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AQA A LEVEL PHYSICS (7408): QUESTIONS BY TOPIC

Measurements and their errors (3.1)

A Level Physics (7408) · Section 3.1

28 questions · 263 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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QUESTIONS

28 questions · 263 marks · 4 sub-topics



SUB-TOPIC 3.1.1

USE OF SI UNITS AND THEIR PREFIXES

Sub-topic 3.1.1 · 4 questions · 12 marks · lowest tariff first



06

Mechanical power

[1 mark]**A** is a vector quantity.☐**B** is measured in J.☐**C** has base units of $\text{kg m}^2 \text{s}^{-3}$.☐**D** can be calculated from force $\times$ distance moved.☐

07Which two quantities have the base unit $\text{kg m}^2 \text{s}^{-2}$?**[1 mark]****A** kinetic energy and momentum☐**B** kinetic energy and Young modulus☐**C** work done and the moment of a couple☐**D** work done and pressure☐

08

Which gives SI prefixes in descending order of magnitude?

[1 mark]**A** G p m☐**B** M G n☐**C** m n μ ☐**D** m μ p☐

0 4 . 1

Explain why the Young modulus and the breaking stress of a wire have the same SI unit.

[1 mark]

Table 1 contains data about four metal wires **W**, **X**, **Y** and **Z**.

Table 1

Wire	Length / m	Diameter / mm	Stiffness / N m^{-1}	Density / kg m^{-3}
W	3.10	1.7	4.90×10^4	2.71×10^3
X	2.17	1.4	5.25×10^4	1.93×10^4
Y	2.50	1.2	5.25×10^4	8.91×10^3
Z	2.50	1.2	3.08×10^4	2.71×10^3

0 4 . 2

The metal used to make wire **X** costs £75 per gram.

Calculate, in £, the cost of wire **X**.

[3 marks]

cost = £ _____

0 4 . 3

State and explain which of the wires in **Table 1** are made from the same material.

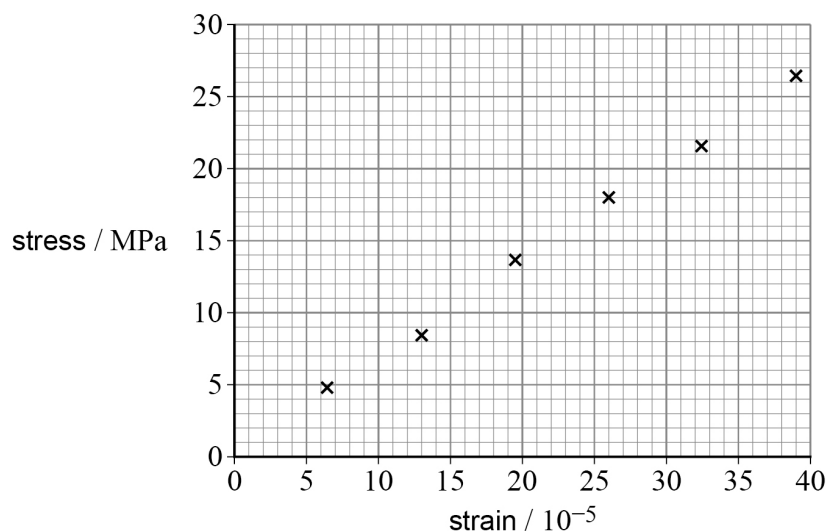
[1 mark]



0 4 . 4

One of the wires in **Table 1** was used to obtain the stress–strain data shown in **Figure 5**.

Figure 5



Draw a line of best fit on **Figure 5**.

Go on to deduce, using your line of best fit and **Table 1**, whether wire **W** could have been used to produce **Figure 5**.

[4 marks]

SUB-TOPIC 3.1.2

LIMITATION OF PHYSICAL MEASUREMENTS: ERRORS AND UNCERTAINTIES

Sub-topic 3.1.2 · 9 questions · 109 marks · lowest tariff first



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

☐☐☐☐

10

10



0 1

A room contains dry air at a temperature of $20.0\text{ }^{\circ}\text{C}$ and a pressure of 105 kPa .

0 1 . 1

Show that the amount of air in each cubic metre is about 40 mol .

[1 mark]**0 1 . 2**

The density of the dry air is 1.25 kg m^{-3} .

Calculate c_{rms} for the air molecules.

Give your answer to an appropriate number of significant figures.

[3 marks]

$$c_{\text{rms}} = \text{_____} \text{ m s}^{-1}$$

0 1 . 3

Calculate, in K, the change of temperature that will double c_{rms} for the air molecules.

[2 marks]

$$\text{change of temperature} = \text{_____} \text{ K}$$



01.4

A room contains moist air at a temperature of 20 °C.
A dehumidifier cools and then condenses water vapour from the moist air.
The final temperature of the liquid water that collects in the dehumidifier is 10 °C.
Drier air leaves the dehumidifier at a temperature of 20 °C.

Table 1 compares the air flowing into and out from the dehumidifier.

Table 1

	mass of water mass of air
moist air flowing in	0.0057
drier air flowing out	0.0037

In one hour, a volume of 960 m³ of air flows through the dehumidifier.
Assume that the density of the air remains constant at 1.25 kg m⁻³.

Determine how much heat energy is removed in one hour from the water vapour by the dehumidifier.

specific heat capacity of water vapour = 1860 J kg⁻¹ K⁻¹
specific latent heat of vaporisation of water = 2.3 × 10⁶ J kg⁻¹

[3 marks]

heat energy removed = _____ J

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

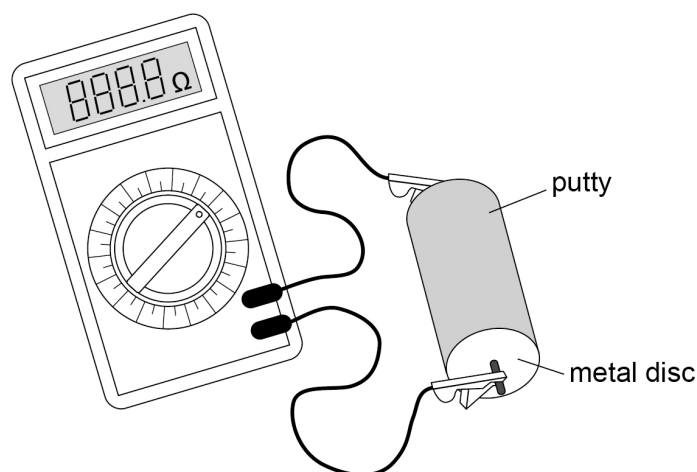


0 3 . 4 A student is given some putty to form into cylinders.

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 $5.83 \times 10^{-5} \text{ m}^3$.

The length L and resistance R are measured for each cylinder.

It can be shown that $R = \frac{\rho L^2}{5.83 \times 10^{-5}}$ 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]

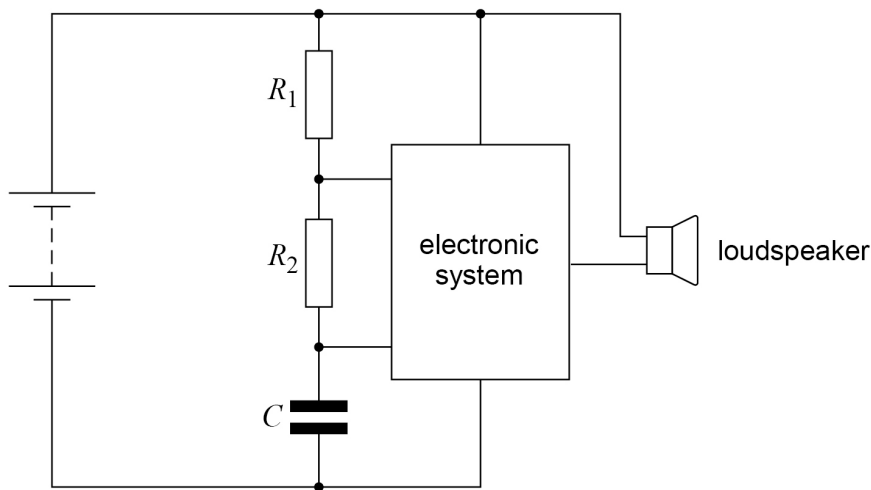
$\rho =$ _____ unit = _____

Figure 8

02

Figure 3 shows a circuit that causes a loudspeaker to emit ‘clicks’ at a constant rate. The time T between successive clicks depends on the resistances R_1 and R_2 and the capacitance C . You do not need to know any details about the electronic system.

Figure 3



A student uses a stopwatch to determine T . **Table 1** shows the student’s repeated measurements of $20T$.

Table 1

$20T / \text{s}$	$20T / \text{s}$	$20T / \text{s}$	$20T / \text{s}$	$20T / \text{s}$
19.22	18.91	19.36	19.04	19.45



0 2 . 1 Suggest why the student measures $20T$.

[1 mark]

0 2 . 2 Suggest why the student repeats their measurements of $20T$.

[1 mark]

0 2 . 3 Determine the percentage uncertainty in the student's result for T .
Assume that all the data in **Table 1** are valid.

[2 marks]

percentage uncertainty in $T =$ _____ %

Question 2 continues on the next page

The student determines T for different values of R_2 .

The values of R_1 and C are not changed.

The student produces the graph in **Figure 4**.

Figure 4



0 2 . 4 It can be shown that

$$T = (R_1 + 2R_2)C \ln 2$$

Determine C and R_1 .

[5 marks]

$$C = \text{_____ F}$$

$$R_1 = \text{_____ } \Omega$$

Question 2 continues on the next page



0	2	.	5
---	---	---	---

The student has access to a range of fixed and variable resistors.
The student wants to modify the circuit in **Figure 3** so that T can be varied continuously from a minimum of 0.70 s to a maximum of 1.25 s.

Show how the student can achieve this by combining two resistors to make R_2 .
You should use information from **Figure 4**.

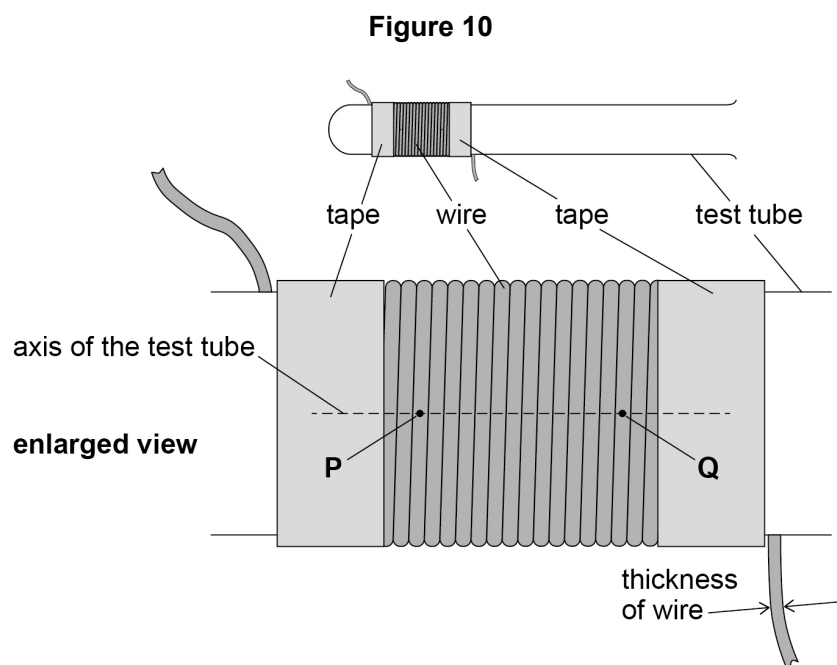
[3 marks]



0 4

This question is about the vertical oscillations of a test tube in a liquid.

Figure 10 shows some wire wound tightly around a test tube. The ends of the wire are secured with tape.



P and **Q** are points marked on the wire, as shown in the enlarged view in **Figure 10**. A travelling microscope with a vernier scale is used to measure the distance between **P** and **Q**.

The microscope reading at **P** is 9.26 mm.

Figure 11 shows the microscope reading at **Q**.

Figure 11

0	4	.	1
---	---	---	---

Show that the wire has a thickness of approximately 1.2 mm.

[2 marks]

0	4	.	2
---	---	---	---

The external diameter of the test tube is 18.0 mm.

Deduce the length of wire between **P** and **Q**.

[3 marks]

length of wire = _____ mm

Question 4 continues on the next page

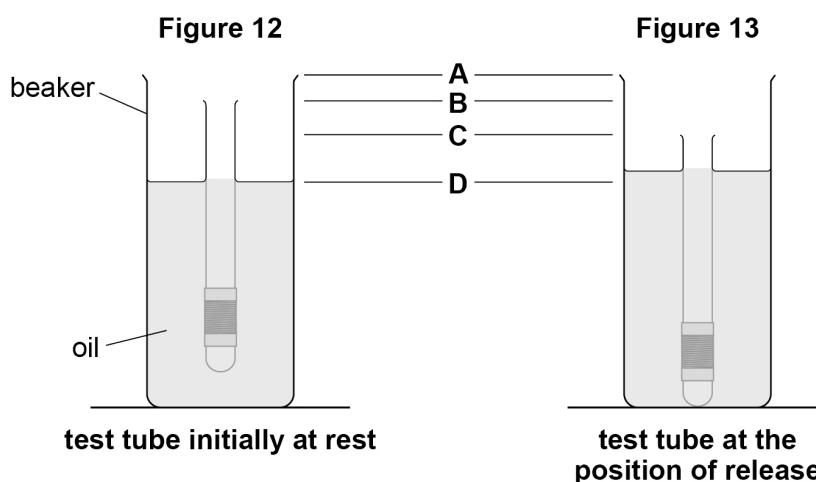


A student investigates vertical oscillations of the test tube in a liquid.

Figure 12 shows the test tube and wire floating at rest in a beaker of dark-coloured oil.

The part of the test tube below the surface cannot be seen clearly through the oil.

The test tube is then pushed downwards as far as possible, as shown in **Figure 13**.



The test tube is now released from the position shown in **Figure 13**.

The test tube oscillates vertically with simple harmonic motion of period T .

0 4 . 3

A horizontal fiducial mark is used to reduce uncertainty in the measurement of T . The fiducial mark is to be placed level with one of the positions **A**, **B**, **C** or **D** shown in **Figures 12** and **13**.

Identify the correct position for the fiducial mark.

Go on to explain why you chose this position.

[2 marks]

position = _____

0 4 . 4 When the total mass of the test tube, wire and tape is constant, it can be shown that:

$$T \propto \frac{1}{\sqrt{\text{density of the liquid}}}$$

When the test tube oscillates in the oil, T is 0.587 s.
The density of the oil is $8.49 \times 10^2 \text{ kg m}^{-3}$.

The test tube is cleaned and placed in an identical beaker containing milk.
When the test tube oscillates in the milk, T is 0.534 s.

Determine the density of the milk.

[2 marks]

density = _____ kg m^{-3}

0 4 . 5 Due to damping, only a small number of oscillations occurs after the test tube is released.

The student wants to produce a greater number of oscillations for a particular liquid **without** changing T .

State and explain **two** ways in which the apparatus can be modified to achieve this.

[3 marks]

1 _____

2 _____

END OF QUESTIONS

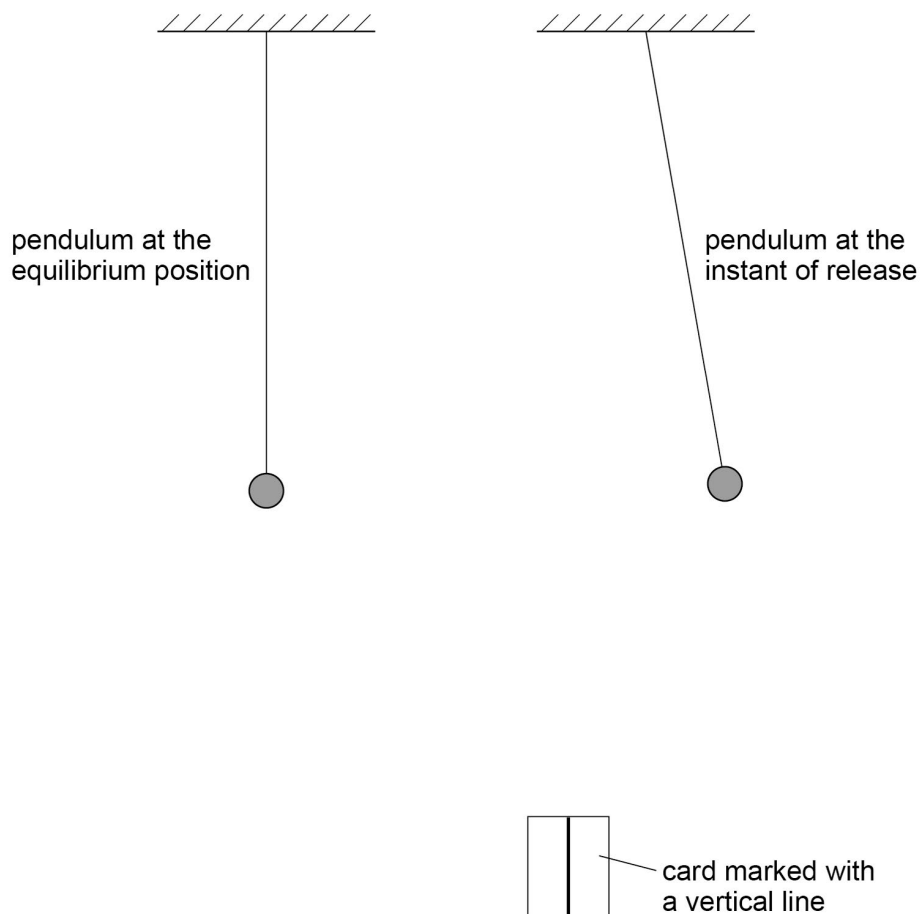


0	1
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A simple pendulum performs oscillations of period T in a vertical plane.

Figure 1 shows views of the pendulum at the equilibrium position and at the instant of release. **Figure 1** also shows a rectangular card marked with a vertical line.

Figure 1



0	1	.	1
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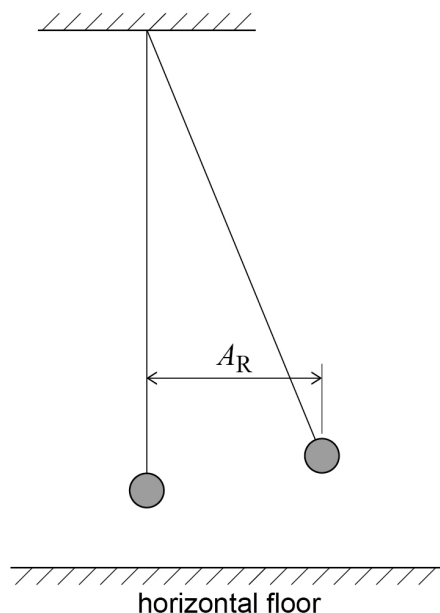
The card can be used as a fiducial mark to reduce uncertainty in the measurement of T .

Annotate **Figure 1** to show a suitable position for the fiducial mark.
Explain why you chose this position.

[2 marks]

0 1 . 2

The period of the pendulum is constant for small-amplitude oscillations. **Figure 2** shows an arrangement used to determine the maximum amplitude that can be considered to be small, by investigating how T varies with amplitude.

Figure 2

Describe a suitable procedure to determine A_R , the amplitude of the pendulum as it is released.

You may add detail to **Figure 2** to illustrate your answer.

[2 marks]

Question 1 continues on the next page

0 1 . 3

Figure 3 shows some of the results of the experiment.

Figure 3

Estimate, using **Figure 3**, the expected percentage increase in T when A_R increases from 0.35 m to 0.70 m.
Show your working.

[3 marks]

percentage increase = _____ %

Question 1 continues on the next page



In another experiment the pendulum is released from a fixed amplitude.
The amplitudes A_n of successive oscillations are recorded, where $n = 1, 2, 3, 4, 5 \dots$.

Table 1 shows six sets of readings for the amplitude A_5 .

Table 1

A_5 / m	0.217	0.247	0.225	0.223	0.218	0.224
------------------	-------	-------	-------	-------	-------	-------

0 1 . 4

Determine the result that should be recorded for A_5 .
Go on to calculate the percentage uncertainty in this result.

[3 marks]

$A_5 =$ _____ m

percentage uncertainty = _____ %

0 1 . 5

Table 2 shows results for A_n and the corresponding value of $\ln(A_n / \text{m})$ for certain values of n .

Table 2

n	A_n / m	$\ln(A_n / \text{m})$
2	0.238	-1.435
4	0.225	
7	0.212	-1.551
10	0.194	-1.640
13	0.183	-1.698

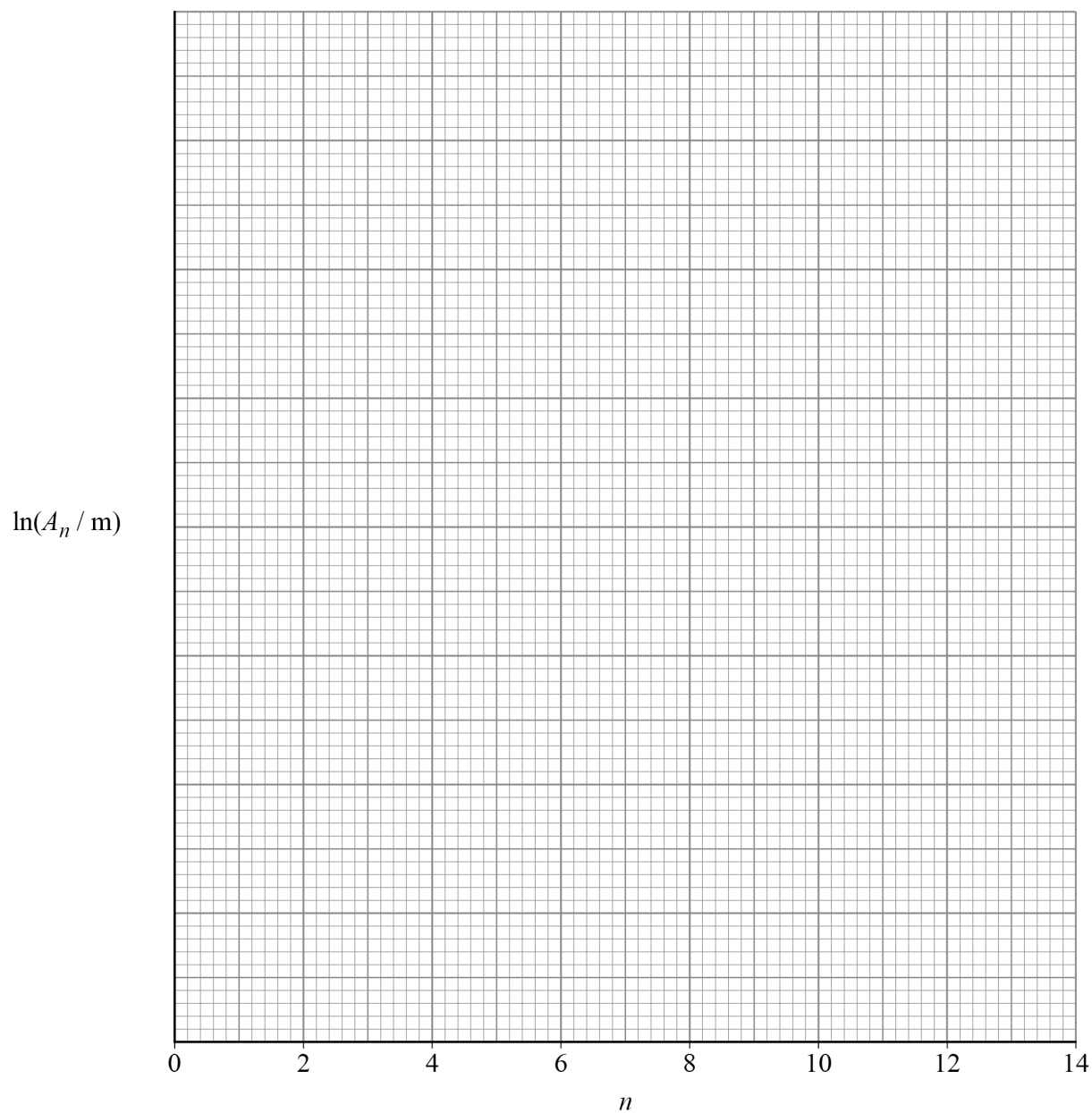
Complete **Table 2**.

[1 mark]

0 1 . 6 Plot on **Figure 4** a graph of $\ln(A_n / \text{m})$ against n .

[2 marks]

Figure 4



Question 1 continues on the next page

0 1 . 7 It can be shown that

$$A_n = A_0 \delta^{-n}$$

where A_0 is the amplitude of release of the pendulum
 δ is a constant called the damping factor.

Explain how to find δ from your graph.
You are **not** required to determine δ .

[2 marks]



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

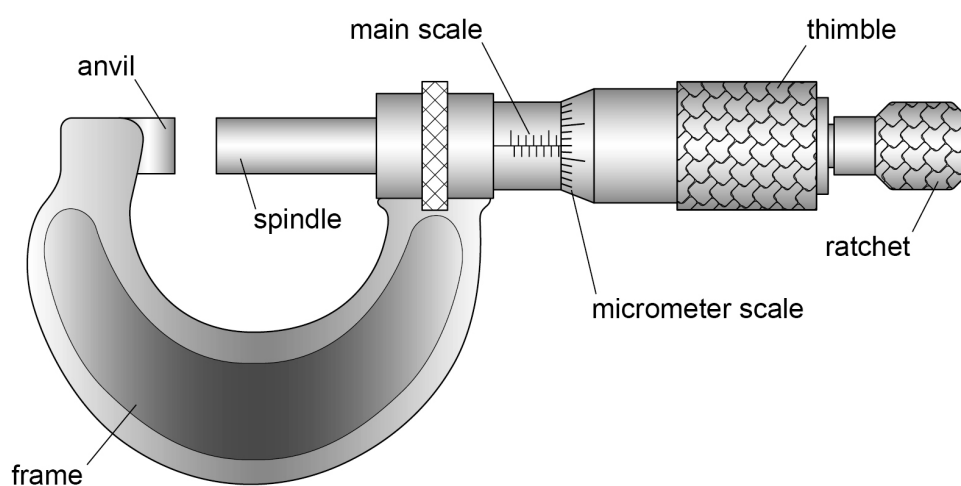


Figure 2 shows an enlarged view of the scales.

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**.

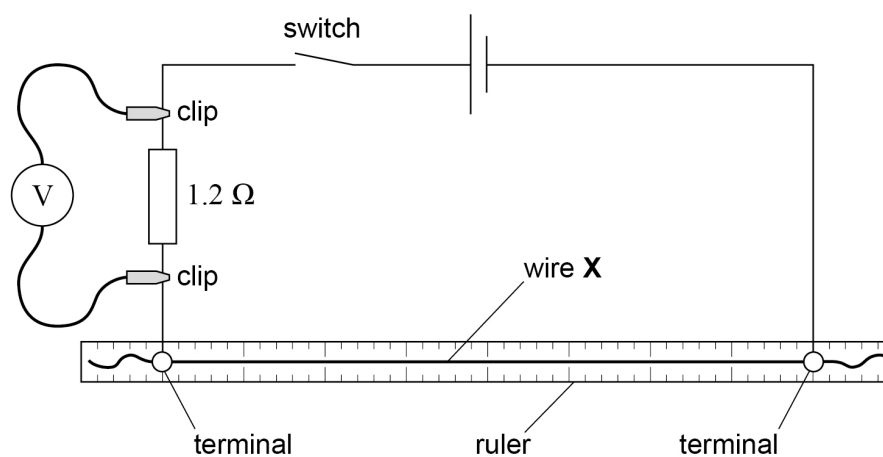
[1 mark]

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 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 mV.

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

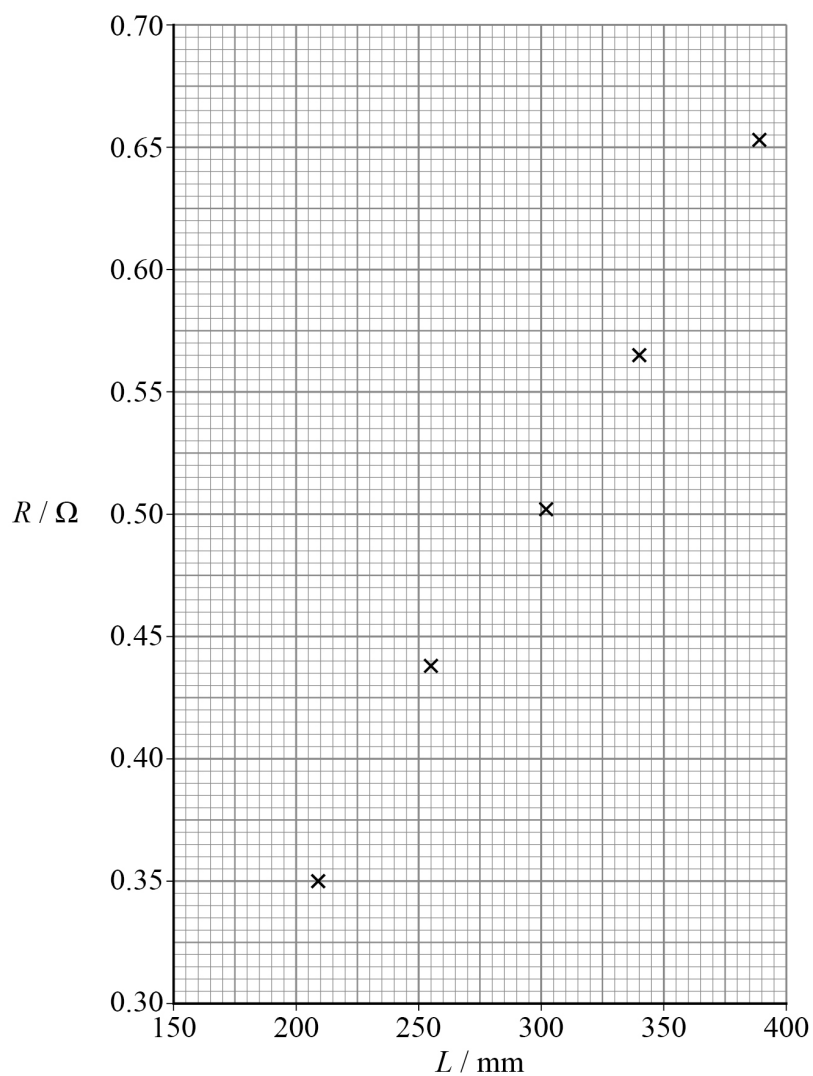
[2 marks]

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 = _____ $\Omega \text{ m}^{-1}$



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 / $\Omega \text{ m}^{-1}$			
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]

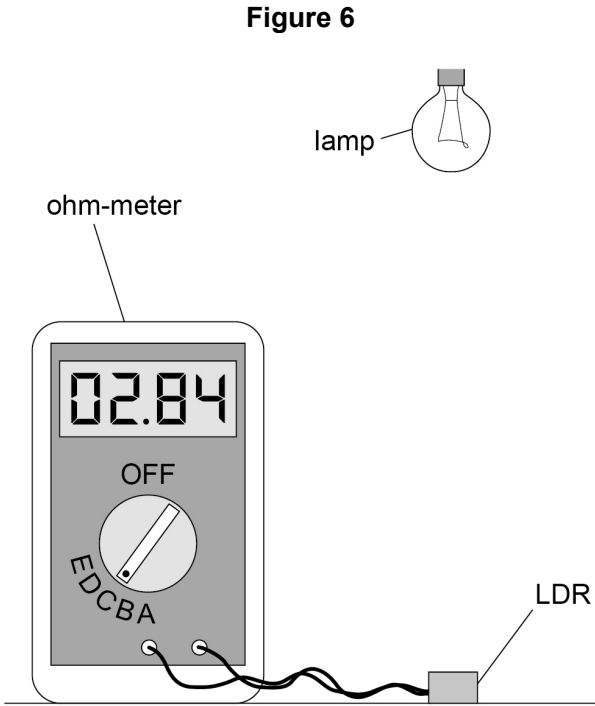
0 1 . 8 Outline how error bars are used to determine the uncertainty in the gradient of a linear graph.

[2 marks]



02

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



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	$\text{k}\Omega$
range D	199.9	000.1	$\text{k}\Omega$
range E	1.999	0.001	$\text{M}\Omega$

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 $E_V = 130 \text{ lx}$.

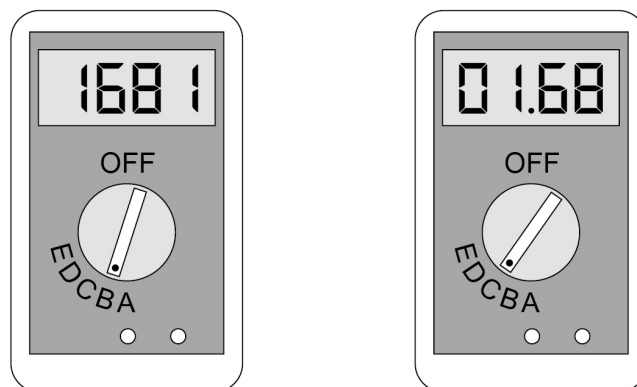
[2 marks]

$x =$ _____ 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 $\pm 2\%$ 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]

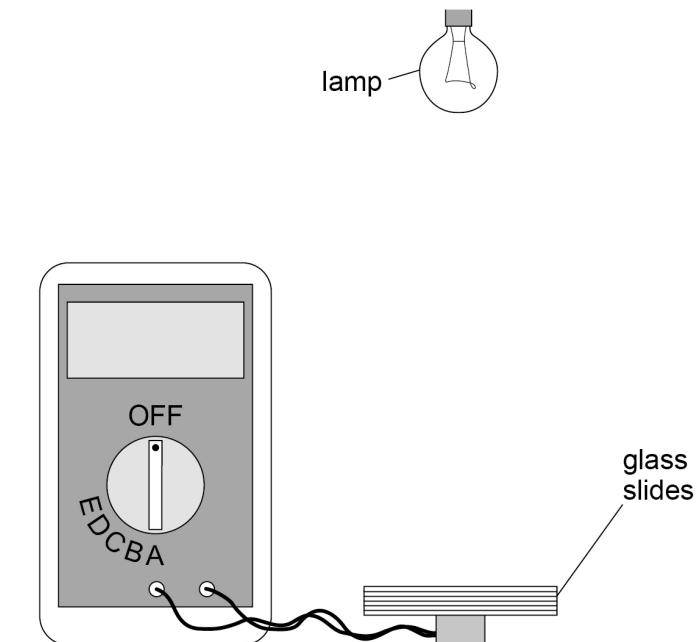
Table 3

Setting	Minimum R	Maximum R
range B	_____ Ω	1717 Ω
range C	1.63 k Ω	_____ k Ω

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 = _____



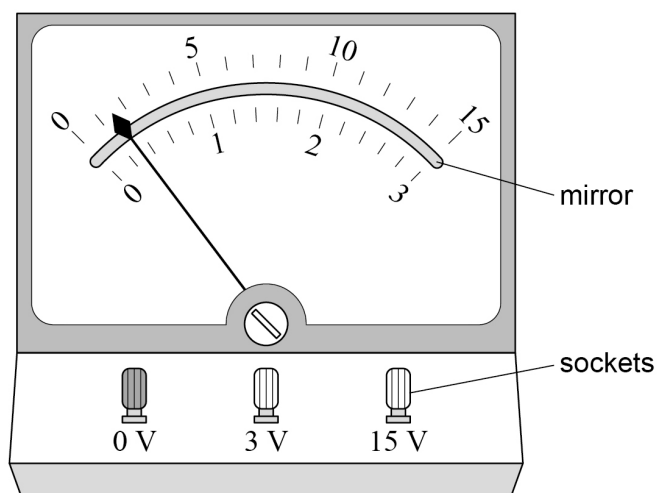
0 3

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

☐

03.2

Explain the use of the mirror when reading the meter.

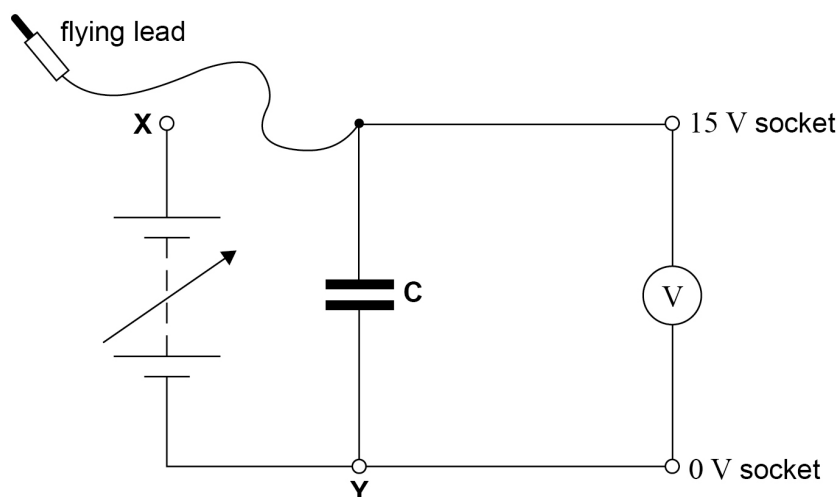
[2 marks]

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 $T_{1/2}$ 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

$T_{1/2} / \text{s}$	12.00	11.94	12.06	12.04	12.16
----------------------	-------	-------	-------	-------	-------

03.3 Determine the percentage uncertainty in $T_{\frac{1}{2}}$.

[2 marks]

percentage uncertainty = _____ %

03.4 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 V range.
She expects $T_{1/2}$ to be about 2.5 s.

Explain:

- what the student should do, before connecting capacitor **C** to the 0 V and 3 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 $820\ \mu\text{F}$ 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



03.7

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

[3 marks]

03.8

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

[2 marks]

current = _____ A

END OF QUESTIONS



SUB-TOPIC 3.1.3

ESTIMATION OF PHYSICAL QUANTITIES

Sub-topic 3.1.3 · 1 question · 1 marks · lowest tariff first



2 2

An asteroid has a mass of 2×10^{17} kg and an escape velocity of 40 m s^{-1} .

What is the order of magnitude of the radius of the asteroid?

[1 mark]**A** 10^3 m ☐**B** 10^4 m ☐**C** 10^5 m ☐**D** 10^6 m ☐

SUB-TOPIC 3.1.4

PRACTICAL SKILLS, GRAPHS AND DATA ANALYSIS

Sub-topic 3.1.4 · 14 questions · 141 marks · lowest tariff first

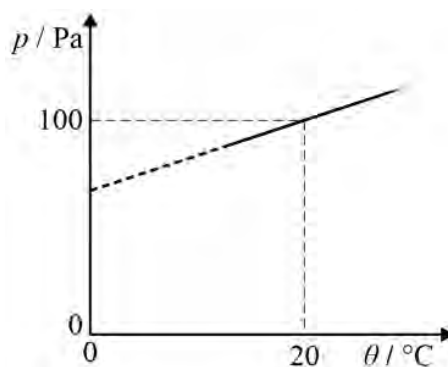


0 8

The graph shows the variation of pressure p with temperature θ for a fixed mass of an ideal gas at constant volume.

What is the gradient of the graph?

[1 mark]



A 0.341

☐

B 0.395

☐

C 2.93

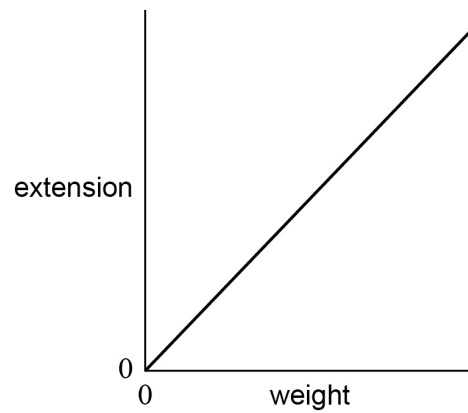
☐

D 5.00

☐

2 6

An experiment is carried out to determine the Young modulus E of steel using a vertical wire of initial length L and cross-sectional area A . Various weights are suspended from the wire. A graph of extension against weight is plotted.



What does the gradient of the graph represent?

[1 mark]

A E

☐

B $\frac{1}{E}$

☐

C $\frac{EA}{L}$

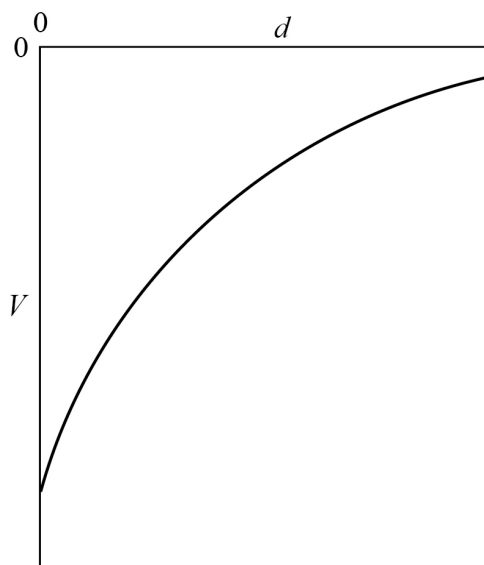
☐

D $\frac{L}{EA}$

☐

1 2

The graph shows how the gravitational potential V varies with the vertical distance d from the surface of the Earth.



What does the gradient of the graph represent at the surface of the Earth?

[1 mark]

A potential energy

☐

B mass of the Earth

☐

C magnitude of the gravitational constant

☐

D magnitude of the gravitational field strength

☐

1 9

An object is moving in a straight line. A graph is plotted to show the variation of the momentum of the object with time.

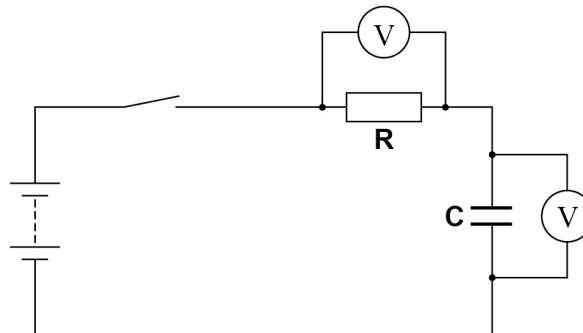
Which quantities can be calculated from the gradient of the graph and the area under the graph?

[1 mark]

	Gradient of graph	Area under graph	
A	power	mass $\times$ displacement	☐
B	force	work done $\times$ time	☐
C	power	work done $\times$ time	☐
D	force	mass $\times$ displacement	☐

0 2

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

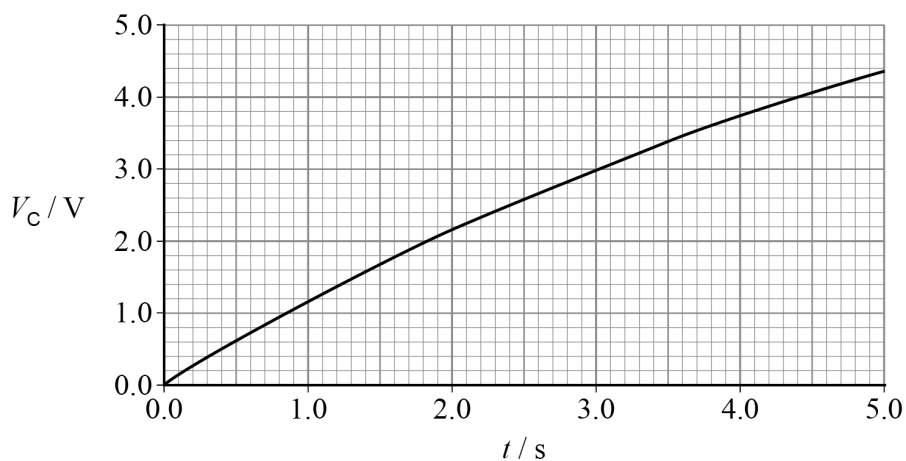
Figure 1

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.

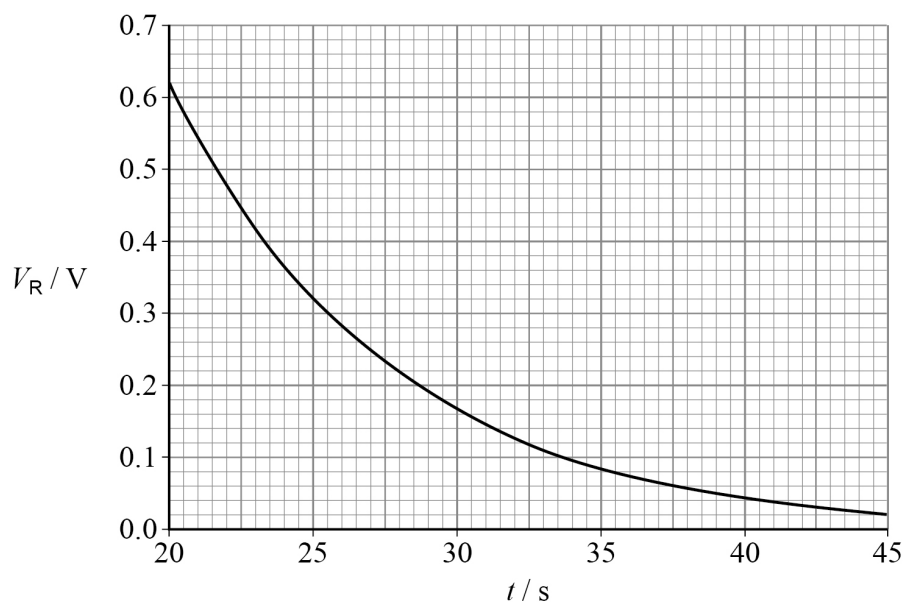
[2 marks]

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 $31.0 \mu\text{F}$.

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 C_1 and C_2 in a circuit. A dielectric fills the space between the plates of C_1 and air fills the space between the plates of C_2 .

Figure 4



Table 2 gives information about C_1 and C_2 .

Table 2

	C_1	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]

$\frac{V_1}{V_2} =$

07.1

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]

07.2

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 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

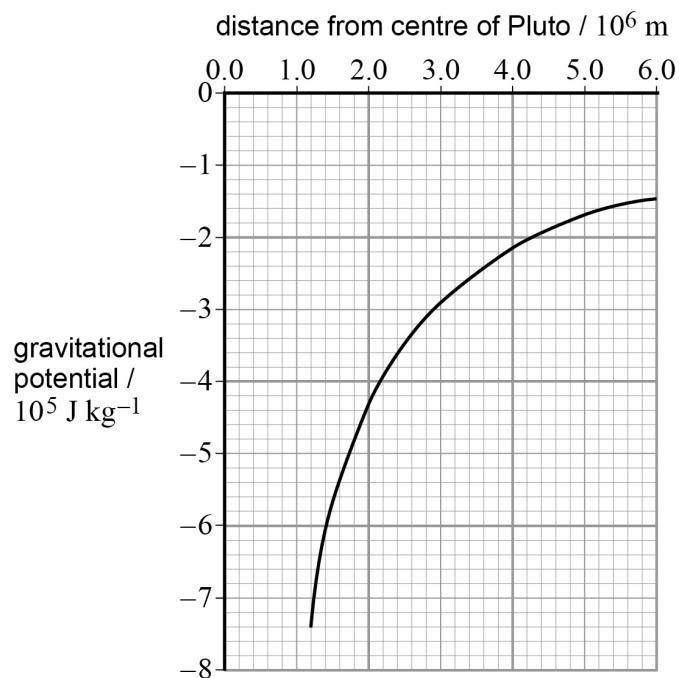
Question 7 continues on the next page



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 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. 

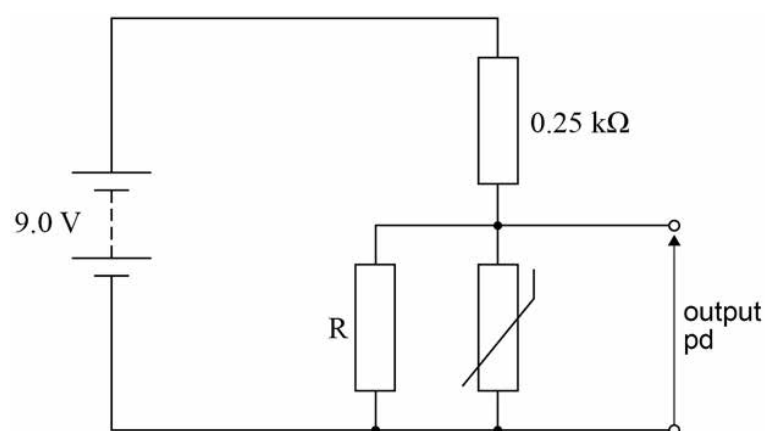
If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown. 

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

0 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 $750\ \Omega$ at room temperature. The student wants the output potential difference (pd) at room temperature to be $5.0\ \text{V}$

0 4 . 1

The $0.25\ \text{k}\Omega$ resistor is made of 50 turns of wire that is wound around a non-conducting cylinder of diameter $8.0\ \text{mm}$

Resistivity of the wire = $4.2 \times 10^{-7}\ \Omega\ \text{m}$

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 W for the 0.25 k Ω 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]



0	2
---	---

This question is about an experiment with a retractable steel tape measure.

The tape measure is placed at the edge of the bench and about 1 m of the steel tape is extended so that it overhangs the bench.

The tape is then locked in this position to stop it from retracting.

A student measures the dimensions x and y , the horizontal and vertical displacements of the free end of the tape, as shown in **Figure 7**.

Figure 7



02.1

Describe a suitable procedure the student could use to measure y .
You may add detail to **Figure 7** to illustrate your answer.

[2 marks]

02.2

By changing the extension of the tape, the student obtains further values of x and y .
These data are shown in **Table 2**.

Table 2

x / cm	y / cm
132.4	61.2
116.8	33.7
105.1	24.3
94.5	15.6
84.3	11.0
73.2	5.7

Suggest why the student chose to make **all** measurements of x greater than 70 cm

[1 mark]

Question 2 continues on the next page

0 2 . 3

The data from the experiment suggest that $y = Ax^n$ where n is an integer and A is a constant.

These data are used to plot the graph in **Figure 8**.

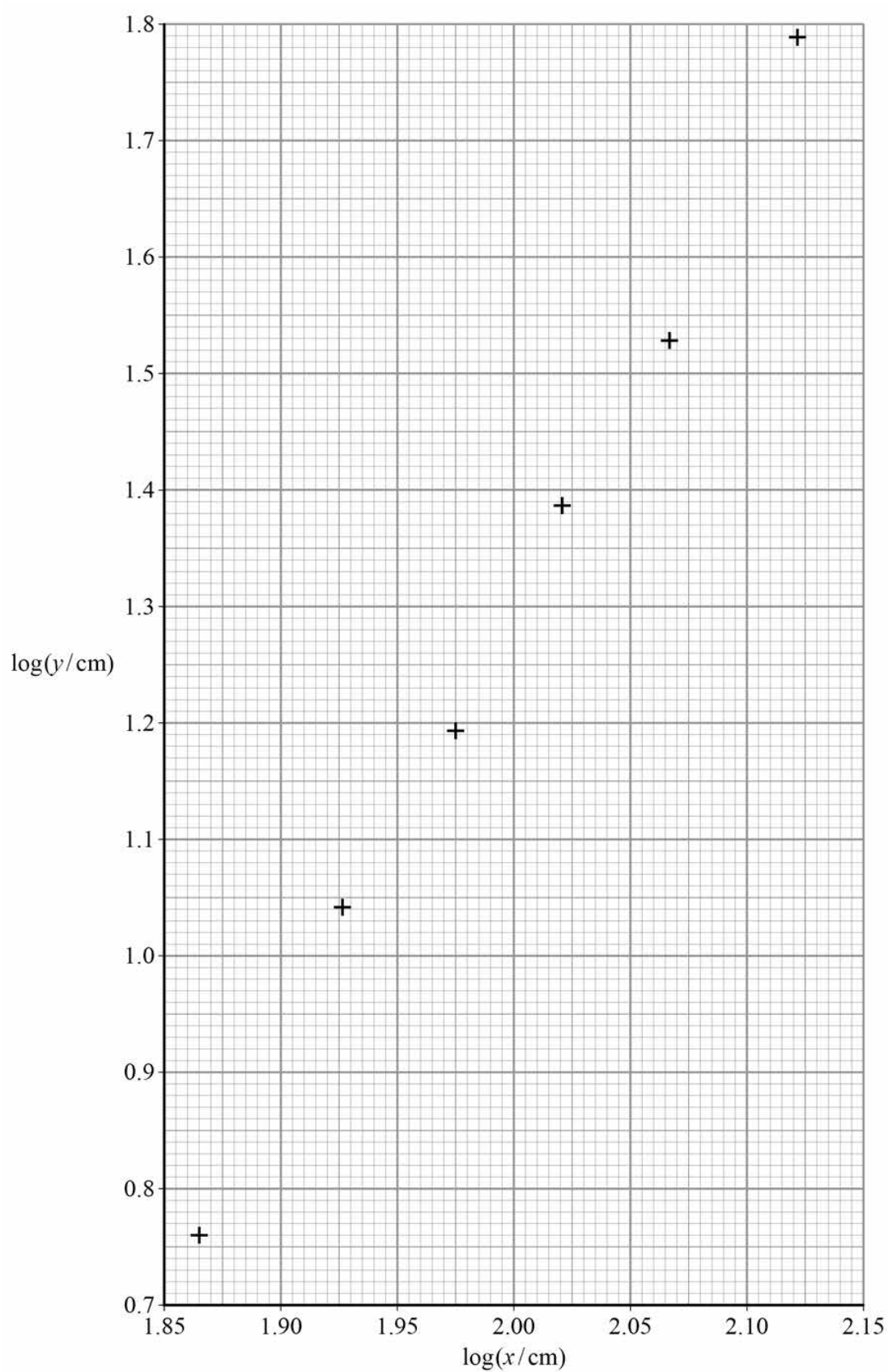
Determine n using **Figure 8**.

[3 marks]

$n =$ _____



Figure 8



Question 2 continues on the next page

0 2 . 4Explain how the numerical value of A can be obtained from **Figure 8**.**[3 marks]**

0 2 . 5Estimate the order of magnitude of A .You should use data for x and y from any **one** row in **Table 2** on page 11.

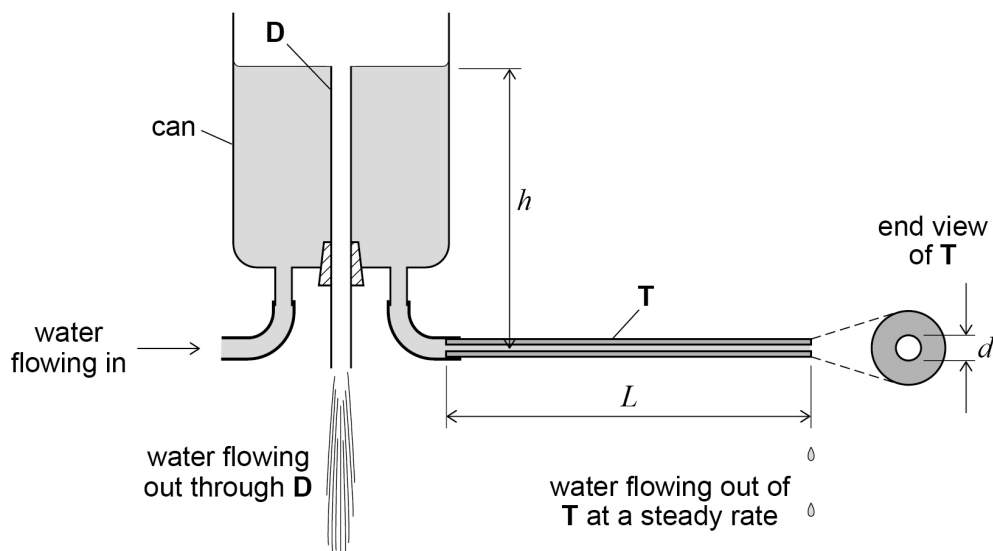
Give your answer with an appropriate unit.

[3 marks]order of magnitude of A = _____ unit _____

0 2

Figure 7 shows apparatus used to investigate the rate at which water flows through a horizontal cylindrical tube **T** of internal diameter d and length L .

Figure 7



The apparatus ensures that the water level in the can is at a constant height h above the centre of **T**.

Water flows out of **T** at a steady rate.

0 2

1

The volume flow rate through **T** is Q , where Q is in $\text{m}^3 \text{s}^{-1}$.
A student wants to measure Q as water flows through **T**.

Outline a procedure the student should follow to measure Q .
Include in your answer

- the measuring instruments used
- how uncertainty in the measurements can be reduced.

[4 marks]

0 2 . 2 It can be shown that

$$Q = \frac{\pi \rho g h d^4}{128 L \eta}$$

where ρ is the density of water

g is the gravitational field strength

η is a property of the water called the coefficient of viscosity.

What is the SI unit for η ?

Tick (✓) **one** box.

[1 mark]

N m⁻¹ s

☐

N m⁻² s

☐

N m⁻¹ s⁻¹

☐

N m⁻² s⁻¹

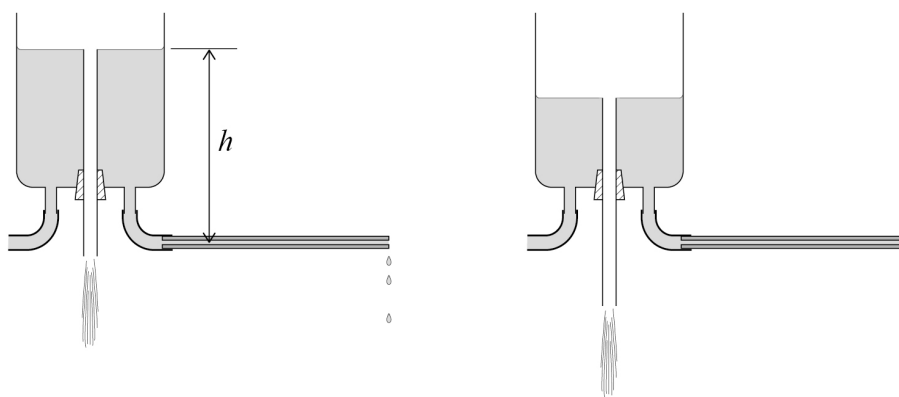
☐

Question 2 continues on the next page

0 2 3

An experiment is carried out to determine η by a graphical method. The rate at which water flows out of **T** is varied by adjusting the height of the drain tube as shown in **Figure 8**.

Figure 8



During the experiment the temperature is kept constant.

Q is found for different values of h and a graph of these data is plotted, with Q on the vertical axis.

The percentage uncertainty in the gradient of the graph is 6.4%.

The dimensions of tube **T** are measured and the uncertainties in these data are calculated.

The percentage uncertainty

- in d is 2.9%
- in L is 1.8%.

The percentage uncertainties in ρ and g are negligible.

Deduce the percentage uncertainty in the result for η .

[2 marks]

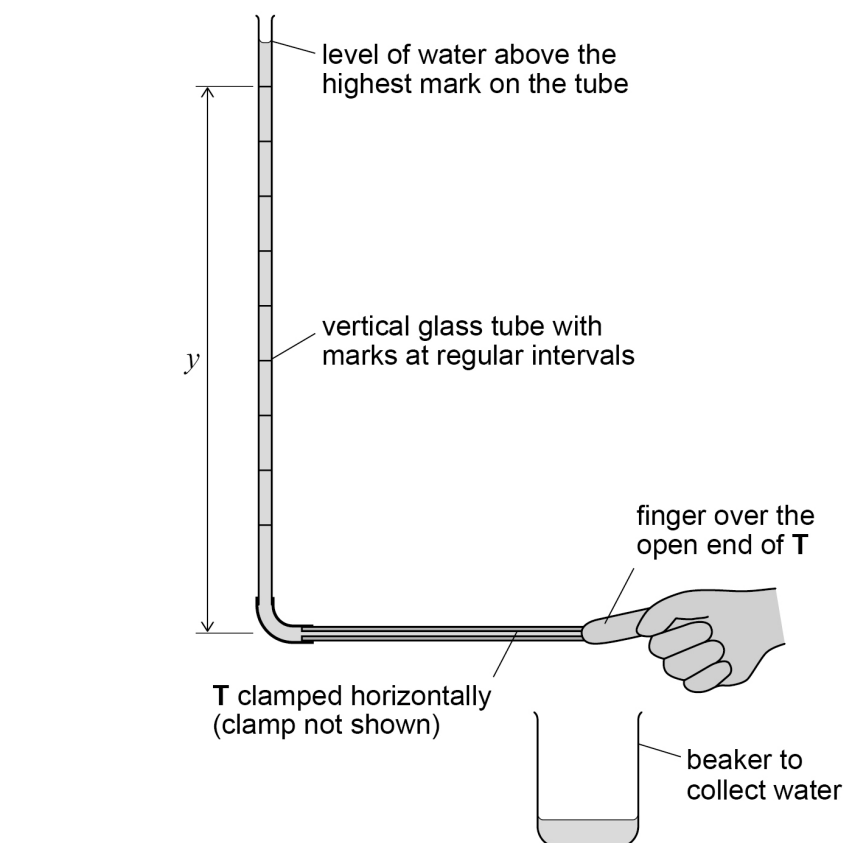
percentage uncertainty in η = _____

0 2 . 4

In a different experiment, the horizontal tube **T** is connected to a vertical glass tube. Marks have been made at regular intervals on the glass tube. The student measures and records the vertical distance y between each of the marks and the centre of **T**.

She seals the open end of **T** and fills the glass tube with water, as shown in **Figure 9**.

Figure 9



T is opened and water flows into a beaker. When the water level falls to the highest mark on the tube, she starts a stopwatch. She records the time t for the water to reach each of the other marks.

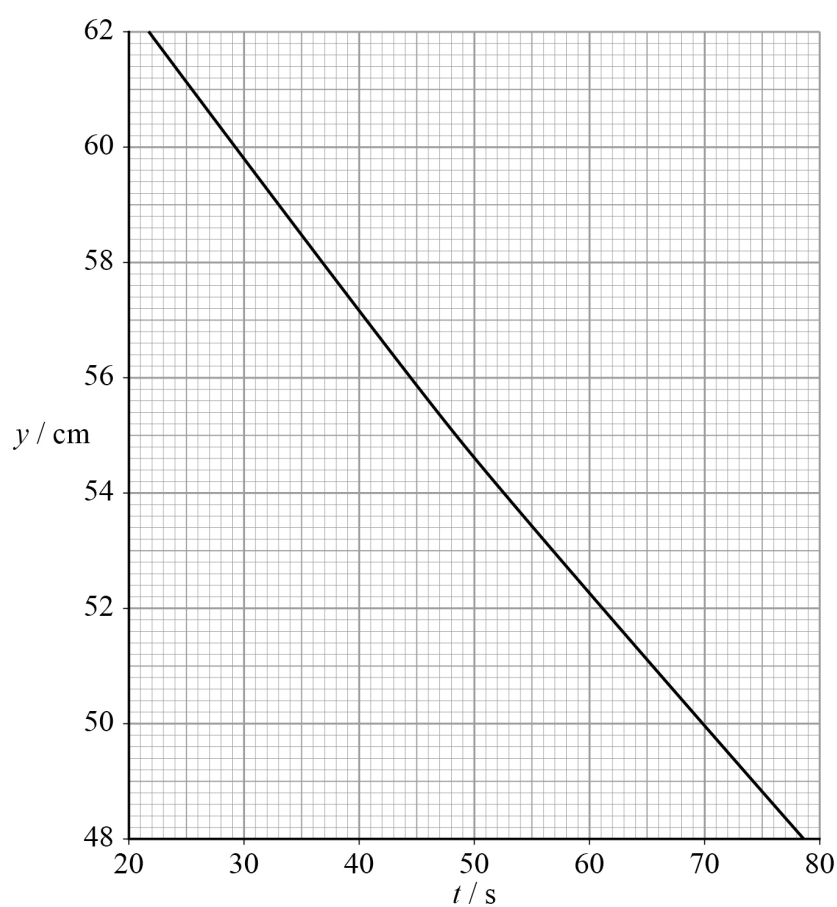
Explain how the student could check that the glass tube was vertical. You may wish to add detail to **Figure 9** to illustrate your answer.

[1 mark]

Question 2 continues on the next page

0 2 . 5 Figure 10 shows part of the graph drawn from the student's data.

Figure 10



It can be shown that y decreases exponentially with t .

Show that λ , the decay constant for this process, is about $4.5 \times 10^{-3} \text{ s}^{-1}$.

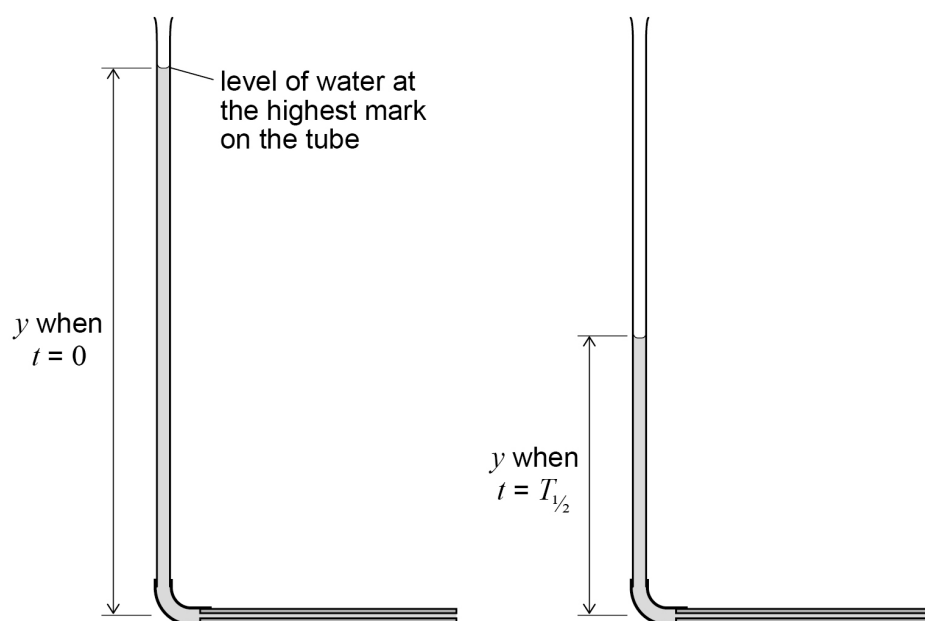
[2 marks]

$\lambda =$ _____ s^{-1}



0 2 . 6 $T_{1/2}$ is the time for y to decrease by 50%, as shown in **Figure 11**.

Figure 11



Determine $T_{1/2}$.

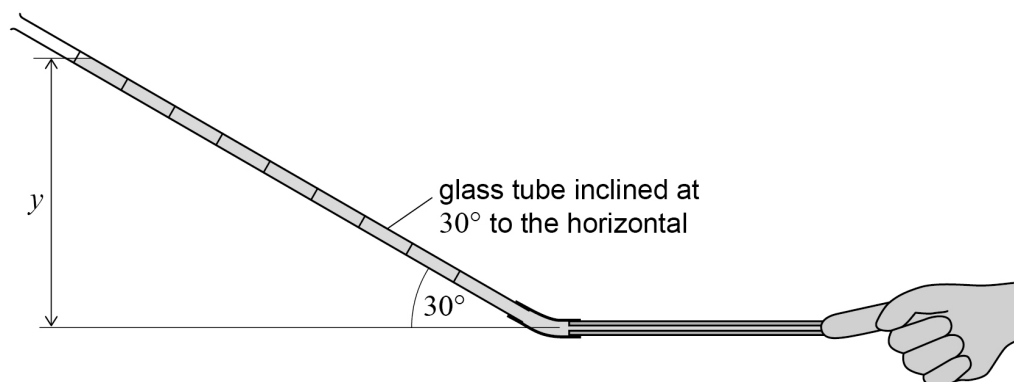
[1 mark]

$T_{1/2} =$ _____ s

Question 2 continues on the next page

- 0 2 . 7** The apparatus is adjusted so that the glass tube is inclined at 30° to the horizontal tube **T**, as shown in **Figure 12**.

Figure 12



The student measures and records the new values of y , the mean vertical distance between each of the marks and the centre of **T**. She then carries out the experiment as before, recording new values of t corresponding to each new value of y .

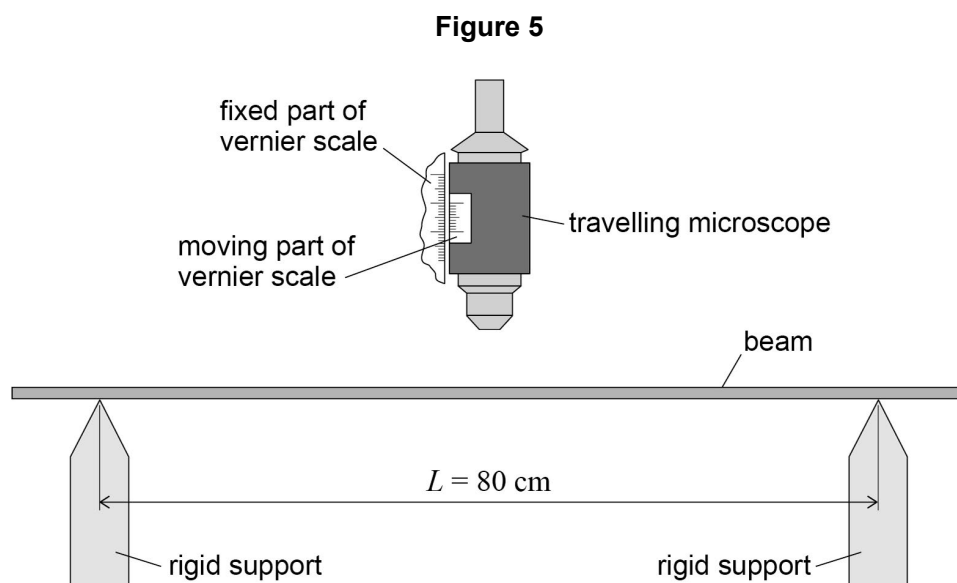
Draw a line on **Figure 13** to show the graph produced using the modified apparatus. The dashed line is the original graph when the glass tube was vertical as shown in **Figure 9**.

[2 marks]

Figure 13

0	2
---	---

Figure 5 shows apparatus used to investigate the bending of a beam.



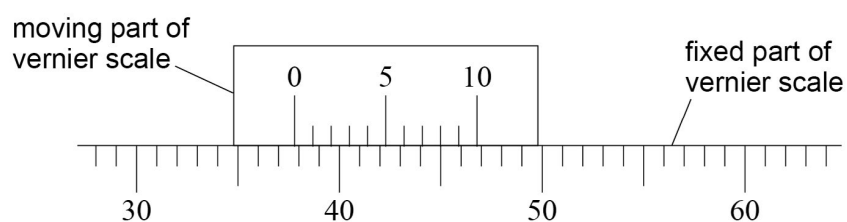
The beam is placed horizontally on rigid supports.
The distance L between the supports is 80 cm.

A travelling microscope is positioned above the midpoint of the beam and focused on the upper surface.

0 2 . 1

Figure 6 shows an enlarged view of both parts of the vernier scale.

Figure 6



The smallest division on the fixed part of the scale is 1 mm.

What is the value of the vernier reading R_0 in mm?

Tick (✓) **one** box.

[1 mark]

34.8

☐

37.8

☐

45.8

☐

49.8

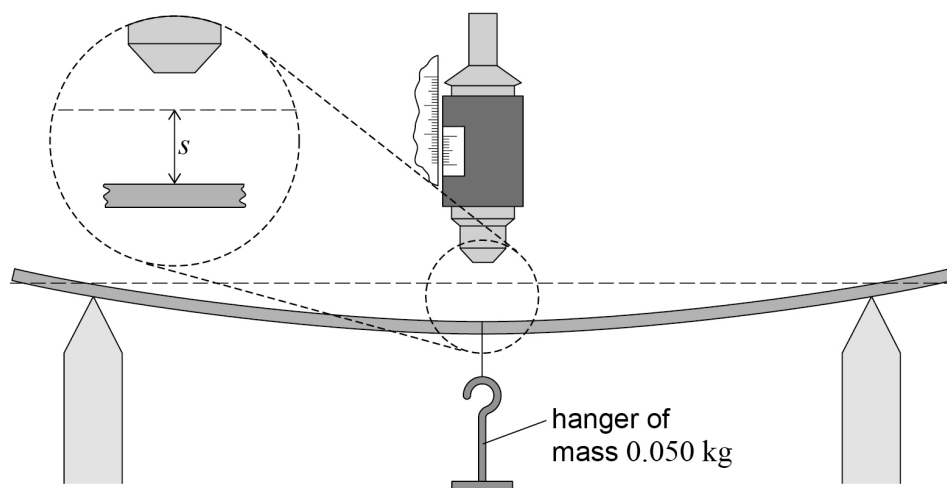
☐

Question 2 continues on the next page

0 2 . 2

Figure 7 shows the beam bending when a hanger of mass 0.050 kg is suspended from the midpoint.

Figure 7



The microscope is refocused on the upper surface and the new vernier reading R is recorded.

The vertical deflection s of the beam is equal to $(R - R_0)$.

The total mass m suspended from the beam is increased in steps of 0.050 kg.

A value of s is recorded for each m up to a value of $m = 0.450$ kg.

Further values of s are then recorded as m is decreased in 0.050 kg steps until m is zero.

Student **A** performs the experiment and observes that values of s during unloading are **sometimes** different from the corresponding values for loading.

State the type of error that causes the differences student **A** observes.

[1 mark]

0 2 . 3

Student **B** performs the experiment using a thinner beam but with the same width and made from the same material as before.

Discuss **one** possible advantage and **one** possible disadvantage of using the thinner beam.

[3 marks]

Advantage _____

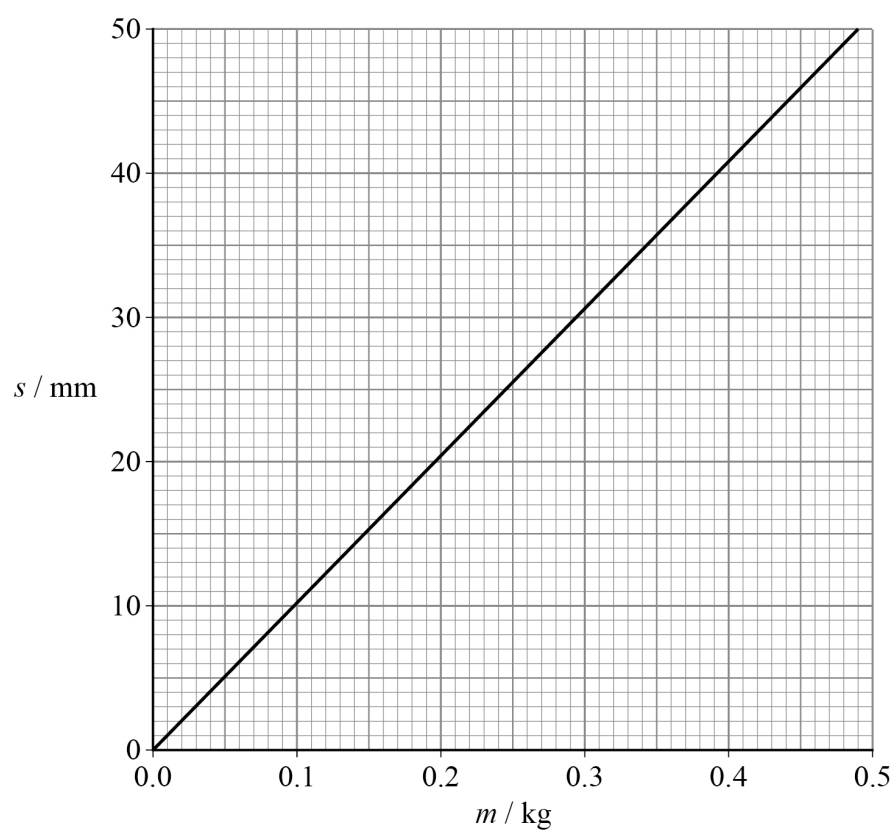
Disadvantage _____

Question 2 continues on the next page



0 2 . 4 Figure 8 shows the best-fit line produced using the data collected by student A.

Figure 8



It can be shown that $s = \frac{\eta m}{E}$

where E is the Young modulus of the material of the beam and η is a constant.

Deduce in s^{-2} the order of magnitude of η .

$$E = 1.14 \text{ GPa}$$

[4 marks]

order of magnitude of $\eta =$ _____ s^{-2}

Question 2 continues on the next page

0 2 . 5

Student **C** performs a different experiment using the same apparatus shown in **Figure 5** on page 10.

A mass M is suspended from the midpoint of the beam.

The vertical deflection s of the beam is measured for different values of L .

Figure 9 shows a graph of the results for this experiment.

Figure 9



Figure 9 shows that $\log_{10}(s / \text{m})$ varies linearly with $\log_{10}(L / \text{m})$.

State what this shows about the mathematical relationship between s and L .
You do **not** need to do a calculation.

[1 mark]

0 2 . 6

Deduce, using **Figure 9**, the value of s when $L = 80 \text{ cm}$.

[2 marks]

$s =$ _____ m

0 2 . 7

Determine M using **Figure 8**.

[1 mark]

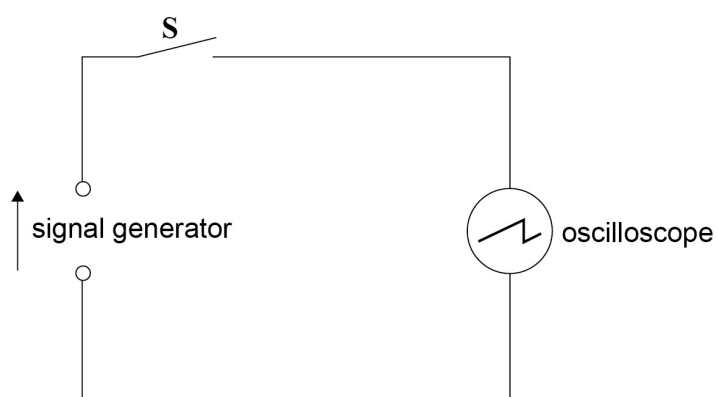
$M =$ _____ kg



0 2

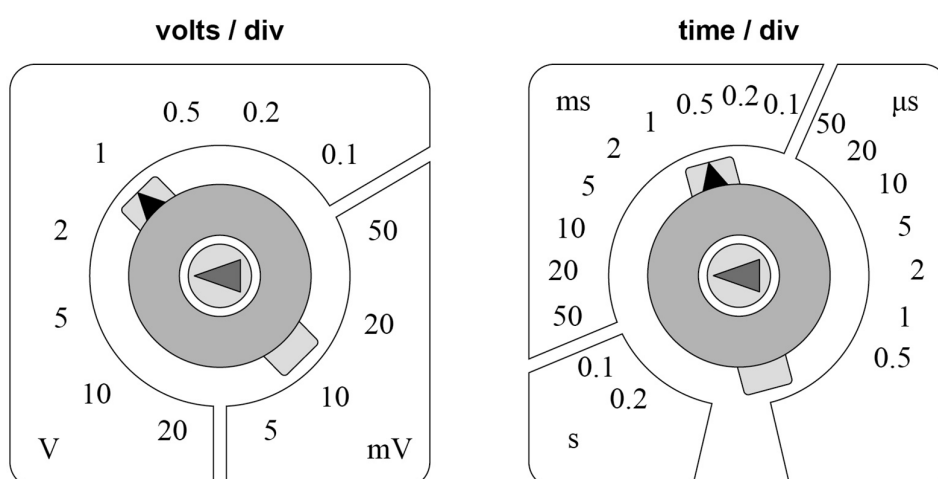
A signal generator is connected to an oscilloscope, as shown in **Figure 5**.

Figure 5



The Y-voltage gain and time-base settings of the oscilloscope are shown in **Figure 6**.

Figure 6



Question 2 continues on the next page

When switch **S** is open (off) the oscilloscope displays the waveform shown in **Figure 7**.

When **S** is closed (on) the oscilloscope displays the waveform shown in **Figure 8**.

0 2 . 1

Determine the peak-to-peak voltage V of the waveform shown in **Figure 8**.

[1 mark]

$V =$ _____ V

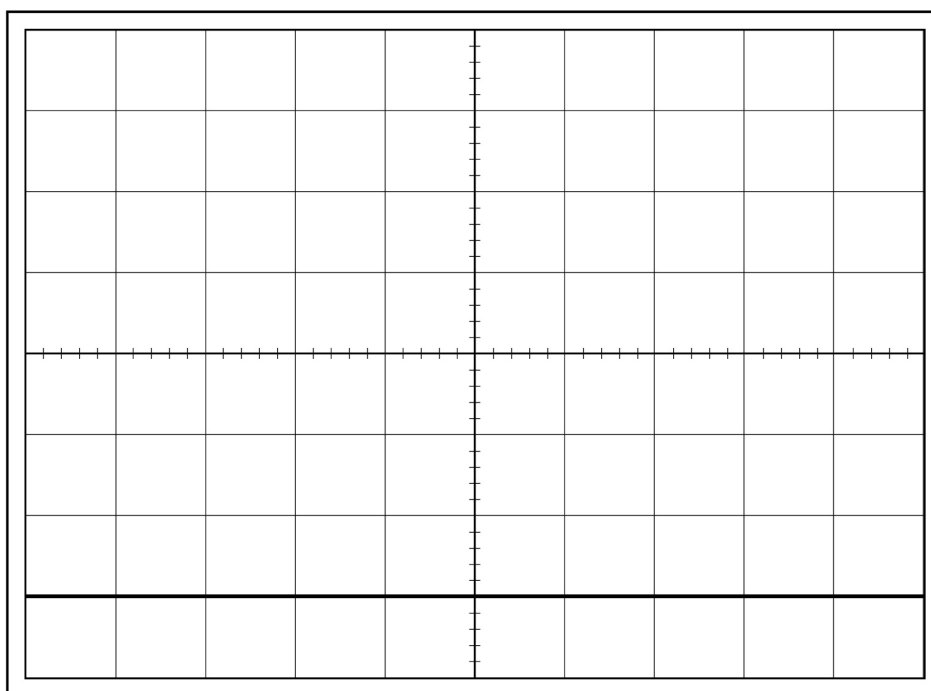
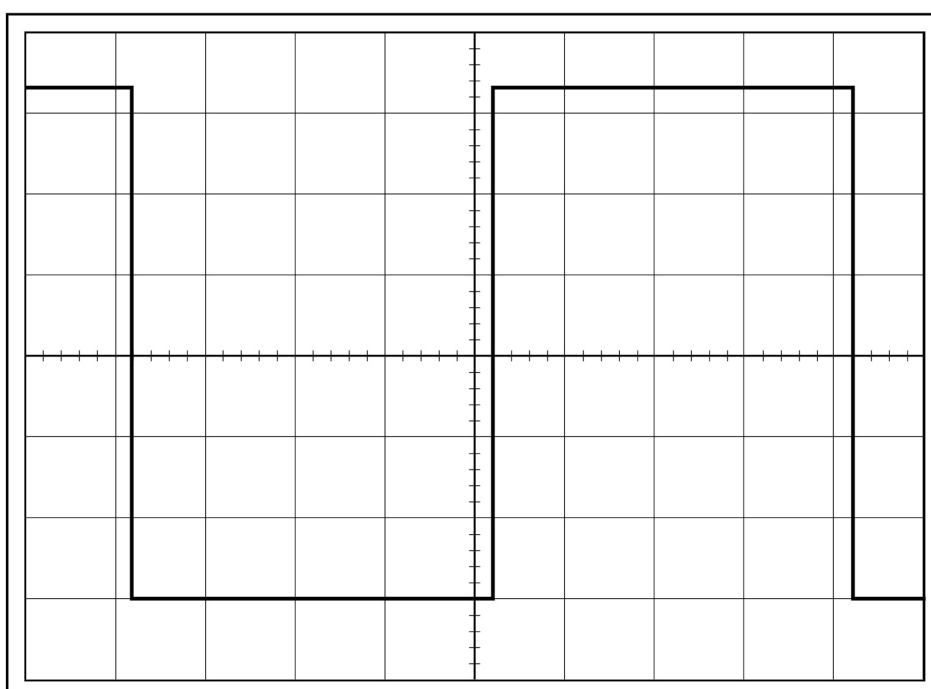
0 2 . 2

Determine the frequency f of the waveform shown in **Figure 8**.

[2 marks]

$f =$ _____ Hz



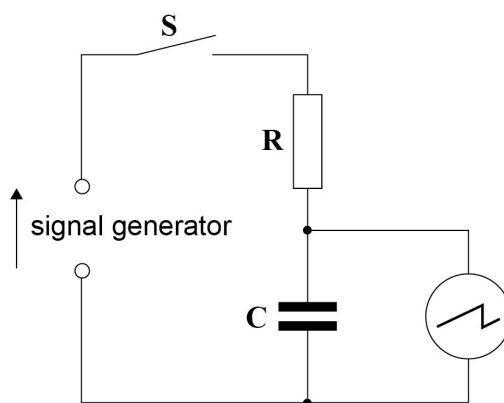
Figure 7**Figure 8**

Question 2 continues on the next page

0	2	3
---	---	---

Figure 9 shows the signal generator connected in series with a resistor **R** and a capacitor **C**.

Figure 9



The oscilloscope is connected across the capacitor.
The Y-voltage gain and time-base settings are still the same as shown in **Figure 6**.

When **S** is closed (on) the oscilloscope displays the waveform shown in **Figure 10**.

Figure 10

Determine the time constant of the circuit in **Figure 9**.

[2 marks]

time constant = _____ s

0 2 . 4

A student suggests that setting the time-base to $0.2 \text{ ms division}^{-1}$ might reduce uncertainty in the determination of the time constant.

State and explain any possible advantage or disadvantage in making this suggested adjustment.

[3 marks]

Question 2 continues on the next page



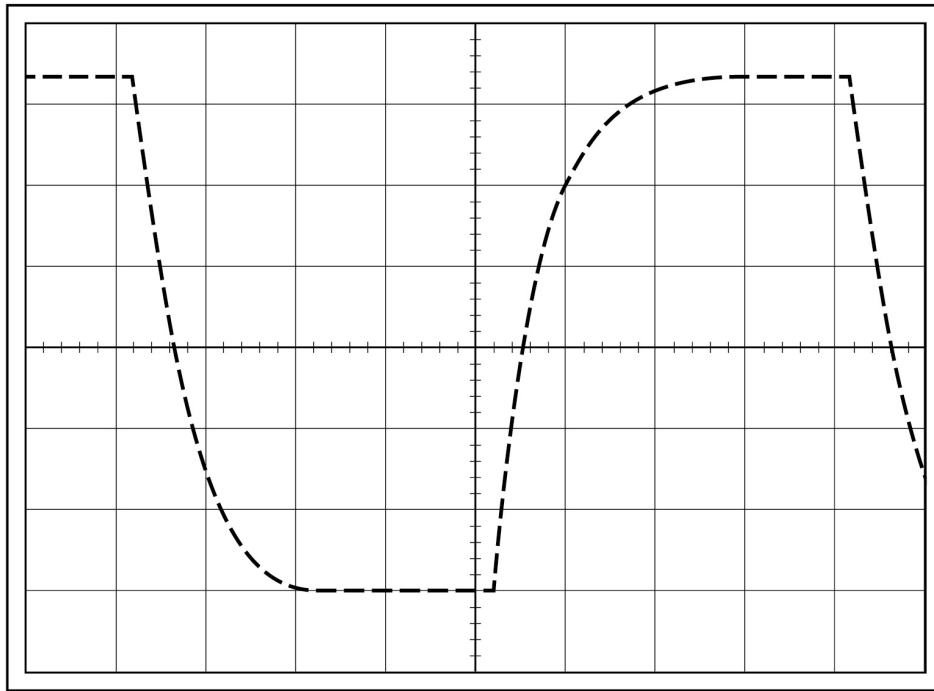
0 2 . 5

The student connects an identical resistor in parallel with **R** and uses the oscilloscope to display the waveform across **C**.

Draw on **Figure 11** the waveform you expect the student to see.

The waveform of **Figure 10** is shown as a dashed line to help you show how the waveform changes.

Figure 11



Explain the change in the waveform.

[2 marks]

0 2 . 6

Figure 12a is a graph of voltage against time showing the output of the signal generator. **Figure 12b** shows the voltage across **C** during the same time interval.

The student interchanges the positions of **R** and **C** and connects the oscilloscope across **R**.

Complete **Figure 12c** to draw the voltage across **R** during the time interval.

[2 marks]

Figure 12a

voltage – time graph
of the output from
the signal generator

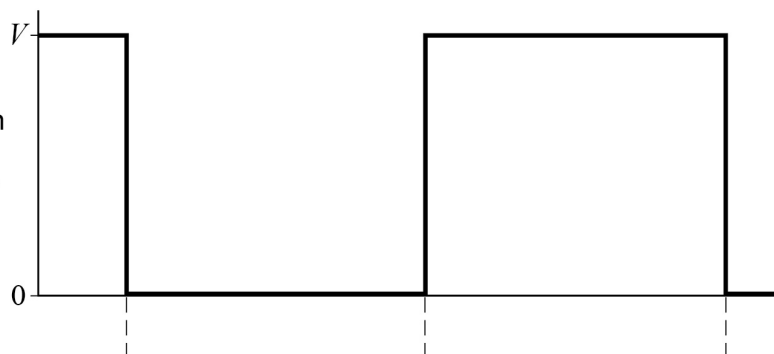


Figure 12b

voltage – time graph
of the voltage
across **C**

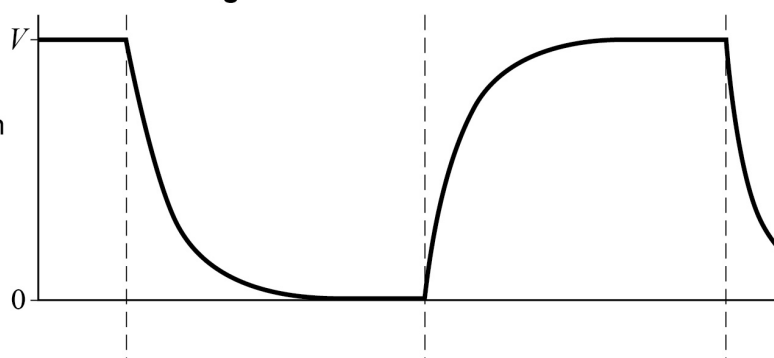
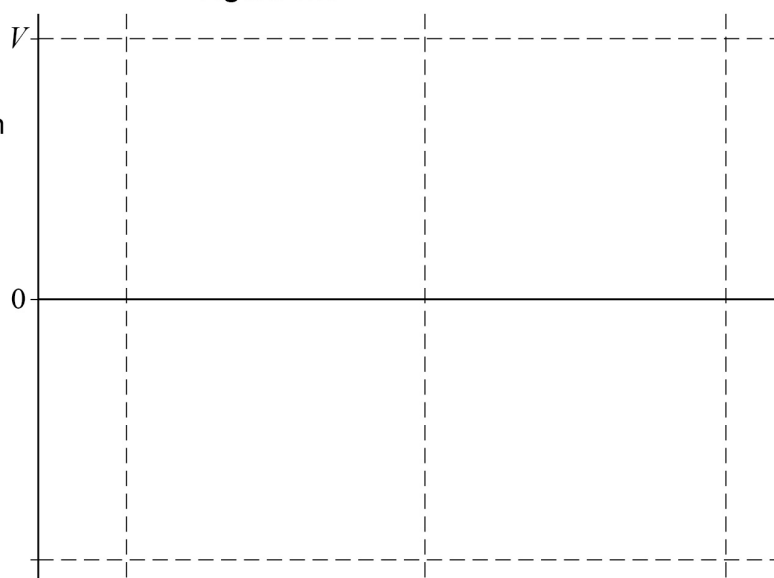


Figure 12c

voltage – time graph
of the voltage
across **R**



Question 2 continues on the next page

0	2	.	7
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State and explain what changes, if any, the student needs to make to the settings of the oscilloscope so the waveform across **R** is fully displayed.

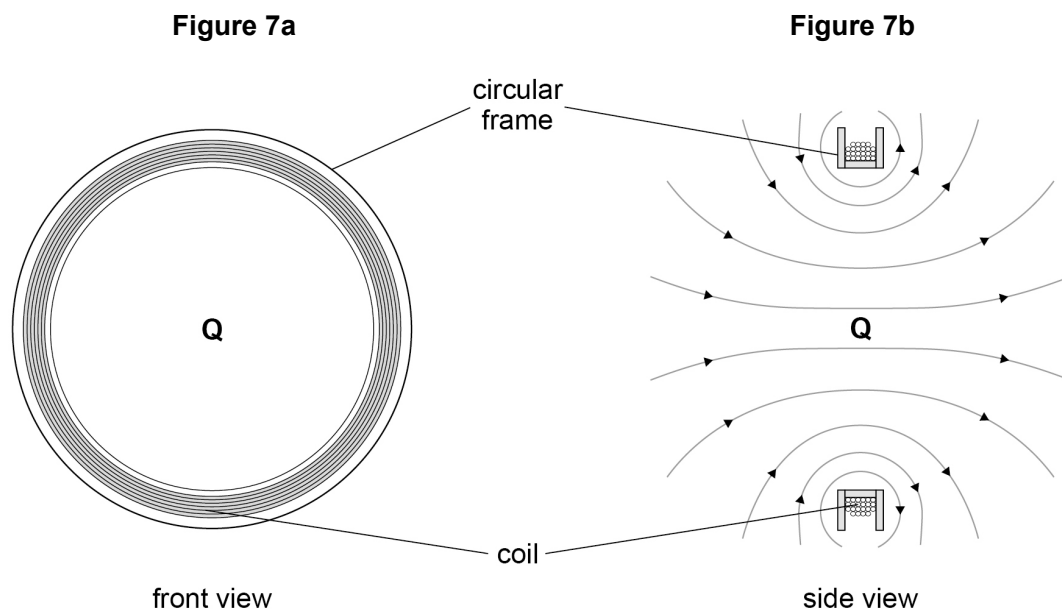
[2 marks]



0 3

Figure 7a shows the front view of a vertical coil mounted on a circular frame.

Figure 7b is a side view showing a section through the frame and coil. A constant direct current in the coil produces magnetic flux represented by the magnetic field lines on this diagram.



Point **Q** is at the centre of the coil.

A sensor placed at **Q** detects B_H , the horizontal component of the magnetic flux density.

The effect of the Earth's magnetic field at **Q** is negligible.

0 3 . 1

Discuss whether a search coil is a suitable sensor to detect B_H .

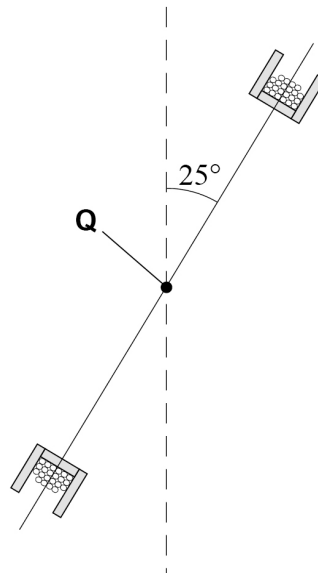
[2 marks]

Question 3 continues on the next page

B_H is measured at **Q** with the coil vertical.

The coil is now rotated about **Q** through 25° as shown in **Figure 8**.
The current in the coil does not change.

Figure 8



A new measurement of B_H is made with the coil fixed in this new position.

0 3 . 2

Determine the percentage change in B_H produced by this rotation of the coil.
Show your working.

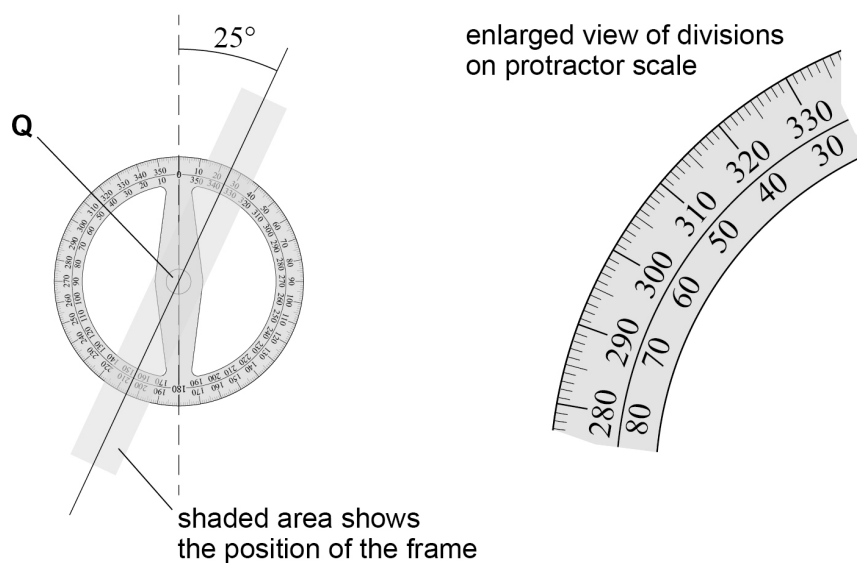
[2 marks]

percentage change = _____ %

0 3 . 3

Figure 9 shows a protractor being used to measure the angle through which the coil is rotated.

Figure 9



Estimate the percentage uncertainty in this result.
Justify your answer.

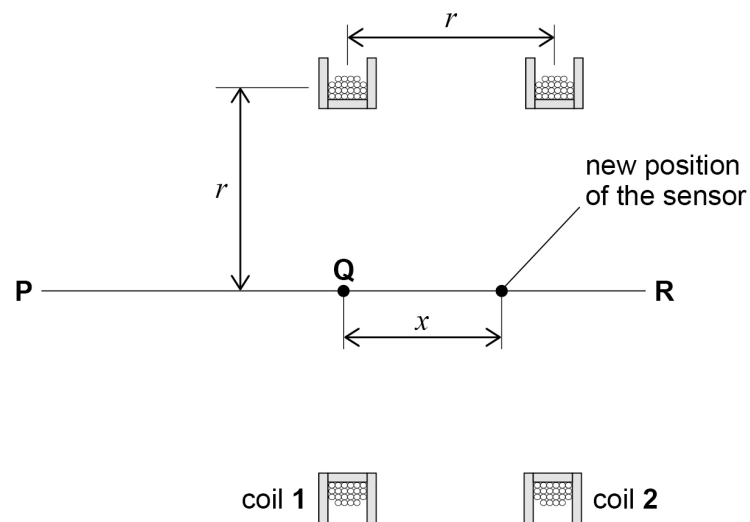
[3 marks]

percentage uncertainty = _____ %

Question 3 continues on the next page

Figure 10 shows an arrangement of two vertical coils. Four experiments are done using this arrangement.

Figure 10



Coil **1** and coil **2** are identical and have a radius r .
 The coils are separated by a distance r and have a common axis **PR**.
Q is at the centre of coil **1**.

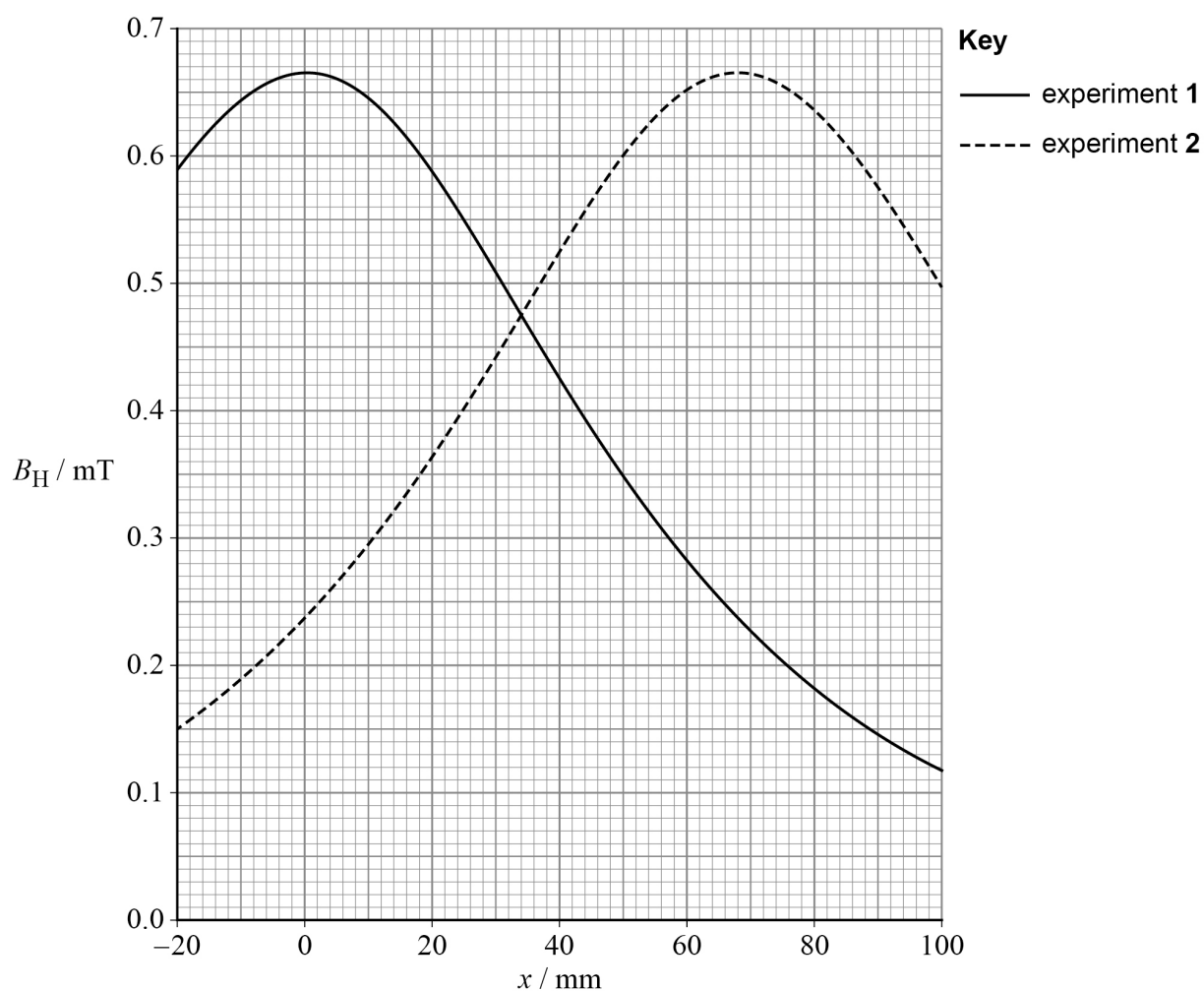
The four different experiments investigate how B_H varies with x , the displacement of the sensor from **Q** along **PR**.

In experiment **1**, the current in coil **1** is 225 mA and the current in coil **2** is zero.

In experiment **2**, the current in coil **1** is zero and the current in coil **2** is 225 mA.

Figure 11 shows the results of experiment 1 and experiment 2.

Figure 11



- 0 3 . 4** During experiment 1, B_H is measured with the sensor at **Q**.
 The sensor is then moved along **PR** until the value of B_H is halved.
 The distance from **Q** to the sensor is $x_{0.5}$

Determine $\frac{x_{0.5}}{r}$

[2 marks]

$$\frac{x_{0.5}}{r} = \underline{\hspace{2cm}}$$

In experiment **3**, the current in both coils is 225 mA so that the magnetic fields produced by coil **1** and coil **2** are combined.

The resultant B_H has a constant maximum value in the region between $x = \frac{r}{4}$ and

$$x = \frac{3r}{4}$$

0 3 . 5 Deduce, in mT, the value of B_H in this region.

[2 marks]

$B_H =$ _____ mT

0 3 . 6 State **two** characteristics of the magnetic field lines in this region.

[2 marks]

1 _____

2 _____



03.7

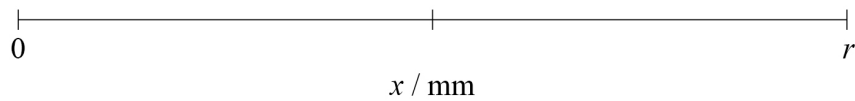
In experiment 4, the current in coil 2 is reversed so that the direction of the magnetic field produced by coil 2 is also reversed.

The magnitudes of the currents in coil 1 and coil 2 are still 225 mA.

Sketch a graph to show how B_H varies between $x = 0$ and $x = r$.

The x -axis has been provided for you.

Your graph should include numerical values on your B_H axis that correspond to $x = 0$ and $x = r$.

[3 marks]**END OF QUESTIONS**

0	1
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Figure 1 shows a sealed radioactive source used in schools and colleges.

Figure 1



0	1	.	1
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State **two** safety procedures to reduce risk when using this type of source.

[2 marks]

Safety procedure 1 _____

Safety procedure 2 _____

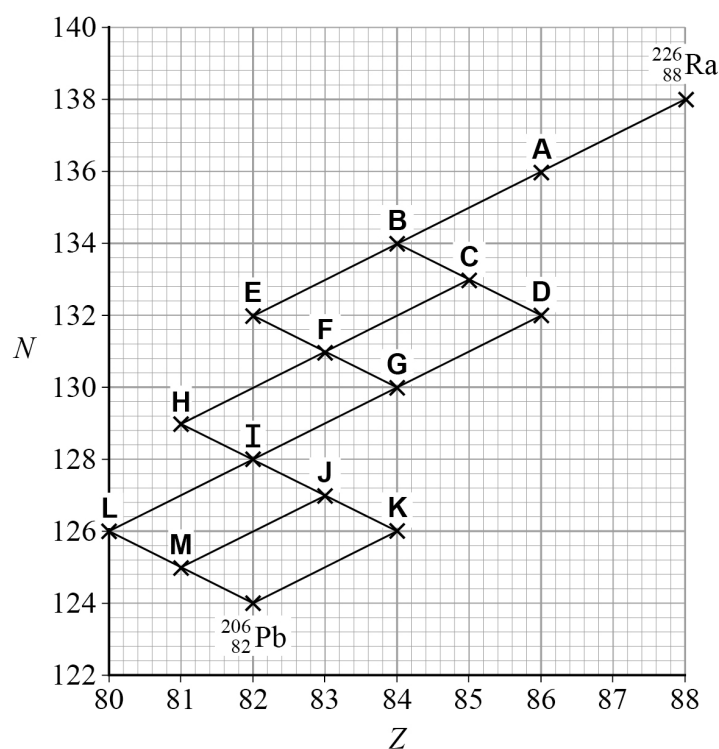
0 1 2 A sealed source contains radium-226 ($^{226}_{88}\text{Ra}$).

$^{226}_{88}\text{Ra}$ decays by emitting α and β^- particles to produce $^{206}_{82}\text{Pb}$ which is stable.

Figure 2 is a graph of neutron number N against proton number Z , showing the different ways that $^{226}_{88}\text{Ra}$ can decay into $^{206}_{82}\text{Pb}$.

Points **A** to **M** represent all the unstable nuclei that may be formed as $^{226}_{88}\text{Ra}$ decays into $^{206}_{82}\text{Pb}$.

Figure 2



Determine the number of routes by which **B** can change into **K**.

[1 mark]

0 1 3 Identify which of the nuclei **A** to **M** are common to all the possible ways that $^{226}_{88}\text{Ra}$ decays into $^{206}_{82}\text{Pb}$.

[3 marks]

Question 1 continues on the next page

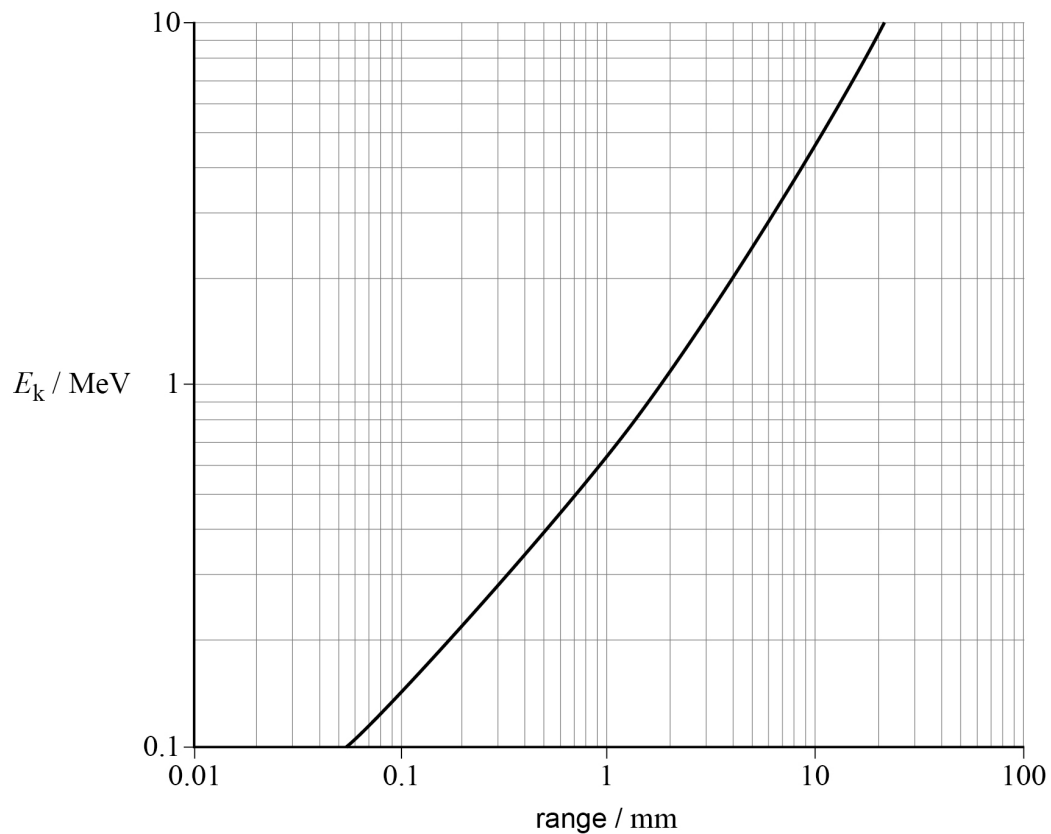


The sealed source emits:

- α particles with energy E_k between 3.8 MeV and 7.8 MeV
- β^- particles with energy E_k between zero and 5.5 MeV.

Figure 4 shows how the range of β^- particles in aluminium depends on E_k .

Figure 4



Deduce the minimum thickness of the aluminium absorber that should be used in the experiment.

[3 marks]

minimum thickness = _____ mm

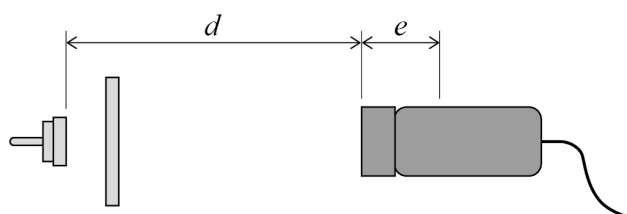
Question 1 continues on the next page



0 1 . 6

Ionisation takes place inside the detector. The effective distance travelled by γ radiation from the source is $(d + e)$.

The distance e , shown in **Figure 5**, cannot be measured directly.

Figure 5

From the inverse-square law for γ radiation, it can be shown that

$$(d + e) = \sqrt{\frac{k}{A}}$$

where A is the count rate, corrected for background radiation
 k is a constant.

The student plots the graph of d against $\frac{1}{\sqrt{A}}$ shown in **Figure 6**.

Deduce k using **Figure 6**.

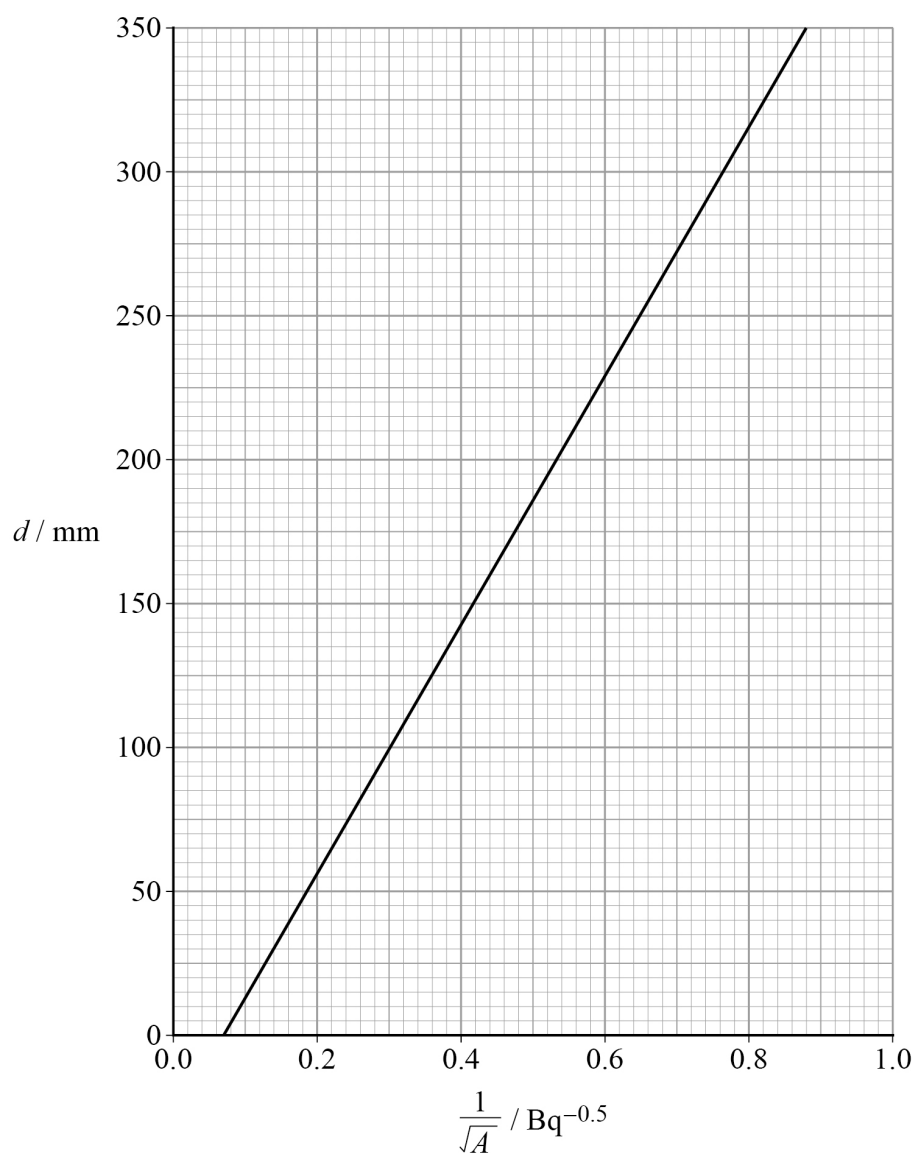
Explain your reasoning.

Give a suitable unit for your result.

[5 marks]

$k =$ _____ unit _____

Figure 6



0 1 . 7 Determine e using **Figure 6**.

[2 marks]

$e =$ _____ mm

0 4

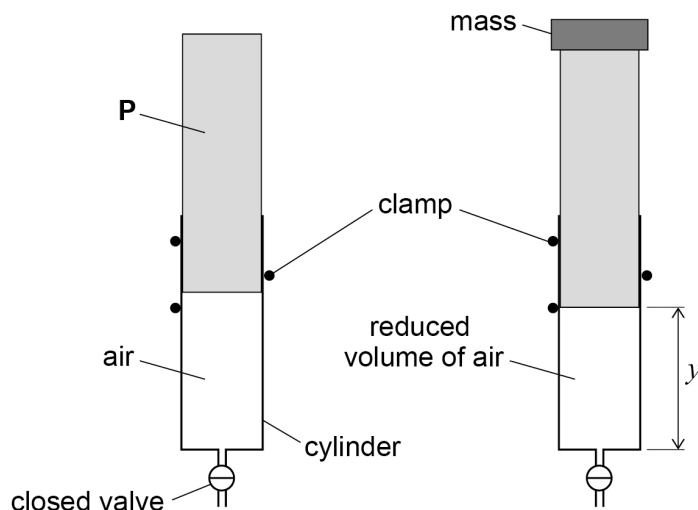
Figure 9 shows air trapped in a vertical cylinder by a valve and a piston **P**. The valve remains closed throughout the experiment.

A mass is placed on top of **P**.

P moves downwards and the volume of the trapped air decreases.

There are no air leaks and there is no friction between the cylinder and **P**.

Figure 9



The vertical distance y between the end of **P** and the closed end of the cylinder is measured.

Additional masses are used to find out how y depends on the total mass M placed on top of **P**.

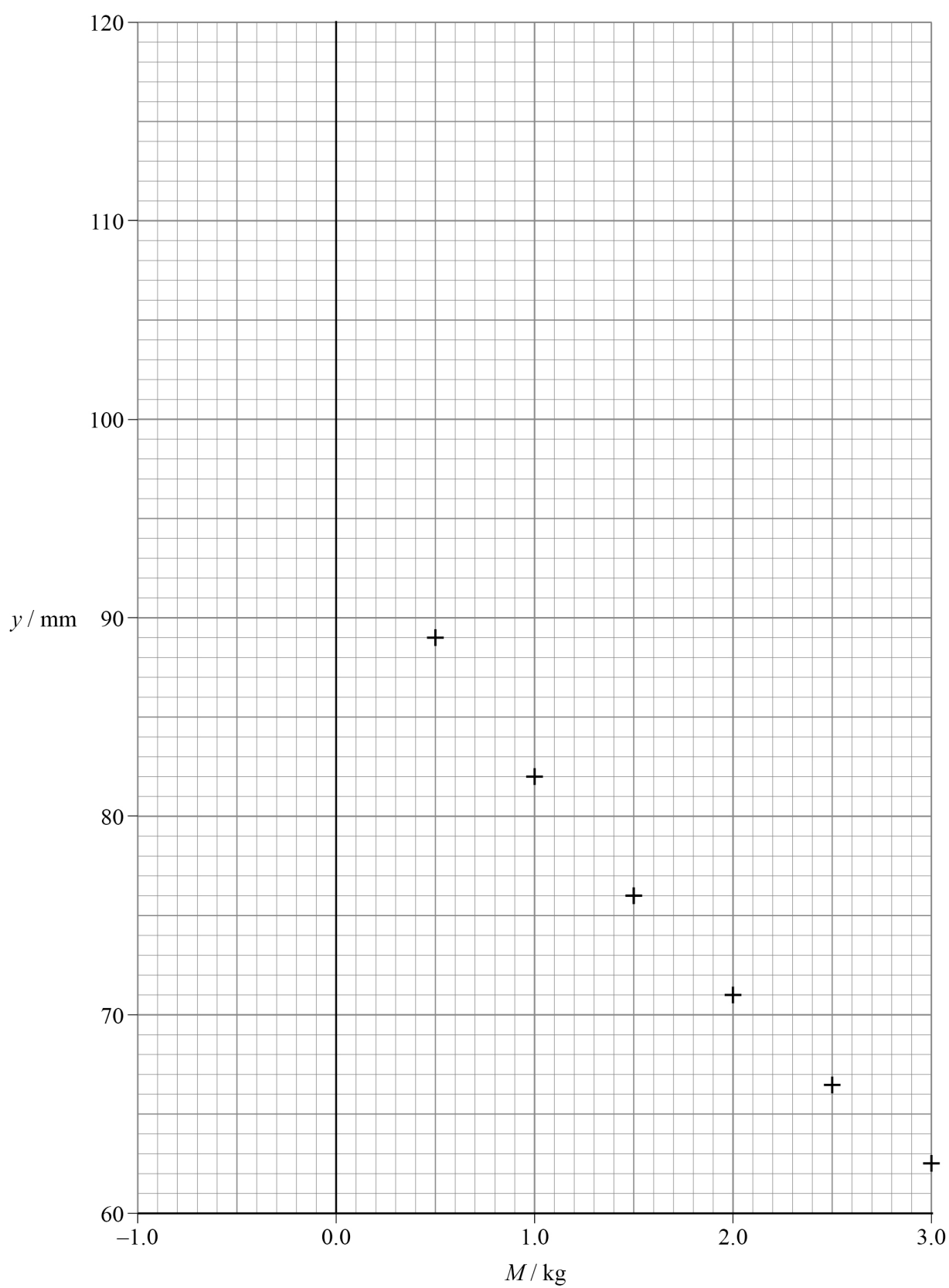
Figure 10 shows a graph of these data.

0 4 . 1

Show that y is **not** inversely proportional to M .
Use data points from **Figure 10**.

[2 marks]

Figure 10



Question 4 continues on the next page

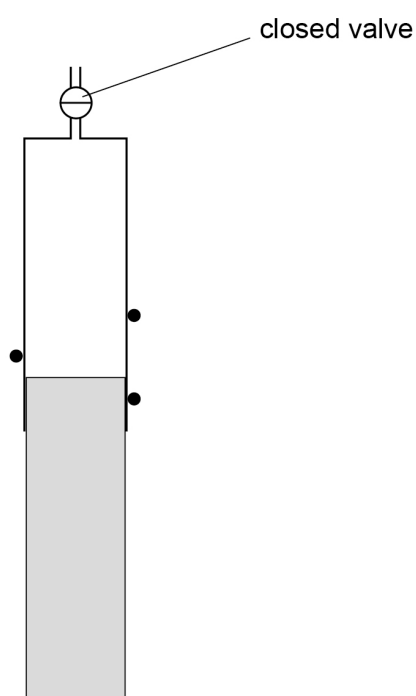


0	4	.	2
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The masses are removed and the cylinder is inverted.

P moves downwards without friction before coming to rest, as shown in **Figure 11**.

Figure 11



Explain why **P** does not fall out of the cylinder unless the valve is opened.

[3 marks]

0 4 . 3 The mass of **P** is 0.350 kg.

Deduce y when the cylinder is in the inverted position shown in **Figure 11**.

Draw a line of best fit on **Figure 10** to arrive at your answer.

[4 marks]

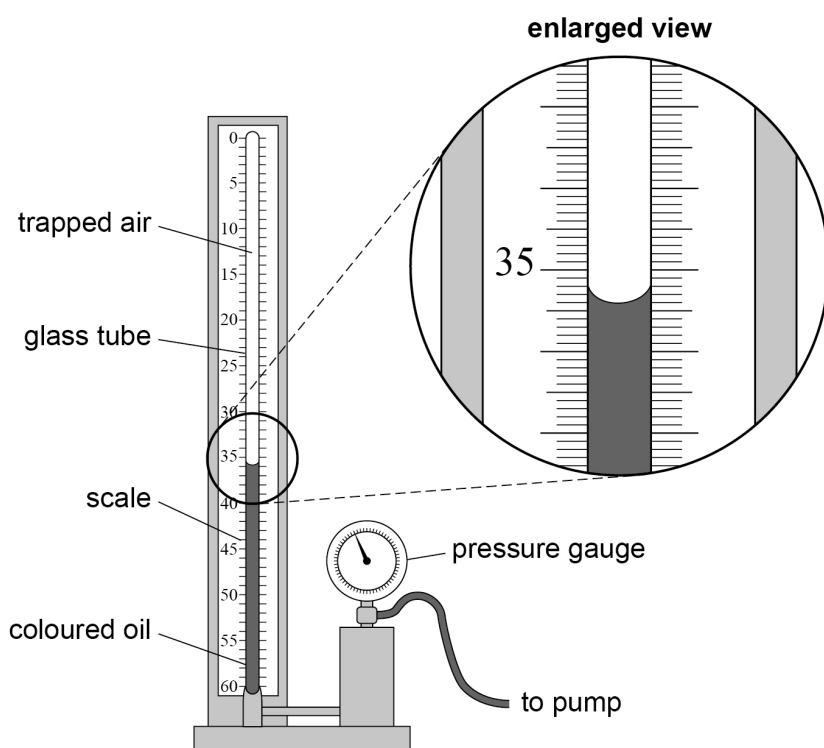
$y =$ _____ mm

Question 4 continues on the next page



Figure 12 shows apparatus used in schools to investigate Boyle's law.

Figure 12



A fixed mass of air is trapped above some coloured oil inside a glass tube, closed at the top.

A pump applies pressure to the oil and the air.

The trapped air is compressed and its pressure p is read from the pressure gauge.

0	4	.	4
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A scale, marked in 0.2 cm^3 intervals, is used to measure the volume V of the air. A student says that the reading for V shown in **Figure 12** is 35.4 cm^3 .

State:

- the error the student has made
- the correct reading, in cm^3 , of the volume.

[2 marks]

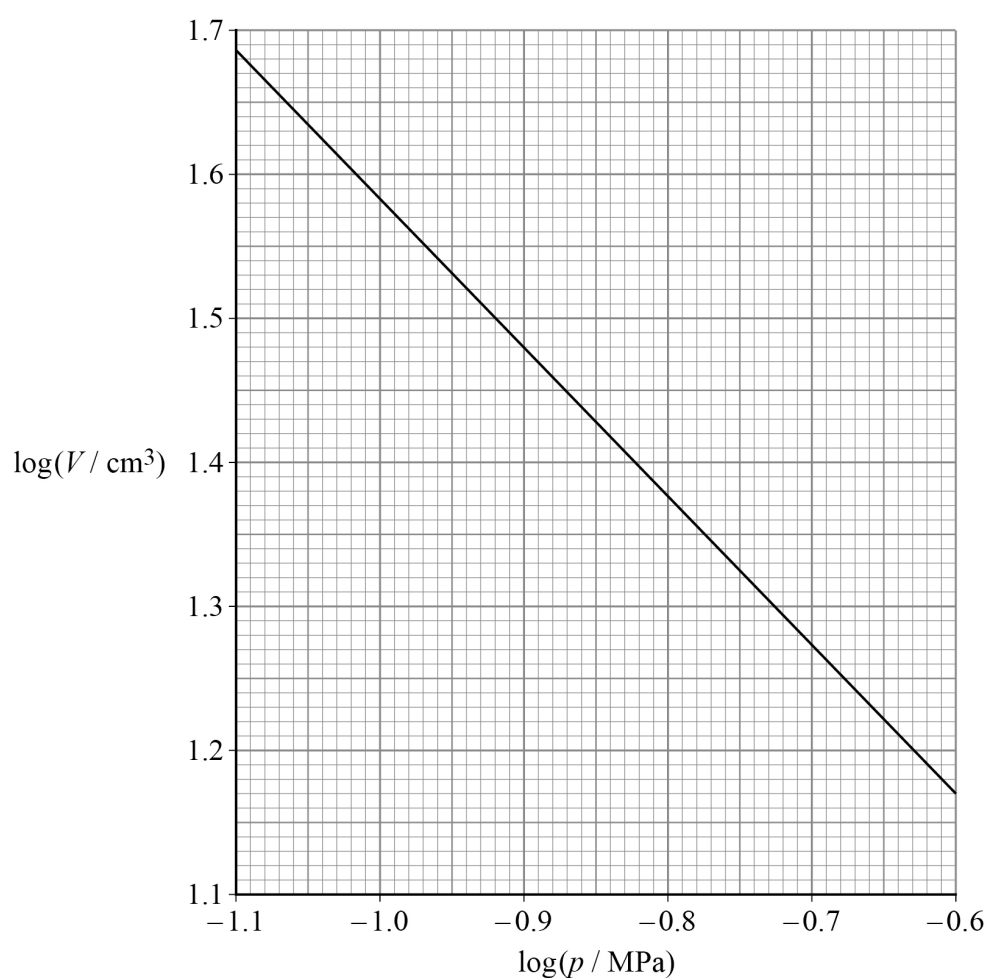
volume = _____ cm^3

Question 4 continues on the next page



0 4 . 5 Figure 13 shows data obtained using the apparatus in Figure 12.

Figure 13



Explain why the gradient of the graph in **Figure 13** confirms that the air obeys Boyle's law.

[3 marks]

0 4 . 6 The largest pressure that can be read from the pressure gauge is 3.4×10^5 Pa.

Determine, using **Figure 13**, the volume V corresponding to this pressure.

[3 marks]

$V =$ _____ cm^3

0 4 . 7 State **one** property of the air that must not change during the experiment.
Go on to suggest how this can be achieved.

[2 marks]

END OF QUESTIONS



MARK SCHEMES

official mark schemes



06	C
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07

C (AO1)

work done and the moment of a couple



08	D (AO3)	m μ p
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04.1	Idea that $YM = \frac{(\text{tensile}) \text{ stress}}{(\text{tensile}) \text{ strain}}$ and (tensile) strain has no units ✓		1	AO1
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Question	Answers	Additional comments/Guidance	Mark	AO
04.2	Evidence of determination of volume of one wire ₁✓ Uses relationship between density of X OR the density of the wire used in MP1 and their volume to determine their mass ₂✓ Answer between £4800 and £4900 ₃✓	When X is used in MP1, condone the use of diameter for radius of X. Expect $V = 3.3 \times 10^{-6} \text{ m}^3$ Condone PoT error Expect $M = 64 \text{ g}$ or 65 g Condone PoT error 75×64 or 75×65	3	AO3

Question	Answers	Additional comments/Guidance	Mark	AO
04.3	W and Z , as their densities are the same (and density is the only one that is a property of the material) ✓	Allow suggestion that the Young modulus is the same provided there is evidence of its determination for both.	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO										
04.4	Draws best-fit line ¹✓ Uses pair of values of stress and strain from point on line more than halfway along the line OR uses a difference in two pairs that is more than half the line ²✓ Evidence of attempt to use equation(s) to determine E, k, l, A or d from graph OR for W (for use in a comparison). ³✓ Compares E for W with value from Figure 5 OR compares k, l, A or d for Figure 5 with value for W With answer yes ⁴✓	For ¹✓ look for an equal scatter of points either side of the line. Allow half square tolerance on graph read-offs. Condone PoT error Copy of W data from table 1 <table border="1"> <thead> <tr> <th>Wire</th><th>Length / m</th><th>Diameter / mm</th><th>Stiffness / N m⁻¹</th><th>Density / kg m⁻³</th></tr> </thead> <tbody> <tr> <td>W</td><td>3.10</td><td>1.7</td><td>4.90×10^4</td><td>2.71×10^3</td></tr> </tbody> </table> eg cross-sectional area of W = $2.27 \times 10^{-6} \text{ m}^2$ Condone PoT error $E = 6.8 \times 10^{10} \text{ (N m}^{-2}\text{)}$ Accept answers that round in the range 6.7×10^{10} to 6.9×10^{10} for E from graph.	Wire	Length / m	Diameter / mm	Stiffness / N m ⁻¹	Density / kg m ⁻³	W	3.10	1.7	4.90×10^4	2.71×10^3	4	AO3
Wire	Length / m	Diameter / mm	Stiffness / N m ⁻¹	Density / kg m ⁻³										
W	3.10	1.7	4.90×10^4	2.71×10^3										
Total			9											

Question	Answers	Additional comments/Guidance	Mark	AO
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B



01.1	$n = 43.1 \checkmark (\geq 2 \text{ SF})$	$n = \frac{105 \times 10^3 \times 1}{8.31 \times (273 + 20.0)}$	1	AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO																					
01.2	Use of $m = \frac{\rho V}{nN_A}$ OR $m = \rho V$ OR use of $m_{\text{molecule}} = \frac{m_{\text{gas}}}{N_A}$ OR $N = nN_A$ OR $(c_{\text{rms}})^2 = \frac{3p}{\rho}$ seen in any form OR use of their mass with $pV = \frac{1}{3}Nm(c_{\text{rms}})^2$ OR use of $\frac{1}{2}m(c_{\text{rms}})^2 = \frac{3}{2}kT \checkmark_1$ Correct answer see table $\checkmark_2$ Correct SF see table $\checkmark_3$ <table><tr><th>n</th><th>$\checkmark_2$ $c_{\text{rms}} / \text{m s}^{-1}$</th><th>$\checkmark_3$ SF</th></tr><tr><td>Without n</td><td>500 – 503</td><td>3 SF (501 – 503)</td></tr><tr><td>n more than 3SF</td><td>500 – 503</td><td>3 SF (501 – 503)</td></tr><tr><td>43.1</td><td>500 – 503</td><td>3 SF (501 – 503)</td></tr><tr><td>43</td><td>500 – 503</td><td>2 SF (500)</td></tr><tr><td>40 (no evidence of $n = 43$ in 1.1)</td><td>482 – 484 or 500</td><td>2 or 1 SF (480 or 500)</td></tr><tr><td>40 (evidence of $n = 43$ in 1.1)</td><td>482 – 484 or 500</td><td>1 SF (500)</td></tr></table>	n	$\checkmark_2$ $c_{\text{rms}} / \text{m s}^{-1}$	$\checkmark_3$ SF	Without n	500 – 503	3 SF (501 – 503)	n more than 3SF	500 – 503	3 SF (501 – 503)	43.1	500 – 503	3 SF (501 – 503)	43	500 – 503	2 SF (500)	40 (no evidence of $n = 43$ in 1.1)	482 – 484 or 500	2 or 1 SF (480 or 500)	40 (evidence of $n = 43$ in 1.1)	482 – 484 or 500	1 SF (500)	Allow ecf for incorrect T and/or n in 1.1 Several approaches are possible $m = \frac{pV}{nN_A} = \frac{1.25 \times 1.00}{43.1 \times 6.02 \times 10^{23}} = 4.82 \times 10^{-26}$ (5.1×10^{-26} if 40 used) $c_{\text{rms}} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 293}{4.82 \times 10^{-26}}} = 502$ OR $pV = \frac{1}{3}Nm(c_{\text{rms}})^2 \quad p \frac{Nm}{\rho} = \frac{1}{3}Nm(c_{\text{rms}})^2$ $(c_{\text{rms}})^2 = \frac{3p}{\rho} \left(= \frac{3pV}{Nm} = \frac{3p \times 1}{\rho} \right)$ $c_{\text{rms}} = \sqrt{\frac{3 \times 105 \times 10^3}{1.25}} = 502$	3	AO2
n	$\checkmark_2$ $c_{\text{rms}} / \text{m s}^{-1}$	$\checkmark_3$ SF																							
Without n	500 – 503	3 SF (501 – 503)																							
n more than 3SF	500 – 503	3 SF (501 – 503)																							
43.1	500 – 503	3 SF (501 – 503)																							
43	500 – 503	2 SF (500)																							
40 (no evidence of $n = 43$ in 1.1)	482 – 484 or 500	2 or 1 SF (480 or 500)																							
40 (evidence of $n = 43$ in 1.1)	482 – 484 or 500	1 SF (500)																							

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	$T = 4 \times 293$ or 4 times the starting temperature in K ✓ change in temperature = 879 (K) ✓ (correct answer gains both marks) Alternative $T = \frac{m(2c_{\text{rms}})^2}{3k}$ correctly calculated for their m, c_{rms} ✓ Their calculated $T - 293$ ✓ 7709	mp1 Using $\frac{1}{2}m(c_{\text{rms}})^2 = \frac{3}{2}kT$ so $(c_{\text{rms}})^2 \propto T$ $\frac{(c_{\text{rms}})^2}{293} = \frac{(2 \times c_{\text{rms}})^2}{T}$ $T = 293 \times 4 = 1172$ K mp2 change in temperature = $1172 - 293 = 879$ K Allow answer that rounds to 880 (K) If no other marks awarded award max 1 when T is 4 times original and $\Delta\theta = 60$	2	AO2f

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	Max 2 from: ✓✓ - Calculation of mass of water condensed in one hour $1.25 \times 960 \times (0.0057 - 0.0037) = 2.4$ (kg) - use of their mass with $mc\Delta\theta$ (expect 4.5×10^4 (J)) - use of their mass with mL (expect $5.5(2) \times 10^6$ (J)) heat energy removed = 5.6×10^6 (J) ✓		3	2 × AO2.2f 1 × AO3.1a
Total			9	

7

Question	Answers	Additional comments/Guidelines	Mark	AO



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
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Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	average d OR uncertainty in d $_1\checkmark$	answers to >3sf rounding to 2.37(%) earns both marks for $_1\checkmark$ either average = 33.8(0) (mm) OR uncertainty from half range = 0.8(0) (mm); allow $\frac{1}{2} \times (34.5 - 32.9)$ seen in working; credit if seen in a percentage uncertainty calculation	1	2 x AO2
	percentage uncertainty 2.37(%) $_2\checkmark$	for $_2\checkmark$ 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 $6.4 (\times 10^4)$ OR sub of all data in to $\Delta V = \frac{\pi \times (\text{their } d)^2 \times L}{4} \times \text{their \% uncertainty}$ $/ \Delta V = \text{their volume} \times \text{their \% uncertainty}$ OR recognisable ΔV with POT error	1	
	Δ volume between 4.8 and $4.9 \times 10^3 \text{ (mm}^3\text{)}$ 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 5 th AND above 4 th ie <u>no overlap between line and either ±</u> ; 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 $\Delta L^2 = 25 (\times 10^{-3} \text{ m}^2)$; 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 $0.0378 \Omega \text{ m}$ as equally acceptable; allow alternative valid answer, eg $37.8 \Omega \text{ mm}$	1	
Total			11	

Question	Answers	Additional comments/Guidelines	Mark	AO
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02.1	(measuring $20T$) (idea of) reduces the effect of random error (on T) OR reduces the percentage uncertainty ✓	allow (idea of) 'reducing the effect of uncertainty due to 'stop-start error' / 'human reactions' / 'human error'; accept 'to improve precision' / 'to reduce relative error' / reduces the percentage error; condone 'reduces the uncertainty in T ' 'to calculate an average' is neutral; to reduce 'uncertainty' / 'measurement error' / 'human error' / 'human reactions' / 'stop-start error' are neutral 'easier to measure' / 'improve accuracy' / comments about systematic error are neutral	1	AO1
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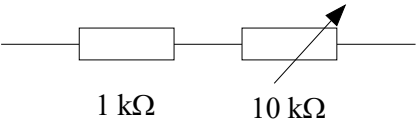
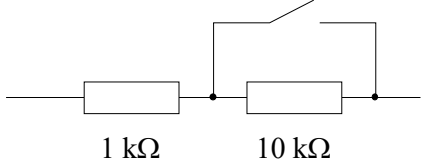
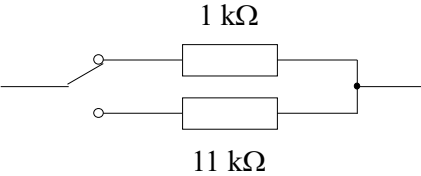
Question	Answers	Additional comments/Guidance	Mark	AO
02.2	(repeating the ($20T$) measurements) (idea of) a check for / enables the detection of / elimination of anomalies (in $20T$) ✓	allow 'to avoid miscounting cycles'; accept 'to improve accuracy' / 'to reduce statistical error' / 'account for systematic error' 'to reduce the effect of anomalies' / 'to calculate an average' are neutral; 'to reduce (effect of) uncertainty' / 'measurement error' / 'human error' are neutral 'improve precision' / comments about random error are neutral	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
02.3	average $(20)T$ OR uncertainty in $(20)T$ ✓ percentage uncertainty based on a correct method = 1.4 % ✓	for 1 ✓ average $20T = 19.2$ (s) (use evidence of calculator value 19.196 to confirm that all 5 sets were used) OR uncertainty in $20T = 0.27$ OR $\frac{19.45 - 18.91}{2}$; allow $19.45 - 19.2(0)$ OR $19.2(0) - 18.91$ average $T = 0.96$ (s) (calculator value 0.9598) OR uncertainty in $T = 0.0135 / 0.014$ (s) OR $\frac{0.973 - 0.946}{2}$; allow $0.973 - 0.96$ OR $0.96 - 0.946$ for 2 ✓ accept any > 2 sf that rounds to 1.4%; condone max 4 sf; do not allow 0.014	2	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
02.4	gradient evaluated from ΔT divided by ΔR_2 with $\Delta R_2 \geq 6 \text{ k}\Omega$; OR evidence of valid simultaneous equations with full substitution using read-offs for T and R_2 with $\Delta R_2 \geq 6 \text{ k}\Omega$ $_1\checkmark$ attempts to determine C by a valid method $_2\checkmark$ C in range 3.8×10^{-5} to $4.1 \times 10^{-5} \text{ (F)}$ $_3\checkmark$ attempts to determine R_1 by a valid method $_4\checkmark$ R_1 in range 2.2 to $2.5 \times 10^4 \text{ (}\Omega\text{)}$ $_5\checkmark$	$_1\checkmark$ is for the process, not the result allow one read off error; allow POT error in substituted data expect gradient $\approx 5.5 \times 10^{-5} \text{ (s } \Omega^{-1}\text{)}$; award $_2\checkmark$ $_3\checkmark$ for C in range with correct POT; $_2\checkmark$ is for the process, not the result: see page 12 for $_3\checkmark$ allow ECF for use of their R_1 ; no ECF for POT OR a calculation error in gradient award $_4\checkmark$ $_5\checkmark$ for R_1 in range with correct POT; $_4\checkmark$ is for the process, not the result etc; do not allow working off grid to determine R_1 for $_5\checkmark$ allow ECF for use of their C or their gradient min 2 sf for $_3\checkmark$ and $_5\checkmark$; allow ≥ 3 sf rounding to 2 sf in range; don't penalise twice for results based on simultaneous equations with R_2 values in $\text{k}\Omega$	5	AO2



Question	Additional comments/Guidelines for 2✓	Additional comments/Guidelines for 4✓
02.4	$C = \frac{\text{their gradient}}{2 \times \ln 2}$ OR $C = \frac{\text{their gradient}}{\ln 4}$ OR $C = \frac{\text{their } \Delta T}{2 \times \ln 2 \times \text{their } \Delta R_2}$ OR correct manipulation of valid simultaneous equations OR $C = \frac{\text{their } T}{\ln 2 \times (\text{their } R_1 + 2(\text{their } R_2))}$ (where their R_1 has been found by a method not involving C; their T and their R_2 are corresponding values read-off Figure 4)	$R_1 = \frac{2 \times \text{their vertical intercept}}{\text{their gradient}}$ OR $R_1 = \frac{\text{their vertical intercept}}{\ln 2 \times \text{their } C}$ OR $R_1 = \frac{\text{their } T}{\ln 2 \times \text{their } C} - 2 \times \text{their } R_2$ (where their T and their R_2 are corresponding values read-off Figure 4) OR correct manipulation of valid simultaneous equations OR $R_1 = \frac{T_P R_{2Q} - T_Q R_{2P}}{T_Q - T_P}$ (based on read-offs from Figure 4 where their R_{2Q} is their value of R_2 at time T_Q etc)

Question	Answers	Additional comments/Guidance	Mark	AO
02.5	marks can be awarded for suitable sketches up to $_{12}\checkmark\checkmark$ for identifying that their R_2 should • have minimum resistance $1\text{ k}\Omega$ $_A\checkmark$ • have maximum resistance $11\text{ k}\Omega$ $_B\checkmark$ • be a (fixed) resistor (or resistors) in series with a variable resistor $_C\checkmark$ one $1\text{ k}\Omega$ resistor in series with one $10\text{ k}\Omega$ variable resistor or valid labelled sketch $_3\checkmark$ eg 	allow $_A\checkmark\text{ }_B\checkmark$ for a switched 2 fixed resistor circuit that can produce both limiting values, eg   allow $_A\checkmark\text{ }_B\checkmark$ (R_2) from $1\text{ k}\Omega$ to $11\text{ k}\Omega$; allow $_AB\checkmark$ for deducing range = $10\text{ k}\Omega$; for $_C\checkmark$ allow any arrangement that allows R_2 to be varied continuously between limiting values; do not allow fixed resistor in parallel with a variable resistor for $_3\checkmark$ CAO	3	$1 \times \text{AO1}$ $2 \times \text{AO3}$
Total			12	

Question	Answers	Additional comments/Guidance	Mark	AO
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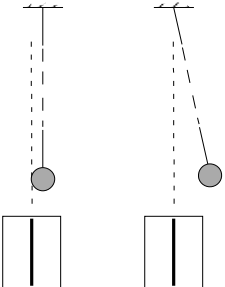
Question	Answers	Additional comments/Guidance	Mark	AO
04.2	MAX $_{1✓2✓}$ from - diameter = $18(.0) + (2 \times)$ their t from 04.1 $_{A✓}$ - circumference = $\pi \times$ their diameter $_{B✓}$ - length = their circumference $\times$ their n from 04.1 $_{C✓}$ correctly calculates L using their $n \times \pi \times (18 + \text{their } t)$ OR using their $n \times \pi \times (18 + (2 \times \text{their } t))$ $_{3✓}$	for $_{A✓}$ accept $t = 1.2$ (mm) for $_{B✓}$ allow $(18 + t)$ OR $(18 + 2t)$ for their diameter; condone $(18 + \frac{t}{2})$ OR 18 the award of $_{3✓}$ is contingent on the award of $_{A✓}$ $_{B✓}$ and $_{C✓}$ for $_{3✓}$ L must be given to 3 sf ie a whole number of millimetres condone the award of $_{1✓2✓3✓}$ if working is missing but recognisable values of n and t are seen	3	AO3

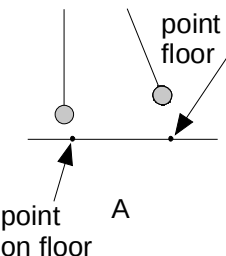
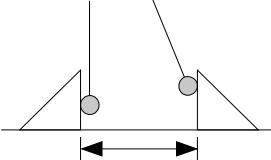
Question	Answers	Additional comments/Guidance	Mark	AO
04.3	identifies B _{1✓} where (the top of the test tube) is moving fastest / has maximum kinetic energy / where the transit time is least _{2✓}	for _{1✓} must reject A and D; allow C only if an additional mark added to the tube at this height when the tube is at the equilibrium position OWTTE _{2✓} is contingent on _{1✓} for _{2✓} comments about the equilibrium position / equilibrium point / centre of oscillation / rest position are neutral; the idea that 'the (top of the) test tube will always pass point' is neutral; explaining why A, C and D are not suitable is neutral	2	AO1



Question	Answers	Additional comments/Guidance	Mark	AO
04.4	derives an expression that can be used to determine ρ for milk OR evaluates $T^2\rho$ OR $T\sqrt{\rho}$ (for oil) 1✓ density of liquid = $\left(849 \times \frac{0.587^2}{0.534^2}\right) = 1.03 \times 10^3 \text{ (kg m}^{-3}\text{)} 2✓$	award 1✓ and 2✓ independently for 1✓ accept a valid expression, any subject, without full substitution, eg $\rho_{\text{milk}} = \rho_{\text{oil}} \frac{T_{\text{oil}}^2}{T_{\text{milk}}^2}$ OR $0.587^2 \times 849$ seen / 293 seen OR $0.587 \times \sqrt{849}$ seen / 17.1 seen for 2✓ 3 sf only but condone 4 sf answer in the range 1025 to 1030 only	2	1 × AO1 1 × AO2

Question	Answers	Additional comments/Guidance		Mark	AO
04.5	MAX 3 from a valid modification ₁ ✓ a rationale for the modification ₂ ✓ an additional valid modification ₃ ✓ a rationale for the second modification ₄ ✓	₁✓ (idea of) increasing the depth of the oil, eg add (more) oil to the beaker do not accept 'use a narrower beaker' as this increases drag ₃✓ (idea of) increasing the distance between the test tube and the beaker walls, eg use a wider / larger diameter beaker AND add oil to (at least) the original depth (to maintain the initial amplitude)	₂✓ (idea of) increasing the (initial) displacement / amplitude / height of the test tube OR increasing the (initial) energy of the system allow 'to produce larger / bigger oscillations' ₄✓ (idea of) reducing the drag / (fluid) resistance / (fluid) friction / velocity gradient; condone (idea of) 'reducing the damping'	3	AO3
Total				12	

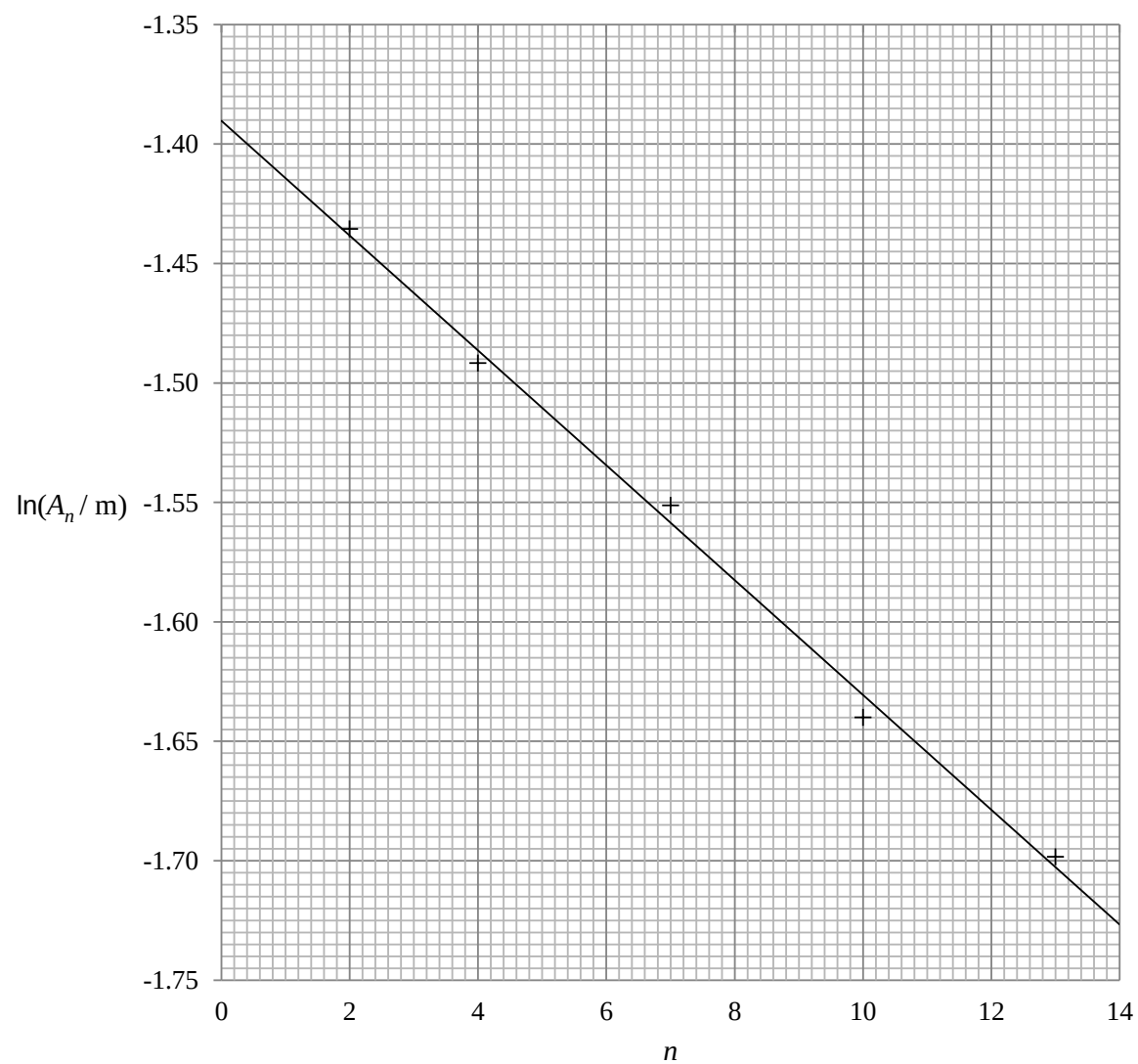
01.1	<u>annotates</u> Figure 1 to identify equilibrium position; some (or all) of the mark should be below the bob or (bottom of mark) should be level with bottom of bob 1✓ this is where (the pendulum / bob) is moving fastest / (pendulum has) maximum kinetic energy or this is where the transit time is least 2✓	for 1✓ condone a poorly-annotated sketch if intention is clarified in 2✓; do not allow talkout do not insist on seeing the outline of the card as long as the <u>vertical</u> line is seen; condone arrows $\uparrow \downarrow$ etc; blobs $\bullet + \times$ are neutral allow <u>vertical</u> line of the mark to be aligned with either edge of the bob in the left-hand view or marked directly below point of suspension (within one-quarter of bob radius) in the right-hand view, eg  if marks are shown on each view of the pendulum, then each separately must satisfy the criteria for 1✓ 2✓ is contingent on award of 1✓ for 2✓ comments about why the mark is not aligned with bob in right-hand view are neutral (at equilibrium) 'acceleration is zero' is neutral	2	AO1-1b
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Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	use of appropriate <u>horizontal</u> scale or wtte 1✓ use of set-square with edge made vertical or other suitable equipment to eliminate parallax error in A_R 2✓ measures A_R from (either) edge of displaced bob 3✓	any of 1✓2✓ or 3✓ can be earned by suitable annotation to Figure 2 for 1✓ ruler or 'mm scale' only; 'measuring with a ruler between points marked on the floor' is acceptable (see A below) or use of a 'ruler placed on floor' (see B)  Diagram B: A ruler is placed on the floor. A bob is suspended from a point on the floor. The distance between the bob and the ruler is labeled B. for 2✓ allow use of plumb line, spirit level, video or photographic equipment; reject clamp stand any use of the fiducial mark or the idea that the supporting beam is horizontal are neutral withhold 3✓ unless candidates explains that allowance is being made for radius / diameter of bob (see C and D below)  Diagram D: A bob is suspended from a point on the floor. The distance between the bob and the floor is labeled D.	MAX 2	AO3.2b

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	extrapolation of curve to (at least) $x = 0.70$ m ^{1✓} consistently-recorded min 3 dp values for $T_{0.35}$ and $T_{0.70}$ ^{2✓} evidence of valid calculation (check denominator correct); percentage increase in range 1.4(0) % to 1.8(0) % ^{3✓}	for ^{1✓}extrapolation must be continuous and smooth; allow (ruled) straight line; reject hairy, thick or dashed lines for ^{2✓}allow values seen in working; $T_{0.35}$ must round to 2.322; condone $T_{0.70}$ by eye don't insist on horizontal or vertical lines between curve and vertical axis on Figure 3 for ^{3✓}expected answer is 1.51%	1 2	AO3.1a AO2.1h
01.4	rejects anomalous 0.247; average $A_5 \geq 3$ sf (that rounds to) 0.22<u>1</u> (s) ^{1✓} correct uncertainty calculation or 0.004(0) (s) seen ^{2✓} or does not reject 0.247; average $A_5 =$ (rounds to) 0.22<u>6</u> (s); correct uncertainty calculation or 0.01<u>5</u> (s) seen ^{12✓} correct % uncertainty from $\frac{\text{their half range}}{\text{their average}} \times 100 \geq 2$ sf ^{3✓}	0.221 and 1.8 % on answer lines earn ^{123✓✓✓} ^{1✓} (0.247 rejected) full answer 0.2214 (s) ^{2✓} from half range; can be inferred from working ^{3✓} if ^{12✓✓}full answer 1.81 %; allow 1.8 % or 1 sf 2 % when 0.247 is not rejected ^{12✓}full answer 0.2257 (s) ^{3✓} full answer 6.647 %; allow 6.6<u>4</u> / 6.6<u>5</u> % or 2 sf 6.6 / 6.7 % for ^{3✓} allow ECF only if uncertainty is from half range	3	AO2.1h

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	$\ln(A_4 / m) = -1.492$ ✓	CAO 3 dp only	1	AO1.1b
01.6	vertical scale with one major (cm) grid square = 0.02 or 0.025; maximum spacing of values marked on the scale = 5 cm ¹✓ points plotted for $n = 2, 4, 7, 10$ and 13; suitable continuous <u>ruled</u> line of negative gradient from $n = 2$ to (at least) $n = 13$; line must pass above $n = 4$ and $n = 10$ points and must pass below $n = 7$ point ²✓	withhold both marks for false plot for ¹✓ scale might go (down page) from -1.40 to -1.72 (1 square = 0.02) or from -1.30 to -1.70 (1 square = 0.025); scale must cover range of plotted points; do not insist on use of broken scale convention no credit for reversed values leading to graph with 'positive' gradient; no credit for missing / inconsistent minus signs or for inconsistent dp in labelled values for ²✓ allow ECF acceptable line based on accurate plot of incorrect $n = 4$ point allow ECF for graph with 'positive' gradient due to reversed scale, eg line must pass below $n = 4$ and $n = 10$ points and must pass above $n = 7$ point accept only 4 points if $n = 4$ is not tabulated; line must pass between $n = 7$ and $n = 10$ ignore any plot of $\ln(A_5 / m)$ based on 01.4 data; withhold mark for poor points eg blobs or for thick / faint / non-continuous line	2	AO2.1h





Question	Answers	Additional comments/Guidelines	Mark	AO
01.7	(any) correct expression with $\ln A_n$ as subject $_1✓$ $\delta = e^{-\text{gradient}}$ or wtte $_2✓$	for $_1✓$ $y = mx + c$ idea is required either $\ln A_n = -n \ln \delta + \ln A_0$ ($y = mx + c$) or $\ln A_n = \ln A_0 - n \ln \delta$ ($y = c + mx$) not $\ln A_n = \ln A_0 - \ln \delta^n$ treat 'lg A' as a slip allow use of 'log A' for $_1✓$ but no ECF in $_2✓$ for $_2✓$ δ must be the subject, reject $\ln \delta = -\text{gradient}$ etc allow ECF if $_1✓$ is withheld for missing – sign; if gradient is evaluated accept $\delta = e^{(+).0.024}$ or $\delta = 1.02(4)$ etc an explanation that δ can be found using $A_n = A_0 \delta^{-n}$ must rely on values of A_n, A_0 and n that are determined using <u>the line</u> in Figure 4	2	AO3.2a
Total			15	

Question	Answers	Additional comments/Guidelines	Mark	AO
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01.1	(±) 0.5(0) mm CAO ✓		1	AO2
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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✓} $R = 0.51 \text{ } (\Omega)$ _{2✓}	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 $\frac{1.2}{1.2 + R} = \frac{0.931}{0.397 + 0.931}$ for _{2✓} condone 0.512 OR 0.5117 (Ω)	2	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	continuous <u>ruled</u> best-fit line drawn ₁✓ gradient evaluated from ΔR divided by ΔL; with correct $\Delta R \geq 0.2 \text{ } (\Omega)$ OR correct $\Delta L \geq 150 \text{ (mm)}$ ₂✓	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✓ is for the process if using points these must lie on their line; do not penalise for AE / POT in result; expect gradient about $1.66 \text{ } (\Omega \text{ m}^{-1})$ withhold both marks for no line on Figure 5	2	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO										
01.6	attempts to find ρ_x using $\frac{\pi d^2}{4} \times \frac{\Delta R}{\Delta L}$ $_1\checkmark$ ρ_x in range below for their metal on the answer line $_2\checkmark$ <table><tr><td>metal</td><td>resistivity / $\Omega \text{ m}$</td></tr><tr><td>copper</td><td>1.6 to 1.8 ($\times 10^{-8}$)</td></tr><tr><td>tungsten</td><td>5.4 to 5.9 ($\times 10^{-8}$)</td></tr><tr><td>alumel</td><td>3.3 to 3.8 ($\times 10^{-7}$)</td></tr><tr><td>nichrome</td><td>1.0 to 1.2 ($\times 10^{-6}$)</td></tr></table> POT correct and unit = $\Omega \text{ m}$ for their metal on the answer line $_3\checkmark$ nichrome CAO $_4\checkmark$	metal	resistivity / $\Omega \text{ m}$	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 $_1\checkmark$ 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; 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 $_2\checkmark$ ignore POT and use the most significant digits in their ρ_x to judge result, eg for alumel $\rho_x = 0.351$ scores $_2\checkmark$ $_3\checkmark$ because this is equivalent to 3.51×10^{-1} allow >2 sf values that round to 2 sf in range for $_3\checkmark$ allow alternative valid answer eg (for nichrome) $1.1 \times 10^{-3} \Omega \text{ mm}$ for $_4\checkmark$ must be consistent with their 01.5 $\frac{\Delta R}{\Delta L}$	4	1 $\times$ AO3 3 $\times$ AO2
metal	resistivity / $\Omega \text{ m}$													
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 ($\times 10^{-6}$)													

Question	Answers	Additional comments/Guidelines	Mark	AO
01.7	the error bars for L / the horizontal error bars are the same length or WTTE $_1✓$ quantitative comment about the error bars for R / the vertical error bars $_2✓$	for $_1✓$ allow 'they are 10 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 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	2	AO3

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✓ explains how to determine uncertainty in gradient ₂✓	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 for ₂✓ allow word equation or any of the following $(m - m_2) \text{ OR } (m_1 - m) \text{ OR } \frac{(m_1 - m_2)}{2}$ 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	2	AO1
Total			15	

Question	Answers	Additional comments/Guidelines	Mark	AO
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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 2 nd and 3 rd 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
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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✓} suggests a valid test of Figure 7 that confirms the inverse square law _{2✓} 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✓}	for _{1✓} allow 'get' / 'obtain'; must specify 3 or more; condone 'several' / 'many' / 'numerous' / 'quite a lot' / 'quite a few'; 'multiple' is neutral 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 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✓}	2	AO1

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

Question	Answers	Additional comments/Guidelines	Mark	AO																								
02.5	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✓	for ₁✓ do not insist on units; condone extra sf that round to these values <table><tr><th>Setting</th><th>Min <i>R</i></th><th>Max <i>R</i></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 <i>R</i> 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	Setting	Min <i>R</i>	Max <i>R</i>	range B	1645 (Ω)	1717 Ω	range C	1.63 kΩ	1.73 (kΩ)		Range (/ Ω)	Uncert. (/ Ω)	% Diff.	% Uncert.	B	72	(±)36	≈ 4%	≈ 2%	C	100	(±)50	≈ 6%	≈ 3%	2	AO3
Setting	Min <i>R</i>	Max <i>R</i>																										
range B	1645 (Ω)	1717 Ω																										
range C	1.63 kΩ	1.73 (kΩ)																										
	Range (/ Ω)	Uncert. (/ Ω)	% Diff.	% Uncert.																								
B	72	(±)36	≈ 4%	≈ 2%																								
C	100	(±)50	≈ 6%	≈ 3%																								

Question	Answers	Additional comments/Guidelines	Mark	AO
02.6	ANY 2 OF $_1\checkmark$ to $_3\checkmark$ below: light level / brightness / intensity in the room OR WTTE $_1\checkmark$ voltage (across) / current in / power of / brightness of the lamp $_2\checkmark$ thickness of the glass / slides $_3\checkmark$	for $_1\checkmark$ allow 'background lighting' / 'external light sources' / 'maintain blackout'; 'temperature' is neutral for $_2\checkmark$ allow 'intensity of (light from) the lamp' / 'luminosity of lamp' / 'pd of power supply'; allow $_{12}\checkmark$ for light incident on slides = 400 (lx) do not allow unqualified 'light intensity' for $_3\checkmark$ 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	2	1 × AO1 1 × AO3



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✓ μ is $-\text{gradient}$ 2✓ 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✓	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 $\begin{array}{ccccccc} \ln E_V & = & \ln 400 & \text{OR } 5.99 & - & \mu N & \\ y & (=) & c & & (+) & mx & \end{array}$ 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; 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✓	2	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.8	evidence for any workable method that would lead to EITHER $N_{1/2} \approx 7.7$ OR a final integer answer that is appropriate to their calculated value $_1\checkmark$ $N_{1/2} = 8$ slides CAO $_2\checkmark$	for $_1\checkmark$ expect use of $\ln 0.5 = -9.0 \times 10^{-2} N_{1/2}$ or similar (including trial and improvement)	2	AO3
Total			15	

Question	Answers	Additional comments/Guidelines	Mark	AO
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03.1	tick in first box (2.7 V) ✓	[cao]	1	AO2-1d
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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 $T_{1/2}$ correct OR uncertainty in $T_{1/2}$ correct $1\checkmark$	for $1\checkmark$ average $T_{1/2} = 12.04$ (s); reject 12.0 allow credit for correct $T_{1/2}$ seen in working for percentage uncertainty; uncertainty in $T_{1/2}$ (from half range) = 0.11 (s)	1	AO2-1h
	percentage uncertainty in $T_{1/2}$ correct $2\checkmark$	for $2\checkmark$ minimum 2 sf; correct answer rounds to 0.91(4)%	1	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	time constant = $\frac{\text{their mean } T_{1/2}}{\ln 2}$ OR $\frac{-(\text{their mean } T_{1/2})}{\ln 0.5} \checkmark$	expect 17.37 (s); allow minimum 3 sf 17.4 / use of $\ln 2 = 0.69$ for leading to 17.45; reject use of $T_{1/2} = 12$ leading to 17.31; reject $\frac{\text{their mean } T_{1/2}}{\ln 0.5}$ (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 V before connecting C to X ₁ ✓ as X is connected ₂ ✓	for ₁ ✓ discharge C / connect flying lead to Y / 'reset to 0 V' (before reconnecting); reject 'reset equipment' for ₂ ✓ reduce the <u>output pd</u> / socket X (or wtte) to ≤ 3 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 $\Delta V > 1.5$ V or wtte _{3a} ✓ OR take repeated readings (of $T_{1/2}$ 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 <u>zero error</u> (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 $T_{1/2}$ reject 'repeat etc to get more reliable result' for ₄ ✓ accept 'check etc for <u>systematic error</u> ' '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 $(-\text{gradient}^{-1})$ '	1	AO2-1d
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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 $V < 2 \text{ V}$ / smallest $V = 2 \text{ V}$ 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 <u>14</u> to <u>2</u> (V) ₇✓	4	AO2-1g



		to maximise evidence available (for graph / Figure 8) or wtte ₈ ✓ no readings for $V > 14 \text{ V}$ / largest $V = 14 \text{ V}$ ₉ ✓ can begin discharge C before starting stopwatch ₁₀ ✓		
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Question	Answers	Additional comments/Guidelines	Mark	AO
03.7	attempts gradient calculation using $\Delta \ln(V / V)$ divided by Δt ; use of $ \text{gradient} = \left \frac{-1}{R \times C} \right $ _{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 $V_0 = 14.1 \text{ (V)}$; $V = 0.37V_0$ when $t = RC \therefore V = 0.37V_0 = 5.2 \text{ V}$	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) $\therefore R = \frac{15}{C}$ 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
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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 $\ln(V_{10} / V)$ read off and I_{10} calculated using $\frac{\text{their } V_{10}}{\text{their voltmeter resistance}}$		
Total			19	

22

B

 10^4 m

A



26	D
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D



19

D

force

mass $\times$ displacement

02.1	Show attempted use of all three equations: gradient = $\frac{\Delta V}{\Delta t}$ AND $I = \frac{\Delta Q}{\Delta t}$ AND $Q = CV$ ✓ $I_0 = C \times \text{initial gradient}$ ✓	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 $I_0 = C \times \text{initial gradient}$ $(\Delta)Q = I(\Delta)t$ can be seen via substitution if both $(\Delta)Q$ 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 $I = C \times \text{gradient}$ or C or gradient as subject.	2	AO2c
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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 ln2 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 $R = \frac{T}{C} = \frac{7.5}{31.0 \times 10^{-6}} = 2.4(2) \times 10^5 \Omega$ 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 $V_0 = I_0 R$ (expect 8.6 V) ✓₁ Use of $V = V_0 \left(1 - e^{-\frac{t}{RC}} \right)$ ✓₂ Alternative Use of $V_0 = I_0 R$ so $I = \frac{I_0 R - 6}{R}$ (expect 1.1×10^{-5} A) ✓₁ Use of $I = I_0 e^{-\frac{t}{RC}}$ ✓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 $C = \epsilon_r \epsilon_0 A/d$ ✓ $\frac{V_1}{V_2} = 0.125$ ✓	mp1 $V = \frac{Qd}{\epsilon_r \epsilon_0 A}$ 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	

11

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



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 $M_s = 1.99 \times 10^{30}$ 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 = $\frac{1}{2} (m) 1400^2 = 9.8 \times 10^5 (m) J$ ✓ Energy needed to escape = $7.4 \times 10^5 (m) J$ ✓ So sufficient energy to escape. ✓ OR For object on surface escape speed given by $7.4 \times 10^5 = \frac{1}{2} v^2$ ✓ 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 $(1.06 \times 10^{-8} \times \sqrt{\text{answer 0.73}})$ 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
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04.1	Substitution of data in resistance formula or $A = \rho L/R$ seen✓ Area of cross section = $2.1(1) \times 10^{-9} \text{ (m}^2\text{)} \checkmark$	Cor for incorrect length from attempt at a calculation	1
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04.2	Maximum possible pd across $0.25\text{ k}\Omega$ is 9 V ✓ (Max power dissipated) = $9^2/250 = 0.32\text{ W}$ so resistor is suitable. ✓ OR When resistor dissipates maximum power $V^2 = 0.36 \times 250$ so max $V = 9.5\text{ V}$ ✓ This is higher than the supply pd so this power dissipation so will not be reached. ✓ OR Power dissipated when output is $5\text{ V} = 4^2/250 = 0.064\text{ W}$ ✓ Which is below the max power dissipation of 0.36 W ✓	$9^2/250 = 0.32\text{ W}$ with incorrect conclusion scores 1 Second mark implies the first $9^2/0.36 = 225\text{ }\Omega$ alone is not a useful calculation in the context. Still need to explain the effect of using the $250\text{ }\Omega$. 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 ✓ $540\text{ }\Omega$ ✓ OR Current in circuit at room temp = $4/250 = 16\text{ mA}$ ✓	Alternative to find resistance of combination Current in circuit at room temp = $4/250 = 16\text{ mA}$ ✓ Resistance of combination = $5/16\text{ mA} = 313\text{ }\Omega$ ✓ OR $\frac{V_{\text{combination}}}{V_{250}} = \frac{R_{\text{combination}}}{250}$ $\frac{5}{4} = \frac{R_{\text{combination}}}{250}$ $R_{\text{combination}} = 313\text{ }\Omega$	1 1 1 1

	Current in thermistor = $5/750 = 6.7 \text{ mA}$ ✓		
	Current in R = 9.3 mA ✓ $R = 5/9.3 = 540 \Omega$ ✓ 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
Total			12

Radius of orbit = $5 \tan 28.5 + 1 = 3.71 \text{ m}$ ✓

Speed = $2 \times 3.14 \times 3.71/5.2 = 4.49 \text{ ()}$ ✓

For second mark only allow

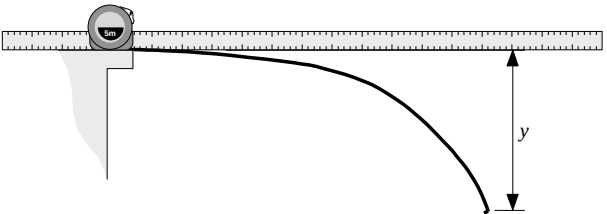
Use of $\sin 28.5$ gives orbit radius 3.39 m and
speed = 4.1 m s^{-1}

Or

1

1



02.1	use a metre ruler or straight edge placed alongside the tape measure and overhanging the (horizontal) bench, eg  y is measured directly using this method using additional ruler₁✓ using additional ruler made vertical (as before) or using set-square placed against horizontal ruler₂✓	annotation to Figure 7 reject suggestions that y can be found without making at least one vertical measurement	2
02.2	(for $x \leq 70$ cm y is small so) <u>percentage/fractional</u> uncertainty in y is (too) large OR (for $x > 70$ cm) <u>percentage/fractional</u> uncertainty in y not (too) large ✓	<u>percentage</u> or <u>fractional</u> and in y are essential; accept 'error' for 'uncertainty'; reject 'small distances are hard to measure'	1

Question	Answers	Additional Comments/Guidelines	Mark
02.3	continuous ruled best-fit line drawn (at least) between 1st and 6th points; line must pass below 2nd point and above 5th point; line must pass above 1st point and below 6th point _{1✓} gradient calculated from their best-fit line; result, minimum 2 sf, in range 3.5 to 4.7 _{2✓} result for n correctly rounded from their gradient to the nearest integer (expect $n = 4$) _{3✓}	for _{1✓} 'pass below' is taken to mean below the intersection of the cross-hairs defining the position of a point; a line that intersects (any of) the cross-hairs of the 1st, 2nd, 5th or 6th points loses this mark for _{1✓} the line must not be thicker than half a grid square, must not vary in thickness and must not be too faint; do not allow two lines unless these are drawn to calculate maximum and minimum gradients from which an average is then calculated for _{2✓} accept answers to greater than 2 sf which round to 2 sf in range 3.5 to 4.7 do not penalise for small steps or read off errors for _{3✓} it must be clear that final result is for n if this is not on the answer line allow ecf for unexpected gradient result that is then correctly rounded to the nearest integer if no line is drawn (losing _{1✓} and _{2✓}) allow _{3✓} if n given as nearest integer to a gradient result obtained using two points on Figure 8	3

Question	Answers	Additional Comments/Guidelines	Mark
02.4	$\log A = (y) \text{ intercept}$ <u>seen</u> OR $\log A = \log y \text{ when } \log x = 0$ OR $\log y = n \log x + \log A$ (or correctly rearranged) <u>seen</u> _{1✓} indirect method to find (vertical) intercept described, eg using (values for) a <u>point on line</u>; substitute into <u>equation</u> (for the line); allow 'into $y = mx + c$'; find $\log A$ (don't penalise incorrect algebra) _{2✓} $A = 10^{(y \text{ intercept})}$ OR $A = 10^{(\log y - n \log x)}$ _{3✓} treat $\ln A = (y) \text{ intercept}$ in _{1✓} as a slip and don't penalise but then insist that following work is consistent, eg insist on use of $\ln y = n \ln x + \ln A$ (if seen) to earn _{2✓} and $A = e^{(y \text{ intercept})}$ to earn _{3✓}	for _{1✓} allow sensible use of $y = mx + c$ idea; reject 'log A is where line crosses y axis' for _{2✓} allow 'use a point on line to find x and y then sub into equation etc'; accept valid similar triangles idea; reject anything such as extrapolating the line to suggest that the intercept can be found directly; for _{3✓} accept '(take/find) anti-log of (log y) intercept'; condone 'inverse log of (log y) for anti-log'; reject 'convert' accept $A = 10^{(\log A)}$ providing _{1✓} awarded accept substitution of n, eg $A = 10^{(\log y - 4 \log x)}$ reject $A = 10^{(-y \text{ intercept})}$ alternative method: using a <u>point on line</u> find $\log x$, $\log y$; <u>anti-log</u> to find x, y _{1✓} use $A = \frac{y}{x^n}$ (equation seen with A the subject or equivalent description of process) _{2✓} repeat (to find A) using a <u>different point on line</u>; calculate average (A) _{3✓} reject averaging of x and y or of log x and log y	3

Question	Answers	Additional Comments/Guidelines	Mark																												
02.5	A evaluated using $A = \frac{y}{x^n}$ OR using $A = 10^{(\log y - n \log x)}$; correct substitution of n (from 02.3) and of y and x in cm from any row in Table 2 (likely values shown opposite), A evaluated correctly to minimum 2 sf and correct POT $_1$✓ order of magnitude of $A = -7$ OR 10^{-7} (accept index or of power of ten) $_2$✓ cm^{-3} $_3$✓ OR $\text{cm}^{(1-n)}$ where n is result given for 02.3	for $_1$✓ ECF for non-integer n values that may be seen in working: <table> <tr> <th>x/cm</th><th>y/cm</th><th>A when $n = 4$</th><th>A when $n = 3.879$ *</th></tr> <tr><td>132.4</td><td>61.2</td><td>1.99E-07</td><td>3.60E-07</td></tr> <tr><td>116.8</td><td>33.7</td><td>1.81E-07</td><td>3.22E-07</td></tr> <tr><td>105.1</td><td>24.3</td><td>1.99E-07</td><td>3.50E-07</td></tr> <tr><td>94.5</td><td>15.6</td><td>1.96E-07</td><td>3.39E-07</td></tr> <tr><td>84.3</td><td>11.0</td><td>2.18E-07</td><td>3.72E-07</td></tr> <tr><td>73.2</td><td>5.7</td><td>1.99E-07</td><td>3.34E-07</td></tr> </table> *equation of best-fit line gives vertical intercept = 3.879 for $_2$✓ accept 1×10^{-7} (cm^{-3}) but reject 1.0×10^{-7} or 2×10^{-7} etc; ECF order of magnitude correct for their value of A; POT must be consistent with unit given eg if cm^{-3} is converted into m^{-3}; for $_3$✓ CAO; use of non-integer, eg $n = 3.6$ requires A in $\text{cm}^{-2.6}$ withhold $_2$✓ and $_3$✓ if A is not evaluated	x/cm	y/cm	A when $n = 4$	A when $n = 3.879$ *	132.4	61.2	1.99E-07	3.60E-07	116.8	33.7	1.81E-07	3.22E-07	105.1	24.3	1.99E-07	3.50E-07	94.5	15.6	1.96E-07	3.39E-07	84.3	11.0	2.18E-07	3.72E-07	73.2	5.7	1.99E-07	3.34E-07	3
x/cm	y/cm	A when $n = 4$	A when $n = 3.879$ *																												
132.4	61.2	1.99E-07	3.60E-07																												
116.8	33.7	1.81E-07	3.22E-07																												
105.1	24.3	1.99E-07	3.50E-07																												
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84.3	11.0	2.18E-07	3.72E-07																												
73.2	5.7	1.99E-07	3.34E-07																												
Total			12																												

Question	Answers	Additional Comments/Guidelines	Mark																																																								
02.5	alternative approaches: A evaluated from $A = \frac{y}{x^n}$ OR from $A = 10^{(\log y - n \log x)}$; correct substitution of n (from 02.3) and of y and x in (in m) etc; A evaluated correctly to minimum 2 sf and correct POT $_1$✓ order of magnitude of $A = -1$ OR 10^{-1} $_2$✓ m^{-3} $_3$✓ A evaluated from $A = \frac{y}{x^n}$ OR from $A = 10^{(\log y - n \log x)}$; correct substitution of n (from 02.3) and of y and x in (in mm) etc; A evaluated correctly to minimum 2 sf and correct POT $_1$✓ order of magnitude of $A = -10$ OR 10^{-10} $_2$✓ mm^{-3} $_3$✓	<table> <thead> <tr> <th>x/m</th><th>y/m</th><th>A when $n = 4$</th><th>A when $n = 3.879$ *</th></tr> </thead> <tbody> <tr><td>1.324</td><td>0.612</td><td>1.99E-01</td><td>2.06E-01</td></tr> <tr><td>1.168</td><td>0.337</td><td>1.81E-01</td><td>1.85E-01</td></tr> <tr><td>1.051</td><td>0.243</td><td>1.99E-01</td><td>2.00E-01</td></tr> <tr><td>0.945</td><td>0.156</td><td>1.96E-01</td><td>1.94E-01</td></tr> <tr><td>0.843</td><td>0.110</td><td>2.18E-01</td><td>2.13E-01</td></tr> <tr><td>0.732</td><td>0.057</td><td>1.99E-01</td><td>1.91E-01</td></tr> </tbody> </table> <table> <thead> <tr> <th>x/mm</th><th>y/mm</th><th>A when $n = 4$</th><th>A when $n = 3.879$ *</th></tr> </thead> <tbody> <tr><td>1324</td><td>612</td><td>1.99E-10</td><td>4.75E-10</td></tr> <tr><td>1168</td><td>337</td><td>1.81E-10</td><td>4.26E-10</td></tr> <tr><td>1051</td><td>243</td><td>1.99E-10</td><td>4.62E-10</td></tr> <tr><td>945</td><td>156</td><td>1.96E-10</td><td>4.48E-10</td></tr> <tr><td>843</td><td>110</td><td>2.18E-10</td><td>4.92E-10</td></tr> <tr><td>732</td><td>57</td><td>1.99E-10</td><td>4.41E-10</td></tr> </tbody> </table> ecf for wrong or non-integer value of n, ie for $\text{cm}^{(1-n)}$	x/m	y/m	A when $n = 4$	A when $n = 3.879$ *	1.324	0.612	1.99E-01	2.06E-01	1.168	0.337	1.81E-01	1.85E-01	1.051	0.243	1.99E-01	2.00E-01	0.945	0.156	1.96E-01	1.94E-01	0.843	0.110	2.18E-01	2.13E-01	0.732	0.057	1.99E-01	1.91E-01	x/mm	y/mm	A when $n = 4$	A when $n = 3.879$ *	1324	612	1.99E-10	4.75E-10	1168	337	1.81E-10	4.26E-10	1051	243	1.99E-10	4.62E-10	945	156	1.96E-10	4.48E-10	843	110	2.18E-10	4.92E-10	732	57	1.99E-10	4.41E-10	
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Question	Answers	Additional Comments/Guidelines	Mark
	pressure (of air) in Figure 9c is greater than (pressure of air) in Figure 9d OR pressure in Figure 9d is lower than pressure in Figure 9c ₁✓ (since) temperature is the same OR	for ₁✓ must refer to either of the relevant figures or give other detail, eg 'when flask is lifted' so their meaning is unambiguous; allow 'when volume decreases pressure increases' but must be comparing 9c with 9d allow 'water pressure decreased in 9d' treat 'air was compressed' (in 9c) as neutral	



02.1	method to reduce uncertainty in volume ₃ ✓	reject weigh / weighed read water level at <u>bottom of the meniscus</u> (or wtte or allow sketch); don't penalise further use of 'beaker' treat as neutral: 'dry cylinder before use' OR procedure to avoid systematic error in determining mass, eg tare / reset / zero the balance with empty beaker on pan / find mass of beaker empty and subtract from mass of beaker plus water; don't penalise further use of 'weigh' / 'scales' allow 'use balance on a <u>horizontal</u> surface'	AO2-1c = MAX 2
	method to reduce uncertainty in time ₄ ✓	ensure stopwatch is zeroed / reset before use	
	added detail ₅ ✓ ₆ ✓ ₇ ✓	collect large(r) <u>volume</u> / for long(er) <u>time</u> / ≥ 60 s ₅ ✓ this reduces <u>percentage</u> / <u>fractional</u> uncertainty ₆ ✓ read at <u>eye level</u> or wtte, to reduce <u>parallax</u> ₇ ✓	

02.2	sensible mark identifying second box indicating ($\text{N m}^{-2} \text{ s}$) only	auto marked question	AO3-1a = 1
02.3	19.8% (from $4 \times 2.9\% + 1.8\% + 6.4\%$) earns both marks ✓✓	don't insist on seeing '%' unless 0.198 etc allow final answer rounded to 20% allow 1 mark for 0.198 or 0.20 but reject 1 sf 0.2 for incorrect answer the following can earn one mark: (percentage uncertainty in d =) $4 \times 2.9\% / 11.6\% / 12\%$ seen in working but wrong final answer OR missing $\times 4$ eg $2.9\% + 1.8\% + 6.4\% = 11(.1)\%$ OR incorrect multiplier applied to 2.9 eg $2 \times 2.9\%$ OR with $\times 4$ applied wrongly eg $2.9 + (1.8 \times 4) + 6.4 = 16.5\% \text{ or } 17\% /$ $2.9 + 1.8 + (6.4 \times 4) = 30(.3)\%$	AO3-1b = 2
02.4	appropriate use (ie close to and parallel with the vertical side of the tube, but not necessarily in contact with the tube) of: a metre ruler made vertical using a set-square in <u>contact with the bench / floor / (flat) surface</u> OR a plumb line / weight on <u>vertical</u> string (reject 'pendulum') OR a spirit level ✓	the mark can be awarded for a convincing sketch, eg use of a very large set square without ruler accept 'tri-square' for set square the only acceptable horizontal reference is the bench: don't allow use of horizontal T, eg set square placed on T even if sketch looks convincing no credit for attempt to show graduations on tube are horizontal / use of 'protractor' for set-square / 'each side of meniscus at same level' / use of clamp stand rod or wall as vertical reference	AO2-1g = 1

02.5	attempted use of $y = y_0 e^{-\lambda \Delta t}$ with substitution of values of y, y_0 and Δt obtained directly from Figure 10 / plausible values obtained from Figure 13 OR tangent drawn on Figure 10 to find $\frac{dy}{dt}$; use of $\frac{dy}{dt} = (-)\lambda \times y^*$ and y^* is where tangent meets the curve $_1\checkmark$ valid calculation seen leading to a result for λ that rounds to 3 sf in range 4.45 to $4.55 \times 10^{-3} \text{ (s}^{-1}\text{)}$; award if seen in body of answer $_2\checkmark$	for $_1\checkmark$ do not penalise y / y_0 interchanged, read off errors, manipulation errors / $\Delta t = t / t_0 / \frac{t}{t_0}$ or use of incorrect symbols eg A, N for y; no ecf for $_2\checkmark$ allow use of Figure 13 $y_0 = 60.0 \text{ cm}$, $y = 52.2 \text{ cm}$; $\Delta t = 60 - 29 = 31 \text{ s}$ $52.2 = 60 e^{-31\lambda}$, $\therefore \lambda = 4.49 \times 10^{-3} \text{ s}^{-1}$ if the intermediate step is seen, eg $\lambda = \frac{1}{\Delta t} \times \ln\left(\frac{y_0}{y}\right) = \frac{1}{31} \times \ln\left(\frac{60}{52.2}\right)$ accept 'log' for 'ln' no credit allowed for reverse-working method in a 'Show that' problem	AO2-1h = 1 AO3-1b = 1
	variation on use of use of $y = y_0 e^{-\lambda \Delta t}$ for $_1\checkmark$: λ can be found if points t_1, y_1 and t_2, y_2 are used and the values substituted into $\frac{y_1}{e^{-\lambda t_1}} = \frac{y_2}{e^{-\lambda t_2}}$; if this approach is used substitute the data into $\lambda = \frac{1}{\Delta t} \times \ln\left(\frac{y_0}{y}\right)$ to confirm that the result for λ is correct before awarding $_2\checkmark$	no credit for assuming straight line and $y = mx + c$, measuring the gradient then by determining the equation of the line or by using $m = \frac{y_2 - y_1}{t_2 - t_1}$ determines the half life; finds λ from $\frac{\ln 2}{\text{half life}}$ no credit for common error $\lambda = \text{gradient} \times 2$ for $_2\checkmark$ look for any answer in the body that deserves credit (for a 'Show that' we can overlook truncation in the value given on the answer line)	

02.6	use of $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ OR $\frac{\ln 0.5}{-\lambda}$ with substitution of recognisable λ ; evaluated to ≥ 2 sf in range 140 s to 170 s ✓	calculation can have any subject; accept use of 2 sf $\lambda = 4.5 \times 10^{-3}$ usually leading to 154 but allow correctly truncated to 150 or 1.5×10^2	AO3-1a = 1																			
02.7	(mostly) continuous line drawn on Figure 13 ; below dashed line and with negative gradient between $t = 0$ and $t = 120$; do not penalise linear line or shaky / thick / hairy line or slight discontinuities; accept $\approx$ horizontal after 100 s $_1$ ✓ line passes through: <table><tr><th rowspan="2">t/s</th><th colspan="2">y/cm</th></tr><tr><th>min</th><th>max</th></tr><tr><td>0</td><td>33</td><td>35</td></tr></table> AND through EITHER of <table><tr><th rowspan="2">t/s</th><th colspan="2">y/cm</th></tr><tr><th>min</th><th>max</th></tr><tr><td>60</td><td>24</td><td>28</td></tr><tr><td>120</td><td>17</td><td>23</td></tr></table> $_2$ ✓	t/s	y/cm		min	max	0	33	35	t/s	y/cm		min	max	60	24	28	120	17	23		AO2-1d = 2
t/s	y/cm																					
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60	24	28																				
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Question	Answers	Additional Comments/Guidelines	Mark
	f (from $\frac{1}{T}$) in range $61 \pm 1 \text{ Hz}$ $_{12}\checkmark_{2}\checkmark$ OR $61 \pm 3 \text{ Hz}$ $_{12}\checkmark$ maximum 1 mark for POT error OR incorrect rounding	for $_{1}\checkmark_{2}\checkmark$ require ≥ 2 sf that rounds to not less than 60 and not more than 62 for $_{12}\checkmark$ require ≥ 2 sf that rounds to not less than 58 but less than 60 OR for $_{1}\checkmark$ require ≥ 2 sf that rounds to more than 62	AO3-1a =

02.1	37.8 ✓	CAO	1	AO2.1h
02.2	<u>random</u> (error) condone 'statistical' ✓	the following are neutral: 'parallax' / 'human (error)' / '(some) results are anomalous'	1	AO1.1b
02.3	advantage (of using thinner beam): (same load produces) larger (values of) s or w_{tte} $1✓$ so the <u>percentage</u> uncertainty / error (in s) is reduced $2✓$	for $1✓$ accept 'beam bends / deflects more' 'beam extends more' / 'easier to bend' are neutral for $2✓$ the following are neutral: 'easier to make readings' / 'values (of s) are more accurate' / 'more precise' / 'less mass needed' / 'wider range of readings'	MAX 3	AO3.2a
	disadvantage (of beam bending more): idea that beam may undergo plastic deformation $3✓$ so the graph will be non-linear / curve or w_{tte} $4✓$ or beam 'may break' / 'slip off knife edges' and relevant comment about safety / health / hazard / 'cannot get unload data' or reduces range of m or w_{tte} and relevant comment about the effect on the graph, eg increase scatter $34✓ = 1$ MAX	for $3✓$ accept / 'beam may become permanently deformed' or w_{tte} / 'necking may occur' / 'hysteresis may occur' / 'beam can reach (go past) elastic limit' the following are neutral: 'causes systematic error' / 'beam may go past limit of proportionality' / 'need to increase height of supports' / 'beam may bend under own weight'		

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	$E \approx 10^9$ or 1.14×10^9 seen 1✓ correct manipulation seen in body of answer of $s = \frac{\eta m}{E}$ 2✓ correct raw result (allow POT in E) 3✓ (on answer line) order of magnitude consistent with their raw result 4✓	for 1✓ accept 10^9 seen in working for 2✓ either substitution of their E and data from Figure 8 leaving η as only unknown: allow POT in s but not in m eg $\eta = \frac{\text{their } E \times 25.5 (\times 10^{-3})}{0.25}$ or substitution of their E and result of a gradient calculation: allow POT in Δs but not in Δm eg $\eta = 1.14 \times 10^9 \times 1.02 (\times 10^{-1})$ or calculation involving orders of magnitude (expect 10^{-1} but allow 10^2 for gradient) eg $\eta \approx 10^9 \times 10^{-1}$ for 3✓ expect 1.16×10^8 but allow 1 sf gradient eg leading to 1.14×10^8 for 4✓ $\eta = 10^8$ or 8 only; allow use of their E award 34✓ = 1 MAX for use of gradient ≈ 100 leading to order of magnitude = 10^{11} or 11 only	1 2 1	AO1.1b AO2.1d AO2.1f



Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	identifies that s and L are linked by a power law ✓	accept any correct expression (unless there is talk-out) with s or $\log s$ as the subject; treat any quantities other than s and L as constant except E and η possible answers are: $s \propto L^n$ allow $s \propto L^m$ if m identified as constant $s \propto L^3$ $s = kL^n$ $\log s = n \log L + (\log) k$ $\log s = 3 \log L + (\log) k$ $\log s = \log L^3 + (\log) k$ reject $s = L^n$ $\log s = n \log L$ $\log s \propto n \log L$ $10^s \propto 10^L$'s and L are linked logarithmically' 's is directly proportional to L'	1	AO3.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
02.6	(log L =) -0.097 seen or working on Figure 9 confirming a value of log L between -0.095 and -0.100 $_{1✓}$ uses Figure 9 to obtain s in range 2.9 to 3.1×10^{-2} (m) $_{2✓}$	for $_{1✓}$ accept any log L rounding to -0.097 ; working can be suitable ruled line or mark on the best-fit line / on graph axes for $_{2✓}$ accept 29, 30 or 31 mm etc reject 1sf 3×10^{-2} (m)	1 1	AO2.1b AO3.1a
	use of wrong base ln $L = -0.22(3)$; uses Figure 9 to obtain s in range 1.49 to 1.51×10^{-1} or 1.5×10^{-1} (m) $_{12✓}$	accept 15 cm etc		
02.7	use of Figure 8 to determine M ✓	their (final answer to) 02.6 $\times$ gradient of Figure 8 ($9.8 \pm 2.5\%$) minimum 2sf condone use of 1sf s	1	AO3.1a
Total			13	

Question	Answers	Additional comments/Guidelines	Mark	AO
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02.1	peak to peak voltage = 6.0 V (✓)	accept any answer that rounds to 6.0 V do not allow power of ten errors, eg 0.0063 V	1
02.2	period = 8 divisions (= $8 \times 0.5 \times 10^{-3}$ (s)) = 4 ms ₁ ✓ $\left(f = \frac{1}{T} = \frac{1}{0.004}\right)$ = 250 (Hz) ₂ ✓	award both marks if 250 Hz seen accept 4.0(0) ms for ₁ ✓ but reject 4.05, 3.95 etc ecf ₂ ✓ for wrong period	2



02.3	any valid approach leading to RC in range 2.1×10^{-4} to 3.4×10^{-4} or 3×10^{-4} (s) OR their T in $0.22 \times 0.069 \pm 10\%$ ✓✓ 1 mark can be awarded for use of any valid approach in which RC is seen with substitutions or with rearranged equations, eg $0.5 = 6.3e^{\frac{-6 \times 10^{-3}}{RC}} \text{ or } RC = \frac{-t}{\ln\left(\frac{V}{V_0}\right)} \text{ or }$ $RC = \frac{t}{\ln\left(\frac{V_0}{V}\right)}$ OR $1.75 \times 10^{-4} = RC \times \ln 2$ OR $RC = \frac{t_{0.5}}{\ln(2)}$	valid approaches; reads off t when C starts to discharge and t at a lower value of V: $\text{rearranges } V = V_0 e^{\frac{-\Delta t}{RC}} \text{ to calculate } RC$ for ecf $2^{\checkmark}$ Δt used must correspond to interpretation of time base used in determining the frequency in 02.2; there is no ecf for misinterpretation of the voltage scale OR reads off t when C starts to charge and t at a higher value of V: $\text{rearranges } V = V_0 \left(1 - e^{\frac{-\Delta t}{RC}}\right) \text{ to calculate } RC \text{ etc}$ OR determines half-life $t_{0.5}$ and finds RC from $\frac{t_{0.5}}{\ln(2)}$ for ecf $2^{\checkmark}$ $t_{0.5}$ used must correspond to etc OR uses idea that during discharge V falls to $0.37V_0$ in one time constant: determines suitable V and reads off RC directly for ecf $2^{\checkmark}$ time interval used must correspond to etc OR uses idea that during charging V rises to $0.63V_0$ in one time constant: determines suitable V and reads off RC directly reject idea that V falls to zero in $5RC$	2
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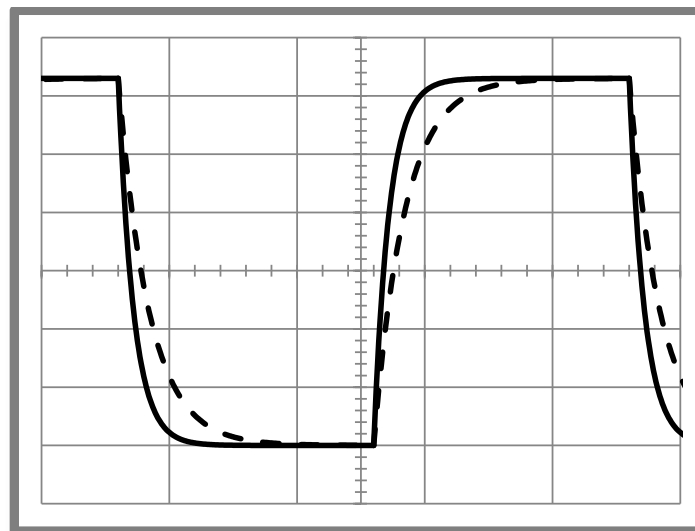
02.4	qualitative comment idea that the waveform will stretch horizontally 1✓ quantitative comment by a factor of $\left(\frac{0.5}{0.2} = \right) 2.5$ 2✓ OR half a cycle now covers 10 (horizontal) divisions on the screen 2✓ (and also earns 1✓) (so the) <u>resolution</u> of the time axis has <u>increased</u> 3✓ (and also earns 1✓) measuring <u>larger distance</u> / across <u>more divisions</u> from the screen <u>reduces</u> (percentage) <u>uncertainty</u> in reading the <u>time</u> (constant / interval / half life) 4✓	for 1✓ look for reference to time axis or direction waveform is re-scaled accept 'graph is longer/stretched' or '<u>will</u> not see whole cycle' or 'fewer cycles shown' or 'period takes <u>more space</u>' or 'distance being measured is larger' or 'time per division is less' or 'larger in x direction' or 'time is stretched' reject 'waveform becomes <u>larger</u>' or '<u>may</u> not see whole cycle' or 'measuring larger <u>time</u>' for 2✓ there needs to be valid quantitative detail award 12✓✓ for '<u>half</u> a cycle now <u>fills the screen</u>' or '<u>half</u> a cycle is displayed' as these clearly recognise the stretching is along the time axis and 'half' is quantitative accept 'new distance (on screen corresponding to half life or time constant) is <u>2.5</u> × answer shown in working for 02.3' the candidate who realises that half a wave now covers the complete width of the screen cannot claim this is a disadvantage; they would still be able to bring either half cycle into view by using the X-shift and find RC for 3✓ uses technical language correctly ignore (but do not penalise) 'times are more precise' or 'more accurate' reject 'smaller resolution' or 'lower resolution' for 4✓ there needs to be a qualifying explanation for the comment about uncertainty reject 'advantage because the (time) scale is easier to read'	3 MAX
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02.5

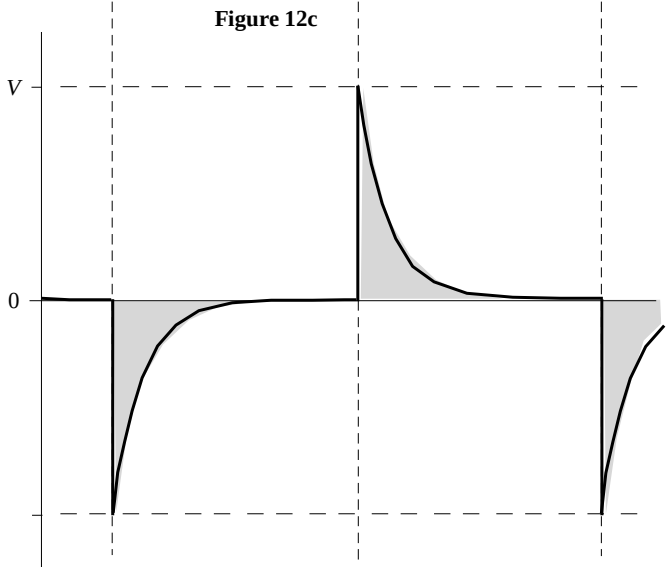
valid sketch on **Figure 11** showing discharge time to 0 V reduced and charging time to peak voltage reduced (see right) ₁✓

connecting resistor in parallel with R halves [reduces by 50%] circuit [total] resistance [time constant] ₂✓



do not insist on seeing second discharge although if shown this must look correct

2

02.6	amendment to Figure 12 showing waveform across R with approximately the correct shape, amplitude $\pm V$ and the correct phase correct waveform shown while signal generator output is low (0 V): only the complete negative half cycle needs to be shown but if second negative half cycle is included it must be correct ₁✓ correct waveform shown while voltage across signal generator output is high; condone no signal or signal = 0 V before going to $-V$ for the first time ₂✓	Figure 12c  don't insist on seeing vertical lines	2
02.7	<u>reduce</u> the (sensitivity of) (Y-voltage)) <u>gain</u> ₁✓ (change) to <u>2 V</u> division⁻¹ ₂✓ (and earns ₁✓) adjust the <u>Y</u> (vertical) <u>shift</u> ₃✓	'make (Y-) gain smaller' or 'increase the volts per division' or 'reduce the Y-resolution' are acceptable substitutes for 'reduce the (Y-)gain' <u>increase</u> the (Y-) gain to <u>2 V</u> division⁻¹ ₂✓ not ₁✓ <u>reduce</u> the (Y-) gain to <u>0.5 V</u> division⁻¹ ₁✓ not ₂✓ ignore any comment about time base or 'X-gain' if all positive waveform is given for 02.6 allow sensible comment about triggering/stability control, eg waveform may not be stable ₁✓; adjust triggering ₂✓	2 MAX

03.1	search coil is not suitable or wtte: no <u>emf</u> (would be induced in a search coil) _{1✓} a search coil needs (to be cut by) changing <u>flux</u> OR search coil is not cut by changing <u>flux</u> OR <u>flux</u> (cutting coil) is constant or wtte _{2✓}	_{1✓} and _{2✓} can be earned independently but are contingent on a statement that the search coil is not suitable; insist on suitable use of the appropriate underlined term for _{1✓} condone 'potential difference' OR 'voltage' for emf for _{2✓} accept ϕ for flux; do not insist on 'flux linkage'; do not allow 'field' for 'flux'; 'current (in the coil on frame) must be ac' is neutral; the suggestion that a search coil cannot be connected to a data logger is neutral	1	AO1-1a
	alternative approach: search coil is suitable or wtte: suggests a valid method that changes the flux cutting the search coil eg rotate either coil / turn (dc) current off / move either coil relative to other coil _{1✓} states their method changes <u>flux</u> through search coil OR if search coil is cut by changing <u>flux</u> or wtte _{2✓}	alternative approach: _{1✓} and _{2✓} can be earned independently but are contingent on a statement that the search coil is suitable	1	AO3-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	use of $1 - \cos 25(^{\circ})$ or $1 - \sin 65(^{\circ})$ in a calculation of percentage change $_1\checkmark$ (–) 9.4 (%) CAO $_2\checkmark$	for $_1\checkmark$ expect either ≥ 3 sf rounding to $1 - 0.906$ OR $1 - 0.91$ seen in working OR $100 - 90.6$ or $100 - 91$ seen in working; for $_2\checkmark$ expect min 2 sf rounding to (–) 9.4; allow (–) 9.0 if $1 - 0.91$ seen in working; do not insist on minus sign or ‘decrease’ on answer line allow $_2\checkmark$ for unsupported answer of (–) 9.4; if no other mark is awarded allow $_{12}\checkmark$ use of $1 - \sin 25(^{\circ})$ or $1 - \cos 65(^{\circ})$ in a % difference calculation leading to 58%	2	AO2-1h

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	uncertainty (in a single reading / judgement) is $\frac{1}{2}^\circ$ $_1\checkmark$	for $_1\checkmark$ accept 0.5 seen in numerator of % calculation OR absolute uncertainty is 2×0.5 ; allow a larger uncertainty up to 3° if justified with a comment about difficulty in judging the reading due to parallax, thickness of frame etc	1	AO1-1a
	(measurement of) θ is based on (difference between) <u>two</u> readings / judgements OR absolute uncertainty in θ (or $\Delta\theta$) = $2 \times$ uncertainty in each reading / judgement $_2\checkmark$ correct percentage uncertainty calculation based on $100 \times$ their absolute uncertainty divided by 25 $_3\checkmark$	for $_2\checkmark$ accept 2×0.5 OR $2 \times$ their uncertainty in (a single) reading seen in numerator OR evidence for use of $2 \times$ their uncertainty in result of % calculation; 'measured twice' is ambiguous for $_3\checkmark$ allow 1 sf result; $\frac{2 \times 0.5}{25} \times 100 = 4\%$ (use of 0.5°) earns $_1\checkmark$ $_2\checkmark$ $_3\checkmark$ $\frac{0.5}{25} \times 100 = 2\%$ (missing $2 \times$) earns $_1\checkmark$ $_2\times$ $_3\checkmark$ $\frac{2 \times 1}{25} \times 100 = 8\%$ (1° unexplained) earns $_1\times$ $_2\checkmark$ $_3\checkmark$ $\frac{1}{25} \times 100 = 4\%$ (1° unexplained) earns $_1\times$ $_2\times$ $_3\checkmark$ $_{123}\checkmark\checkmark\checkmark$ for two-judgement explanation leading to 1° used in a correct % uncertainty calculation	2	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	r in range 67 to 69 mm OR $x_{0.5}$ in range 50 to 55 mm ₁ ✓ $\frac{x_{0.5}}{r}$ in range 0.73 to 0.81 ₂ ✓	$\frac{x_{0.5}}{r}$ in range gets both marks for ₁ ✓ either value can be seen in working OR on (along horizontal axis in) Figure 13 for ₂ ✓ answer with no unit and minimum 2 sf	2	AO3-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	use of Figure 11: adds B_{H1} for experiment 1 to B_{H2} for experiment 2 at any point between $x = 17$ and $x = 51$ (mm); resultant B_H , minimum 2 sf, in range 0.91 to 0.99 (mT) ₁ ✓ resultant B_H , minimum 2 sf, in range 0.93 to 0.97 (mT) ₂ ✓	ignore any sign given with result	2	AO3-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.6	for more than 2 ideas mark as a list (field lines are) parallel or wtte ₁✓ evenly-spaced or wtte ₂✓	for ₁✓ accept 'in the same direction' / 'uniform-direction'; 'horizontal' / 'directed to the right' / 'straight' / 'linear' / 'perpendicular to the coil' are neutral for ₂✓ accept 'equally-spaced' / 'equidistant' / 'uniform-spacing' / 'equal distance between lines' or wtte; 'close together' / 'do not touch' are neutral; 'uniform field' / 'field lines are uniform' / 'they are uniform' are neutral	2	AO1-1a



Question	Answers	Additional comments/Guidelines	Mark	AO
03.7	a vertical axis drawn (at any point between $x = 0$ and $x = r$); continuous line (accept poorly-marked) between $x = 0$ and $x = r$ (by eye); intersecting or meeting horizontal axis / $B_{(H)} = 0$ at $x = \frac{r}{2}$ $_1\checkmark$ vertical axis drawn, labelled with symbol B; negative gradient, line continuous between $x = 0$ and $x = r$; 2-quadrant graph $_2\checkmark$ vertical axis drawn with symbol and unit eg $B_{(H)} / \text{mT}$; continuous line between $x = 0$ and $x = r$; $B_{(H)} = 0.43 \pm 0.01$ at $x = 0$ OR $B_{(H)} = -0.43 \pm 0.01$ at $x = r$ $_3\checkmark$ 2-quadrant graph, continuous line between $x = 0$ and $x = r$; approximately correct shape: see opposite; their y-value at $x = 0$ equal and opposite to their y-value at $x = r$ (by eye) $_4\checkmark$	for $_1\checkmark$ use checkmark on axis for guidance; for $_2\checkmark$ allow 'magnetic flux density' in words; condone any flat section $\leq r/4$ (judge by eye); allow (always) positive gradient for $_1\checkmark$ and $_2\checkmark$ allow a straight line; single quadrant can score $_1\checkmark$ or $_3\checkmark$ for $_3\checkmark$ apply usual symbol-separator-unit convention / allow $B_{(H)} = 4.3 \times 10^{-4}$ etc; adjust criteria for positive gradient graph for $_4\checkmark$ if no values are marked on the axis, assume $B_{(H)} = 0$ is aligned horizontally with the x-axis (judge by eye); condone missing vertical axis	MAX 3	AO3-2b
Total			16	

01.1	₃✓ is about shielding using a <u>named</u> absorber stand behind a <u>lead</u> absorber / screen (when source is in the open) ₄✓ is safe use of source <u>when removed</u> from castle <u>never point</u> (open end of) the source at anyone / at yourself OR do not <u>look directly</u> at / look <u>into</u> the source ₅✓ is about good practice read local <u>rules</u> (about the use of radioactive sources) / OR read / post <u>warning</u> / <u>notice</u> on the door	source sealed' for ₃✓ accept aluminium or steel for lead; use of lead apron for ₄✓ accept 'avoid <u>eyes</u>' treat as neutral: 'avoid direct contact' / 'don't touch source' / 'always point source at ground' for ₅✓ accept 'report any damage to a source' treat as neutral: 'use safety screen' / 'don't stand in front' / 'don't ingest / swallow' / 'wash hands after use' / 'wear safety glasses / goggles / gloves / lab coats' / 'use film badge' no credit for procedures that are the responsibility of the teacher / radiation protection adviser, eg 'obtained signed consent form'	AO2-1g = MAX 2
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01.2	5 ✓	correct answer only	AO3-1a = 1
01.3	A OR $^{222}_{86}\text{Rn}$ / radon 222 / Rn 222 ✓ B OR $^{218}_{84}\text{Po}$ / polonium 218 / Po 218 ✓ I OR $^{210}_{82}\text{Pb}$ / lead 210 / Pb 210 ✓	if candidates have provided more than 3 responses, each extra error / contradiction negates one correct response; if there are 3 or more errors / contradictions, award no marks answers may be given in any order accept unnamed isotope with correct A, Z eg $^{222}_{86}\text{X}$ eg while the suggestion that A, B and I are correct earns 3 the suggestion that A, B, I and J are correct earns 3 – 1 = 2	AO3-1a = 3



01.4	suitable procedures to eliminate systematic error are: remove (all radioactive) <u>source(s)</u> (from the room) OR measure A_b before the source is present / in another room OR put source in (lead) castle / (lead) container / behind a (lead) absorber ₁✓ zero / reset the <u>counter</u> AND/OR <u>stopwatch</u> (before use) OR check the <u>counter</u> AND/OR <u>stopwatch</u> has no zero error ₂✓ measure A_b on same day as experiment is carried out ₃✓ measure A_b in same room / location / area as that where experiment is to be carried out ₄✓ suitable procedure to reduce percentage uncertainty in A_b is: use long(er) (integration) time / prolonged time OR (total of) at least 100 s ₅✓	do not insist on references to systematic or random error but give no credit for explicit talk-out eg 'use a long integration time to eliminate systematic error' for ₁✓ treat as neutral: 'measure A_b with no source near' / 'check source is shielded / far away / out of range / sealed' / 'in another area' / 'point detector away from the source (or vice-versa)' / 'don't point source at counter' / 'put detector behind source' for ₂✓ treat as neutral: 'zero / reset the equipment (before use)' / 'zero the detector' for ₃✓ treat as neutral: 'measure A_b after experiment to double-check' for ₄✓ treat as neutral: / 'keep detector in the same position' / 'measure A_b in different positions' for ₅✓ accept idea of a suggested <u>total</u> time, taking account of repeats, exceeding 100 s (eg 10 repeated 10 s counts and 1 single 100 s single count amount to the same thing) treat as neutral: 'repeat and average' ignore anomalous results' / 'use room with high background count / record large reading' / 'use more than one detector'	AO2-1g = MAX 3
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01.5	use of 5.5 MeV shown by working on Figure 4 _{1✓} minimum thickness MAX 3sf that rounds to 12 mm _{2✓3✓} OR minimum thickness MAX 3sf that rounds to 11 mm / MAX 3sf that rounds to 13 mm _{23✓}	for _{1✓} use of 5.5 MeV can be inferred from Figure 4 as a (horizontal) line, a mark on the vertical axis or a mark on the curve / intersection between curve and a vertical line, above 5 MeV and below 6 MeV; a single line / mark between 5 and 6 MeV with no subsequent working can score _{1✓} any line does not have to be ruled or perfectly parallel to the grid line; allow a cross or a small blob as the mark on the curve; do not insist on seeing a vertical line if more than one line is drawn / mark is made then mark as per scheme if a clear decision has been made about which read-off has been used to provide the result for the thickness; allow only one thickness given as final answer _{2✓3✓} OR _{23✓} can be earned without any working on the grid / other intermediate working	AO3-1a = 1 AO3-1b = 2
	OR use of 7.8 MeV shown by working on Figure 4 AND minimum thickness is 16, 17 or 18 mm _{123✓}	for _{123✓} use of 7.8 MeV can be inferred from Figure 4 as a line, mark on axis / curve etc above 7 MeV and below 8 MeV; accept MAX 3 sf result that rounds to 16, 17 or 18 mm	

01.6	$d = \sqrt{k} \times \frac{1}{\sqrt{A}} - e$ OR $d = \sqrt{k} \times \sqrt{\frac{1}{A}} - e$ OR $d = \sqrt{\frac{k}{A}} - e$ seen ₁✓ states $\sqrt{k}$ = gradient OR k = gradient² ₂✓ gradient from Δd divided by $\Delta \frac{1}{\sqrt{A}}$ with $\Delta \frac{1}{\sqrt{A}} \geq 0.5$ ₃✓ k minimum 2 sf in range $1.7(0) \times 10^5$ to $1.9(5) \times 10^5$ ₄✓ unit for k = mm² Bq or mm² s⁻¹ ₅✓ for statement that k = gradient mark as follows: for $d = k \times \frac{1}{\sqrt{A}} - e$ AND k = gradient ₁₂✓ = 1 MAX; award ₃✓ as above ₄₅✓ = 1MAX ecf for the following: k in range 410 to 450 or 2 sf 4.1 to 4.5×10^2 mm Bq^{0.5} or mm s^{-0.5} OR k in range 0.41(0) to 0.45(0) m Bq^{0.5} or m s^{-0.5} OR k in range 41.(0) to 45(.0) cm Bq^{0.5} or cm s^{-0.5}	for ₁✓ d must be the subject; allow obvious slips, eg D for d for ₂✓ allow $\sqrt{k} = m$ if $y = mx + c$ is quoted so inference that $\sqrt{k}$ = gradient is clear; this mark is for explaining the step and not for performing the calculation for ₃✓ the mark is for the process, not the result; evidence of acceptable steps on grid with plausible result are enough; no credit if false origin missed allow working subsumed into calculation of k for ₄✓ gradient based on d in mm (expected = 433 mm Bq^{0.5}) POT 10⁵ required for ₅✓ the unit given for k must be consistent with the POT of the result for k / gradient² order not important Bq mm² is acceptable; do not accept incorrect symbol, eg bq for Bq otherwise: if for ₄✓ gradient based on d in m (expected ≈ 0.43 m Bq^{0.5}) k in range 0.17(0) to 0.19(5) then for ₅✓ m² Bq or m² s⁻¹ if for ₄✓ gradient based on d in cm (expected ≈ 43 cm Bq^{0.5}) k in range $1.7(0) \times 10^3$ to $1.9(5) \times 10^3$ then for ₅✓ cm² Bq or cm² s⁻¹	AO2-1d = 2 AO2-1h = 1 AO3-1b = 2
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01.7	second mark ($_2\checkmark$) is contingent on award of first ($_1\checkmark$) an unsupported answer or an answer obtained by scale drawing or by extrapolation off the grid score zero attempts to find e by <u>calculation</u> by any valid method using gradient or k with all data correctly substituted in their expression; allow use of y for d, x for $\frac{1}{\sqrt{A}}$, m for $\sqrt{k}$ and c for e; attempts to solve for e $_1\checkmark$ ≥ 2 sf result in range $\geq 28(.0)$ and $\leq 32(.0)$ (mm) $_2\checkmark$	for $_1\checkmark$ use of $y = mx + c$ with recognisable data correctly substituted, eg $e = \text{their gradient} \times \frac{1}{\sqrt{A}} - d$ with substitution of their gradient and values of values of d and $\frac{1}{\sqrt{A}}$ from a point on the line from Figure 6 OR $e = \sqrt{k} \times \frac{1}{\sqrt{A}} - d$ with substitution of their k etc OR $(-)e = \text{gradient} \times \text{horizontal intercept}$, with substitution of their gradient and horizontal intercept ignore POT errors in their gradient / their k; allow mixed units and read-off errors of 1 small square for $_2\checkmark$ answer in range only (no ecf from 01.6) allow negative answer	AO2-1d = 1 AO3-1b = 1
Total			19

Question	Answers	Additional Comments/Guidelines	Mark
	general procedure - collect water for a measured time; divide measured / calculated volume by time to determine rate ₁✓	static volume should be measured after timing , eg reject 'measure time to fill cylinder' or ₁ ✓ = 0 accept 'find V for different t, plot V against t, gradient = Q' but not if by continuous flow method	AO2-1g = 1
	names 2 suitable instruments ₂ ✓	for time use <u>stopwatch</u> or <u>stopclock</u> ; treat as neutral: 'timer' or 'light gate / data logger' for volume use <u>measuring cylinder</u> / graduated beaker; treat as neutral: 'measuring beaker' / 'burette' OR for mass use <u>balance</u> ; use of $V = \frac{m}{\rho}$ (any subject) condone 'volume of 1 g is 1 cm ³ '; reject 'weigh'/'weighed'	AO2-1g = 1

04.1	attempts two calculations that would lead to a conclusion ₁ ✓	for ₁ ✓ the result of at least one calculation of $M \times y$ must be correct (see table) otherwise withhold both marks; allow use of y in m but reject POT error; allow use of correct read-offs from valid BFL; condone use of two rows of data to show that when M doubles, y does not halve; award of ₂ ✓ is contingent on valid ₁ ✓	1	1 x AO1 1 x AO2
	a reasoned judgement explaining why y not inversely proportional to M ₂ ✓	for ₂ ✓ two correct calculations of $M \times y$; see table for min sf in result for $M \times y$ OR one correct calculation of $M \times y$ and an appropriate reverse-working calculation; statement rejecting inverse-proportion supported by suitable quantitative reasoning, eg calculation of the percentage difference between the results of their calculations; condone 'large' / 'significant differences' (between calculation results) / use of >> etc; reject 'values are different' / 'not same' / 'not constant' / 'not close enough' use of > etc; reasoning must be based on the data points, eg reject 'best-fit line crosses y-axis'	1	

M / kg	y / mm	acceptable $M \times y$	min sf
0.5	89(.0)	44.5 / 45	2
1.0	82(.0)	82(.0)	
1.5	76(.0)	114(.0)	3
2.0	71(.0)	142(.0)	
2.5	66.5	166(.3)	
3.0	62.5	187.5 / 188	

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	(as P moves down trapped air expands so) pressure (of trapped air) is reduced ₁✓ pressure less than atmospheric pressure ₂✓ this leads to an upwards force balancing the weight of P OR pressure difference across P × area of piston = weight of piston ₃✓ why P falls when the valve is opened ₄✓	must address situation in Figure 11 for ₁✓ allow 'pressure reaches lower value' reject 'pressure is low' for ₂✓ allow 'there is a pressure difference across P' / 'external pressure > pressure of trapped air' award ₁✓₂✓ for pressure of air reduced below atmospheric" for ₃✓ allow any correct idea about how two opposing forces act to produce equilibrium; 'no resultant force' is not enough reject 'weight = gravity' / ideas about 'suction' / equating pressure with force for ₄✓ idea of external and internal pressures equalising; reject 'pressure released / returns to normal'	Max 3	3 x AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	smooth curve of decreasing negative gradient through all 6 points _{1✓}	for _{1✓} must be a single continuous line for $M \geq 0.5$ that overlaps with all 6 +;	1	1 × AO1
	line with negative gradient extrapolated (backwards) to $M \leq -0.35$ _{2✓}	condone poorly-marked line (note that poor line quality may only be penalised in Question 03.4)		2 × AO2
	records y corresponding to $M = -0.7$ _{3✓}			1 × AO3
	y in range 108 mm to 116 mm _{4✓}	for _{2✓} condone linear extension of curve with negative gradient for $M < +0.5$	1	
	OR			
	for incorrect M (3 MAX)	for _{3✓} curve must extend to where read off is being made	1	
	smooth curve etc _{1✓}			
	line with negative gradient extrapolated (backwards) to $M \leq -0.35$ _{2✓}	award of _{4✓} is contingent on valid _{3✓}	1	
	records y corresponding to $M = -0.35$;	for _{4✓} answers that round to nearest mm are acceptable		
	y in range 101 mm to 107 mm _{34✓}			
	OR			
	for linear graph (2 MAX)			
	ruled line with negative gradient extrapolated (backwards) to $M \leq -0.35$ _{12✓}			
	records y corresponding to $M = -0.7$;			
	y in range 97 mm to 103 mm _{34✓}			

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	correctly identifies error ₁ ✓	for ₁ ✓ reading has been taken at / from the top of the meniscus / top of coloured oil / top of liquid OR should have taken / did not take reading from the bottom / lowest point of the meniscus / lowest point on surface of coloured oil OR '(student thinks) sub-divisions are 0.1 cm ³ and not (as question states) 0.2 cm ³ ' reject 'should have read from bottom of coloured oil' / 'failed to read meniscus properly' / 'read at the top of the air' / 'has read divisions incorrectly' or wtte	1	1 x AO1 1 x AO2
	correct reading is 35.8 ₂ ✓	for ₂ ✓ CAO	1	

Question	Answers	Additional comments/Guidelines	Mark	AO
04.5	gradient from $\Delta \log(V / \text{cm}^3)$ divided by $\Delta \log(p / \text{MPa})$; evaluated to ≥ 3 sf result between -1.05 and -1.01 $_1\checkmark$	don't insist on large steps / read off accuracy accept result that rounds to 3sf between -1.05 and -1.01 ; sign essential	1	1 x AO2 2 x AO3
	relevant algebra enabling comparison with $y = mx + c$ $_2\checkmark$	for $_2\checkmark$ (eg Boyle's Law written as) $\log V = -\log p + \text{constant}$ condone variation based on Ideal Gas Law in which case must establish that $(nR)T / (Nk)T$ is constant (which then implies Boyle's Law) (recognisable data book symbols only) OR (Figure 13 shows) $\log V = \text{gradient} \times \log p + \text{constant}$; accept $(\log) k$, $(\log) c$ etc as recognisable symbols for the constant; condone (any) numerical value given for the constant eg $10^{1.685}$; accept m as recognisable symbol for the gradient	1	
	why gradient ≈ -1 confirms Boyle's Law $_3\checkmark$	for $_3\checkmark$ allow gradient is / equals / should be -1 if $_2\checkmark$ not given accept 'gradient ≈ -1 demonstrates inverse proportion or wtte	1	

Question	Answers	Additional comments/Guidelines	Mark	AO
04.6	reads off and attempts to make use of $\log p_1$ AND $\log V_1$ for any point on the line $_1\checkmark$	V_2 in range 10.5 to 11.5 (cm^3) earns $_1\checkmark_2\checkmark_3\checkmark$ for $_1\checkmark$ check $\log V_1$ is within half a grid square of correct position for their $\log p_1$ or vice-versa; 'make use of' excludes use in a gradient calculation	1	1 x AO2 2 x AO3
	applies a workable method $_2\checkmark$	for $_2\checkmark$ creditworthy examples are a calculation of the intercept in Figure 13 eg $\log V + \log p = 0.585$ OR use of gradient = $\frac{\Delta \log V}{\Delta \log p}$ (eg similar triangles idea) OR a calculation of $p \times V$ (by any means) OR use of $\log V = -1 \times \log 0.34 + \text{their intercept}$ no credit for claiming 1.685 (or 1.170) are intercepts; this cannot earn $_2\checkmark$	1	
	further manipulation to determine unknown V_2 $_3\checkmark$	for $_3\checkmark$ accept result that rounds to 10.5 or 11.5; accept 2sf 11 (cm^3)	1	

Question	Answers	Additional comments/Guidelines	Mark	AO
04.7	temperature (of air) ₁ ✓	for ₁ ✓ accept 'mean ke of air molecules' (or wtte) / 'vapour pressure <u>of air</u> ' 'keep mass of air constant' is neutral (this information is given below Figure 13)	1	1 x AO1 1 x AO2
	change the pressure of the gas slowly or wtte OR wait (after a change) between taking readings / until the oil level stabilises ₂ ✓	award of ₂ ✓ is contingent on valid ₁ ✓ for ₂ ✓ condone 'keep lab temperature constant'; 'use a water bath' is neutral reject 'do the experiment slowly' / 'do not heat the apparatus' / 'keep windows closed' etc	1	
Total			19	