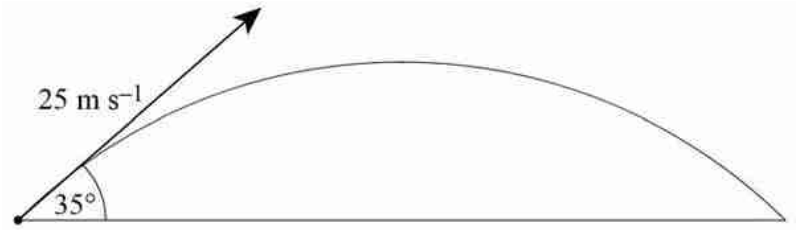
A the discovery of the electron. ⬭

B the quark model of hadrons. ⬭

C the discovery of the nucleus. ⬭

D evidence for wave-particle duality. ⬭

2 3 A projectile is launched with a speed of $25\ \text{m s}^{-1}$ at an angle of $35°$ to the horizontal, as shown in the diagram.



Air resistance is negligible.

What is the time taken for the projectile to return to the ground?

[1 mark]

A 1.5 s ⬭

B 2.1 s ⬭

C 2.9 s ⬭

D 4.2 s ⬭

2 3 An air-filled parallel-plate capacitor is charged from a source of emf. The electric field has a strength E between the plates. The capacitor is disconnected from the source of emf and the separation between the isolated plates is doubled.

What is the final electric field between the plates?

[1 mark]

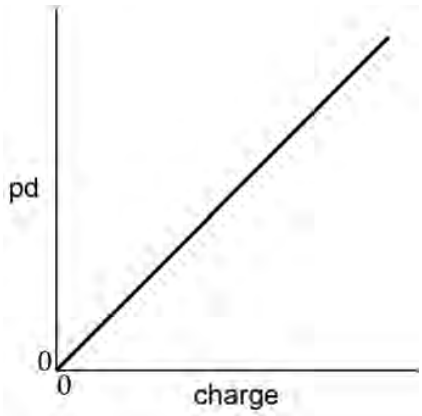
A $2E$ ⬭

B E ⬭

C $\frac{E}{2}$ ⬭

D $\frac{E}{4}$ ⬭

2 5 The graph shows the variation of potential difference (pd) with charge for a capacitor while it is charging.



Which statement can be deduced from the graph?

[1 mark]

A The charging current is constant. ⬭

B The energy stored in the capacitor increases uniformly with time. ⬭

C The capacitance of the capacitor is constant. ⬭

D The power supply used to charge the capacitor had a constant terminal pd. ⬭

1 7 An electric vehicle is driven by a motor which produces a constant driving force.
The vehicle travels from rest along a straight horizontal road.
Friction and air resistance are negligible.

Which statement describes the variation with time of the power developed by the motor?
[1 mark]

A It stays constant. ⬭

B It increases linearly from zero. ⬭

C It increases non-linearly from zero. ⬭

D It increases from zero to a maximum and then decreases. ⬭

2 1 A $1.0\ \mu F$ capacitor initially stores $15\ \mu C$ of charge. It then discharges through a $25\ \Omega$ resistor.

What is the maximum current during the discharge of the capacitor?

[1 mark]

A $0.60\ mA$ ⬭

B $1.2\ mA$ ⬭

C $0.60\ A$ ⬭

D $1.2\ A$ ⬭

2 8 A steady current I dissipates power P in a resistor of resistance R.
An alternating current through a resistor of resistance $2R$ has a peak value of I.

What is the power dissipated in the second resistor?

[1 mark]

A $\frac{P}{\sqrt{2}}$ ⬭

B P ⬭

C $\sqrt{2}\,P$ ⬭

D $2P$ ⬭

2 2 A 10 μF capacitor stores 4.5 mJ of energy.
It then discharges through a 25 Ω resistor.

What is the maximum current during the discharge of the capacitor?

[1 mark]

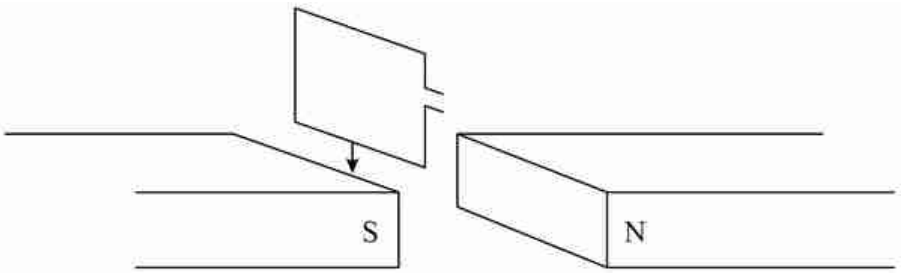
A 1.2 A ⬭

B 18 A ⬭

C 30 A ⬭

D 36 A ⬭

2 4 The diagram shows a small rectangular coil falling between two magnetic poles.

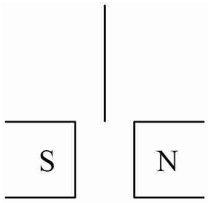


The coil is shown at four instants as it passes through the magnetic field.

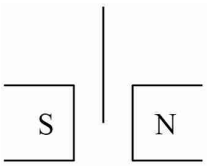
At which instant will the induced emf be a maximum?

[1 mark]

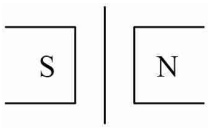
A



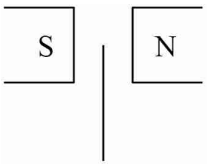
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

2 5 An alternating emf is induced in a coil rotating in a magnetic field.

What is the phase difference between the magnetic flux linkage through the coil and the emf?

[1 mark]

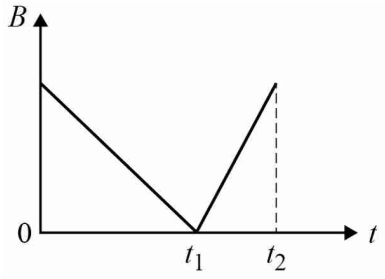
A 0 ⬭

B $\frac{\pi}{3}$ rad ⬭

C $\frac{\pi}{2}$ rad ⬭

D π rad ⬭

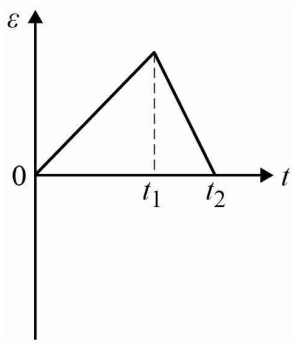
2 6 The diagram shows the variation with time t of the magnetic flux density B of the field linking a coil.



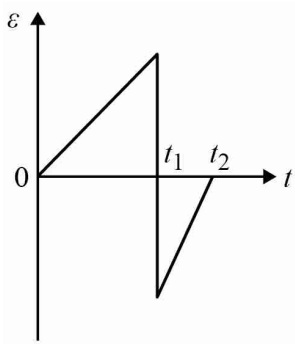
Which graph shows the variation of induced emf ε in the coil during this time interval?

[1 mark]

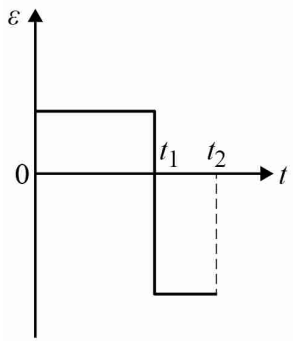
A



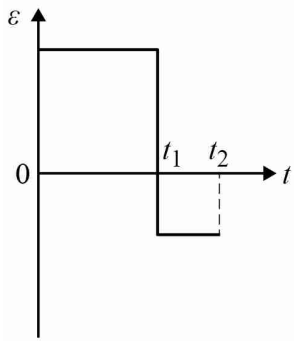
B



C



D



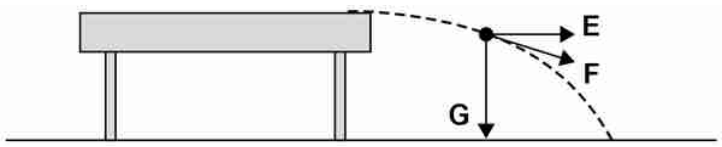
A ⬭

B ⬭

C ⬭

D ⬭

2 3 A coin is projected horizontally from the top of a desk.
The diagram shows the coin at one point in its path. The air resistance is negligible.



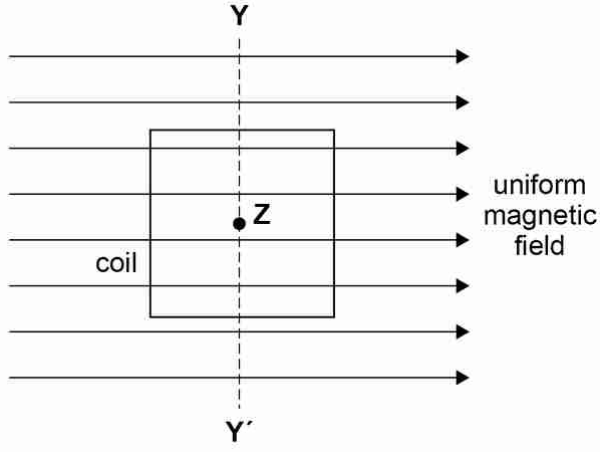
The arrows **E**, **F** and **G** represent different directions.

Which row gives the direction of the acceleration and the direction of the momentum of the coin at this point?

[1 mark]

	Acceleration	Momentum	
A	**F**	**F**	⬭
B	**F**	**E**	⬭
C	**G**	**F**	⬭
D	**G**	**E**	⬭

2 2 The diagram shows a square coil with its plane parallel to a uniform magnetic field.



The coil always remains within the magnetic field.
There are four possible changes to the position of the coil:

- moving it to the left
- moving it towards **Y**
- rotating it about the axis **YY´**
- rotating it about an axis **Z** that is at its centre and perpendicular to the plane of the coil.

How many of these changes will result in an induced emf in the coil while the change occurs?

[1 mark]

A one ⬭

B two ⬭

C three ⬭

D four ⬭

2 4 In a resistor of resistance R, a steady current I dissipates a power P.

In a resistor of resistance $\frac{R}{2}$ there is an alternating current of root mean square value $3I$.

What is the mean power dissipated in the resistor of resistance $\frac{R}{2}$?

[1 mark]

A $9P$ ⬭

B $\frac{9}{2}P$ ⬭

C $\frac{9}{4}P$ ⬭

D $\frac{3}{2}P$ ⬭

2 3 A ball is thrown vertically upwards and returns to its original position 2.4 s later.
The effect of air resistance is negligible.

What is the total distance travelled by the ball?

[1 mark]

A 5.9 m ⬭

B 7.1 m ⬭

C 14 m ⬭

D 28 m ⬭

2 6 A tennis ball has a mass of 58 g.
The ball is dropped from rest from a height of 1.8 m above the ground and falls vertically.
The ball rebounds vertically to a height of 1.1 m.
The effect of air resistance is negligible.

What is the change in momentum of the ball during its collision with the ground?

[1 mark]

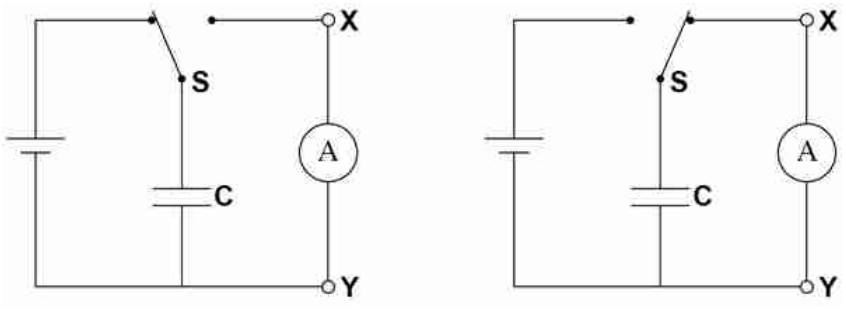
A 0.040 N s ⬭

B 0.075 N s ⬭

C 0.215 N s ⬭

D 0.614 N s ⬭

1 7 A switch **S** allows capacitor **C** to be completely charged by a cell and then completely discharged through an ammeter.
The emf of the cell is $4.0\ \text{V}$ and it has negligible internal resistance.
The capacitance of **C** is $0.40\ \mu\text{F}$ and there are 8000 charge–discharge cycles every second.



charging discharging

What are the magnitude and direction of the average conventional current in the ammeter?
[1 mark]

	Magnitude of current / A	Direction of current	
A	1.3×10^{-2}	**X** to **Y**	⬭
B	1.3×10^{-2}	**Y** to **X**	⬭
C	2.0×10^{-10}	**X** to **Y**	⬭
D	2.0×10^{-10}	**Y** to **X**	⬭

1 8 A $30\ \mu\text{F}$ capacitor is charged by connecting it to a battery of emf $4.0\ \text{V}$.
The initial charge on the capacitor is Q_0.

The capacitor is then discharged through a $500\ \text{k}\Omega$ resistor.
The time constant for the circuit is T.

Which is correct?

[1 mark]

A T is $15\ \text{ms}$. ⬭

B Q_0 is $12\ \mu\text{C}$. ⬭

C After a time T the pd across the capacitor is $1.5\ \text{V}$. ⬭

D After a time $2T$ the charge on the capacitor is Q_0e^2. ⬭

2 3 A coil is rotated at frequency f in a uniform magnetic field.
The magnetic flux linking the coil is a maximum at time t_1 and the emf induced in the coil is a maximum at time t_2.

What is the smallest value of $t_1 - t_2$?

[1 mark]

A 0 ⬭

B $\frac{1}{4f}$ ⬭

C $\frac{1}{2f}$ ⬭

D $\frac{3}{4f}$ ⬭

2 4 Power P is dissipated in a resistor of resistance R carrying a direct current I.

A second resistor of resistance $2R$ carries an alternating current with peak value I.

What is the power dissipated in the second resistor?

[1 mark]

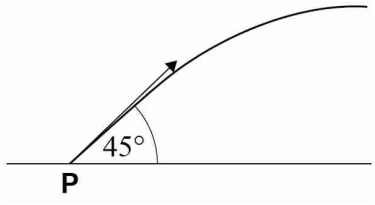
A $\sqrt{2}P$ ⬭

B P ⬭

C $2P$ ⬭

D $4P$ ⬭

1 8 A ball is kicked from point **P** on level ground. The ball initially travels at 45° to the horizontal.
The ball reaches its maximum height after a time of 2.0 s.
Air resistance can be ignored.



What is the displacement of the ball from **P** when at its maximum height?

[1 mark]

A 20 m ⬭

B 40 m ⬭

C 45 m ⬭

D 60 m ⬭

2 4 A trolley moves down a slope with constant acceleration.
The mass of the trolley is doubled and the trolley moves down the same slope again.
Air resistance and friction are negligible.

Which is correct?

[1 mark]

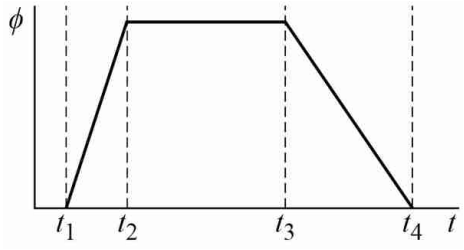
A The accelerating force is unchanged. ⬭

B The accelerating force is halved. ⬭

C The acceleration is unchanged. ⬭

D The acceleration is halved. ⬭

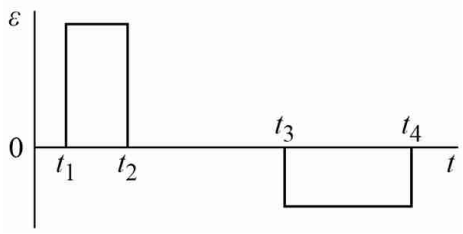
2 2 The magnetic flux ϕ in a coil varies with time t as shown.



Which graph shows how the emf ε induced in the coil varies with t?

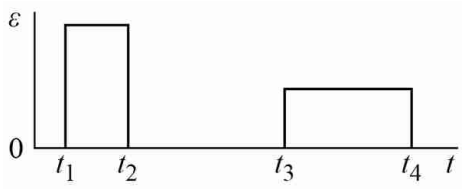
[1 mark]

A



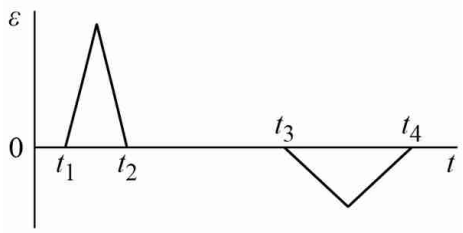
⬭

B



⬭

C



⬭

D



⬭

2 3 The distance between the wing tips of a metal aircraft is $30\ \text{m}$.
The aircraft flies horizontally at a steady speed of $100\ \text{m s}^{-1}$.
The aircraft passes through a vertical magnetic field of flux density $2.0 \times 10^{-7}\ \text{T}$.

What is the emf induced between its wing tips?

[1 mark]

A $0.2\ \mu\text{V}$ ⬭

B $20\ \mu\text{V}$ ⬭

C $300\ \mu\text{V}$ ⬭

D $600\ \mu\text{V}$ ⬭

2 4 A circular coil with a radius of $0.10\ \text{m}$ has 200 turns.
The coil rotates at 50 revolutions per second about an axis which is perpendicular to a uniform magnetic field and in the plane of the coil.
The magnetic flux density of the field is $0.20\ \text{T}$.

What is the maximum emf induced in the coil?

[1 mark]

A 63 V ⬭

B 126 V ⬭

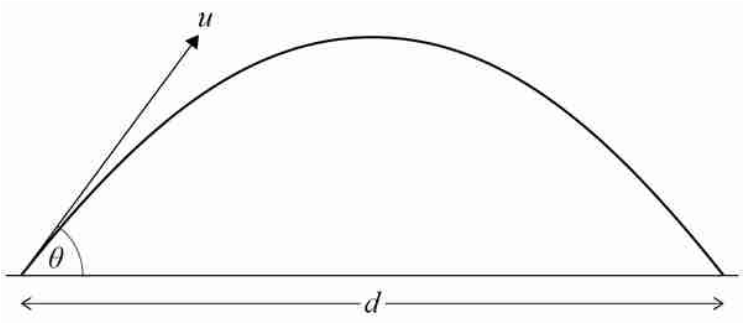
C 195 V ⬭

D 395 V ⬭

2 0 A projectile is fired from ground level over horizontal ground.

Its initial velocity is u at an angle θ to the horizontal.

The range of the projectile is d.



A second projectile is fired with a velocity $2u$ at the same angle.

What is the range of this projectile?
Assume that air resistance is negligible.

[1 mark]

A $\sqrt{2}d$ ⬭

B $2d$ ⬭

C $2\sqrt{2}d$ ⬭

D $4d$ ⬭

1 5 A transmission cable consists of many strands of wire. Electrical energy is transmitted along the cable at a frequency of 50 Hz.

Which change gives the largest increase in the efficiency of the electrical energy transfer along the cable?

[1 mark]

A doubling the transmission voltage of the cable ⬭

B doubling the current in the cable ⬭

C halving the resistivity of the material of the wires ⬭

D halving the number of wires in the cable ⬭

2 1 A skydiver is falling at a terminal velocity v_1.
When she is at a height h_1 she opens her parachute.
When she is at a height h_2 she reaches a new terminal velocity v_2.

Which is true?

[1 mark]

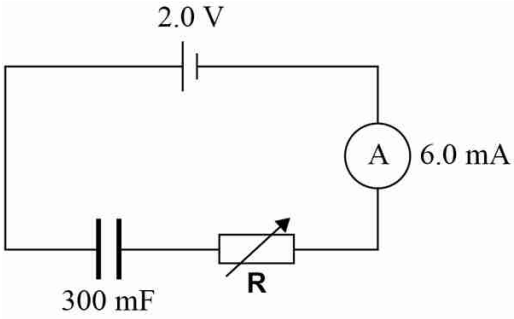
A The increased air resistance when her height is h_1 causes her initially to move upwards. ⬭

B The drag force when her velocity is v_2 is equal to the drag force when her velocity is v_1. ⬭

C At v_1, her weight and the drag force are an action–reaction pair according to Newton's third law. ⬭

D Between h_1 and h_2, the work done by the drag force is equal to the change in the kinetic energy of the parachute and skydiver. ⬭

1 8 A capacitor is initially uncharged and is then charged using a constant current. This is achieved by reducing the resistance of a variable resistor **R** as the charge on the capacitor increases.



The capacitor has a capacitance of 300 mF and is fully charged in a time $t = 100$ s.
The cell has an emf of 2.0 V and negligible internal resistance.
The charging current is 6.0 mA.

What is the resistance of **R** at $t = 30$ s?

[1 mark]

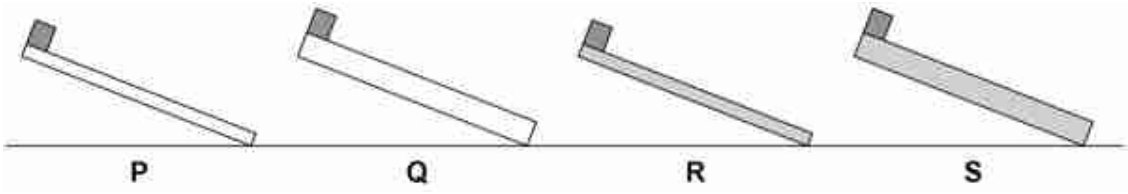
A 58 Ω ⬭

B 100 Ω ⬭

C 233 Ω ⬭

D 333 Ω ⬭

1 9 Four identical magnets slide down four ramps **P**, **Q**, **R** and **S** of the same length and width. The slope of each ramp is the same.



The table shows the resistivity and thickness of each ramp.

	Resistivity	Thickness
P	ρ	d
Q	ρ	$2d$
R	2ρ	d
S	2ρ	$2d$

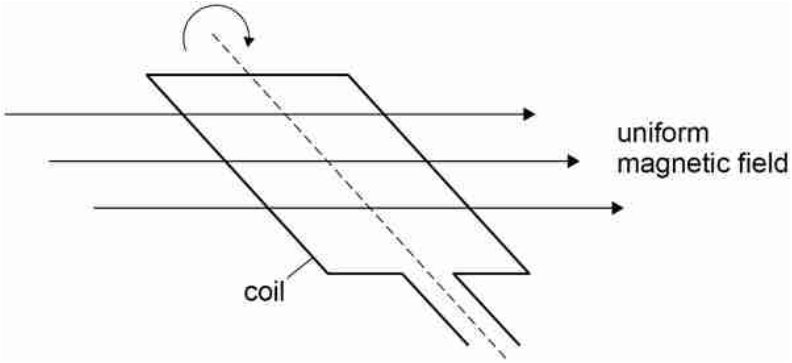
Friction is the same for each ramp.
The time t for each magnet to slide down the entire length of its ramp is measured.

Which row shows the ramp with the smallest t and the ramp with the largest t?

[1 mark]

	Smallest t	Largest t	
A	**R**	**S**	⬭
B	**R**	**Q**	⬭
C	**Q**	**S**	⬭
D	**Q**	**P**	⬭

2 1 A coil rotates at a constant angular speed in a uniform horizontal magnetic field.
The diagram shows the instant when the plane of the coil is horizontal.



cross-sectional area of coil = 20×10^{-3} m^2
number of turns in coil = 500 turns
magnetic flux density = 50 mT
frequency of rotation = 50 Hz

What is the mean induced emf, in V, as the coil rotates through π rad from the position shown?

[1 mark]

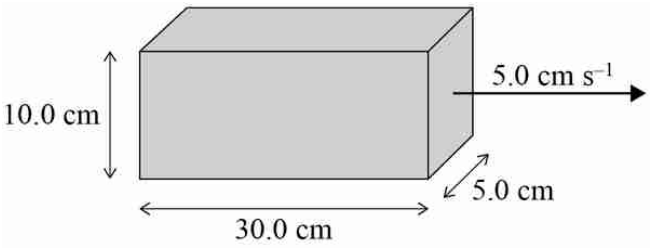
A 0 ⬭

B 0.50 ⬭

C 100 ⬭

D 157 ⬭

2 2 A metal block has dimensions $30.0\ \text{cm} \times 10.0\ \text{cm} \times 5.0\ \text{cm}$ as shown.



The block is moved at a constant horizontal velocity of $5.0\ \text{cm s}^{-1}$ through a uniform vertical magnetic field so that an emf is induced across the block.

The magnetic field has a magnetic flux density of $2.5\ \text{mT}$.

What is the induced emf?

[1 mark]

A $150\ \mu\text{V}$ ⬭

B $37.5\ \mu\text{V}$ ⬭

C $12.5\ \mu\text{V}$ ⬭

D $6.25\ \mu\text{V}$ ⬭

2 3 A transformer is used to connect an ac power supply to a 100 W filament lamp.

When the lamp is operating at its rated power, the power supply has a peak potential difference of 50 V and supplies a peak current of 5.0 A.

What is the efficiency of the transformer?

[1 mark]

A 80% ⬭

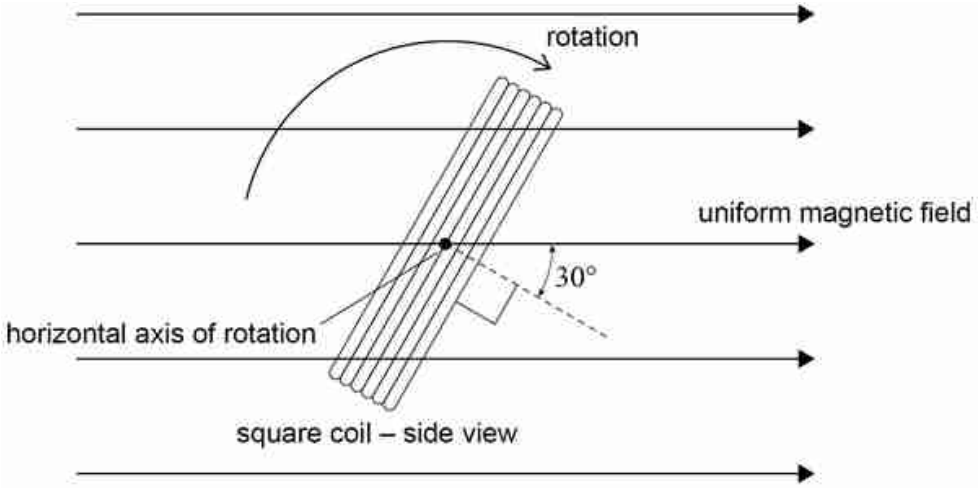
B 57% ⬭

C 40% ⬭

D 28% ⬭

0 5 A square coil of wire is rotating at a constant angular speed about a horizontal axis. **Figure 4** shows the coil at one instant when the normal to the plane of the coil is at $30°$ to a magnetic field.

Figure 4



The area of the coil is 5.0×10^{-4} m^2 and the flux density of the uniform magnetic field is 2.5×10^{-2} T.

0 5 . 1 The maximum flux linkage of the coil during its rotation is 1.5×10^{-3} Wb turns.

Calculate the number of turns in the coil.

[2 marks]

number of turns = _____

0 5 . 2 Calculate the flux linkage of the coil at the instant shown in **Figure 4**.

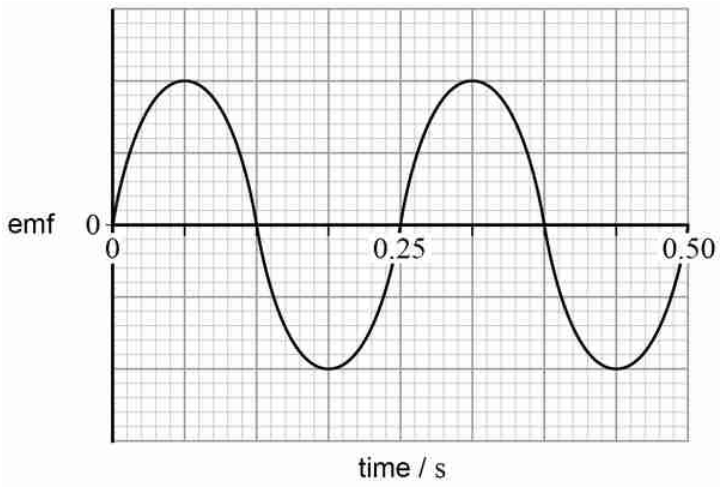
[1 mark]

flux linkage = _____ Wb turns

Question 5 continues on the next page

0 5 . 3 The coil forms part of an electrical generator. **Figure 5** shows the emf generated by the coil.

Figure 5



Calculate the peak value of the emf generated.

[2 marks]

emf = _____ V

0 5 . 4 Sketch on **Figure 6** the variation with time of flux linkage for the same time interval as **Figure 5**.

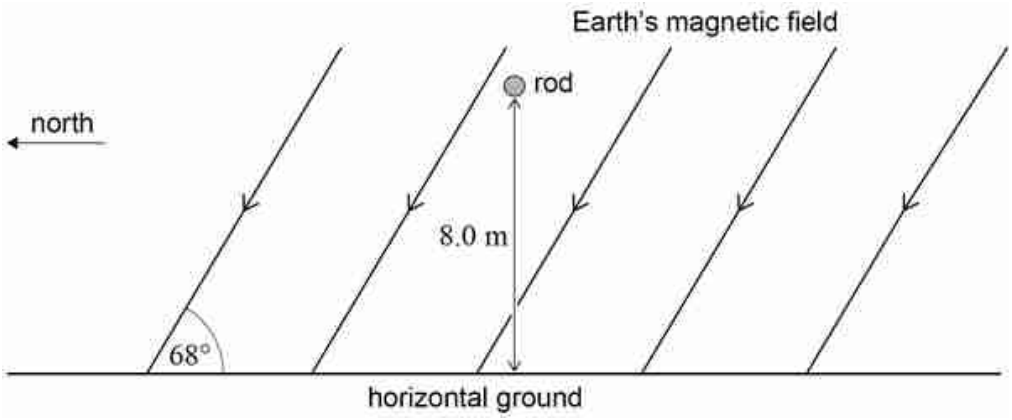
[1 mark]

Figure 6

0 3 A conducting rod is held horizontally in an east–west direction.
The magnetic flux density of the Earth's magnetic field is 4.9×10^{-5} T and is directed at an angle of $68°$ to the ground.

0 3 . 1 **Figure 5** shows the arrangement. The rod has a length of 2.0 m.

Figure 5



The rod is released and falls 8.0 m to the ground. It remains in a horizontal east–west direction as it falls.

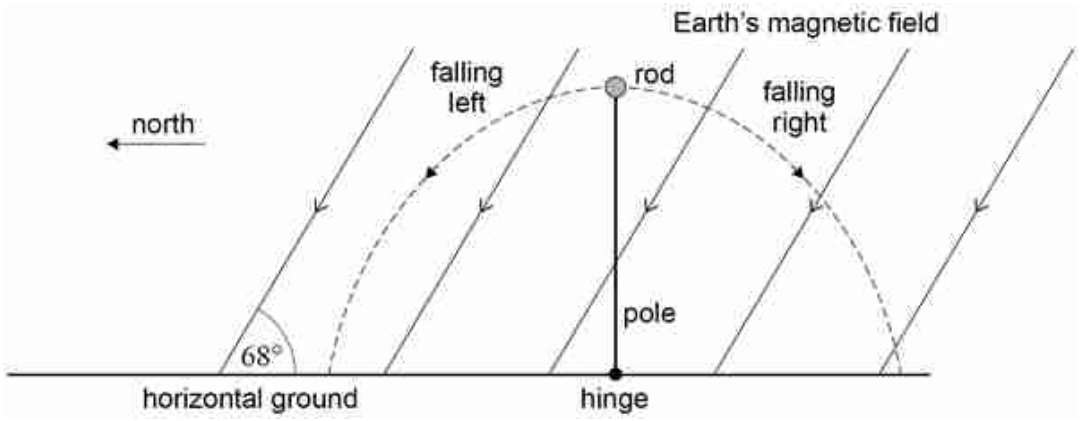
Determine the average emf across the rod during its fall to the ground.
Assume that air resistance is negligible.

[3 marks]

average emf = _____ V

0 3 . 2 The rod is returned to its original position. It is now supported by a non-conducting pole that is hinged on the ground as shown in **Figure 6**.
The pole is initially vertical and is then released.
The rod and pole can fall to the ground to the left or to the right.

Figure 6



During each fall there are changes in the magnitude and direction of the induced emf.
These changes differ depending on whether the rod falls to the left or to the right.

Explain any changes in the magnitude and direction of the induced emf as the rod falls:
- to the left
- to the right.

[4 marks]

left _____

_____

_____

_____

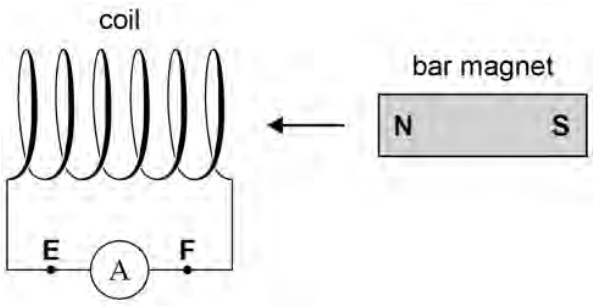
right _____

0 4 . 1 State Lenz's law.

[1 mark]

0 4 . 2 Lenz's law can be demonstrated using a bar magnet and a coil of wire connected to a sensitive ammeter as shown in **Figure 6**.

Figure 6



The bar magnet is moved towards the coil and is then brought to a halt.

State how the reading on the ammeter changes during this process.

[1 mark]

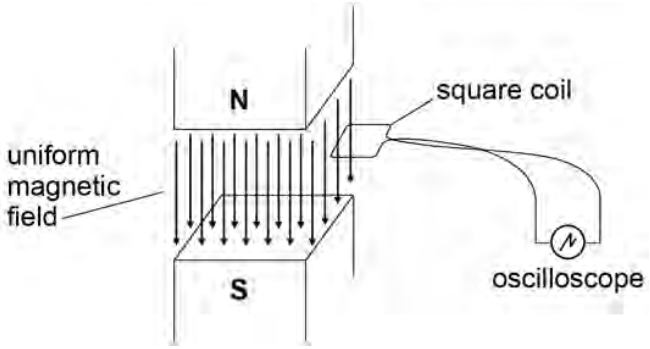
0 4 . 3 During the demonstration an induced current is detected by the ammeter. The induced current is in the direction **E** to **F**.

Explain how this demonstrates Lenz's law.

[2 marks]

0 4 . 4 **Figure 7** shows an arrangement for investigating induced emf.

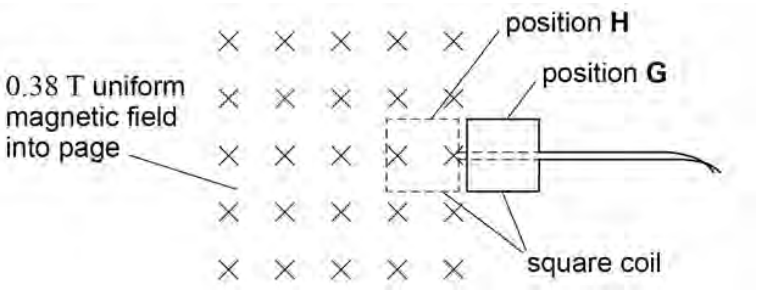
Figure 7



As shown, the uniform vertical magnetic field is confined to the gap between the poles of the magnet. The plane of the square coil is horizontal and is made of conducting wire. The coil consists of a single turn and is attached by flexible wire to an oscilloscope.

The oscilloscope gives a reading of 2.9×10^{-4} V when the coil is moved at uniform speed from position **G** outside the field to position **H** inside the field, as shown in **Figure 8**.

Figure 8



Length of side of square coil = 32 mm

Magnetic flux density of uniform magnetic field = 0.38 T

Calculate the time taken to move the coil from position **G** to position **H**.

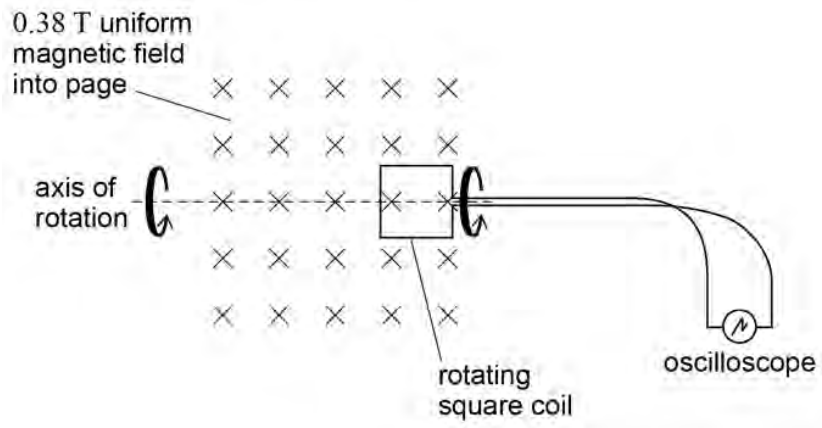
[2 marks]

time = _____ s

Question 4 continues on the next page

0 4 . 5 The square coil is rotated through 360° at a constant angular speed about the horizontal axis shown in **Figure 9**.

Figure 9



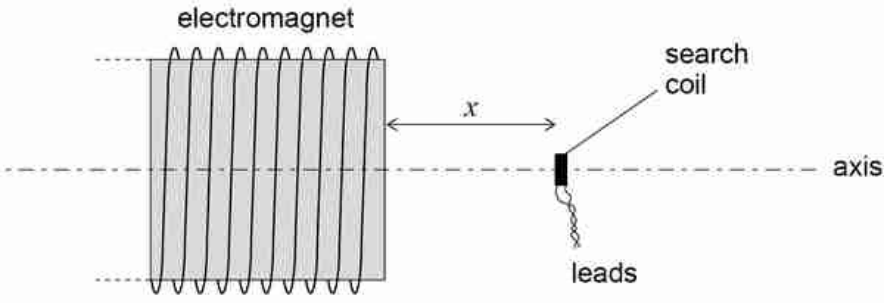
Calculate the angular speed of the coil when the maximum reading on the oscilloscope is 5.1 mV

[2 marks]

angular speed = _____ rad s^{-1}

0 4 **Figure 7** shows a search coil positioned on the axis of an electromagnet, with the plane of the search coil perpendicular to the axis. A magnetic field is produced by a constant current in the electromagnet.
Assume that the magnetic flux density inside the search coil is uniform.

Figure 7



The distance between the search coil and the end of the electromagnet is x.
Figure 8 shows how the magnetic flux density B of the field varies with x.

Figure 8

The search coil has 200 turns and a cross-sectional area of 3.5×10^{-5} m^2.

0 4 . 1 The search coil is placed at $x = 0.070$ m.

Show that the magnetic flux linkage through the search coil is about 5×10^{-4} Wb.

[2 marks]

Question 4 continues on the next page

The search coil is now moved at a constant speed of $0.80\ \text{m s}^{-1}$ along the axis so that x is increasing. An emf is induced across the terminals of the search coil.

0 4 . 2 Explain what happens to the value of the emf as the search coil moves.

[2 marks]

0 4 . 3 The search coil passes through the position where $x = 0.10\ \text{m}$.

Deduce whether the emf can exceed $5\ \text{mV}$ for values of x greater than $0.10\ \text{m}$.

[4 marks]

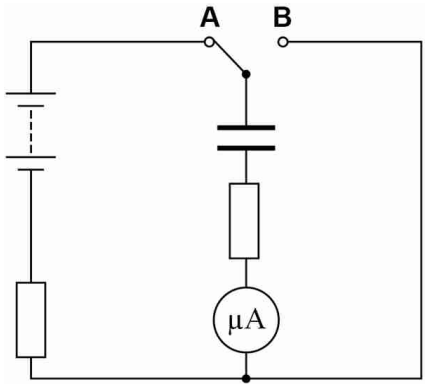
0 5 . 1 A material used between the plates of a capacitor has a dielectric constant of 7.0

State what is meant by a dielectric constant of 7.0

[1 mark]

Figure 3 shows a circuit that is used to charge and discharge a capacitor.

Figure 3



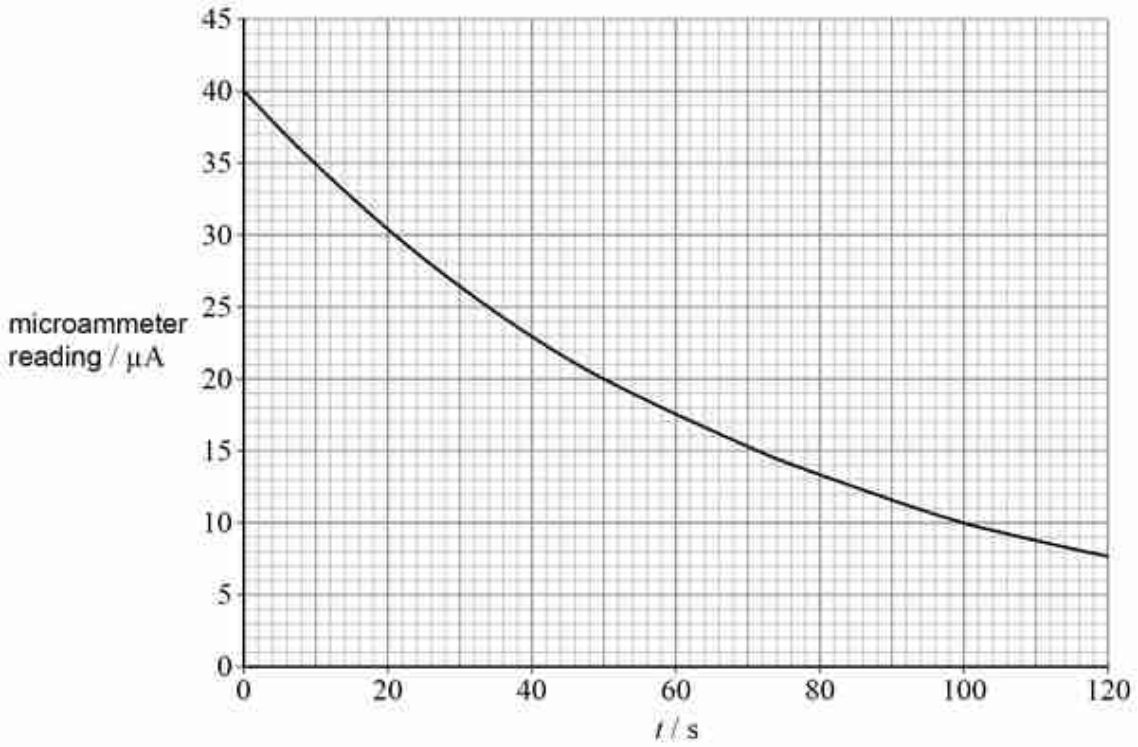
The battery has negligible internal resistance.

The two resistors in the circuit are identical.

The capacitor is fully charged and the switch is then moved from position **A** to position **B** at time $t = 0$

Figure 4 shows the variation of the microammeter reading with t until $t = 120$ s.

Figure 4



The time constant of the discharging circuit is T.

0 5 . 2 Determine T using **Figure 4**.

[2 marks]

$T =$ _____ s

0 5 . 3 Electronic engineers consider a capacitor to be fully discharged when $t = 5T$.

Calculate $\frac{\text{current when } t = 5T}{\text{current when } t = 0}$ as a percentage.

[2 marks]

$\frac{\text{current when } t = 5T}{\text{current when } t = 0} =$ _____ %

0 5 . 4 The capacitor is fully discharged and then the switch is moved from position **B** to position **A** as shown in **Figure 3**.

Draw, on **Figure 5**, the variation of the microammeter reading with time after the switch is moved to position **A**.
In **Figure 5**, the time is 0 at the instant when the switch is moved to position **A**.

[3 marks]

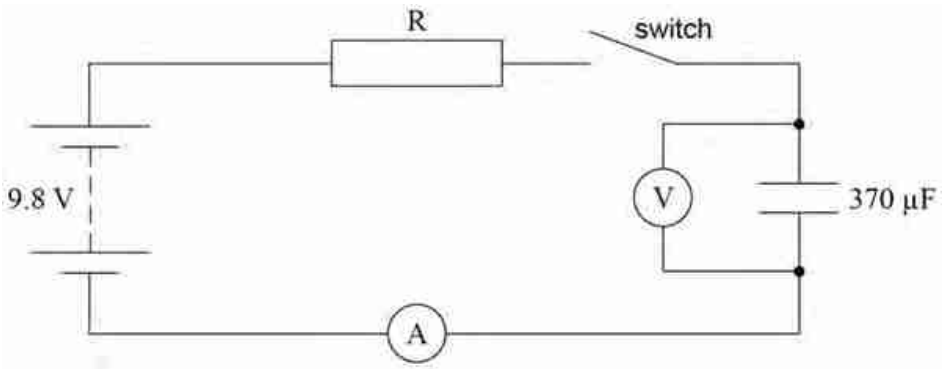
Figure 5

0 3 . 1 State what is meant by a capacitance of $370\ \mu F$

[2 marks]

0 3 . 2 The charging of a $370\ \mu F$ capacitor is investigated using the circuit shown in **Figure 4**. Both meters in the circuit are ideal.

Figure 4



The power supply of emf $9.8\ V$ has a negligible internal resistance. The capacitor is initially uncharged. When the switch is closed at time $t = 0$ charge begins to flow through resistor R. The time constant of the charging circuit is $1.0\ s$

Calculate the resistance of R.

[1 mark]

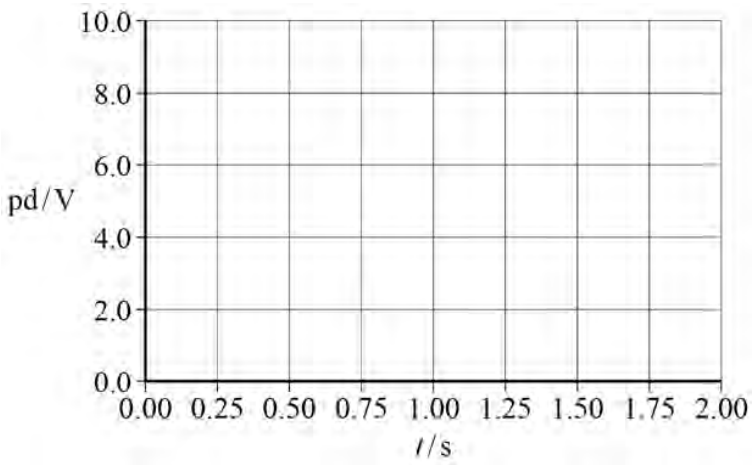
resistance of R = _____ Ω

Question 3 continues on the next page

0 3 . 3 Identify, with the symbol X on **Figure 5**, the potential difference (pd) across the capacitor when the switch has been closed for 2.0 s
Sketch the graph that shows how the pd varies from $t = 0$ to $t = 2.0$ s

[2 marks]

Figure 5



0 3 . 4 Calculate the time taken for the charging current to fall to half its initial value.

[1 mark]

time = _____ s

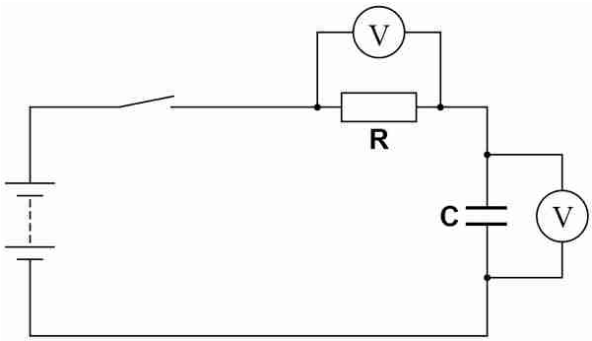
0 3 . 5 Calculate the time taken for the charge on the capacitor to reach $3.0\ \text{mC}$

[3 marks]

time = _____ s

0 2 **Figure 1** shows a circuit used to charge capacitor **C**.
The battery has negligible internal resistance.

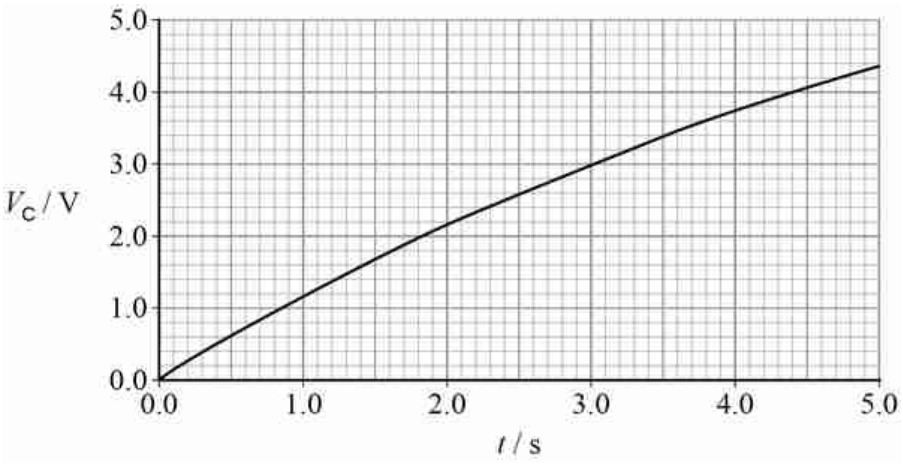
Figure 1



The capacitance of **C** is known.

0 2 . 1 The switch is closed at time $t = 0$ and the potential difference V_C across **C** is recorded at different times t.
Figure 2 shows the variation of V_C with t.

Figure 2

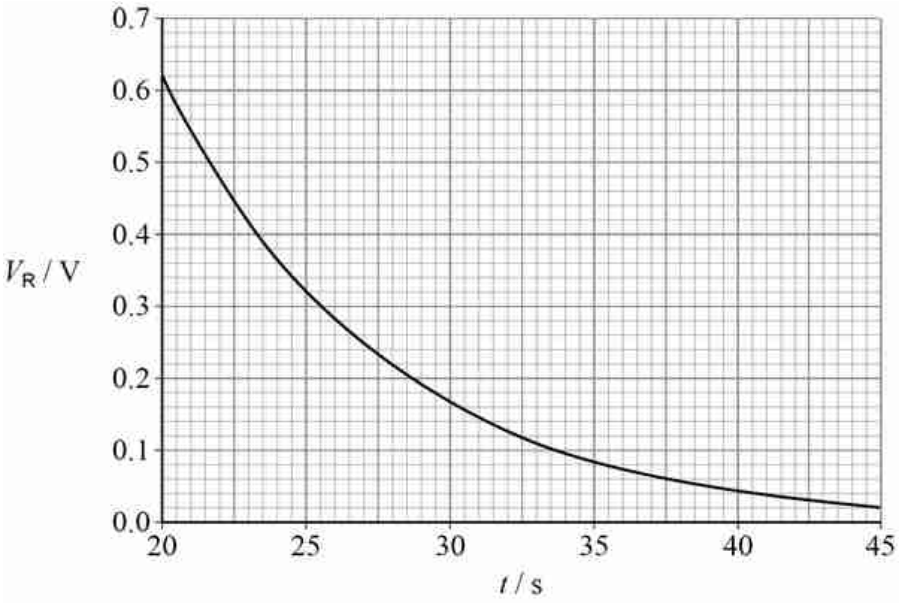


Explain how a gradient of the graph in **Figure 2** can be used to determine the initial current I_0 in the circuit.

[2 marks]

0 2 . 2 The potential difference V_R across **R** is also recorded.
Figure 3 shows the variation of V_R with t between $t = 20$ s and $t = 45$ s.

Figure 3



The capacitance of **C** is $31.0\ \mu F$.

Determine, using **Figure 3**, the time constant of the circuit.
Go on to show that the resistance of **R** is about $2.4 \times 10^5\ \Omega$.

[2 marks]

time constant = _____ s

resistance = _____ Ω

Question 2 continues on the next page

0 2 . 3 The current I_0 at time $t = 0$ is 3.6×10^{-5} A.

Determine the time at which V_C is 6.0 V.

[3 marks]

time = _____ s

0 2 . 4 **Figure 4** shows two fully charged parallel-plate capacitors $\mathbf{C}_1$ and $\mathbf{C}_2$ in a circuit.
A dielectric fills the space between the plates of $\mathbf{C}_1$ and air fills the space between the plates of $\mathbf{C}_2$.

Figure 4

Table 2 gives information about $\mathbf{C_1}$ and $\mathbf{C_2}$.

Table 2

	$\mathbf{C_1}$	$\mathbf{C_2}$
charge	Q	Q
surface area	S	S
potential difference	V_1	V_2
plate separation	d	$2d$
dielectric constant	4.0	1.0

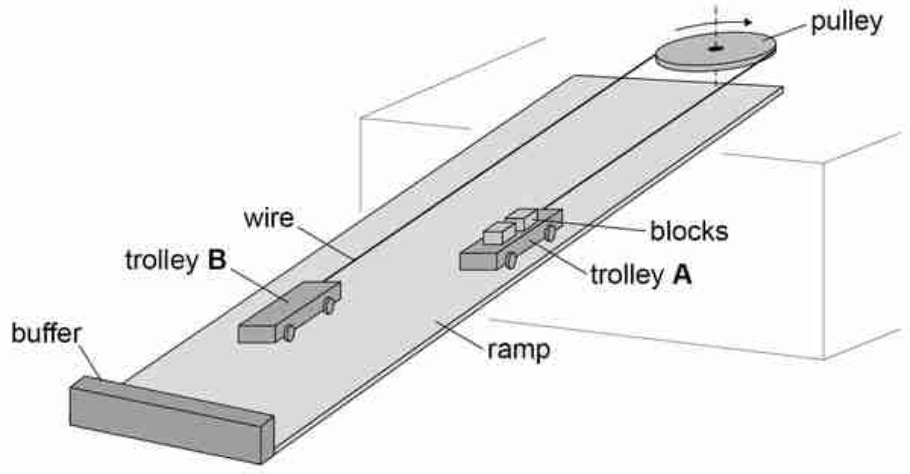
Determine $\frac{V_1}{V_2}$.

[2 marks]

$\frac{V_1}{V_2} =$ _____

0 6 **Figure 8** shows a model of a system being designed to move concrete building blocks from an upper to a lower level.

Figure 8



The model consists of two identical trolleys of mass M on a ramp which is at $35°$ to the horizontal. The trolleys are connected by a wire that passes around a pulley of negligible mass at the top of the ramp.

Two concrete blocks each of mass m are loaded onto trolley **A** at the top of the ramp. The trolley is released and accelerates to the bottom of the ramp where it is stopped by a flexible buffer. The blocks are unloaded from trolley **A** and two blocks are loaded onto trolley **B** that is now at the top of the ramp. The trolleys are released and the process is repeated.

Figure 9 shows the side view of trolley **A** when it is moving **down** the ramp.

Figure 9

0 6 . 1 The tension in the wire when the trolleys are moving is T.

Draw and label arrows on **Figure 9** to represent the magnitudes and directions of any forces and components of forces that act on trolley **A** parallel to the ramp as it travels down the ramp.

[1 mark]

0 6 . 2 Assume that no friction acts at the axle of the pulley or at the axles of the trolleys and that air resistance is negligible.

Show that the acceleration a of trolley **B** along the ramp is given by

$$a = \frac{mg \sin 35^\circ}{M + m}$$

[2 marks]

0 6 . 3 Compare the momentum of loaded trolley **A** as it moves downwards with the momentum of loaded trolley **B**.

[2 marks]

Question 6 continues on the next page

0 6 . 4 In practice, for safety reasons there is a friction brake in the pulley that provides a resistive force to reduce the acceleration to 25% of the maximum possible acceleration.

The distance travelled for each journey down the ramp is 9.0 m.

The following data apply to the arrangement.

Mass of a trolley M = 95 kg
Mass of a concrete block m = 30 kg

Calculate the time taken for a loaded trolley to travel down the ramp.

[3 marks]

time = _____ s

0 6 . 5 It takes 12 s to remove the blocks from the lower trolley and reload the upper trolley.

Calculate the number of blocks that can be transferred to the lower level in 30 minutes.

[2 marks]

number = _____

0 7 . 1 Derive an expression to show that for satellites in a circular orbit

$$T^2 \propto r^3$$

where T is the period of orbit and r is the radius of the orbit.

[2 marks]

0 7 . 2 Pluto is a dwarf planet. The mean orbital radius of Pluto around the Sun is 5.91×10^9 km compared to a mean orbital radius of 1.50×10^8 km for the Earth.

Calculate in years the orbital period of Pluto.

[2 marks]

orbital period of Pluto = _____ yr

0 7 . 3 A small mass released from rest just above the surface of Pluto has an acceleration of $0.617\ \text{m s}^{-2}$.

Assume Pluto has no atmosphere that could provide any resistance to motion.

Calculate the mass of Pluto.

Give your answer to an appropriate number of significant figures.

radius of Pluto = $1.19 \times 10^{6}\ \text{m}$

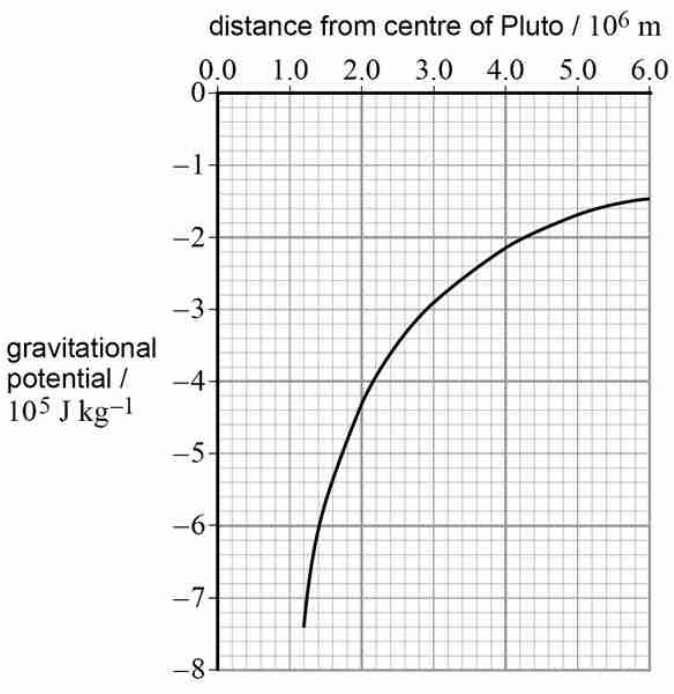
[3 marks]

mass of Pluto = _____ kg

Question 7 continues on the next page

0 7 . 4 **Figure 8** shows the variation in gravitational potential with distance from the centre of Pluto for points at and above its surface.

Figure 8



A meteorite hits Pluto and ejects a lump of ice from the surface that travels vertically at an initial speed of $1400\ \text{m s}^{-1}$.

Determine whether this lump of ice can escape from Pluto.

[3 marks]

END OF SECTION A

Section B

Each of Questions **8** to **32** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each answer completely fill in the circle alongside the appropriate answer.

CORRECT METHOD 

WRONG METHODS 

If you want to change your answer you must cross out your original answer as shown. 

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown. 

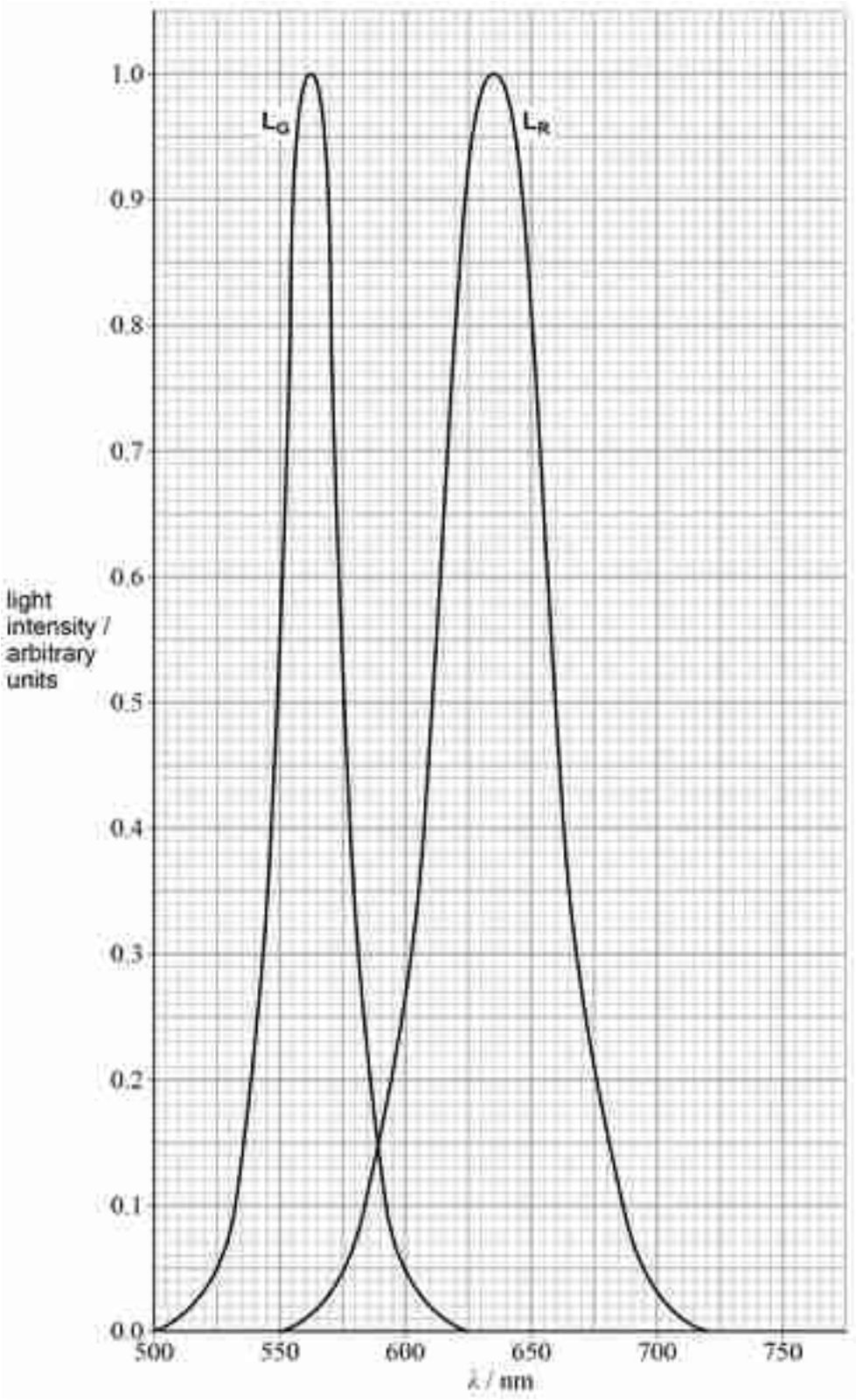
You may do your working in the blank space around each question but this will not be marked.

0 2 A light-emitting diode (LED) emits light over a narrow range of wavelengths. These wavelengths are distributed about a peak wavelength λ_p.

Two LEDs $\mathbf{L_G}$ and $\mathbf{L_R}$ are adjusted to give the same maximum light intensity. $\mathbf{L_G}$ emits green light and $\mathbf{L_R}$ emits red light.

Figure 3 shows how the light output of the LEDs varies with the wavelength λ.

Figure 3



Question 2 continues on the next page

0 2 . 1 Light from **L_R** is incident normally on a plane diffraction grating.
The fifth-order maximum for light of wavelength λ_p occurs at a diffraction angle of $76.3°$.

Determine N, the number of lines per metre on the grating.

[3 marks]

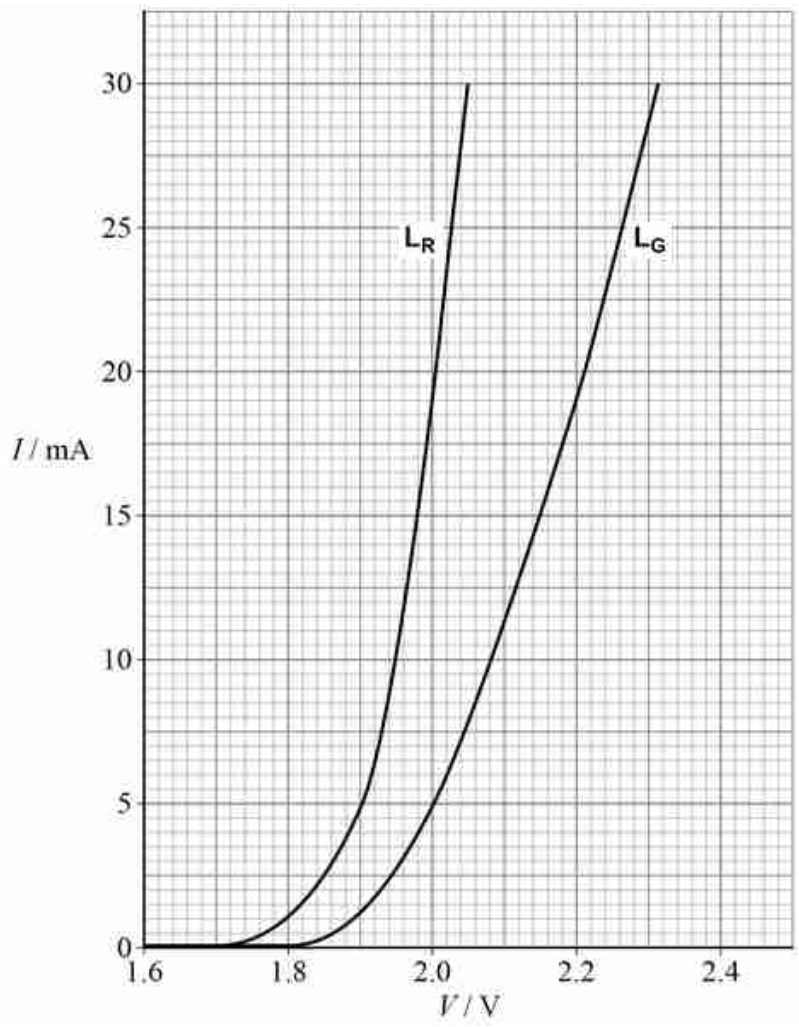
$N =$ _____ m^{-1}

0 2 . 2 Suggest **one** possible disadvantage of using the fifth-order maximum to determine N.

[1 mark]

0 2 . 3 **Figure 4** shows part of the current–voltage characteristics for **L_R** and **L_G**.

Figure 4



When the linear part of the characteristic is extrapolated, the point at which it meets the horizontal axis gives the activation voltage V_A for the LED.
V_A for **L_G** is 2.00 V.

Determine, using **Figure 4**, V_A for **L_R**.

[2 marks]

V_A for **L_R** = _____ V

Question 2 continues on the next page

0 2 . 4 It can be shown that:

$$V_A = \frac{hc}{e\lambda_p}$$

where h = the Planck constant.

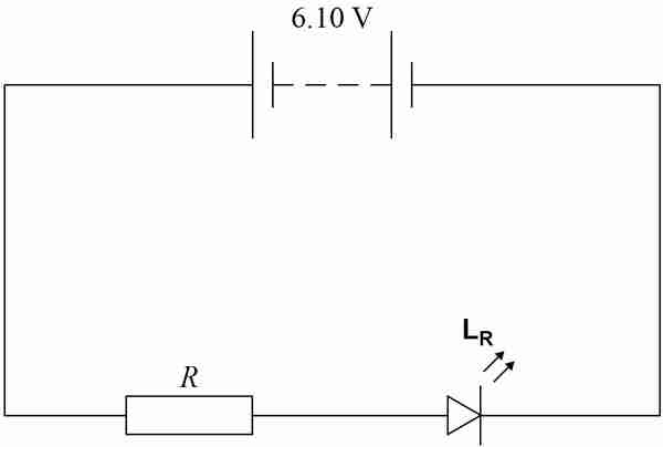
Deduce a value for the Planck constant based on the data given about the LEDs.

[2 marks]

$h =$ _____ J s

0 2 . 5 **Figure 5** shows a circuit with $\mathbf{L_R}$ connected to a resistor of resistance R.

Figure 5



The power supply has emf 6.10 V and negligible internal resistance.
The current in $\mathbf{L_R}$ must not exceed 21.0 mA.

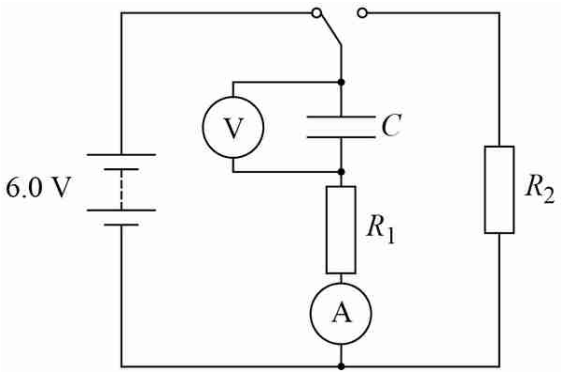
Deduce the minimum value of R.

[2 marks]

minimum value of R = _____ Ω

0 5 **Figure 8** shows a circuit used to investigate the charge and discharge of a capacitor of capacitance C using resistors of resistances R_1 and R_2.

Figure 8



The battery has an emf of 6.0 V and negligible internal resistance.

0 5 . 1 Show that the time taken for the capacitor to charge from 2.0 V to 4.0 V is approximately $0.7R_1C$.

[3 marks]

Question 5 continues on the next page

The capacitor is fully discharged.
The capacitor is then charged until the potential difference (pd) across it is $4.0\ \text{V}$.
Figure 9 shows the variation with time of the ammeter reading as the capacitor is charged.

Figure 9

0 5 . 2 Show that the capacitance of the capacitor is about 1×10^{-4} F.

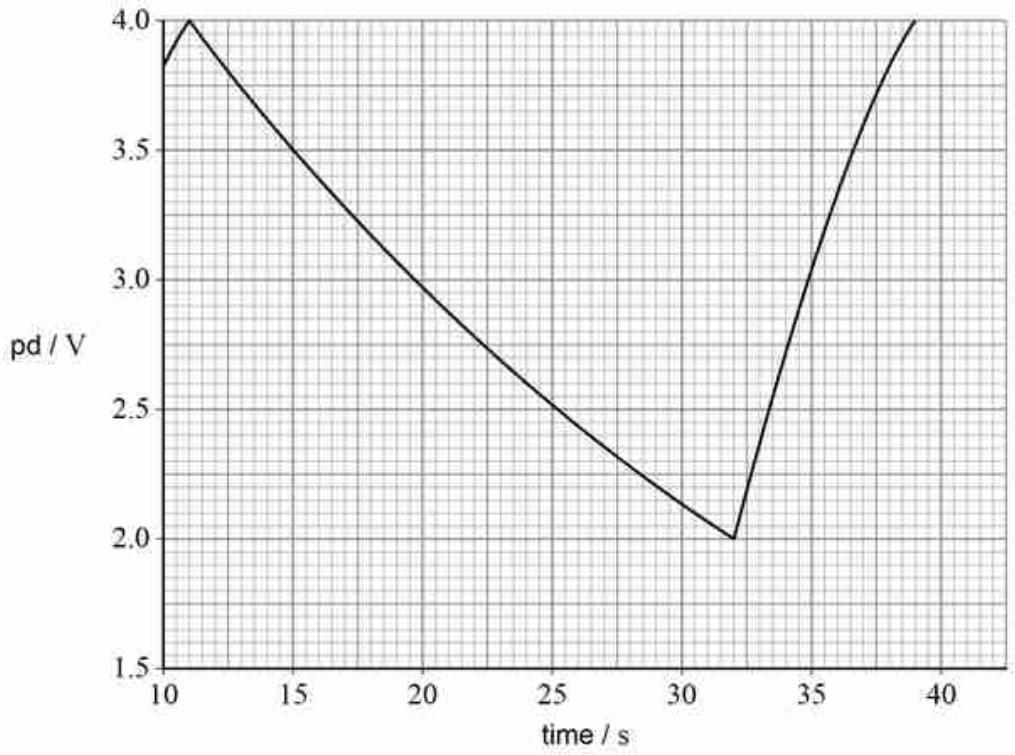
[4 marks]

Question 5 continues on the next page

0 5 . 3 When the pd reaches $4.0\ \text{V}$ the switch is immediately set to discharge the capacitor. When the pd reaches $2.0\ \text{V}$ the switch is immediately set to charge the capacitor.

Figure 10 shows how the pd across the capacitor varies with time.

Figure 10



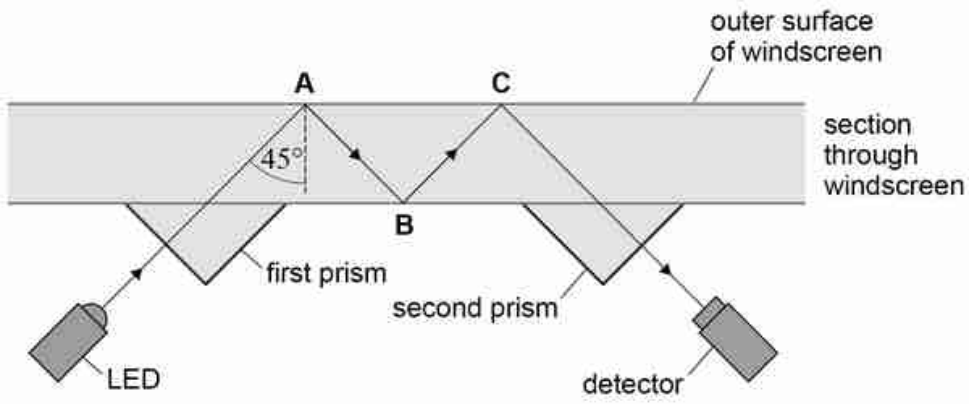
Determine the value of R_2.

[3 marks]

$R_2 =$ _____ Ω

0 2 Some cars are fitted with a water sensor designed to switch on windscreen wipers automatically when it rains. **Figure 1** shows a simplified diagram of the sensor.

Figure 1



A light ray travels from the light-emitting diode (LED) through the first prism and into the windscreen. The ray reflects off the surfaces of the windscreen at **A**, **B** and **C** and then passes through the second prism into the detector.

0 2 . 1 Suggest how the design ensures that there is no deviation of the ray as it enters the first prism.

[1 mark]

0 2 . 2 Suggest **two** features of the design that ensure that there is no deviation of the ray as it leaves the first prism and enters the windscreen glass.

[2 marks]

1 _____

2 _____

0 2 . 3 The refractive index of the windscreen glass is 1.52

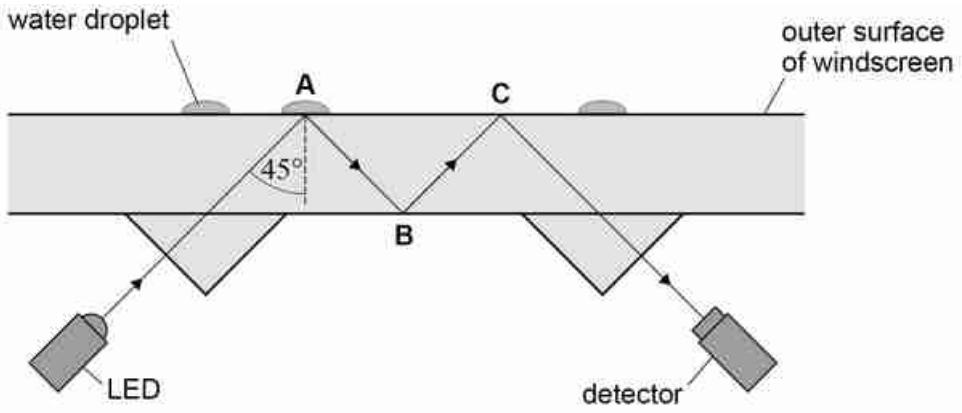
Explain why the ray follows the path shown inside the windscreen glass in **Figure 1**.
Support your answer with a suitable calculation.

[2 marks]

Question 2 continues on the next page

0 2 . 4 When it starts to rain, water droplets form on the outside of the windscreen as shown in **Figure 2**.

Figure 2



The refractive index of water is 1.33

Explain why the presence of water at **A** causes the intensity of the light at the detector to decrease.

Support your answer with a suitable calculation.

[2 marks]

0 2 . 5 The refractive index of the windscreen glass can vary by a few per cent across the thickness of the glass.

Discuss how this variation may affect the path of the ray through the windscreen glass.

[2 marks]

0 2 . 6 A different design has the LED and the detector further apart. The ray undergoes more reflections inside the windscreen glass before reaching the detector.

Discuss **two** ways in which this different design affects the sensitivity of the sensor to the presence of water droplets.

[2 marks]

1

2

0 3 A radioisotope thermoelectric generator (RTG) uses radioactive decay to generate electrical energy.

A vehicle that is used to examine the surface of Mars includes an RTG that initially contains 3.23×10^{24} atoms of plutonium-238 $\left({}^{238}_{94}\mathrm{Pu}\right)$.

0 3 . 1 Determine the initial mass of plutonium-238 in the RTG.

[2 marks]

initial mass = _____ kg

0 3 . 2 The plutonium-238 undergoes alpha decay.
The energy released by this decay is converted into electrical energy with an efficiency of 4.58%.

The power provided by the RTG decreases over time as the plutonium-238 decays.

The vehicle requires a minimum electrical power of 29.6 W to operate.

Calculate the initial activity of the plutonium-238.
Go on to determine, in Earth years, the time for which the RTG can provide sufficient power for the vehicle to operate.

decay constant of plutonium-238 $= 2.51 \times 10^{-10}\ s^{-1}$
energy of alpha particle emitted by plutonium-238 $= 8.94 \times 10^{-13}\ J$

[5 marks]

initial activity = _____ Bq

time = _____ Earth years

Question 3 continues on the next page

0 3 . 3 The vehicle has a battery-powered laser that is used to vaporise small samples of ice. On Mars, ice changes directly from solid to vapour at a temperature of $0\ °C$. The ice does not form a liquid.

The energy required to vaporise $1.0\ g$ of solid ice directly into water vapour is the same as the total energy required to melt $1.0\ g$ of ice and then to vaporise the melted ice.

The laser produces an output power of $1.0\ kW$ for a maximum time of $3.0\ s$ before its battery needs to be recharged.

The laser heats the ice from an initial temperature of $-25\ °C$ to a temperature of $0.0\ °C$. The laser then transfers energy to vaporise the ice at $0.0\ °C$.

Determine whether the laser is able to vaporise $1.0\ g$ of the ice that is initially at $-25\ °C$ before the battery needs to be recharged.

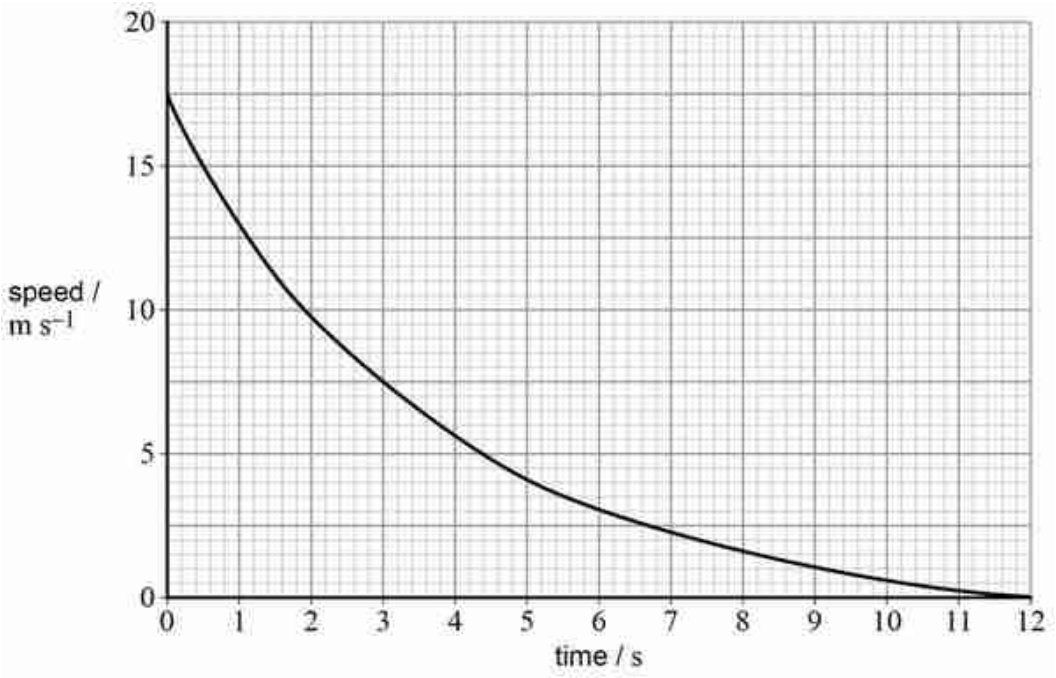
specific heat capacity of ice $= 2.1\ kJ\ kg^{-1}\ K^{-1}$
specific latent heat of fusion of ice $= 334\ kJ\ kg^{-1}$
specific latent heat of vaporisation $= 2500\ kJ\ kg^{-1}$

[4 marks]

0 1 Horizontal escape lanes made of loose gravel have been constructed at the side of some roads on steep hills so that vehicles can stop safely when their brakes fail.

Figure 1 shows an engineer's prediction of how the speed of an unpowered vehicle of mass 1.8×10^4 kg will vary with time as the vehicle comes to rest in an escape lane.

Figure 1



0 1 . 1 Determine the force decelerating the vehicle 2.0 s after entering the escape lane.

[3 marks]

force decelerating the vehicle = _____ N

0 1 . 2 Deduce whether a lane of length $85\ \text{m}$ is long enough to stop the vehicle, assuming that the engineer's graph is correct.

[3 marks]

0 1 . 3 Discuss the energy transfers that take place when a vehicle is decelerated in an escape lane.

[2 marks]

Question 1 continues on the next page

0 1 . 4 An alternative to an escape lane containing gravel is an escape lane that consists of a ramp. An escape ramp is a straight road with a concrete surface that has a constant upward gradient.

One escape ramp makes an angle of $25°$ to the horizontal and is $85\ \text{m}$ long.

Deduce whether this escape ramp is sufficient to stop the vehicle.

Assume that any frictional forces and air resistance that decelerate the vehicle are negligible.

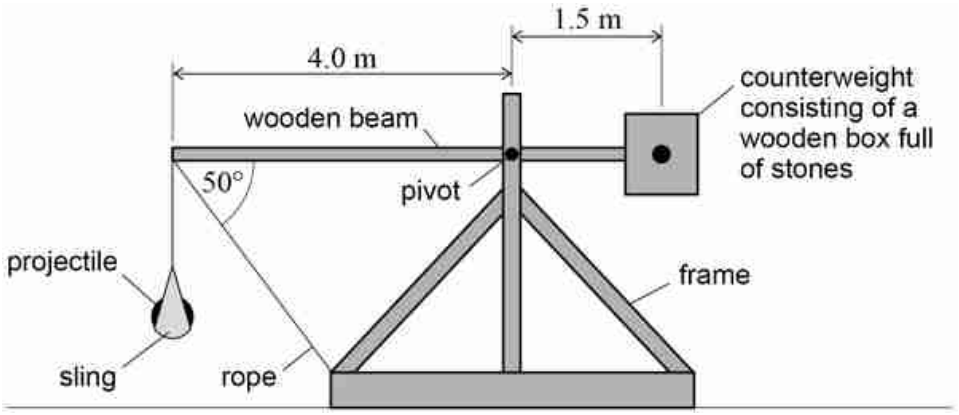
[3 marks]

0 1 . 5 Discuss whether an escape lane containing gravel or an escape ramp would provide the safer experience for the driver of the vehicle as it comes to rest.

[1 mark]

0 4 **Figure 5** shows a simplified catapult used to hurl projectiles a long way.

Figure 5



The counterweight is a wooden box full of stones attached to one end of the beam.
The projectile, usually a large rock, is in a sling hanging vertically from the other end of the beam. The weight of the sling is negligible.
The beam is held horizontal by a rope attached to the frame.

0 4 . 1 The catapult is designed so that the weight of the beam and the weight of the **empty** wooden box have no effect on the tension in the rope.

Suggest how the pivot position achieves this.

[2 marks]

Question 4 continues on the next page

0 4 . 2 The stones in the counterweight have a total mass of $610\ \text{kg}$ and the projectile weighs $250\ \text{N}$.

Calculate the tension in the rope.

[5 marks]

tension = _____ N

0 4 . 3 When the rope is cut, the counterweight rotates clockwise. When the beam is vertical it is prevented from rotating further. The projectile is then released horizontally with a velocity of $18\ \text{m s}^{-1}$, as shown in **Figure 6**.

The projectile is released at a height of $7.5\ \text{m}$ above ground level.

Figure 6

The range of the catapult is the horizontal distance between the point where the projectile is released to the point where it lands.

Calculate the range.
Ignore air resistance.

[2 marks]

range = _____ m

0 4 . 4 In another release, the sling is adjusted so that a projectile of the same mass is released just before the wooden beam is vertical. The projectile is not released horizontally.

Discuss the effect this change has on the range of the catapult.

[3 marks]

0 5 **Figure 8** shows the H-shaped posts used in a game of rugby.

Figure 8

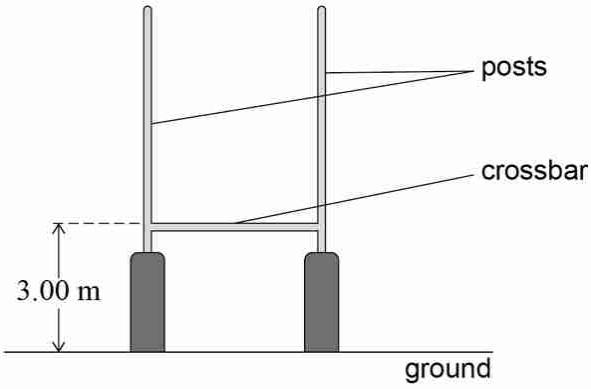
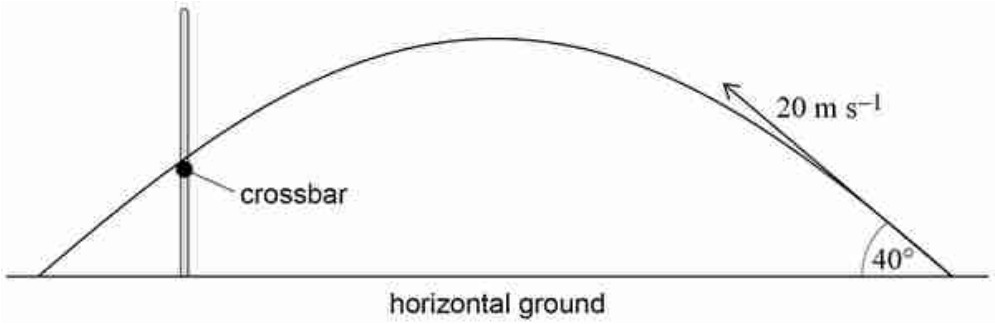


Figure 9 shows the path of a ball that is kicked and just passes over the crossbar. The initial velocity of the ball is $20.0\ \text{m s}^{-1}$ at an angle of $40.0°$ to the ground.

You should consider air resistance to be negligible and treat the ball as a simple projectile.

Figure 9



The top of the crossbar is $3.00\ \text{m}$ above the horizontal ground.

0 5 . 1 Show that the minimum speed of the ball in flight is about $15\ \text{m s}^{-1}$.

Explain your answer.

[2 marks]

0 5 . 2 The ball just passes over the crossbar at a time t after it is kicked.

Show that t must satisfy the following equation:

$$4.91t^2 - 12.9t + 3.00 = 0$$

[2 marks]

Question 5 continues on the next page

0 5 . 3 There are two solutions to the equation

$$4.91t^2 - 12.9t + 3.00 = 0$$

Discuss which of the two solutions is the time taken for the ball to pass over the crossbar from when it is kicked.

In your answer you should

- state the value for t given by each solution
- explain the physical significance of the other solution.

[4 marks]

solution 1 = _____ s

solution 2 = _____ s

0 5 . 4 Another attempt is made to kick the ball over the crossbar. The initial velocity of the ball is the same as in the first attempt.
This kick is made from a horizontal distance of $38\ \text{m}$ from the posts.

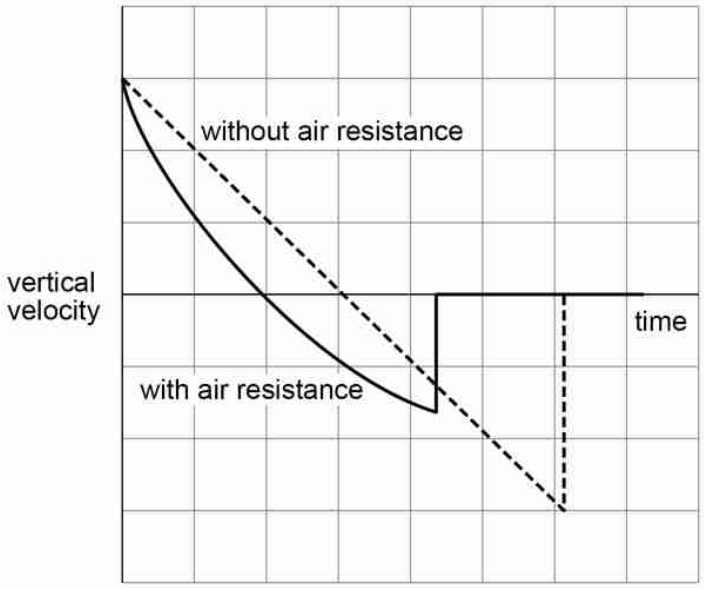
Deduce whether the ball can pass over the crossbar.

[1 mark]

Question 5 continues on the next page

0 5 . 5 **Figure 10** shows the variations with time of the vertical velocity of a ball with and without air resistance.

Figure 10



Discuss the features of the motion of the ball shown by the two graphs.

In your answer you should refer to

- the gradients of the graphs
- the area between each line and the time axis.

[5 marks]

MARK SCHEMES

official mark schemes

B

C

B

29	A (AO2)	1.1×10^{18}

29	B	36
		v^2

29	A	1.44 C	AO1

27

		q	

01.1	Combining and making use of $Q = Pt$ and $Q = mc\Delta\theta$ equations without the need to make t the subject. ✓1 t = 27 (s) ✓2	✓1 numerical errors are ignored for this mark. Provided the temperature difference is correct then subsequent changes that involve 273 ^{0}C can be ignored. ✓2 $t = (1.2 \times 450)\frac{(125-20)}{2100}$ No ecf for the second mark but correct answer gains both marks Condone use of c_{water} for c_{metal}.	2	2 x AO2 3.6.2.1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	(The power supplied in time t raises the temperature of m kg of water and converts it to steam) Use of appropriate equation. ✓1 Correct evaluation of Δm or P. No ecf. ✓2 Deduction that claim is false (consistent with their value) supported by their calculated quantity OR Deduction that their calculated quantity is greater / smaller than required ✓3	The award of MP3 is dependent on the award of MP1 OR MP2. Evidence for MP1 can be seen in MP2 via the correct answers in the exemplars below. Condone error in time / temperature change / POT for MP1. Use of m from the metal is not condoned ✓1 $Pt = mc_w\Delta\theta + ml$ OR $P = \frac{mc_w\Delta\theta + ml}{t}$ ✓2 Several methods can be followed including in 1 minute 2100×60 $= \Delta m \times 4200 \times (100 - 20) + \Delta m \times 2.3 \times 10^6$ $\Delta m = 0.048$ kg min^{-1} OR in one second 2100 $= \Delta m \times 4200 \times (100 - 20) + \Delta m \times 2.3 \times 10^6$ $\Delta m = 0.00080$ kg s^{-1} OR $P = \frac{0.060 \times 4200 \times (100 - 20) + 0.060 \times 2.3 \times 10^6}{60}$ $P = 2.6(4) \times 10^3$ W OR Comparing the energy supplied in time eg in a minute (126000 J) with energy needed (138000 + 20160 = 158000 J) OR	3	2 x AO3 1 x AO1 3.6.2.1

		= 75.3 s. ✓3 So claim is not true. 0.048 kg min^{-1} is smaller than 60 g min^{-1} OR 0.00080 kg s^{-1} = 48 g min^{-1} is smaller than 60 g min^{-1} OR 2.6×10^3 W is greater (than 2.1 kW / power available) OR time to generate 60 g of steam is too long. (The most common ecf will be to leave out the raising of the water temperature before changing the water to steam giving calculated values of Δm = 0.055 kg min^{-1}, or Δm = 0.00091 kg s^{-1} or $P = 2.3 \times 10^3$ W)		

Total			**5**

Question	Answers	Additional comments/Guidelines	Mark	AO

05.1	Use of power equation Or combination of power equation and $V = IR$ To get $R = 96\ (\Omega)$.✓	Must see some working Do not allow reverse arguments	1	AO2.1h
05.2	Either calculation of current through one lamp And multiply by 3 OR calculate total resistance ✓ (and use $V = IR$) To give 0.38 A. ✓ (at least 2sf)	Condone use of any other method eg use of power = 4.5 W and power equation. Allow ecf for their R from 5.1 used or their I Use of 100 Ω gives 0.36 A (0.4A)	2	AO2.1h
05.3	Evidence of equation to calculate area . ✓ $2.8 \times 10^{-8}\ m^2$✓ Use of resistivity equation to get $49\ \Omega$.✓	Allow POT error in MP1 Evidence for MP2 may be in final answer Accept 48 Ω	3	AO2.1h AO1.1a AO2.1h

Question	Answers	Additional comments/Guidelines	Mark	ID details
05.4	Total resistance = 46 + 46 + 100/3 = 125 Ω. ✓ Calculation of circuit current = 12/125 = 0.096 A. ✓ operating current of lamp (=1.5/12 = 0.13)/current for all 3 lamps to be fully on = 0.38 A. ✓ Yes demo works as lamps will be dimmer/ off (with constantan). ✓	Allow ecf for incorrect resistance If no other marks awarded, one mark each can be given for (max 2) • for resistance increases with length. • Too much p.d. dropped across constantan • Resistivity of constantan is greater than resistivity of copper For MP3 allow quoted comparison to previously calculated current in 5.2 For MP4 allow ecf if answer is yes and is consistent with their calculation	4	AO3.1b
05.5	**Advantage** Zero resistance/resistivity. ✓ Reduce heat/energy transfer / power loss in cables✓ **Difficulty** Difficult to maintain low temperature (over long distances) ✓ Must be kept at/below the critical temperature. ✓	Ignore references to critical field. Allow very low resistance	Max 3	AO1.1a 2 × AO3.1a
Total			**13**	

Question	Key
06	C
07	A
08	B
09	B
10	C
11	C
12	D
13	A
14	D
15	A
16	A
17	C
18	D
19	B
20	C
21	B
22	A
23	A
24	B
25	C
26	D
27	D
28	A
29	C
30	B

16	A	The resistance of the diode decreases as V increases for $V > V_s$.	AO1
		Ys	

03.1		for $_1$✓ and $_2$✓ allow ≥ 4 sf rounding to 3 sf in range	3	2 × AO2
	α in range with correct POT $_1$✓$_2$✓	for $_1$✓ α in range 4.45 to 4.57		1 × AO1
	α in range with incorrect OR missing POT $_1$✓	for $_1$✓ $_2$✓ α in range 4.45 to 4.57×10^{-3} allow $_{12}$✓ for α in range 4.39 to 4.63×10^{-3} OR allow $_{12}$✓ for 2 sf $\alpha = 4.5 \times 10^{-3}$		
	K^{-1} $_3$✓	for $_3$✓ condone $°K^{-1}$ OR $\frac{1}{K}$ OR $\frac{1}{{}^{o}K}$ do **not** accept $(°)C^{-1}$ do **not** accept k for K		

Question	Answers	Additional comments/Guidance	Mark	AO
03.2		allow valid work in 'wrong' answer space	2	AO1
	determines P using $V \times I$ in some form OR determines R using $\frac{V}{I}$ in some form $_1$✓	for $_1$✓ AND / OR $_2$✓ accept formulae in symbols or in words eg 'power = current × voltage'; accept 'voltmeter reading' for V / 'ammeter reading' for I; treat as neutral the idea of plotting an IV graph to find P and / or to find R		
	determines P using $V \times I$ AND R using $\frac{V}{I}$ in some form AND determines T using (their) R $_1$✓$_2$✓	for $_2$✓ allow 'use the equation with R'; any rearranged equation must be correct eg $T = \frac{R - R_0}{\alpha R_0} + T_0$; treat the following as neutral: (unqualified) 'use the equation' / 'use $T \propto R$ to determine T'/ 'use (extrapolate) **Figure 6**' / 'use **Figure 8**'		

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidance</th><th>Mark</th><th>AO</th></tr>
<tr><td>03.3</td><td>2nd row of Table 2 P correct
AND
4th row of Table 2 P_2 correct $_1$✓

3rd row of Table 2:
P correct $\pm$ 0.2
AND
P_2 correct $\pm$ 0.2 $_2$✓

their P_1 = their P – their P_2
AND
all the data added to Table 2 is to 1 dp $_3$✓

<table>
<tr><th>T / K</th><th>P / W</th><th>P_1 / W</th><th>P_2 / W</th></tr>
<tr><td>960</td><td>3.7</td><td>1.2</td><td>2.5</td></tr>
<tr><td>1100</td><td>5.0</td><td>2.0</td><td>3.0</td></tr>
<tr><td>1370</td><td>8.8</td><td>4.8</td><td>4.0</td></tr>
<tr><td>1680</td><td>16.2</td><td>11.0</td><td>5.2</td></tr>
</table>
</td><td>only penalise dp in $_3$✓
for $_1$✓ (2nd row) P = 5.0 (W)
AND
(4th row) P_2 = 5.2 (W)

for $_2$✓ (3rd row) P = 8.6 to 9.0 (W)
AND
P_2 = 3.8 to 4.2 (W)

for $_3$✓ expect P_1 = 4.4 to 5.2 (W)</td><td>3</td><td>2 × AO2

1 × AO3</td></tr>
</table>

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr><td>03.4</td><td>intention to use a logarithmic plot to test power law:

suitable headings in Table 3
OR
suitable graph axis labels in Figure 9 $_1$✓

their P_1 data in Table 2 transferred to 3rd row / their P_1 used to complete 3rd row
AND
4 sets of $\log T$ and $\log P_1$ recorded in columns 3 and 4 of Table 3 $_2$✓

<table><tr><th>T / K</th><th>P_1 / W</th><th>log (T / K)</th><th>log (P_1 / W)</th></tr><tr><td>960</td><td>1.2</td><td>2.98</td><td>0.08</td></tr><tr><td>1100</td><td>2.0</td><td>3.04</td><td>0.30</td></tr><tr><td>1370</td><td>4.8</td><td>3.14</td><td>0.68</td></tr><tr><td>1680</td><td>11.0</td><td>3.23</td><td>1.04</td></tr></table></td><td>award $_1$✓ for use of bracket, solidus AND unit eg $\log (T / \mathrm{K})$ AND $\log (P_1 / \mathrm{W})$;
can be shown EITHER in the Table 3 headings OR for the Figure 9 axis labels;
accept $\lg (T / \mathrm{K})$ / $\log (T / \mathrm{k})$ for $\log (T / \mathrm{K})$;
accept columns interchanged / axes reversed

for $_2$✓ check that the $\log T$ AND $\log P_1$ values are correct to at least 2 dp;
all $\log T$ values to the same (minimum 2) dp;
all $\log P_1$ values to same (minimum 2) dp OR all to same (minimum 3) sf
ECF wrong P_1;
allow 4 sets of $\ln (T / \mathrm{K})$ and $\ln (P_1 / \mathrm{W})$

<table><tr><th>T / K</th><th>P_1 / W</th><th>ln (T / K)</th><th>ln (P_1 / W)</th></tr><tr><td>960</td><td>1.2</td><td>6.87</td><td>0.18</td></tr><tr><td>1100</td><td>2.0</td><td>7.00</td><td>0.69</td></tr><tr><td>1370</td><td>4.8</td><td>7.22</td><td>1.57</td></tr><tr><td>1680</td><td>11.0</td><td>7.43</td><td>2.40</td></tr></table></td><td>MAX 5</td><td>2 × AO1
2 × AO2
1 × AO3</td></tr>
</table>

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4 (cont)	**Figure 9 and processing**: suitable scales for their data; each axis labelled with (at least) their plotted quantity; allow interchanged axes $_3$✓	for $_3$✓ each scale must • accommodate all **their** data • have at least 4 evenly-spaced values marked along each axis • be linear, avoiding 'difficult' intervals • allow points to cover ≥ half the grid in both directions (expect use of a false origin) condone a suitably scaled and labelled **non-logarithmic** plot including P_1 against T		
	4 points plotted and a **ruled** line that is **continuous** (at least) from 1st point to 4th point $_4$✓	for $_4$✓ the 1st, 2nd and 4th points should lie on a straight line (by eye); check possible errant point(s) but allow minor plotting errors (≤ 2 minor squares); do **not** allow blobs, thick or faint points; allow a ruled line that is not the best line but do **not** allow a thick / faint / discontinuous line		
	an unrounded gradient result in the range 3.6 to 4.4 OR a gradient result correctly rounded to the nearest integer $_5$✓	for $_5$✓ do not penalise small steps; condone **one** read off error for reversed axes unrounded gradient range is 0.23 to 0.28 or inverse of gradient rounded		
	$n = 4$ CAO $_6$✓	$_6$✓ is contingent on $_5$✓		
	if the plot is not log-log or ln-ln award $_{12}$✗$_3$✓$_{456}$✗ = 1 MAX if plot is T^4 against P_1 allow up to $_1$✓$_2$✓$_3$✓$_4$✗$_5$✗$_6$✗ = 3 MAX			

Question	Answers	Additional comments/Guidelines	Mark	AO

03.4 (cont)

Figure 9 with log (P_1 / W) against log (T / K)

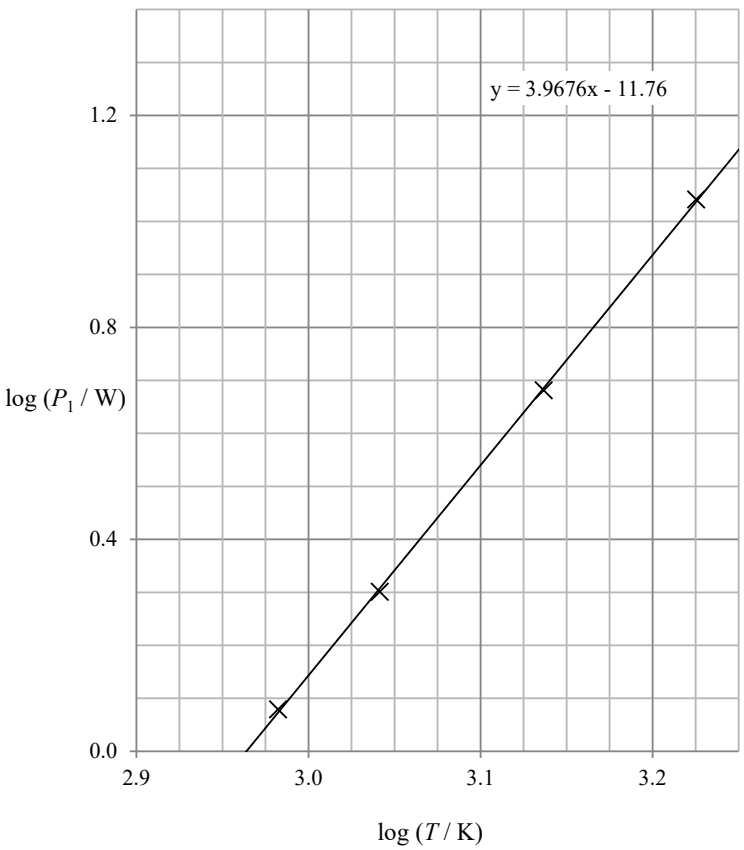
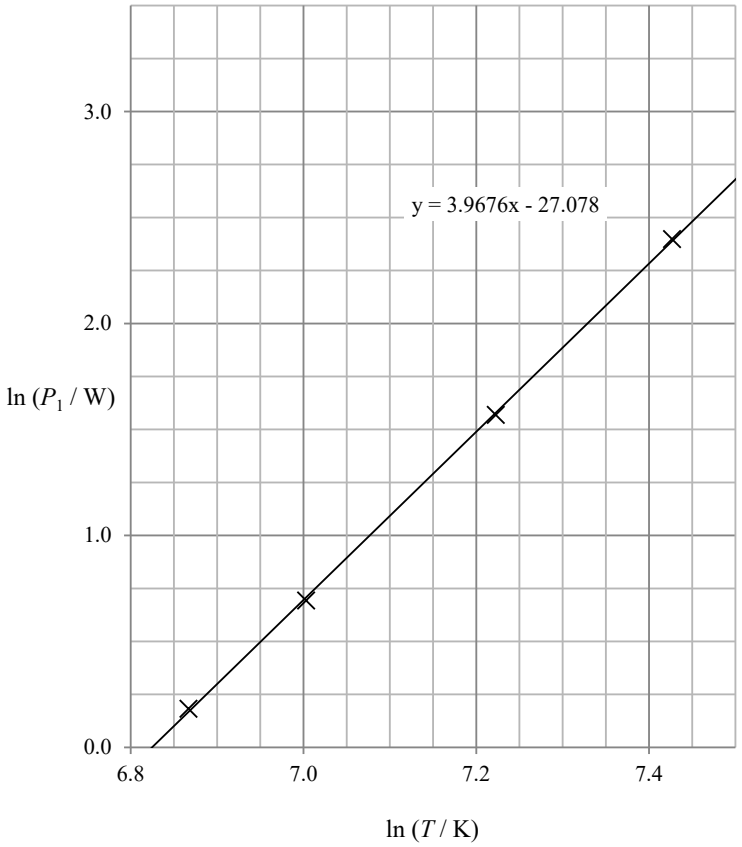


Figure 9 with ln (P_1 / W) against ln (T / K)



	typical graphs using the14 cm × 14 cm grid on **Figure 9**: grid lines shown are at the semi-major (1 cm) intervals note the false origin is required for a suitable $\log T$ scale for these scales a minimum of 4 evenly-spaced values on each axis are expected for $_3$✓

Total			**13**

Question	Answers	Additional comments/Guidance	Mark	AO

02.1	(**C** because the ohm-meter) reading is 2 dp OR explains where the decimal point is ✓	must refer to the decimal places displayed or the position of the decimal point: allow 'displays 2 figures before decimal point' / 'displays 2 figures after decimal point' / decimal point between 2nd and 3rd digit / 'in format XX.XX' or WTTE; condone 'resolution (shown) **is** 0.01' / 'decimal point is after the second digit' / 'decimal point is in the middle' / reject 'because of where the decimal point is' / / 'decimal point is in the same place' / 'decimal places are the same' / 'reading is between maximum and minimum for the range on C setting' / 'readings have same resolution' / 'reading is 3 sf'	1	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	valid attempt to determine E_V using $R = 2840$ $_1$✓ $E_V = 132$ (lx) $_2$✓	> 3 sf that rounds to 132 get both marks for $_1$✓ expect $3.45(3)$ in a calculation; allow $_{12}$✓ = 1 MAX for use of 2.84 leading to 1.01×10^6 (lx) OR allow use of $\ln(2840)$ leading to 2.46×10^{-2} (lx)	2	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	reads off from at least **three** different points on the line / graph $_1$✓	for $_1$✓ allow 'get' / 'obtain'; must specify 3 or more; condone 'several' / 'many' / 'numerous' / 'quite a lot' / 'quite a few'; 'multiple' is neutral	2	AO1
	suggests a valid test of **Figure 7** that confirms the inverse square law $_2$✓	for $_2$✓ eg calculates $E_V \times x^2$ for each point; shows that '(percentage) differences (between results) are 'small' / 'insignificant' OR shows that values are 'close' / 'same' / 'similar' / 'consistent' condone values should be 'close' / 'see if values are / should be constant' / 'agree' etc allow a reverse-working approach		
	OR proposes a valid graph (using data from **Figure 7**) $_1$✓ a valid test to confirm the inverse square law based on their graph $_2$✓	OR **plot** of log E_V against log x $_1$✓ gradient is ≈ -2 $_2$✓ OR **plot** of E_V against $\frac{1}{x^2}$ $_1$✓ linear graph through (0, 0) $_2$✓		

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	result in range $627(.0)$ to $646(.0)$ mm $_1$✓ result in range $634(.0)$ to $639(.0)$ mm $_2$✓	use result on answer line for $_1$✓ accept 630 and 640 but not 6.3×10^2 OR 6.4×10^2	2	AO2

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr><td>02.5</td><td>1645 AND 1.73 correctly added to Table 3 $_1$✓

valid reasoned judgement to support use of range;
allow ECF for incorrect values in Table 3 $_2$✓</td><td>for $_1$✓ do not insist on units;
condone extra sf that round to these values
<table><tr><th>Setting</th><th>Min R</th><th>Max R</th></tr><tr><td>range B</td><td>1645 (Ω)</td><td>1717 Ω</td></tr><tr><td>range C</td><td>1.63 kΩ</td><td>1.73 (kΩ)</td></tr></table>for $_2$✓ states that B should be used because
(half) range is smaller / (percentage) difference between max and min R is smaller
OR
any valid and correct quantitative comparison between both settings, eg
<table><tr><th></th><th>Range (/ Ω)</th><th>Uncert. (/ Ω)</th><th>% Diff.</th><th>% Uncert.</th></tr><tr><td>B</td><td>72</td><td>(±)36</td><td>≈ 4%</td><td>≈ 2%</td></tr><tr><td>C</td><td>100</td><td>(±)50</td><td>≈ 6%</td><td>≈ 3%</td></tr></table>allow ‘resolution is smaller’ not ‘better’;
‘more precise’ / ‘more accurate’ / ‘(percentage) uncertainty is smaller’ are neutral</td><td>2</td><td>AO3</td></tr>
</table>

Question	Answers	Additional comments/Guidelines	Mark	AO
02.6	ANY 2 OF $_1$✓ to $_3$✓ below:		2	1 × AO1
	light level / brightness / intensity in the room OR WTTE $_1$✓	for $_1$✓ allow 'background lighting' / 'external light sources' / 'maintain blackout'; 'temperature' is neutral		1 × AO3
	voltage (across) / current in / power of / brightness of the lamp $_2$✓	for $_2$✓ allow 'intensity of (light from) the lamp' / 'luminosity of lamp' / 'pd of power supply'; allow $_{12}$✓ for light incident on slides $= 400$ (lx) do not allow unqualified 'light intensity'		
	thickness of the **glass** / slides $_3$✓	for $_3$✓ allow 'transparency / opacity / colour of the glass / slides'; condone 'surface of slides must be clean' the following are neutral: μ / refractive index / density / 'type' of glass 'type' / 'size' / 'width' / 'area' / 'shape of slide' (vertical) distance between the lamp and the LDR' / 'ohm-meter setting' type of power supply / lamp / LDR / ohm-meter / connecting wires / shape of bulb positions of equipment		

Question	Answers	Additional comments/Guidelines	Mark	AO
02.7	**plot** $\ln E_V$ against N OR plot **implied** by comparison between **correct algebra** $\ln E_V = -\mu N + \ln 400$ and $y = mx + c$ $_1$✓	for $_1$✓ allow plot $\ln\left(\frac{E_V}{400}\right)$ against N; must clearly imply that N is the abscissa; allow aligned expressions eg $\ln E_V = \ln 400$ OR $5.99 - \mu N$ $y (=) c (+) mx$	2	AO1
	μ is –gradient $_2$✓	allow $_2$✓ for '$-\mu$ is gradient' / 'μ is absolute value of gradient' / 'μ is modulus of gradient value' where $\ln E_V = -\mu N + \ln 400$ without comparison with $y = mx + c$ seen;		
	plot $\ln E_V$ against N with incorrect algebra is talk out for $_1$✓ allow ECF if linking μ to **gradient** based on their incorrect algebra for $_2$✓	use of 'log-linear graph paper' is only acceptable with further explanation use of 'logarithmic graph paper' is neutral OR allow **plot** $\log E_V$ against N OR plot **implied** by $\log E_V = -\mu \log(e) N + \log 400$ compared with $y = mx + c$ $_1$✓ μ is $\frac{-\text{gradient}}{\log(e)}$ $_2$✓		

Question	Answers	Additional comments/Guidelines	Mark	AO
02.8	evidence for any workable method that would lead to EITHER $N_{½} \approx 7.7$ OR a final integer answer that is appropriate to their calculated value $_1$✓ $N_{½}$ **=** 8 slides CAO $_2$✓	for $_1$✓ expect use of $\ln 0.5 = -9.0 \times 10^{-2}\ N_{½}$ or similar (including trial and improvement)	2	AO3
Total			**15**	

Question	Answers	Additional comments/Guidelines	Mark	AO

02.1	rate = 1.40 to 1.75 (V s^{-1}) $_1$✓ rate = 1.50 to 1.65 (V s^{-1}) $_2$✓	for $_1$✓ accept 2 sf 1.5, 1.6 and 1.7 (V s^{-1}) for $_2$✓ accept >3 sf rounding to value in range; accept 2 sf 1.6; expected answer is 1.57(2) (V s^{-1})	2	AO3-1b

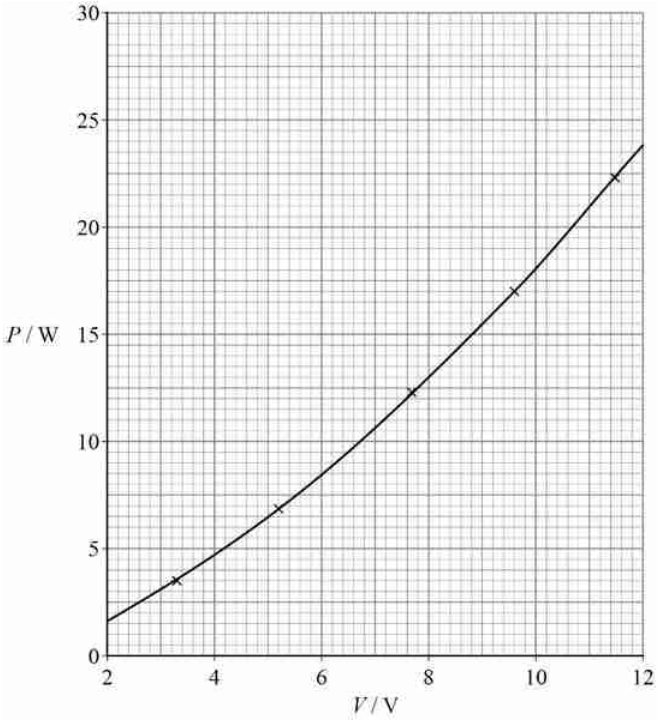
Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	maximum 1 mark per marking point (see $_1$✓ to $_4$✓ below) reduces impact of statistical error (involved in reading and recording data manually) $_1$✓ data can be collected at a high(er) rate or wtte $_2$✓ idea that data (in digital form) may be easily processed $_3$✓ two (or more) sets of data (I and V) can be made simultaneously or wtte $_4$✓ treat suggestions that data logging improves 'precision' / 'resolution' / reduces 'uncertainty' / eliminates 'systematic' / 'parallax errors' / 'anomalous readings' as neutral	for > 2 ideas mark as a list for $_1$✓ allow reducing 'human error' / 'random error' / 'improving accuracy' as same idea; idea that random error / uncertainty can be eliminated is talk out; condone 'no human error / reaction'; for $_2$✓ condone 'quickly' / 'works faster' 'collect data at a steady rate'/ 'saves time' / comments about 'reaction time' are neutral for $_3$✓ eg can be transferred to / graphed with / analysed using a digital device or application eg computer / spreadsheet allow 'can be processed automatically' treat the following as neutral since they are not specifically applicable to this experiment: can carry out experiment 'remotely' / 'in inaccessible or dangerous environments' / 'automatically' / 'without any human (being present)' or wtte; can 'start / stop data collection at some suitable (future) time' / 'collect large amount of data' or wtte; 'a wide variety of sensors are available' / 'data logging is (increasingly) cheap'	Max 2	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	identifies that **circuit 2** can produce the data because the pd can be varied between 0 V and 12 V $_1$✓	for $_1$✓ allow 'can achieve 12 V range' or wtte; reject 'can produce 0 V and 12 V'	2	AO1-1b
	identifies that **circuit 1** cannot produce (all of) the data shown on **Figure 4** $_2$✓	for $_2$✓ allow '**circuit 1** is not suitable' / 'not **circuit 1**'; award $_1$✗$_2$✓ for 'neither can produce the data'		
	for **circuit 1** with **X** set to maximum resistance calculates (minimum) I OR calculates (minimum) V $_3$✓	for $_3$✓ (at least one) result should be evaluated to min 2 sf but condone '≈ 0.7' if decimal intermediate result is ok; do not accept rounding to 0.69; allow use of 17.2 without justification; minimum $I \left(= \frac{12}{17.2}\right) = 0.70$ A OR minimum $V \left(= 12 \times \frac{2.3}{17.2}\right) = 1.6$ V	2	AO3-2a
	their minimum I or minimum V for **circuit 1** compared with value of first (or second) point in **Figure 4** $_4$✓	for $_4$✓ could say their minimum $I > 0.36$ / I for first data point $< 0.7(0)$ / $0.70 > 0.36$ etc allow 'cannot produce $I < 0.7(0)$ in Fig 4'; 'cannot produce all the values' is not enough		

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr><td>02.4</td><td>P = 6.82 in row 2 $_1$✓

I = 1.77 in row 4 $_2$✓

P = 17.0 in row 4 $_3$✓</td><td>
<table>
<tr><th></th><th>V / V</th><th>I / A</th><th>P / W</th></tr>
<tr><td></td><td>3.30</td><td>1.07</td><td>3.53</td></tr>
<tr><td>$_1$✓</td><td>5.17</td><td>1.32</td><td>6.82</td></tr>
<tr><td></td><td>7.69</td><td>1.59</td><td>12.2</td></tr>
<tr><td>$_2$✓$_3$✓</td><td>9.58</td><td>1.77</td><td>17.0</td></tr>
<tr><td></td><td>11.47</td><td>1.94</td><td>22.3</td></tr>
</table>
for $_1$✓ CAO
for $_2$✓ allow 1.77 ± 0.01
for $_3$✓ ECF for their (incorrect) I × 9.58;
deduct MAX 1 mark if any are not to 3 sf
</td><td>3</td><td>AO2-1h</td></tr>
</table>

Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	vertical axis labelled P / W ₁✓ suitable vertical scale for their data ₂✓ 5 points plotted AND smooth curve of increasing gradient ₃✓  	for ₁✓allow P (W), P in W; reject comma separator, eg P, W; allow words, eg power for P / watt(s) for W for ₂✓ expect 1 cm interval = 2 W OR 2 cm intervals = 5 W vertical scale must • be linear • be marked in integer values • be marked with a frequency of not less than 4 cm intervals • cover the range of plotted points assume $P = 0$ at unmarked origin for ₃✓ check the plotting of any obviously suspect point; points must **not** be thick / faint / dots / blobs; line must • be a continuous **curve** • be neither thick or faint • (at least) extend from the first to the fifth point • be a reasonable best-fit for their data; withhold mark if line deviates by ≥ 2 minor squares from examiner's best line (by eye) if I / A is plotted award ₂✓ if the effective range of vertical scale is ≥ half height of grid	2 1	AO1-1b AO2-1h

Question	Answers	Additional comments/Guidelines	Mark	AO
02.6	evidence that P_r read-off to ± 1 minor grid square $_1$✓ reads off P_2 corresponding to 6 V; evaluates $\frac{2 \times \text{their } P_2}{\text{their } P_r} \times 100$ $_2$✓	for $_1$✓ best-fit line must be extrapolated to V = 12 V (at the right-hand margin of the grid); P_r correct to ± half a minor grid square; expect P_r = 23.8 W for a curve but accept a read-off obtained from a straight best-fit line $_2$✓is not contingent on $_1$✓ for $_2$✓ expect P_2 = 8.5 W for a curve; expected % in range 70% to 73% if no read-off evidence is seen on **Figure 6** check for the possibility that **Figure 4** was used to obtain P_r and P_2 eg by drawing a curve through points to intersect at V = 12 V, then using V (= 12) × I (= 1.98) P_r = 23.7 using V (= 6) × I (= 1.42) P_2= 8.5(2) would lead to 72%	2	AO3-1a
Total			**16**	

16

| Question | Answers | Additional comments/Guidelines | Mark | AO |

B

B

D

B

21	B	A current in it causes no heating effect.

26	A	$\rho_1 + \rho_2$	AO2

03.1	callipers may **reduce** the (reading of the) diameter ✓	treat ‘change reading’ / ‘give incorrect reading’ as neutral; accept the idea that the callipers may ‘distort’ / ‘deform’ / ‘push in’ the putty, eg ‘change the shape’ / ‘crush’ / ‘squash’ / ‘cut into’ / ‘squeeze’ reject implication that density could change, eg ‘volume will change’ / ‘will compress’; reject ‘putty will move’ / ‘not able to grip the putty hard enough’	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	average d OR uncertainty in d $_1$✓	answers to >3sf rounding to $2.37(\%)$ earns both marks for $_1$✓ either average = $33.8(0)$ (mm) OR uncertainty from half range = $0.8(0)$ (mm); allow ½ ×$(34.5–32.9)$ seen in working; credit if seen in a percentage uncertainty calculation	1	2 x AO2
	percentage uncertainty $2.37(\%)$ $_2$✓	for $_2$✓ percentage uncertainty to ≥ 3 sf; reject decimal answer or incorrect rounding to 2.36%; reject answers if either 32.9 or 34.5 are (wrongly) rejected as anomalous (leading to 1.62% and 1.64% respectively)	1	

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	% uncertainty in length correct $_1$✓	for $_1$✓ minimum 2sf CAO; 2.8(2)%	1	1 × AO1
	calculates % uncertainty in volume $_2$✓	for $_2$✓ % uncertainty in $V = 2 \times$ their % uncertainty in d + their % uncertainty in L; allow 2.4% for % uncertainty in d minimum 2 sf; expect 7.6 %	1	3 × AO2
	evidence for volume evaluated OR evidence for Δ volume evaluated $_3$✓	for $_3$✓ accept answers including: sub of **all data** in to $V = \frac{\pi \times (\text{their } d)^2 \times L}{4}$ OR recognisable V eg 6.4 (× 10^4) OR sub of **all data** in to $\Delta V = \frac{\pi \times (\text{their } d)^2 \times L}{4}$ × their % uncertainty / ΔV = their volume × their % uncertainty OR recognisable ΔV with POT error	1	
	Δ volume between 4.8 and 4.9 × 10^3 (mm^3) $_4$✓	answers that round to 4.8 or round to 4.9 are acceptable; $_{34}$✓✓for Δ volume in range and correct POT	1	

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	ruled line $_1$✓	for $_1$✓ line passing below 5th AND above 4th ie no overlap between line and either **+**; line passing through or extrapolated to $(0, 0)$ to half a minor grid square; withhold this mark if line is poorly-marked (if doing so annotate clip to explain)	1	2 x AO1 1 x AO3 1 x AO2
	gradient calculated $_2$✓	for $_2$✓ gradient calculated from ΔR divided by ΔL^2; minimum $\Delta L^2 = 25$ ($\times 10^{-3}$ m^2); allow read-off errors in calculation / allow missing or incorrect POT	1	
	ρ in range 3.72 to 3.84 ($\times 10^{-2}$) $_3$✓	for $_3$✓ accept 2 sf 3.8	1	
	POT and unit correct $_4$✓	for $_4$✓ treat 3.78×10^{-2} and $0.0378\ \Omega$ m as equally acceptable; allow alternative valid answer, eg $37.8\ \Omega$ mm	1	
Total			**11**	

Question	Answers	Additional comments/Guidelines	Mark	AO

01.1	(±) 0.5(0) mm CAO ✓		1	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	6.72 mm ✓	tick in second box	1	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	use of ratchet with valid justification OR use of thimble **and then** the ratchet with valid justification ✓	allowable ideas should focus on the possible consequences of **not** using the ratchet: can cause the object being measured to be distorted / squeezed / crushed / subject to excessive force or WTTE; can change the diameter / shape of the object; may lead to the reading shown being **smaller** than true value; damage might occur (to the mechanism); the frame (of the micrometer) might become warped; condone 'will over-tighten (micrometer)'; condone 'thimble used to close gap / clamp wire' then use ratchet to tighten or WTTE + justification treat following as neutral: 'use the thimble then the ratchet to save time' / 'to get accurate reading' 'use ratchet to make sure wire is secure' 'using thimble (or **not** using ratchet) might change the reading' / 'affect results' / 'might cause a zero error' / 'cause a reading below zero' / 'could lead to systematic error'	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	use of $I = \frac{(0.)931}{1.2}$ OR $R = \frac{(0.)397}{\text{their } I}$ 1✓	for 1✓ allow I > 2 sf rounding to 0.78 (A) OR $\frac{(0.)397}{(0.)776}$ OR $\frac{(0.)397}{(0.)78}$ in working OR $R = \frac{(0.)397 \times 1.2}{(0.)931}$ with any subject OR use of a valid potential divider approach eg $\frac{1.2}{1.2+R} = \frac{0.931}{0.397+0.931}$	2	AO2
	$R = 0.51$ (Ω) 2✓	for 2✓ condone 0.512 OR 0.5117 (Ω)		

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	continuous <u>ruled</u> best-fit line drawn $_1$✓	for $_1$✓ line **must not** pass above centre of 2nd point AND below centre of 4th point; reject hairy, thick or dashed lines if withholding mark examiner must add comment to clip	2	AO2
	gradient evaluated from ΔR divided by ΔL; with correct $\Delta R \geq 0.2\ (\Omega)$ OR correct $\Delta L \geq 150\ (\text{mm})$ $_2$✓	$_2$✓ is for the process if using points these must lie on their line; do not penalise for AE / POT in result; expect gradient about $1.66\ (\Omega\ \text{m}^{-1})$ withhold both marks for no line on **Figure 5**		

Question	Answers	Additional comments/Guidelines	Mark	AO
01.6	attempts to find ρ_X using $\frac{\pi d^2}{4} \times \frac{\Delta R}{\Delta L}$ $_1$✓	for $_1$✓ expect use of their $\frac{\Delta R}{\Delta L}$ OR the closest value in **Table 1**; allow use of concordant $\frac{\Delta R}{\Delta L}$ and d values for the metal that is the valid choice for their $\frac{\Delta R}{\Delta L}$; d must be correct for their $\frac{\Delta R}{\Delta L}$; if value not seen in working, judge d from their ρ_X;	4	1 × AO3 3 × AO2
	ρ_X in range below for their metal on the answer line $_2$✓ metal / resistivity / Ω m: copper: 1.6 to 1.8 ($\times 10^{-8}$) tungsten: 5.4 to 5.9 ($\times 10^{-8}$) alumel: 3.3 to 3.8 ($\times 10^{-7}$) nichrome: 1.0 to 1.2 ($\times 10^{-6}$)	for no **01.5** result condone the substitution of concordant R and L values for a point on **Figure 5** don't penalise for AE or POT for $_2$✓ ignore POT and use the most significant digits in their ρ_X to judge result, eg for alumel $\rho_X = 0.351$ scores $_2$✓$_3$✗ because this is equivalent to 3.51×10^{-1} allow >2 sf values that round to 2 sf in range		
	POT correct and unit = Ω m for their metal on the answer line $_3$✓	for $_3$✓ allow alternative valid answer eg (for nichrome) $1.1 \times 10^{-3}\ \Omega$ mm		
	nichrome CAO $_4$✓	for $_4$✓ must be consistent with their **01.5** $\frac{\Delta R}{\Delta L}$		

Question	Answers	Additional comments/Guidelines	Mark	AO
01.7	the **error bars** for L / the horizontal error bars are the same length or WTTE $_1$✓	for $_1$✓ allow' they are $10\ \text{mm}$' / the width is same'; any quantitative detail eg limiting values / percentage uncertainty about the horizontal error bars is neutral condone 'bars are same' / 'have same range' 'bars are constant' is neutral	2	AO3
	quantitative comment about the **error bars** for R / the vertical error bars $_2$✓	for $_2$✓ expect (about) ± 0.02 / (height) 0.04 (Ω) AND fifth (about) ± 0.04 / (height) 0.08 (Ω); allow suitable limiting values of the error bars eg $(0.)329 - (0.)371$ AND $(0.)614 - (0.)692$; allow 'fifth is (about) twice the length of first' detail in an annotated sketch can earn $_1$✓ and $_2$✓ 'bars aligned with respective axes' / 'bars are equidistant above / below data point' are neutral		

Question	Answers	Additional comments/Guidelines	Mark	AO
01.8	idea that **any two** of maximum gradient, minimum gradient or mean gradient are determined using **lines** that pass through (all) the error bars $_1$✓	for $_1$✓ allow 'measure / find gradient' / 'gradient can be found'; insist on idea of a line but don't insist on 'draw / construct'; allow mean = 'best', maximum = 'steepest' etc, maximum OR minimum = 'worst'; 'using the error bars' / 'draw line from top of first bar to bottom of last bar' etc are neutral	2	AO1
	explains how to determine uncertainty in gradient $_2$✓	for $_2$✓ allow word equation or any of the following $(m - m_2)$ OR $(m_1 - m)$ OR $\frac{(m_1 - m_2)}{2}$ where m = mean gradient m_1 = maximum gradient, m_2 = minimum gradient allow 'G' for gradient allow 'best gradient – worst gradient' or vice-versa etc condone valid expressions for fractional uncertainty or for percentage uncertainty		
Total			**15**	

12

Question	Answers	Additional comments/Guidelines	Mark	AO

C

B

B

B

27	D	4.2 V 1.4 V

29	D	24 V

30	D (AO2)	25 Ω

27	D		

03.1	tick in **first** box (2.7 V) ✓	[cao]	1	AO2-1d

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	move position until needle / pointer hides / is aligned with its reflection in the mirror or wtte $_1$✓ this reduces / eliminates <u>parallax</u> error OR to ensure scale is read from directly above $_2$✓	for $_1$✓ allow 'view scale so needle / pointer hides reflection'; condone 'there is no reflection' for $_2$✓ reject 'reduces / eliminates human error' allow 'reading is made when at right angles' / 'perpendicular to the scale'; reject 'view scale at eye level' / 'so not looking at an angle' / 'so ~~not~~ looking straight at needle'	2	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	average $T_{½}$ correct OR uncertainty in $T_{½}$ correct $_1$✓	for $_1$✓ average $T_{½}$ = 12.04 (s); reject 12.0 allow credit for correct $T_{½}$ seen in working for percentage uncertainty; uncertainty in $T_{½}$ (from half range) = 0.11 (s)	1	AO2-1h
	percentage uncertainty in $T_{½}$ correct $_2$✓	for $_2$✓ minimum 2 sf; correct answer rounds to 0.91(4)%	1	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	time constant = $\frac{\text{their mean } T_{½}}{\ln 2}$ OR $\frac{-(\text{their mean } T_{½})}{\ln 0.5}$ ✓	expect 17.37 (s); allow minimum 3 sf 17.4 / use of ln 2 = 0.69 for leading to 17.45; reject use of $T_{½}$ = 12 leading to 17.31; reject $\frac{\text{their mean } T_{½}}{\ln 0.5}$ (ignoring –sign in result)	1	AO2-1d

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	ways ensure pd across **C** doesn't exceed $3\ \text{V}$ before connecting **C** to **X** $_1$✓ as **X** is connected $_2$✓	for $_1$✓ discharge **C** / connect flying lead to **Y** / 'reset to $0\ \text{V}$' (before reconnecting); reject 'reset equipment' for $_2$✓ reduce the output pd / socket **X** (or wtte) to $\leq 3\ \text{V}$ (then reconnect **C** and adjust pd so meter reads full-scale); reject 'only charge **C** to 3 V' idea of adding resistance to limit pd is neutral	MAX 3	AO3-2b
	suggests timing for $\Delta V > 1.5\ \text{V}$ or wtte $_{3a}$✓ OR take repeated readings (of $T_{½}$ or time constant); any valid processing eg calculate an average value / reject anomalies / check results are concordant or wtte $_{3b}$✓ check / correct / compensate for any zero error (on the voltmeter) $_4$✓	for $_{3a}$✓ accept 'increase timing interval' / time for concurrent half lives or wtte; reject 'measure time for **C** to fully discharge' for $_{3b}$✓ accept 'repeat the experiment and calculate a mean' only if this refers to $T_{½}$ reject 'repeat etc to get more reliable result' for $_4$✓ accept 'check etc for systematic error' 'student' is repeating previous experiment so reject idea of making V the dependent variable / plot V against t / using data logging		

	suggests a valid quantitative test of theory by comparison with the result obtained using the 15 V range $_5$✓	(theory will be correct if) half-life / time constant is one fifth / 20% (of previous value) / about 3.5 s / time constant reduced by 80% / ratio of time constant to range / ratio of half-life to range is same / similar reject 'plot ln V against t, find (–gradient^{-1})'	1	AO2-1d

Question	Answers	Additional comments/Guidelines	Mark	AO
03.6	in answer space 1: any valid comment about the values of V in **Table 2** $_1$✓ corresponding explanation $_2$✓ (contingent on $_1$✓) in answer space 2: different valid comment about the values of V in **Table 2** $_3$✓ corresponding explanation $_4$✓ (contingent on $_3$✓) only credit one comment and explanation per answer space comments about the number of data sets are neutral	give credit for any good physics, eg V recorded to nearest volt $_1$✓ because of (low) scale resolution / hard to interpolate between markings; reject 'values easier to plot' $_2$✓ different / decreasing intervals between values of V / more lower values of V $_3$✓ to make intervals between t readings about the same / or wtte; allow 'to distribute data on graph' or wtte / to allow (convenient interval for) t to be read / recorded $_4$✓ no readings for $V < 2$ V / smallest $V = 2$ V $_5$✓ because difficult to establish exact moment to read stopwatch / needle is moving too slowly / sensible comment about parallax $_6$✓ V data over wide range / from 14 to 2 (V) $_7$✓	4	AO2-1g

		to maximise evidence available (for graph / **Figure 8**) or wtte $_{8}$✓ no readings for V > 14 V / largest V = 14 V $_{9}$✓ can begin discharge **C** before starting stopwatch $_{10}$✓		

Question	Answers	Additional comments/Guidelines	Mark	AO
03.7	attempts gradient calculation using $\Delta\ln(V / \text{V})$ divided by Δt; use of $\lvert\text{gradient}\rvert = \left\lvert\frac{-1}{R \times C}\right\rvert$ $_{1a}$✓ OR reads off ln V_0, ln V and corresponding Δt from **Figure 8**; use of $V = V_0 e^{-\frac{t}{RC}}$ $_{1b}$✓	for $_{1a}$✓ expected gradient is -0.077; condone one read-off error in gradient calculation or missing sign; allow any subject / (at least) substitution of their gradient into a valid calculation for R condone missing / wrong POT for capacitance for $_{1b}$✓ condone one read off error; allow any subject / (at least) substitution of all their data into a valid calculation for R condone missing / wrong POT for capacitance $_{1b}$✓variation below: reads off ln V_0 and finds V_0 = 14.1 (V); $V = 0.37V_0$ when $t = RC$ $\therefore V = 0.37V_0 = 5.2$ V	1	AO2-1h

	valid working leading to voltmeter resistance ≥ 3 sf in range 15.0 kΩ to 16.6 kΩ $_2$✓ voltmeter resistance ≥ 3 sf in range 15.5 kΩ to 16.1 kΩ $_3$✓	reads of ln 5.2 = 1.65; $\Delta t \approx 13$ (s) $\therefore R = \frac{13}{C}$ accept > 3 sf that rounds to 3 sf in range allow $_{23}$✓ = 1 MAX for POT error allow $_{123}$✓ = 1 MAX for using **Table 2** data	2	AO3-a1a

Question	Answers	Additional comments/Guidelines	Mark	AO
03.8	reads ln(V_{10} / V) from **Figure 8**; deduces V_{10} in range 6.36 to 6.69 (V) $_1$✓	for $_1$✓ V_{10} to ≥ 3 sf required; accept > 3 sf that rounds to 3 sf in range; accept V_0 from ln V_0 read off and V_{10} deduced from $V_{10} = V_0 e^{\frac{-10}{CR}}$; condone use of V_0 = 15(V); if V_{10} is not recorded allow $_1$✓ for use of $e^{\ln V_{10}}$ in the calculation of I_{10} where ln(V_{10} / V) is in the range 1.85 to 1.90	1	AO1-1b
	≥ 2 sf result in range 3.9 to 4.3 × 10^{-4} (A) $_2$✓	for $_2$✓ allow use of resistance = 16 × 10^3 (Ω); accept ≥ 3 sf result that rounds to 2 sf in range	1	AO2-1g

		allow ECF if V_{10} is **correctly obtained** from an incorrect $\ln(V_{10} / \text{V})$ read off and I_{10} calculated using $\frac{\text{their } V_{10}}{\text{their voltmeter resistance}}$		

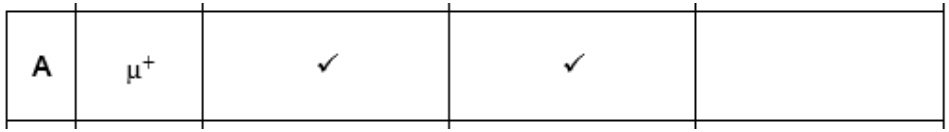
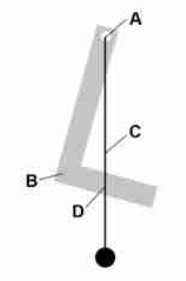
Total			**19**

C

A

27	D

06.1	R_{LDR} without light = 300 kΩ ✓ $I = \frac{V}{R} = \frac{5}{310 \times 10^3} = 16.1 \times 10^{-6}$ A ✓	Allow ecf for their R	2	AO3 AO1 L3 Maths 1
06.2	V with without light = $IR = 16.1 \times 10^{-6} \times 300 \times 10^3 = 4.84$ V✓ With light $V = \left(\frac{93}{93+10}\right) \times 5.0 = 4.51$ V ✓ Conclusion and calculate of change in voltage and comparison with 1.25 V✓	ecf from **06.1** Allow 92–100 kΩ 4.8 – 4.5 = 0.3 V so no. Allow 1 sf (allow ecf)	3	AO1 AO1 AO3 L3 Maths 2
Total			**5**	

Question	Key	Answer
07	D	1×10^{7} J
08	B	10^{-14} km
09	A	
10	A	$\alpha + \beta^{-} + \beta^{-} + \alpha + \alpha$
11	A	up quark down quark neutrino
12	B	It has a charge of -1.6×10^{-19} C.
13	B	3.3×10^{-19} J
14	D	It emits photons of UV light following ionisation or excitation.
15	C	1.6×10^{-18} J
16	B	muon electron
17	D	The frequency is 0.17 Hz.
18	A	**P** is in antiphase with **R** **P** has the same amplitude as **Q**
19	C	433 nm
20	D	9.6 N
21	B	2.25 m
22	C	
23	C	G F
24	A	the acceleration of the car increases.

25	C	250 J
26	C	$\frac{\rho}{4}$ $\frac{E}{4}$
27	D	4.2 V 1.4 V
28	B	0.47 A
29	D	24 V
30	B	$2T$ T
31	D	$\frac{2\pi^2 mA^2}{T^2}$

20

06.1	Appropriate use of $V = IR$ ✓ Variable resistor resistance = 190 (Ω) ✓	e.g. for MP1: • determines total circuit resistance • determines pd across thermistor • use of $= I(R_{XY}+R_{YZ})$✓ Condone POT error in MP1 Expect to see total circuit resistance of 542 (Ω) Expect to see pd across resistor of 2.3 V. Condone POT error in MP1 Calculator value: 191.67 Ω	2	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	Evidence of 22 °C converted to K ✓ Determines R OR $\frac{3.2}{12}$ OR $\frac{3.2}{12\times10^{-3}}$ ✓ Evidence of use of $\ln(\frac{R}{R_0})$ with their values✓ $B = 1110$ ✓ K ✓	Allow ecf from MP1. Expect 295 K Expect to see 267 Ω Condone use of $R_0 = 190$ Ω in MP3 Accept 1100 Accept answers that round to 1110 or 1120 Allow ecf only from temperature conversion. Do not accept k for K	5	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	Current causes thermistor temperature to change ✓ Thermistor resistance decreases as temperature increases✓	Allow a clear description of thermal runaway for both marks.	2	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
06.4	Uses ammeter(s) (in series) to show current at X = current at Y = current at Z OR Uses voltmeter(s) to show that emf/terminal pd / 6.5 V = pd across XY + pd across YZ✓ Links current readings to (conservation of) charge AND Links pd readings to (conservation of) energy✓	Do not allow ‘currents across’. Do not accept ‘battery pd’ unless it is clearly being measured. If points XYZ are not referred it must be clear where the meters are attached.	2	AO1
Total			11	

Question	Answers	Additional comments/Guidelines	Mark	AO

04.1	Substitution of data in resistance formula or $A = \rho L/R$ seen ✓ Area of cross section = $2.1(1) \times 10^{-9}$ (m^2) ✓	ecf for incorrect length from attempt at a calculation	1 1

04.2	Maximum possible pd across $0.25\ \text{k}\Omega$ is $9\ \text{V}$ ✓ (Max power dissipated) = $9^2/250 = 0.32\ \text{W}$ so resistor is suitable. ✓ OR When resistor dissipates maximum power V^2 = 0.36 x 250 so max V = 9.5 V✓ This is higher than the supply pd so this power dissipation so will not be reached. ✓ OR Power dissipated when output is 5 V = $4^2/250$ = 0.064 W✓ Which is below the max power dissipation of 0.36 W✓	$9^2/250$ = 0.32 W with incorrect conclusion scores 1 Second mark implies the first $9^2/0.36 = 225\ \Omega$ alone is not a useful calculation in the context. Still need to explain the effect of using the 250 Ω. First mark is for a valid useful calculation	1 1
04.3	Use of potential divider formula to determine resistance of parallel combination✓ $0.313\ \text{k}\Omega$ ✓ Use of equation for resistors in parallel ✓ 540 Ω✓ **OR** Current in circuit at room temp = 4/250 = 16 mA✓	Alternative to find resistance of combination Current in circuit at room temp = 4/250 = 16 mA✓ Resistance of combination = 5/16mA = 313 Ω✓ OR $\frac{V_{combination}}{V_{250}} = \frac{R_{combination}}{250}$ $\frac{5}{4} = \frac{R_{combination}}{250}$ $R_{combination}$ = 313 Ω	1 1 1 1

	Current in thermistor = 5/750 = 6.7 mA✓		
	Current in R = 9.3 mA ✓ R = 5/9.3 = 540 Ω✓ 2sf answer ✓ (only allowed with some relevant working leading to a resistor value)		1

04.4	Resistance of <u>thermistor</u> decreases✓ <u>Output pd decreases since</u> resistance of the parallel combination /circuit decreases OR lower proportion of pd across the parallel combination (or higher proportion across 250Ω) OR higher current so greater pd across the 0.25 k resistor. ✓	Accept correct consequences for R increasing with temperature for 1 mark.	1 1 1

Total			**12**

	Radius of orbit = 5 tan 28.5 + 1 = 3.71 m ✓ Speed = 2 × 3.14 × 3.71/5.2 = 4.49 () ✓	For second mark only allow Use of sin 28.5 gives orbit radius 3.39 m and speed = 4.1 m s^{-1} Or	1 1

28	A

29	C

28	B	0.47 A

27	D	1.50 V	AO2

28	C		18	18		AO2

05.1	$V_T = 3.46$ (V) ✓	$E = V + Ir$ $3.66 - (6.77 \times 0.0300) = 3.46$ Do not accept rounding errors. Calculator value = 3.4569 Accept 3.5	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
05.2	Resistance of cells in series $= 5 \times 0.0300\ \Omega = 0.150\ \Omega$ OR In parallel: *their series resistance* $\div 4$ $(= 0.0375\ \Omega)$ $_1$✓ $r = 0.0375\ (\Omega)$ $_2$✓	Condone method that uses 5 sets of 4 parallel cells in series. Condone POT error in MP1 Accept 0.038	2	1 × AO1 1 × AO2

Question	Answers	Additional comments/Guidance	Mark	AO
05.3	emf per module = 352 ÷ 16 = 22.0 V $_1$✓ Number of cells in one row = their emf per module ÷ 3.66 OR Number of rows in parallel = 500 ÷ 6.77 (= 73.9) = 74 $_2$✓ Number of cells = 444 ✓	Expect to see: Number of cells in one row = 6 **MAX 2** if answer not a whole number If no other mark given: award **max 1** for 96 cells (divided by 16) to give 6 per module	3	AO3
Total			**6**	

Question	Answers	Additional comments/Guidance	Mark	AO
		For ✓ expect to see		

04.1	emf is the intercept on the pd/y axis✓ gradient of the graph is –r /internal resistance is minus the gradient of the graph/modulus of gradient is r/absolute value of gradient is r/magnitude of gradient is r✓		1 1
04.2	figure 5 circuit supplies 50 mA ✓ figure 6 circuit has emf of 1.4 V ✓ and internal resistance of 12 Ω ✓ hence current of 78 mA which is >75 mA ✓ OR calculate required pd is 0.45 V (0.075 × 6.0)✓ show pd for cell in fig. 5 is 0.1 V ✓ show pd across parallel cells in fig. 6 is 0.4 V✓ show total pd in fig 6 is 0.5 V which is greater than 0.45 V✓ OR calculate emf needed for 75 mA in fig 5 (1.05)✓ calculate emf needed in fig 6 (1.35)✓ comment on emf needed in fig. 5 is larger than cell provides✓ comment on emf in fig. 6 being close to what is required✓	Can use different routes independently for fig 5 and fig 6 If candidates calculated current is not 50 mA or 75 mA allow CE for correct conclusion relating to 75 mA Must explain which circuit is suitable. If their calculation shows neither circuit suitable must explain why both circuits not suitable from graph for current for current of 75 mA from graph for current of ½ of 75 mA i.er. 37.5 mA i.e. 0.1 V from single cell and 0.4 V from parallel cells	4
04.3	useful power dissipated = $(75 \times 10^{-3})^2 \times 6$✓ (= 0.03375 (W)) input power (at the cells) = 0.03375/.04 = (W)✓ solar power =0.8437 /(32×10^{-4})=260 (263.7 or 264) W m^{-2}✓	Condone use of 78 mA gives answer of 285 W If use resistance of 18 Ω then lose first mark but CE to give answer of 791 W CE from power calculation but not from % calculation if incorrect % calculation at any stage only qualify for useful power mark	1 1 1

Total			**9**

Question	Answers	Additional Comments/Guidelines	Mark

04.1	$R = \frac{V^2}{P} = \frac{6.2^2}{4.5} = 8.5(4)\ (\Omega)$✓	Condone use of *W* for *P*.	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	Calculation of current in lamp (0.73 A) OR Calculation of current in 12 Ω resistor (0.52 A) OR Calculation of parallel pair resistance (5.0 Ω) ✓ Calculation of total circuit current (1.2(4) A) OR Calculation of total circuit resistance (7.5 Ω) OR Expression of potential divider arrangement $\frac{\varepsilon - 6.2}{r} = \frac{6.2}{\text{external } R}$ OR $\frac{\varepsilon}{\text{total circuit restance}} = \frac{6.2}{\text{external R}}$ ✓ (emf = terminal pd + Ir = 6.2 + (1.24 × 2.5)) 9.3(1) V ✓	Allow ecf from **04.1** Allow alternative methods Give full credit to answers that use 9Ω : Expected values for this method are Lamp current = 0.69 A Current in 12 Ω resistor = 0.52 A Parallel pair resistance = 5.1(4) Ω Total circuit resistance = 7.6(4) Ω Total circuit current = 1.2(1) A emf = 9.2(1) V	3	3 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	Evidence of calculation of $A\ (=\pi\ (d/2)^2 = 2.84 \times 10^{-8})$ ✓ Use of their A in the resistivity equation $= RA/l$ ✓ To give $5.1\times 10^{-8}\ (\Omega m)$✓	Allow POT errors in MP1 and MP2 Allow answers that round to $5.10\times 10^{-8}\ (\Omega m)$	3	3 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	Resistance increases ✓ Reduces current through lamp and lamp dimmer OR Greater pd across plugs as potential divider and lamp dimmer✓	Do not condone explanations that confuse current and potential difference. Do not condone “current across” or “pd through”.	2	2 x AO3

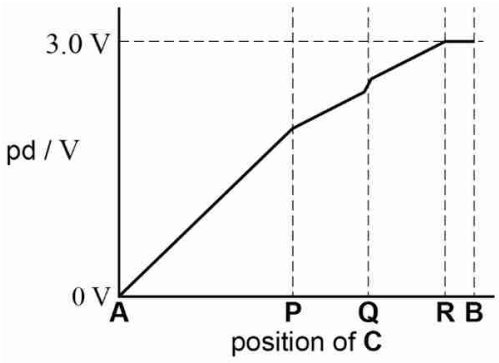
Question	Answers	Additional comments/Guidelines	Mark	AO
04.5	(Resistance increases) Reduces current in circuit / battery OR Increases (external) circuit resistance ✓ Reduces pd dropped across internal resistance of cell / increases terminal pd so lamp brighter. ✓	Award MAX 1 for arguments dealing with initial dimming of bulb when wire attached. Condone “pd across lamp and resistor / parallel section” for “terminal pd”. Condone “lost volts”.	2	2 x AO3
Total			**11**	

Question	Answers	Additional comments/Guidelines	Mark	AO

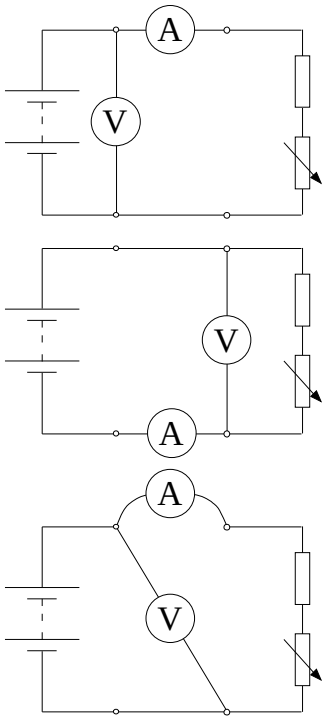
03.1	(1 C of) the charge gains ε J on passing through cell OR energy transferred (by 1 C) in R_1 is V_1 (J) OR energy transferred (by 1 C) in R_2 is V_2 (J) OR energy transferred (by 1 C) in r is Ir (J) ✓ (for conservation of energy) $\varepsilon = IR_1 + IR_2 + Ir$ ✓	If no other mark awarded, allow one mark for definition of emf in terms of energy transfer. accept: 'dissipated' accept 'lost volts' for Ir but reject 'voltage across r' accept 'work done' for 'energy transferred' Alternative for MP2 $\varepsilon = V_1 + V_2 + Ir$ provided that MP1 is awarded.	2	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	Equates emf to $Ir + 2.89$ in some form ✓1	If no other mark awarded, award one mark for use of emf value in MP2. Allow in MP1 (their current/A) ×125Ω for 2.89 V	3	AO2 × 3
	Calculates I from $2.89 \div 125$ (=0.02312 A) ✓2	Allow alternative routes for ✓1 and ✓2. E.g. 'Lost volts'= 0.11 V ✓1 Applies potential-divider equation e.g. $0.11 \div 2.89 = r \div 125$ ✓2 OR $3 \div (125 + r) = 2.89 \div 125$ ✓1✓2		
	Giving $r = 4.76$ (Ω) ✓3	Must see at least 3 sf answer Answer must round to 4.76(Ω)		

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	(Resistance splits $25\ \Omega$ and $104.8\ \Omega$) Applies potential divider formula eg $\frac{V}{3.00}=\frac{25}{129.8}$ ✓ $V = 0.58$ (V) ✓	Accept other routes for MP1 e.g. using $V = IR$, with $25\ \Omega$ and their current, for example from • $I = 0.023$ A (from Q03.2) • $I = \frac{\text{emf}}{\text{total resistance}} = \frac{3}{125+r}$ • $I = \frac{terminal\ pd}{125}$ **OR** using $V = \frac{2.89}{5}$ with an identification of 2.89 V as the terminal pd. If no other mark awarded, allow one mark for using $29.8\ \Omega$ instead of $129.8\ \Omega$ for total resistance giving $2.5(2)$ V.	2	AO2× 2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	Any **four** from: Straight line 0 V **A** to **P** $_1$✓ Less steep non-zero gradient from **P** to **Q** $_2$✓ Short steep increase at **Q** $_3$✓ **Q** to **R** about same non-zero gradient as **P** to **Q** $_4$✓ Horizontal line from **R** to **B** at 3.0 V $_5$✓	 For $_3$✓ allow range no greater than width of "**Q**" label on horizontal axis. If graph sketched from 3 V (at **A**) to 0V (at **B**) award **max 2** (based on $_2$✓ and $_4$✓). If a single diagonal straight line from 0 V (at A) to B, award $_1$✓only. If a single diagonal straight line from 0 V (at A) to R and then horizontal to B, award only $_1$✓ **and** $_5$✓ if scored (**ie max 2**).	Max 4	AO3 × 4
Total			**11**	

Question	Answers	Additional comments/Guidelines	Mark	AO
	Uses			

03.1	valid continuous series circuit that includes ammeter, and one wire link (condone diagonal connections) **and** voltmeter between any two sockets that enable the terminal pd to be measured ✓ all of the following are acceptable:  	**links and connections** reject broken / dashed lines tolerate diagrams with diagonal or non-straight connections between sockets if these will produce a valid circuit don't insist on connection blobs circuit must be continuous unless a switch is included: otherwise no gaps wider than the thickness of their links inclusion of a switch is neutral but the length of the open switch must be ≥ length of the gap where the switch is connected: condone the whole gap between terminals vertically opposite the ammeter to be marked as an open switch **meters** correct ASE symbol for ammeter and correct ASE symbol for voltmeter are essential one voltmeter and one ammeter only meters must not be 'transparent' positions of meters assume that the ammeter has negligible resistance and voltmeter has infinite resistance	1	AO1.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	(with any switch closed) read ammeter and voltmeter **or** record / measure I and V; adjust / vary / change resistance / (setting of) variable resistor / Q and repeat (readings) 1✓ plot V (against) I 2✓ ε = (vertical / y-axis) intercept 3✓ r = –gradient 4✓ 2✓3✓and 4✓ can be awarded for a suitable sketch graph	for 1✓must produce a range of I, V values (>2 sets) and identify how this is achieved; it is not necessary to suggest range or number of sets condone 'use the (variable) resistor to vary current and read I, V' idea that R can be read from Q is neutral mark 2✓ independently of 1✓ for 2✓(and further credit in 3✓and 4✓) the ordinate and the abscissa must be identified; allow 'plot V over I ' or 'plot V/I ' allow 2✓for reverse plot 'I (against) V' then 4✓ for $r = \frac{-1}{\text{gradient}}$ and 3✓ intercept = $\frac{\varepsilon}{r}$ for 3✓open circuit methods involving ε read directly using voltmeter are neutral for 4✓ any subject but minus sign essential	2 2	AO1.1a AO1.1b
	variation	1✓as above; 3✓find R from V divided by I ; disconnect external circuit and measure ε directly; 4✓plot $\frac{\varepsilon}{V}$ against $\frac{1}{R}$; 2✓gradient = r		

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	gradient calculation seen with Δn^{-1} divided by ΔI^{-1}; ε from 22 × gradient $_1$✓ ε minimum 3 sf; in range 1.58 to 1.61 (V) $_2$✓	for $_1$✓ do not penalise one read off error, (allow use of 0, 0) or for small steps expect gradient ≈ $7.2(5) \times 10^{-2}$ leading to ε = 1.594 (V) do not allow reverse working based on answer to 03.5 **$_2$✓ is contingent on award of $_1$✓**	1 1	AO3.1a AO2.1h
03.4	use of **Figure 12** to read off I^{-1} corresponding to n^{-1} = 0.25; calculates I in range 0.23(2) to 0.24(4) (A) ✓	do not insist on seeing evidence of working on **Figure 12** expect I^{-1} = 4.2 ± 0.1 (A^{-1}) leading to I = 0.238 (A) (should expect 1 more sf than in 0.25 for 'show that' but condone 0.23 and 0.24 since result based on 2 sf data) do not allow reverse working based on answer to 03.5	1	AO3.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	circuit resistance $R = 5.5$ (Ω) seen **in 03.5** working 1✓ minimum 2sf V from their $I \times 5.5$ **or** V from their ε – their $I \times r$ 2✓	for 1✓ allow $R = \frac{22}{4}$ or $\frac{11}{2}$; allow $R^{-1} = \frac{4}{22}$ etc for 2✓ correct R only; expect $V = 1.3(1)$ V; use of $I = 0.25$ A gives $V = 1.38$ V do not allow $V \geq$ their ε	4	AO3.1a
	r using lost volts divided by current; full substitution of their valid data eg $r = \frac{1.58 - 1.31}{0.238}$ 3✓ **or** r using formula for **Figure 12**; full substitution of their valid data eg $r = \frac{\varepsilon}{I} - \frac{22}{4} = \frac{1.58}{0.238} - 5.5$ 3✓ **or** r using either intercept on **Figure 12**; full substitution of their valid data eg their vertical intercept $\times -22$ **or** their horizontal intercept $\times \varepsilon$ 3✓	use of 'show that' or 2 sf data: $r = \frac{\varepsilon - V}{I}$ with $\varepsilon = 1.6$ V, $V = 1.4$ V and $I =$ 0.25 A gives $r = 0.80$ Ω $\frac{22}{n} = \frac{\varepsilon}{I} - r$ with $\varepsilon = 1.6$ V, $I = 0.25$ A and $n =$ 4 gives $r = 0.90$ Ω; (can find r first, then V using $\varepsilon - Ir$) a vertical intercept must be calculated; result is negative, eg vertical intercept = -0.053: $r = -1 \times -0.053 \times 22 = 1.17$(Ω) horizontal intercept = 0.73: $r = 1.6 \times 0.73 = 1.18$(Ω)		
	minimum 2 sf result in range 0.80 and 1.3(0) (Ω) 4✓	allow 4✓only if there is clear evidence of a valid method leading to a result in range		

Question	Answers	Additional comments/Guidelines	Mark	AO
03.6	$n = 2$ **and** $n = 3$ 1✓ $n = 5$ **or** $n = 6$ **or** $n = 7$ 2✓ to improve distribution of points (along the line) or wtte 3✓	for 1✓ and 2✓ if suggesting more than three values for n accept only the last three for 3✓ allow: 'spread out' / 'avoid concentrating' points' where current / n is smaller' or wtte 'reduce distance between points (data)' / (add) detail 'most uniform distribution' / 'most equally spread out' / 'roughly evenly spaced' reject: 'making points (data) 'equally' / 'evenly-spaced' / 'even spread' (without qualification) 'easier to plot / draw line' / 'line more accurate' / 'easier to see trend' are neutral	3	AO3.2b
03.7	both points move (by ≥ half a grid square) to the right 1✓ both points move (by ≥ half a grid square) causing the gradient of a straight line between them to be reduced 2✓	allow badly-marked points / use of arrows ignore any best-fit line added to **Figure 14** for 1✓ rightwards motion of each point must be parallel to gridlines ± half small square award of 2✓mark is independent of 1✓mark for 2✓the points do not need to move in the same direction	2	AO3.1b
Total			**17**	

C

B

C

C

C

B

C

B

C

B

A

D

C

C

23	C	G F

22	A	one

24	B	$\frac{9}{2}P$

23	C (AO2)	14 m	

26	D (AO2)	0.614 N s	

17	A (AO2)	1.3×10^{-2}	**X** to **Y**

18	C (AO2)	After a time T the pd across the capacitor is $1.5\ \text{V}$.

23	B (AO2)	1

24	B (AO2)	P

18	C	45 m	

24	C	The acceleration is unchanged.

22	A	○	

23	D	600 μV

24	D	395 V

20	D	$4d$	AO2

15	A	doubling the transmission voltage of the cable
		Be

21	B	The drag force when her velocity is v_2 is equal to the drag force when her velocity is v_1.	AO2

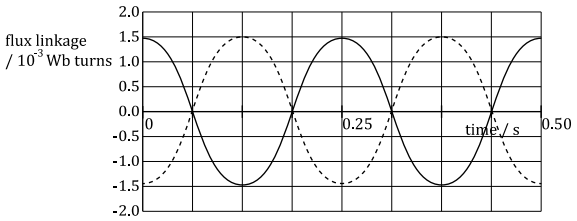
18	C	233 Ω	AO2

19	B		**R**	**Q**		AO2	

21	A	0	AO2

22	D	6.25 μV	AO2

23	A	80%	AO2

05.1	AB 2.5 x 10 x 3.0 x 10 N = 120 (turns) ✓2	✓2 A correct answer gains both marks. If no mark is awarded a single mark can be given for $\Phi = BAN\cos 30^o$ being used to find N =139.	2	1 AO2-1f-1 Math2-1
05.2	$\Phi\left(= \text{NAB}\cos\theta = 1.5 \times 10^{-3}\cos 30^o\right)$ Flux linkage = 1.3×10^{-3} (Wb turns) ✓		1	AO2-1f-1 Math2-1
05.3	$f = \frac{1}{T} = \frac{1}{0.25}$ = 4.0 (Hz) or ω = 25.1 or 8π (rad s^{-1}) ✓1 Peak emf (= $BAN\frac{2\pi}{T}$= $1.5 \times 10^{-3} \times \frac{2\pi}{0.25}$) = 0.038 (volt) ✓2 (0.0377 volt)	✓1 Condone using 1 sig fig for f but not ω or T. The mark can be gained from seeing f or ω or T given explicitly or from a substitution in the peak emf equation in the second mark. ✓2 A correct answer gains both marks.	2	AO1-1a-1 AO2-1h-1 Math2-2
05.4	 Either solid or dashed line gains mark ✓	The mark is dependent on the exact crossing of the time axis which has a tolerance of ± 1 small square. The vertical axis figures is not expected. Also ignore errors in height and the exact positions of the peaks. Only a rough sinusoidal shape is expected. A	1	AO3-1a-1 Math2-1

		triangular shape with very slightly rounded edges would be acceptable.		

Total			**6**

Question	Answers	Additional Comments/Guidance	Mark	ID details
	To increase the probability/chance of fission (when neutron collides with fissile material/ U-235)	Condone because thermal/slow moving neutrons are needed for fission to take place 'fuel' but not 'fuel rod' to be used in the		AO2-1a-

03.1	Max 2 from one route ✓✓ **Alternative 1** • $\Phi = BA\cos\theta = 4.9 \times 10^{-5} \times (2 \times 8.0) \times \cos 68° = 2.9(4) \times 10^{-4}$ (Wb) OR $\Phi = BA = 4.9 \times 10^{-5} \times (2 \times 8.0) = 7.84 \times 10^{-4}$ (Wb) • Time to fall to the ground = 1.3 (1.28) (s) • $\varepsilon = \frac{\Delta\Phi}{\Delta t}$ with their $\Delta\Phi$ and t **Alternative 2** • $\varepsilon = Blv$ or $\varepsilon = Blv\cos\theta$ seen • $v = \sqrt{2g\Delta h}$ OR $\sqrt{2as} = 12.5$ (m s^{-1}) OR Time to fall to the ground = 1.3 (1.28) (s) • $v_{avg} = \frac{v}{2}$ with their v OR $v_{avg} = \frac{s}{t}$ for their t $\varepsilon = 2.3 \times 10^{-4}$ ✓ (V)	Marks can only be awarded from one route. mp1 and 2 the mark can be awarded from seeing a substitution. For mp1 condone $\sin 68°$ in both routes $t = \left(\frac{2s}{a}\right)^{\frac{1}{2}} = \left(\frac{2\times 8.0}{9.81}\right)^{\frac{1}{2}} = 1.28$ In 3rd bullet do **not** allow $\varepsilon = \frac{\Delta B}{\Delta t}$ or $\varepsilon = \frac{\Delta B\cos\theta}{\Delta t}$ but condone any value for A.	3	1 × AO1a 1 × AO2a 1 × AO3-1a

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr><td>03.2</td><td>Max 4✓✓✓✓
Fall to the left
<table>
<tr><td>Statement</td><td>Explanation</td></tr>
<tr><td>the direction of the emf changes</td><td>the rod cuts across the magnetic field in both directions / passes parallel point</td></tr>
<tr><td>the emf goes through a zero (when $68°$ to the vertical)</td><td>momentarily the rod travels parallel to the field or does not cut lines of flux / 0 change in flux</td></tr>
<tr><td>emf reduces (and then increases)</td><td>as (direction of) velocity or motion gets closer to being parallel to field / same direction as field / cuts less flux per unit time</td></tr>
</table>
Fall to the right
<table>
<tr><td>Statement</td><td>Explanation</td></tr>
<tr><td>the direction of the emf stays the same</td><td>the rod cuts across the magnetic field always in the same direction</td></tr>
<tr><td>Idea that the emf goes through a maximum (when $22°$ to the vertical)</td><td>the rod cuts across the magnetic field at right angles or the cutting of field line is a maximum</td></tr>
<tr><td>emf increases (and then decreases)</td><td>as (direction of) velocity or motion gets closer to perpendicular to field / cuts more flux per unit time</td></tr>
</table></td><td>All marking points are to be OWTTE.
Ignore comments about different direction falling left and right.
Statement and explanation are separate marking points.
Explanation must not contradict statement to be awarded.

Condone emf increases as speed of fall increases (Blv) or smaller time $\left(N\frac{\Delta\Phi}{\Delta t}\right)$✓ ✓ for either direction but not both.
Allow the following statement and explanation as an alternative to either a fall to the left or to the right but not both:
Statement – when falling left the average emf is less than falling to the right.
Explanation – as the total change in flux / number of flux lines cut is less than when falling to the right.</td><td>4</td><td>2 × AO2g
2 × AO3-1a</td></tr>
<tr><td>Total</td><td></td><td></td><td>7</td><td></td></tr>
</table>

Question	Answers	Additional comments/Guidelines	Mark	AO

04.1	flux linkage) is such that it will (try) to oppose the change (of flux) that is producing it ✓ owtte	induced current as this is dependent on a circuit. Ignore reference to current if emf is given.	1	AO1

04.2	(The reading shows a dc) current flow which then becomes zero (when the magnet stops moving) ✓	The reading does not have to be steady. So reading increasing or pulsing up before falling to zero is okay. There should be no hint that the reading changes direction.	1	AO2
04.3	(The induced current produces) a north pole on the right hand side of the coil. ✓ which opposes the motion of the bar magnet **OR** and the two north poles repel each other **OR** to try to maintain the (small) magnetic field as the magnet approaches the coil (without this the magnet would increase the magnetic field beside the coil) ✓	The polarity of the coil may be shown on the diagram. The two marks are independent but the second mark does not stand completely alone as it has to be said in context. EG 'Two North poles repel' on its own will not gain a mark.	2	AO1 AO2
04.4	(Use of $\varepsilon = BlV$ as the straight leading edge of the coil is the only conductor that cuts the magnetic flux lines. Also using $v = s / t$) $t = Bls/\varepsilon$ ✓ (There must be some evidence of use for the mark but the mark can come from substituting numbers, eg $t = 0.38 \times 0.032 \times 0.032 / 2.9 \times 10^{-4}$) $t = 1.3(4)$ (s)✓ **OR** (Using $\varepsilon = (-)N\,\Delta\phi/\Delta t$ then $\Delta t = \Delta(BA)/\varepsilon$) $t = BA/\varepsilon$ ✓ (There must be some evidence of use for the mark but the	Useful numbers $BA = 3.89 \times 10^{-4}$ Although the first mark can come from substituting numbers the equation mark may be lost if it is obvious that the equation is not understood by the way substitutions are made (this does not include a simple AE slip). This loss of a mark is directed at the candidate who quotes several equations and happens to hit on the correct equation but fails to use it properly. Failure to square the side length is a PE. Answer only gains 2 marks.	2	AO2

	mark can come from substituting numbers, eg. $t = 0.38 \times .032^2 / 2.9 \times 10^{-4}$) t = 1.3(4) (s) ✓			

04.5	(using $\varepsilon = BAN\omega \sin \omega t$ which give a maximum value of $\varepsilon_{max} = BAN\omega$) ω (= ε_{max}/BAN) = $5.1 \times 10^{-3} / (0.38 \times (0.032)^2$ ✓ ω = 13(.1) (rad s^{-1}) ✓	Candidates who cannot maximise/remove sin ωt gain no marks. {may see $\omega = 5.1 \times 10^{-3} / 3.9 \times 10^{-4}$}	2	AO2

Total			**8**

Question	Answers	Additional Comments/Guidance	Mark	ID details
	γ radiation because it is very / the most penetrating **OR** γ radiation because it is penetrating enough to irradiate all sides of the instruments	The quoted radiation must be gamma only and not a mixture.		

04.1	Magnetic flux density at $0.070\ \text{m} = 0.07 \pm 0.005\ \text{T}$ ✓ (use of flux linkage $N\Phi = BAN$ $= 0.07 \times 3.5 \times 10^{-5} \times 200$) Flux linkage $= 4.9 \pm 0.2 \times 10^{-4}$ (Wb-turns) ✓	shown calculated to at least 2 sig figs	2	3.7.5.3 AO2 1d ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	(As the coil moves) there is a rate of change of flux through the coil ✓$_1$ (owtte) The induced emf is proportional to the rate of change of flux (linkage) so the (magnitude) of the emf decreases ✓$_2$ (owtte)	✓$_1$ The first part ie the induced emf is proportional to the rate of change of flux linkage may be given in a number of ways eg emf $= N\frac{\Delta\Phi}{\Delta t}$ or $N\frac{\Delta(BA)}{\Delta t}$ or simply saying 'because of Faraday's law'. Ignore the sign of the emf ✓$_2$ It's not enough to say the emf decreases Connection between rate of change of flux and change of flux with distance must be made	2	3.7.5.4 AO1 1b AO2 1c

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	Finding a gradient from a tangent ✓$_1$ Attempting to use Faraday's law emf = $N\frac{\Delta(BA)}{\Delta t}$ OR incorporating velocity into Faraday's law $NA\left(\frac{\Delta B}{\Delta x}\right)v$ ✓$_2$ emf = $\left(200 \times 3.5 \times 10^{-5}(0.693) \times 0.80\right)$ emf = 3.6 to 4.2×10^{-3} (V) ✓$_3$ The maximum emf (in the range considered) is the greatest at x = 0.10 m (as the gradient is the greatest) So No ✓$_4$ owtte	✓$_1$ This can be calculated at any x eg at x = 0.10 m gives $\frac{\Delta B}{\Delta x} = \left(\frac{0.095}{0.137}\right) = 0.69(3)$ (T m^{-1}) ✓$_2$ The mark is given for an attempt to use Faraday's law. Allow errors provided the form of the equation remains correct. ✓$_3$ The expected value is $3.8(8) \times 10^{-3}$ V {range to be decided at standardisation} ✓$_4$ No and an indication that the emf at x = 0.10 m is the maximum available. This could come earlier in the answer and can be inferred by a reference to the maximum gradient in the range considered. No ecf. If no marks are awarded allow 1 mark if candidate states that the largest emf is expected at x = 0.10 m If only the second mark is awarded allow a mark for finding $\frac{\Delta B}{\Delta t}$ or $N\frac{\Delta \phi}{\Delta t}$ between x = 0.07 and 0.10 m (e.g. $\frac{200 \times 3.5 \times 10^{-5}(0.07-0.024)}{0.0375}$)	4	3.7.5.4 AO2 1d ×2 AO3 1a ×2

Total			8

16

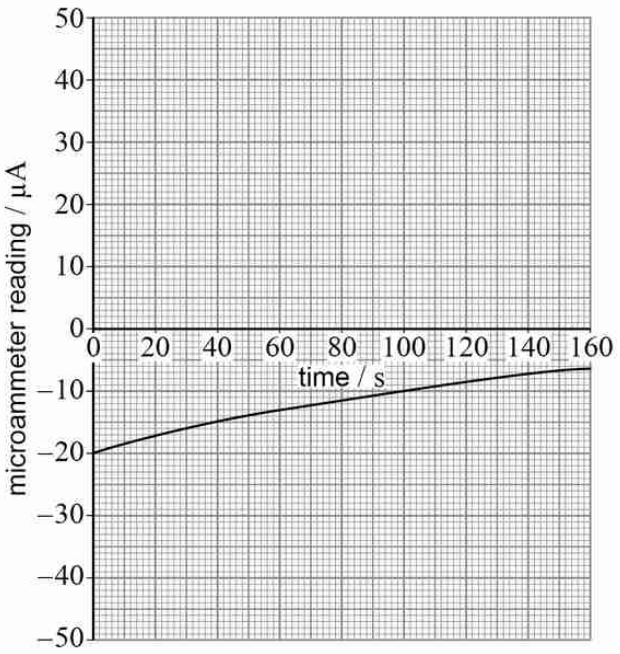
Question	Answers	Additional comments/Guidelines	Mark	AO

05.1	Idea that capacitance / charge stored with dielectric is seven times greater than with vacuum / air / free space (for same geometry and pd) ✓	Allow material for dielectric. Allow $\frac{\text{permittivity of dielectric}}{\text{permittivity of free space}} = 7.0$ Allow ε or $\varepsilon_{\text{dielectric}}$ (but not ε_r) only if it is named as the permittivity of the dielectric. Allow the permittivity of the dielectric is seven times greater than the permittivity of free space/vacuum/air. Do **NOT** allow the **relative** permittivity of the dielectric is seven times greater than the permittivity of free space. Do **NOT** allow $\frac{\varepsilon_r}{\varepsilon_0} = 7.0$	1	AO1

20

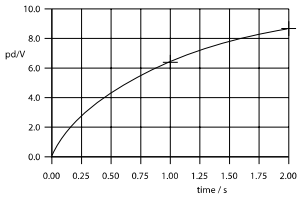
Question	Answers	Additional comments/Guidance	Mark	AO
05.2	Attempt at a valid method ✓ (allow minor read-off errors) 73 ± 2 (s) ✓	**Valid methods** Measuring time until $\frac{40}{e} = 14.7\ \mu A$ Condone 14-15 microammeter read off for MP1. Measuring one or two half-lives with $\frac{t_{0.5}}{\ln 2}$ Picking a point and substituting into $I = I_0 e^{-\frac{t}{T}}$ Some working must be seen for MP1 and may be seen on graph only for a direct read off of the time constant.	2	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
05.3	Use of e^{-5} **or** use of $I = I_0\, e^{-\frac{5T}{T}}$ with their I_0 and T ✓ (convert to a percentage) 0.67% ✓	Condone 0.37^5 for MP1… …leading to 0.69% for MP2.	2	1 × AO1 1 × AO2

Question	Answers	Additional comments/Guidance	Mark	AO
05.4	**Award MAX 3 for ✓✓✓** The magnitude of the current generally decreases with time, together with • Starts at (−)20 μA • Half-life of 100 ± 4 s $I_0 = \pm 20\ \mu A$: check $(100, \pm 10)$ $I_0 = \pm 40\ \mu A$: check $(100, \pm 20)$ • Line to at least 120 s with correct shape including: decreasing gradient **throughout** does **not** have a non-zero asymptote • Negative current shown for all times	When **increasing** magnitude of current seen, **MAX 1** for either: • correct half life: shown by passing through (0,0) **AND** either $(100, \pm 10)$ or $100, \pm 20)$ • negative current shown for all times. Award MAX 2 when two curves given and one is not clearly deleted/erased. 	3	AO3
Total			8	

22

Question	Answers	Additional comments/Guidance	Mark	AO

03.1	**OR** reference to charge to pd OR charge to voltage ratio✓ includes units C or coulomb and V or volt ✓	An equation may contribute towards the first mark but only if the symbols are identified. A second mark can be given if the units are identified. Ignore poor phrasing like 'per unit volt passing through'.	2	AO1
03.2	(Using time constant = *R C*) (R = 1.0 / 370 × 10^{-6}) R = 2.7 × 10^{3} (Ω) ✓	Check that the unit on answer line has not been altered	1	AO1
03.3	First mark for marking a cross at 2 s and 8.5 V (by eye) ✓ Second mark for graph starting at the origin and having a decreasing gradient ie not reaching horizontal ✓  	Cross must be in the bottom half but not on the 8.0 V major grid line or exactly half way up (9.0 V) If a series of plotting crosses are given only consider the one placed at 2 s for the first mark.	2	AO2

10

03.4	(Using $T_{½} = 0.69\,RC = 0.69 \times 1.0$) $T_{½} = 0.69$ (s) ✓	1 sig fig is not acceptable	1	AO1
03.5	(Use of $Q = Q_o(1 - e^{-\frac{t}{RC}}) = CV_o(1 - e^{-\frac{t}{RC}})$) mark for max charge = CV_o which may come from substitution or seeing $3.6(2) \times 10^{-3}$ C ✓ $3.0 \times 10^{-3} = 370 \times 10^{-6} \times 9.8\,(1 - e^{-t})$ ✓ mark for substitution ($0.8274 = (1 - e^{-t})$ so $e^t = 1/0.173 = 5.79$) $t = 1.7$ s or 1.8 s ✓ **OR** voltage $V = Q/C = 3 \times 10^{-3} / 370 \times 10^{-6}$ $= 8.1(1)$ V✓ (Substitute into $V = V_o(1 - e^{-\frac{t}{RC}})$) $8.1 = 9.8\,(1 - e^{-t})$ ✓ $t = 1.7$ s or 1.8 s ✓	Alternative mark scheme uses the voltage as proportional to the charge. Do not allow use of the graph for 2nd mark and 3rd mark. An answer only gains only the last mark. Evidence of working must be shown which shows substitution into a $(1\text{-}e^{-t})$ form of the equation.	3	AO2
Total			**9**	

Question	Answers	Additional Comments/Guidance	Mark	ID details
	The direction of the induced emf (when there is a change of	A reference to emf is needed rather than induced current as this is dependent on a		

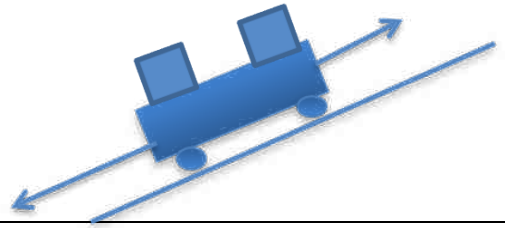
02.1	Show attempted use of all three equations: gradient $= \frac{\Delta V}{\Delta t}$ AND $I = \frac{\Delta Q}{\Delta t}$ AND $Q = CV$ ✓ $I_0 = C \times$ **initial** gradient ✓	mp2 $V = \frac{Q}{C}$ so $\Delta V = \frac{\Delta Q}{C}$ so gradient $\frac{\Delta V}{\Delta t} = \frac{\Delta Q}{C\Delta t} = \frac{I}{C}$ hence $I_0 = C \times$ initial gradient $(\Delta)Q = I(\Delta)t$ can be seen via substitution if **both** (Δ)Q and $I(\Delta)t$ are seen in equivalent expressions e.g. $I(\Delta)t = CV$ is insufficient without $(\Delta)Q = CV$. Condone omission of Δ's in MP1. Condone C or initial gradient as subject for mp2. Condone a calculation and an **initial** gradient shown on Figure 2 mp1 and mp2 are independent. If no other marks award 1 for $I = C \times$ gradient or C or gradient as subject.	2	AO2c

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	time constant = 7.5 ± 0.5 (s) ✓ evaluated $R = \frac{\text{their } T}{C}$ correctly ✓	Do NOT allow $T = RC$ for mp1. Value must come from Figure 3 using a valid method. 7.44 s is likely to come from RC and not from the graph. mp1 Time taken to fall to $1/e$ or 0.37 of its value = time constant eg 0.45 V to 0.166 V takes 7.5 s This may be calculated over a larger range or the time to halve the voltage found and this value divided by $\ln 2$ eg 0.45 V to 0.225 V takes 5.2 s giving = 7.5 s Half life 5.2 ± 0.5 (s) and $T = \frac{T_{\frac{1}{2}}}{\ln(2)} = \frac{T_{\frac{1}{2}}}{0.69}$ mp2 $T = RC$ so $R = \frac{T}{C} = \frac{7.5}{31.0\times10^{-6}} = 2.4(2) \times 10^5\ \Omega$ Condone 2SF for mp2 if working is shown.	2	1 × AO1b 1 × AO3-1a

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	Supply voltage $V_0 = I_0R$ (expect 8.6 V)✓$_1$ Use of $V = V_0\left(1 - e^{\frac{-t}{RC}}\right)$ ✓$_2$ **Alternative** Use of $V_0 = I_0R$ so $I = \frac{I_0R-6}{R}$ (expect 1.1×10^{-5} A)✓$_1$ Use of $I = I_0e^{-\frac{t}{RC}}$ ✓$_2$ Calculation of the time from correct physics (expect 8.8 to 9.0 s) ✓$_3$	Allow 9V for mp1 or mp2 but do not allow ecf for rounded value in mp3 mp2 allow substitutions OR rearrangements using ln or use of $V = \frac{Q}{C}$ and $Q = Q_0\left(1 - e^{\frac{-t}{RC}}\right)$ Allow ecf for ✓$_3$ R, T values but not from the wrong equation or mix up of V and I.	3	1 × AO2d 2 × AO3-1a

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	use of $C = Q/V$ and $C = \varepsilon_r\varepsilon_0 A/d$ ✓ $\frac{V_1}{V_2} = 0.125$ ✓	mp1 $V = \frac{Qd}{\varepsilon_r\varepsilon_0 A}$ may be seen anywhere in the working, possibly with subscripts or rearranged. mp2 $\frac{V_1}{V_2} = \frac{d}{4\times 2d} = 0.125$ Condone $\frac{1}{8}$ for mp2 Award 1 mark for 8 regardless of working mp2 implies mp1	2	AO2f
Total			9	

Question	Answers	Additional comments/Guidelines	Mark	AO
	Max 2 from one route ✓✓			

06.1	arrow parallel to slope labelled (M+2m)gsin35 and label parallel to slope labelled tension OR T✓ 	Ignore arrows not parallel to ground e.g. weight Ignore friction W not acceptable for (M +2m)g	1

06.2	T – Mgsin35 = Ma AND (M+2m)gsin35 – T = (M+2m)a ✓ add two equations (M + 2m)gsin35 – Mg sin35 = Ma + (M +2m)a ✓ HENCE (a= mgsin35/(M+m)) OR (M +2m)gsin35 – Mgsin35✓ (= (2M+2m)a) a = 2mgsin35 /(2M +2m) ✓ HENCE (a= mgsin35/(M+m))		1 1

06.3	SECOND MARK CONDITIONAL ON FIRST mass/impulse/acceleration (of trollies) is the same✓	SECOND MARK CONDITIONAL ON FIRST both have same <u>speed / magnitude of velocity</u> but different	1

	momenta (trolley A and B) the same	masses✓ (hence)momentum of A is greater/momenta in opposite directions✓	1

06.4	acceleration = $\frac{1}{4} \times \frac{30 \times 9.81 \times \sin 35^{o}}{(30+95)} = 0.338$ ✓ (use of $v^2 = 2as$) $v = \sqrt{(2 \times 0.338 \times 9.0)} = 2.47$ ✓ $t = \frac{2.47}{0.338} = 7.3$ s ✓ OR (use of $s = 1/2at^2$) $9 = ½ \times 0.338 \times t^2$ ✓ $t = 7.3$ s✓	CE from acceleration calculation If used g for acceleration then no marks awarded	1 1 1

06.5	number of journeys = (1800/(12 + 7.3) = 93 or 94✓ number of blocks = 2 × 93 = 186 or 2 × 94 = 188✓	Allow CE from 06.4 Allow between 93 to 94 Allow CE from incorrect number of journeys Allow 186 to 188	1 1

Total			**10**

Question	Answers	Additional Comments/Guidelines	Mark

07.1	(centripetal) force = $m\,r\,(2\,\pi / T)^2$ Or $m\,r\,(\omega)^2$ (is given by the gravitational) force = $G\,m\,M / r^2$ ✓ (mark for both equations) (equating both expressions and substituting for ω if required) $T^2 = (4\pi^2 / GM)\,r^3$ ✓ ($4\pi^2 / GM$ is constant, the constants may be on either side of equation but T and r must be numerators)	First mark is for two equations (gravitational and centripetal) The second mark is for combining.	2

07.2	(use of $T^2 \propto r^3$ so $(T_P / T_E)^2 = (r_P / r_E)^3$) $(T_P /1.00)^2 = (5.91 \times 10^9 /1.50 \times 10^8)^3$ ✓ (mark is for substitution of given data into any equation that corresponds to the proportional equation given above) (T_P^2 = 61163) T_P = 250 (yr) ✓ (247 yr)	Answer only gains both marks The calculation may be performed using data for the Sun in $T^2 = (4\pi^2 / GM)\,r^3$ easily spotted from M_s = 1.99 x 10^{30} kg giving a similar answer 247 – 252 yr.	2

07.3	using M (= $g\,r^2 / G$) = $0.617 \times (1.19 \times 10^6)^2 / 6.67 \times 10^{-11}$ ✓ $M = 1.31 \times 10^{22}$ kg ✓ answer to 3 sig fig ✓ (this mark stands alone)	The last mark may be given from an incorrect calculation but not lone wrong answer.	3

07.4	Initial KE = ½ (m) 1400^2 = 9.8 x 10^5 (m) J✓ Energy needed to escape = 7.4 x 10^5 (m) J✓ So sufficient energy to escape. ✓ ***OR*** For object on surface escape speed given by 7.4 x10^5 = ½ v^2✓ escape speed = 1200 m s^{-1}✓(if correct equation is shown the previous mark is awarded without substitution) So sufficient (initial) speed to escape. ✓ ***OR*** escape velocity = $\sqrt{\frac{2GM}{R}}$ substituting *M* from 07.3 ✓ escape speed = 1200 m s^{-1}✓ (1210 m s^{-1}) So sufficient (initial) speed to escape. ✓ ***OR*** escape velocity = $\sqrt{2Rg}$ substituting from data in 07.3 ✓	Third alternative may come from a CE from 07.3 (1.06 x 10^{-8} x $\sqrt{\text{answer } 0.73}$) Conclusion must be explicit for third mark and cannot be awarded from a CE	3
Total			**10**

	Keys to Objective Test Questions (each correct answer is worth 1 mark)												
Q	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
A	B	A	C	D	C	A	A	A	A	C	D	C	D
Q	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	

A	A	C	B	B	C	C	D	B	B	A	D	C

02.1	reads off λ_{p} 1✓	for 1✓ condone POT; expect $\lambda_p = 635 \pm 2$ (nm) / $635 \pm 0.02 \times 10^{-9}$ / $6.35 \pm 0.02 \times 10^{-7}$ (m) allow evidence of working on **Figure 3**	1	AO1-1a
	use of $n \times$ their $\lambda_p = d \sin\theta$ 2✓	for 2✓ accept subject N with no / incomplete substitution, eg $N = \frac{\sin\theta}{n \times \lambda_p}$ OR subject d and full substitution, eg $d = \frac{5 \times \text{their } \lambda_p}{\sin 76.3}$ / $5.15 \times$ their λ_p OR correct result $d = 3.27$ ($\times 10^{-6}$ (m)); allow ECF in λ_p including POT; allow recognisable d / 2 sf intermediate result	1	AO2-1h
	$N = \left(= \frac{1}{d} = \frac{1}{3.27 \times 10^{-6}}\right) = 3.06 \times 10^5$ 3✓	for 3✓ accept ≥ 3 sf in range 3.05 to 3.07 $\times 10^5$ OR	1	AO3-1b

		$N = \frac{0.194}{\text{their } \lambda_p}$ (allow ECF for λ_p out of range but not if due to POT)		

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	identifies an appropriate physical characteristic that makes the measurement of the (5th) maximum more difficult ✓	take 'it' to be the 5th maximum / peak (see rubric marking point 3.3) (centre difficult to locate because) (5th) 'maximum is wider' / 'peak less pronounced' / 'less defined' or wtte; allow 'maximum more spread out' / 'less pronounced' OR maximum 'is fainter' / 'less bright' / 'intensity reduced'; reject 'not as clear' OR (cannot use edges to determine location of centre because) 'whole maximum (may be) not visible' / 'can't see edges' OR (**L_R** produces a range of wavelengths so) 4th and 5th / adjacent fringes may overlap	1	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	extrapolation of linear region of the $\mathbf{L_R}$ characteristic $_1$✓	for $_1$✓ reads off where a ruled extrapolation to the linear region of the $\mathbf{L_R}$ characteristic reaches the horizontal axis the line must be free from discontinuities; condone a ruled dashed line condone tangent meeting curve at $I \geq 10$ mA	2	AO1-1b
	V_A for $\mathbf{L_R}$ in range 1.91 to 1.93 (V) $_2$✓	for $_2$✓ > 3 sf acceptable if rounding to 3 sf		

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	any fully correct calculation of the Planck constant $_1$✓	for $_1$✓ allow 2 sf use of $c = 3(.00) \times 10^8$ AND $e = 1.6(0) \times 10^{-19}$ AND EITHER V_A from **02.3** AND λ_p in range 620 to 650 nm / ECF their λ_p from **02.1** OR $V_A = 2.00$ AND λ_p in range 550 to 580 nm;	1	AO3-1b

	calculates mean of two valid calculations of the Planck constant; result in range 6.10 to 6.50×10^{-34} (J s) $_2$✓	for $_2$✓ Planck constant result rounding to correct 3 sf (check very carefully working leading to data booklet value 6.63×10^{-34})	1	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	V_F corresponding to $I_F = 21$ mA read from **L_R** graph in **Figure 4**; calculates R from $\frac{6.1 - \text{their } V_F}{21(.0 \times 10^{-3})}$ $_1$✓	use of $V_F = 2.01$ (V) leading to $R = 195$ (Ω) earns both marks for $_1$✓ accept evidence of working on **Figure 4** condone 2 sf eg $V_F = 2.0$ (V) allow POT error for I_F	1	AO1-1b
	$R = 195$ (Ω) from $\frac{6.10 - 2.01}{21(.0) \times 10^{-3}} = 195$ $_2$✓	for $_2$✓ evidence to show use of $V_F = 2.01 \pm 0.01$ (V) must be seen, ie allow $\frac{6.10 - 2.00}{21(.0) \times 10^{-3}} = 195$ OR $\frac{6.10 - 2.02}{21(.0) \times 10^{-3}} = 194$	1	AO2-1d
Total			**10**	

Question	Answers	Additional comments/Guidelines	Mark	AO

05.1	$V = V_0\left(1 - e^{-\frac{t}{RC}}\right)$ with substitution attempted with V_0 being larger than V ✓1 Time to charge to 4.0 V = $t_2 = -R_1 C \ln\left(1 - \frac{4}{6}\right)$ **OR** Time to charge to 2.0 V = $t_1 = -R_1 C \ln\left(1 - \frac{2}{6}\right)$ ✓2 $t = t_2 - t_1 = -R_1 C \ln\left(\frac{1}{3}\right) - \left\{-R_1 C \ln\left(\frac{2}{3}\right)\right\}$ $\left(= -R_1 C\left(\ln\frac{1}{3} - \ln\frac{2}{3}\right) = -R_1 C \ln\left(\frac{\frac{1}{3}}{\frac{2}{3}}\right) = -R_1 C \ln\left(\frac{1}{2}\right) = 0.69 R_1 C\right.$ **OR** $= R_1 C(1.10 - 0.41) = 0.69 R_1 C$ ✓3	NB The answer can be obtained incorrectly by finding the time to charge to 2V using a 4V supply. This approach may only gain the first mark for an attempted use of the equation. Award 0 for a solution using the discharge equation. Condone R for R_1 ✓2 If given in an equation then then time must be the subject or be in a form that is used to obtain mp3 can be awarded for $t_2 = 1.10 \times R_1 C$ **OR** $t_1 = 0.41 \times R_1 C$ ✓3 Must see $0.69\ R_1\ C$ for 3 marks. Only award MP3 for $0.69 R_1 C$ if the solution involves a time difference.	3	AO1 AO2 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	Attempt to find usable data from **Figure 9** ✓1 Determine scaling factor **OR** Determine R_1 ✓2 Calculate Q the charge stored at 4 V or the charging time constant **from a valid method** ✓3 Determine C to a value that rounds to 1×10^{-4} (F) to 2 or more sf (expect to see 1.0×10^{-4} F) ✓4 **Method 1 (from area)** ✓1a Attempt at finding area under I–t graph by counting boxes ✓2a 1 cm^2 box corresponds to charge 0.5×10^{-5} C ✓3a Number of 1 cm^2 boxes = 80 (78 to 82) $Q = (80 \times 0.5 \times 10^{-5}) = (3.9 \text{ to } 4.1) \times 10^{-4}$ (C) ✓4a $C = \frac{\text{their } Q}{4}$ = a value that rounds to 1×10^{-4} (F) (≥ 2 sf required) Award **MAX 1** for estimating the average current by sight and using $C = \frac{IT}{V}$.	**Method 2 (from individual data points)** Possible methods are shown but only final answers requested are needed to gain marks. ✓1b Use of a current and voltage across the resistor, e.g. $I = 2.0 \times 10^{-5}$ A and voltage across resistor = 2 V (when capacitor has 4 V) **OR** $I = 6.0 \times 10^{-5}$ A and voltage across resistor = 6 V (when capacitor has 0 V) ✓2b $R_1 = \frac{V}{I} = \frac{2.0}{2.0 \times 10^{-5}}$ **OR** $\left(\frac{V}{I} = \frac{6}{6 \times 10^{-5}}\right) = 1.0 \times 10^5$ (Ω) ✓3b Charging time constant = R_1C Eg using $I = I_0 e^{\frac{-t}{R_1 C}}$ then $R_1 C = \frac{t}{\ln\left(\frac{I_0}{I}\right)}$ Substituting $I = 2 \times 10^{-5}$ A and $I_0 = 6 \times 10^{-5}$ A and $t = 11$ s. OR Graphical method must include evidence from Figure 9 charging time constant $(R_1C) = 10.(0)$ (s) ✓4b $C = \frac{\text{time constant}}{R_1} = \frac{10.0}{1.0 \times 10^5}$ = a value that rounds to 1×10^{-4} (F) (≥ 2 sf required)	4	AO2 ×3 AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	Reading of relevant discharge data from **Figure 10** provided there is an attempt to use data ✓1 A valid substitution of their data into a relevant equation to find R_1 or R_{Total} ✓2 $R_2 = R_{Total} - \text{their } R_1 = 2.0 \times 10^5\ \Omega$ ✓3 allow **one** ecf from either their R_{Total} **or** their R_1 When R_1 is derived in an earlier question accept this value of R_1 and allow ecf for R_{total} When R_1 is derived in this question, allow one ecf from either their R_{total} or their R_1	✓1 From **Figure 10** this can be the time taken for the voltage to fall to half its value. ✓2 Finding R_{Total} from **Figure 10** 4.0 V to 2.0 V in $(32 - 11)$ s using $t_{\frac{1}{2}} = 0.69RC$ allow $= 0.7RC$ $R_{Total} = 3.0 \times 10^5\ \Omega$ Finding R_1 from **Figure 9** 6.0 A to 3.0 A in 6.8 s using $t_{\frac{1}{2}} = 0.69RC$ allow $= 0.7RC$ $R_1 = 1.0 \times 10^5\ \Omega$ **OR** Using $I = I_o e^{\frac{-t}{R_1 C}}$ for example, with $I = 2 \times 10^{-5}$ A and $I_o = 6 \times 10^{-5}$ A and $t = 11$ s Note R_1 may be taken from **05.2** and not use the graph information.	3	AO3 ×3

Total			10

20

Question	Answers	Additional comments/Guidelines	Mark	AO

02.1		surface Accept “angle of incidence is 0”.	1

02.2	Treat each point independently. Prism material/it has/they have same refractive index / optical density as windscreen ✓ Prism fitted to windscreen without gaps ✓	 Condone ‘it has’ or ‘they have’ or just ‘same’ Allow “no change of speed between prism and windscreen” Allow “made from same material” Do not allow “same refractive index between them” Treat “monochromatic” as neutral Allow “contact between prism and windscreen is clean” etc. Allow “touching the windscreen” Condone suggestion that any bonding material has same refractive index (as prism and windscreen). Do not accept ‘no boundary’	2

02.3	C = arcsin (1/1.52) = arcsin (0.66) = 41(.1)° ✓ 45° > critical angle / 41.1° resulting in total internal reflection / tir (at each boundary) ✓	The first mark is for the calculation. The second is for the discussion but is contingent on obtaining a value for C. Ecf for any C < 45°	2

		Accept clear reference to angle at point A in place of 45° statement. Do not allow “angle of incidence> critical angle” on its own.	
02.4	Calculation of critical angle at glass–water boundary (61.0^{o}) OR Calculation of possible *n* from glass to water (0.707) or absolute *n* for glass (1.88) OR Calculation of angle of refraction in water (53.9°) ✓ So total internal reflection no longer takes place **OR** some light escapes/refracts (into water) / less light reflects ✓ (Less light stays within windscreen so less light detected at sensor)	Do not allow suggestion that TIR occurs at critical angle/when angle of incidence=critical angle. Do not allow “ray/all the light escapes/refracts” or “no light reflects” or ”less TIR”. Do not condone “total internal refraction/diffraction”	2
02.5	Statement of effect of change in *n* on the path direction ✓ (Sensible reference to the variation of a few per cent) leads to the idea that change is unlikely to be significant ✓	Eg for MP1 • Light may change direction inside windscreen • Light may change direction at a windscreen boundary Eg for MP2 • Variation too small to deviate significantly within windscreen – internal effect • Variation too small to affect tir at A without	Max 2

			droplet – boundary effect • Variation too small to significantly affect transmission at A with droplet – boundary effect Allow discussions that *may* cause a difference, eg there is a summative effect from multiple reflections etc	

02.6	**More sensitive because** more likely to encounter/detect water drop OR will encounter more water drops ✓ bigger decrease in light intensity, so more sensitive to rain ✓ **Less sensitive because** more likely to encounter imperfections in glass/on surface of glass /dirt on surface of glass ✓ any curvature effects will be greater so may not hit detector ✓ light intensity reduced without presence of water / greater absorption in windscreen due to greater path length ✓	Allow any 2 comments taken from list . There must be a sense of whether the comment relates to an improvement or decrease in sensitivity. Treat as list; mark 1 and 2 independently. Allow idea of larger area Do not allow a response that discusses travel time of ray.	Max 2
Total			**11**

Question	Answers	Additional Comments/Guidelines	Mark
	Central maximum with lower intensity maxima (either side) ✓ Central maximum is twice as wide/wider than other maxima ✓	MP1 is for comparison of intensity. Condone references to brightness/dimness. MP2 is for comparison of width Award credit for a drawn answer eg on Fig 3.	

03.1	$238 \times 1.661 \times 10^{-27}$ or 3.953×10^{-25} seen OR their mass $\times 3.23 \times 10^{24}$ ✓ 1.28 (kg) ✓ **Alternative method`** $n = \frac{3.23 \times 10^{24}}{6.02 \times 10^{23}}$ or 5.37 mol seen OR their number of moles × 238 ✓ 1.28 (kg) ✓	Allow use of 1.67×10^{-27} kg Allow inclusion of electron masses. Allow use of 1.673×10^{-27} and 1.675×10^{-27} leading to 1.29	2	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
03.2	$A_0\ (=\lambda N) = 8.11 \times 10^{14}$ (Bq) ✓ Any **three** from: ✓✓✓ • dividing an output power / A / N / m by 0.0458 or multiplying an input power / α energy / A_0 / N_0 / m_0 by 0.0458 • Use of $A = \frac{\text{any power}}{8.94\times10^{-13}}$ or $\frac{\text{any power}}{8.94\times10^{-13}\times0.0458}$ to calculate P or A • use of $t = \frac{\ln\left(\frac{A}{A_0}\right)}{-\lambda}$ or $t = \frac{\ln\left(\frac{N}{N_0}\right)}{-\lambda}$ or $t = \frac{\ln\left(\frac{m}{m_0}\right)}{-\lambda}$ or $t = \frac{\ln\left(\frac{P}{P_0}\right)}{-\lambda}$ • convert time to years (divide a time by $365 \times 24 \times 60 \times 60$) or decay constant to yr^{-1}. Time = 14.5 (Earth years) ✓	Condone small rounding errors. $\frac{29.6}{0.0458} = 646$ W $\frac{646}{8.94\times10^{-13}} = 7.23\times10^{14}$ Bq $t = \frac{\ln\frac{7.23}{8.11}}{-2.51\times10^{-10}} = 4.58\times10^{8}$ s Allow use of $0.5^{\frac{t}{t_{0.5}}}$ **and** $t_{0.5} = \frac{\ln 2}{\lambda}$ instead of $e^{-\lambda t}$. Allow conversion of half-life to years. Allow ecf for their A_0 Accept answers that round to 14 or 15 years based on working seen. Missing efficiency results in 404 y.	5	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
03.3	Any **three** from: ✓✓✓ • valid $Q = mc\Delta\theta$ substitution or answer • valid $Q = mL$ substitution or answer • 3 valid Q calculations • energy provided by laser between charges $(= 1000 \times 3) = 3000$ (J) OR a valid power calculation for their Q Total energy required $= 2900$ (J) < 3000 (J) so yes ✓	Ignore PoT in bullet points Heat ice to 0.0 °C: $10^{-3} \times 2100 \times 25 = 52.5$ J Melt ice at 0.0 °C: $10^{-3} \times 334 \times 10^{3} = 334$ J Vaporise water at 0.0 °C: $10^{-3} \times 2500 \times 10^{3} = 2500$ J Allow $(L_f + L_v)$ in $Q = mL$ as two calculations. Allow any correct comparison for MP4 e.g. Energy required 2887 < 3000 J Powers 962 < 1000 W Mass of ice 0.00104 > 0.001 kg time 2.8865 < 3 s Δθ 79.0 > 25 K Allow other valid comparisons.	4	AO3
Total			**11**	

Question	Answers	Additional comments/Guidance	Mark	AO

01.1	(correct Δv and Δt) and answer in range (-)2.5 to (-)2.9 ($m\ s^{-2}$) ✓ Use of $F = ma$ using their a with answer i.e Force =1. 8 x 10^4 x their a from an attempt at a tangent or trying to use *suvat* equation✓	$-15/5.5 = 2.7(3)$ $m\ s^{-2}$ Allow if answer rounds to these values answers from best attempts at tangent in range 4.7 to 4.9 x 10^4 N	
01.2	Attempt to estimate area under the graph. ✓ Correct square count 21 to 23 10 mm squares (525-575 small squares) **OR** distance per square = 2.5 m or 0.1 m✓ Value in range 50 m to 60 m **and conclusion** that escape lane would be long enough✓	Use of *suvat* equation = 0 For attempt to find area using trapezium rule expect use of 1 s intervals for this mark.	1 1 1

7

01.3	KE of lorry : to KE of gravel (as it is pushed aside/moved)✓ OR PE of gravel (as it may be ejected upwards)✓ transfer to thermal energy /internal energy/heating of gravel /ground/lorry **OR** work done on the gravel/vehicle increasing internal energy/raising temperature✓	Ignore losses due to friction Not KE of the ground Must refer to what is heated	Max 2 1 1

1.4	Appreciates that KE converted into PE or May be stated or by attempt to use of $mgh = ½ mv^2$ or Calculates initial KE of lorry $\frac{1}{2}1.8 \times 10^4 \times 17.5^2 = 2.76 \times 10^6$ (J) ✓		1
	Height needed in escape lane $= 2.76 \times 10^6/(1.8 \times 10^4 \times 9.81) = 15.6$ m or Length of lane required $=15.6/\sin 25 = 37$ m **(**compare with 85 m) or vertical height of ramp = 35.9 m (compare with height needed 15.6 m) or maximum change in PE possible = 85 sin 25 x 9.81 x 1,8 x 10^4= 6.3 x 10^6 (J) (compare with initial KE) ✓	Allow max 2 if height = 85 tan 25 or length of lane = 15.6/tan 25 i.e allow these incorrect values when drawing conclusion	1
	Comparison and conclusion that escape lane would be long enough.This must follow from correct working✓		1
	Deceleration produced by slope = 9.8(1) sin 25 or 4.15 (4.1 or 4.2) m s^{-2} seen✓		
	Distance to stop from $v^2 = 2as$ give s = 37 m (compare with 85 m)✓ Or Minimum deceleration needed = $17.5^2/2 \times 85 = 1.8$ m s^{-2} (compare with 4.15 m s^{-2})	Arriving at 37 m gets first two marks	

	Comparison and conclusion that escape lane would be long enough This must follow from correct working✓		

01.5	The straight road of uniform gradient because: The deceleration (condone acceleration) is uniform ✓ with the gravel the initial deceleration is larger/may vary ✓ Travelling through gravel could make the vehicle unstable/bounce erratically(owtte) ✓ Gravel because: On the ramp the lorry would roll backwards after stopping (as it has no brakes)	Do not allow deceleration less when on gravel(It is greater initially) Do not allow answers that (average) force using gravel lane is less than decelerating force on the ramp (due to increased stopping distance or stopping time) Or because stopping time is longer	Max 1
Total			**12**

	Clear indication of correct process two correct values for λv from working plus conclusion (7.35; 7.25; 7.35)✓	Condone no or misuse of powers of 10 Allow use of v alue of *h* as the constant to show that v values in table are consistent with the λ values	1 1	

04.1	moment (of weight of the box) ✓ Links pivot position to a consideration of moments ✓	Award 2 for 1.25 x weight of beam = 1.5 x weight of empty box Confusion of moments with eg work done/forces = max 1	2
04.2	Clockwise moment = $610 \times 9.81 \times 1.5$ (= 8976 N m) ✓ Anticlockwise moment = $250 \times 4 + T \sin 50 \times 4.0$ (N m)✓ Use of clockwise = anticlockwise✓ Use of T sin 50° seen / relates vertical component to tension✓ T (= 1994/sin 50°) = 2600 (N)✓	Credit any evidence to work out a moment with one mark Condone cos 50 in MP2. Allow ecf for clockwise moment Allow ecf for anticlockwise moment Use of g = 10 N kg^{-1} gives 2990 N Omission of 4.0 m (g = 9.8) gives 10410 N. Use of cos 50 (g = 9.8) gives 3100 N	5

		Allow max 4 for use of g = 10 N kg^{-1}.	

04.3	$7.5 = ½\ g\ t^2$ ✓ (t = 1.2 s) (calculate distance) s (= ut = 18 × 1.2) = 22 (m)✓	Allow ecf from incorrect t for MP2	2

04.4	**(Range will be greater:)** component of velocity upwards ✓ rock will spend longer in the air ✓ greater *t* ✓ ***therefore*** the range is greater ✓ **OR** **(Range will be smaller)** Counterweight will fall less far before projectile released ✓ Less energy transferred to rock ✓ Initial speed of rock less/horizontal velocity reduced ✓ ***therefore*** the range is smaller ✓ **OR** (balanced arguments) ***therefore*** the range is unchanged / answer is indeterminate✓	Candidates can argue from both lists to reach a balanced view suggesting that there is no change. Full credit can be obtained from 2 deductions from one list ✓✓+ consistent conclusion✓ 1 deduction from each list ✓✓+ consistent conclusion ✓ Do not allow an unsupported conclusion. Conclusion must be consistent with **correct** statements. Treat incorrect statements as neutral. Do not reward arguments based on a longer time of flight.	Max 3
Total			12

Question	Answers	Additional Comments/Guidelines	Mark
	Conversion of 110 km h^{-1} to 31 m s^{-1} ✓ = ½ × 1.5 × 10^3 × *their conversion*^{2} with a consistent answer✓	Allow ecf for incorrect or failure to carry out speed conversion Expect answer to be calculated correctly and to 2+	

05.1	horizontal velocity = $20\cos 40° = 15.3$ ✓(m s^{-1}) horizontal velocity (is constant) / minimum when vertical velocity = 0 ✓	Needs minimum 3 sf For MP1 it must be clear that the horizontal velocity has been determined.	2	AO2 L2 Maths 1

Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	(vertical velocity) $v = 20\sin 40°$ $(= 12.9)$ ✓ (m s^{-1}) $s = ut + \frac{1}{2}at^2$ $-3 = -12.9t + \frac{1}{2} \times 9.81t^2$ or $3 = 12.9t - \frac{1}{2} \times 9.81t^2$✓ $(4.91t^2 - 12.9t + 3.00 = 0)$	For second mark both suvat equation and substitution must be shown. Equation may be rearranged before substitution	2	AO1 AO2 L2 Maths 2

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	Use of quadratic formulae with $+$, $-$ or $\pm$ ✓ 0.258 s and 2.37 s✓ Time to reach 3 m once on the way up and once on the way down (OWTTE)✓ Larger value ✓	eg $t = \frac{12.9 \pm \sqrt{(-12.9)^2 - 4 \times 4.91 \times 3.00}}{2 \times 4.91}$ Two correct answers alone scores first 2 marks. ecf available for last 2 marks	4	AO1 AO1 L2 Maths 2 AO2 AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	$s = vt = 20 \cos 40° \times 2.37 = 36.3$ m so no✓	ecf from **05.3** Calculation must be seen	1	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
05.5	Gradient is the acceleration **AND** area under graph = <u>vertical</u> distance travelled ✓1 Without air resistance: comment about gradient ✓2 comment about area ✓3 With air resistance comment about gradient ✓4 comment about area ✓5	For each comment on the graph a reason must be given not just a description. e.g for ✓2 • constant gradient = g or $9.81\ \text{m s}^{-1}$ e.g. for ✓4 • initially steeper gradient since air resistance in same direction as weight (so $a > g$) • when line crosses time axis, gradient = g /9.81 / gradient without air resistance as air resistance = 0 when $v = 0$ / • After crossing time axis, gradient decreases as air resistance increases with speed E.g. for ✓3 or ✓5 • total area under graph = 0 since ball starts and finishes on ground • area between graph and axis is max height/**vertical** distance • without air resistance reaches a higher height as area greater statement referring to area under both graphs gains ✓3 and ✓5	5	AO1 AO2 AO2 AO3 AO3
Total			**14**	

Question	Answers	Additional comments/Guidelines	Mark	AO