Section A

Answer **all** questions in this section.

0 1 This question is about an experiment to measure the wavelength of microwaves.

A microwave transmitter **T** and a receiver **R** are arranged on a line marked on the bench.

A metal sheet **M** is placed on the marked line perpendicular to the bench surface.

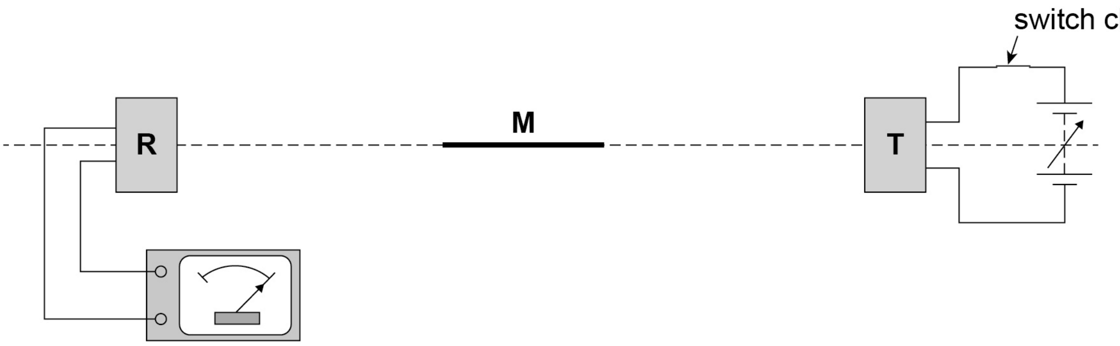
Figure 1 shows side and plan views of the arrangement.
The circuit connected to **T** and the ammeter connected to **R** are only shown in the plan view.

Figure 1

The distance y between **T** and **R** is recorded.

T is switched on and the output from **T** is adjusted so a reading is produced on the ammeter as shown in **Figure 2**.

Figure 2



M is kept parallel to the marked line and moved slowly away as shown in **Figure 3**.

Figure 3

The reading decreases to a minimum reading **which is not zero**.
The perpendicular distance x between the marked line and **M** is recorded.

0 1 . 1 The ammeter reading depends on the superposition of waves travelling directly to **R** and other waves that reach **R** after reflection from **M**.

State the phase difference between the sets of waves superposing at **R** when the ammeter reading is a **minimum**.
Give a suitable unit with your answer.

[1 mark]

Question 1 continues on the next page

0 1 . 2 Explain why the minimum reading is **not** zero when the distance x is measured.

[1 mark]

0 1 . 3 When **M** is moved further away the reading increases to a maximum then decreases to a minimum.

At the first minimum position, a student labels the minimum $n = 1$ and records the value of x.
The next minimum position is labelled $n = 2$ and the new value of x is recorded.
Several positions of maxima and minima are produced.

Describe a procedure that the student could use to make sure that **M** is parallel to the marked line before measuring each value of x.
You may wish to include a sketch with your answer.

[2 marks]

0 1 . 4 It can be shown that

$$n\lambda = \sqrt{4x^2 + y^2} - y$$

where λ is the wavelength of the microwaves and y is the distance defined in **Figure 1**.

The student plots the graph shown in **Figure 4**.
The student estimates the uncertainty in each value of $\sqrt{4x^2 + y^2}$ to be $0.025\ \text{m}$ and adds error bars to the graph.

Determine

- the maximum gradient G_{max} of a line that passes through all the error bars
- the minimum gradient G_{min} of a line that passes through all the error bars.

[3 marks]

G_{max} = ______________________________

G_{min} = ______________________________

0 1 . 5 Determine λ using your results for G_{max} and G_{min}.

[2 marks]

λ = ______________________________ m

Figure 4

Question 1 continues on the next page

0 1 . 6 Determine the percentage uncertainty in your result for λ.

[3 marks]

percentage uncertainty in λ = ____________________ %

0 1 . 7 Explain how the graph in **Figure 4** can be used to obtain the value of y.
You are **not** required to determine y.

[2 marks]

0 1 . 8 Suppose that the data for $n = 13$ had not been plotted on **Figure 4**.

Add a tick (✓) in each row of **Table 1** to identify the effect, if any, on the results you would obtain for G_{max}, G_{min}, λ and y.

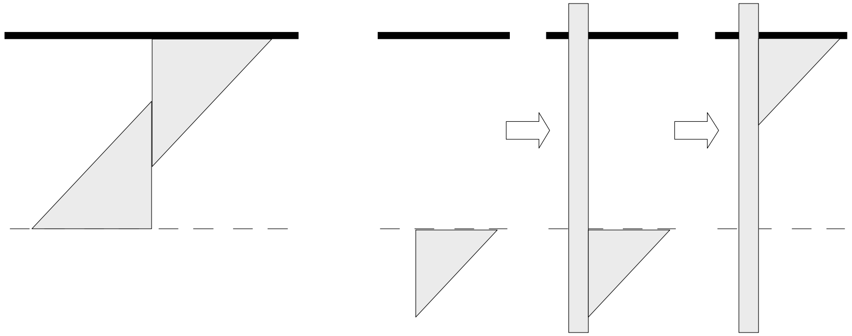
[4 marks]

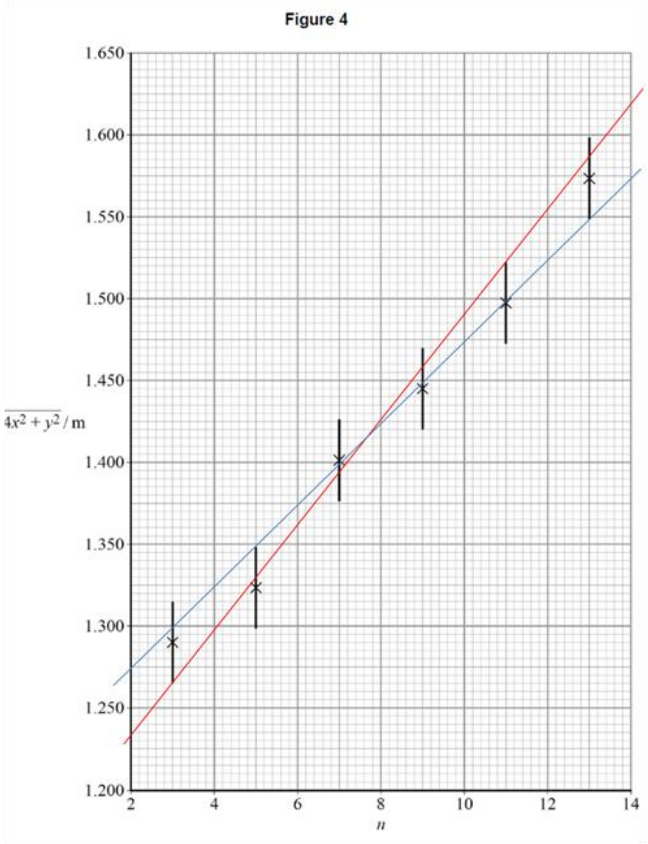
Table 1

Result	Reduced	Not affected	Increased
G_{max}			
G_{min}			
λ			
y			

18

Question	Answer	Additional Comments/Guidance	Mark
01.1	180 degrees OR π radians ✓	accept ° for degrees condone ^{c} or 'rad' for radian reject 'half a cycle' treat 'π radians in phase' as talk out	1
01.2	(idea that) sets of combining waves do not have the same amplitude ✓	condone 'waves do not have same intensity' or 'same energy' or 'some energy is absorbed on reflection' or 'same power' or 'same strength' or idea that non point source or non point receiver would lead to imperfect cancellation condone the idea that the waves may not be monochromatic ignore 'some waves travel further' or 'waves do not perfectly cancel out' reject 'waves may not be 180° out of phase'	1

01.3	valid use of a set square or protractor against TR (to ensure perpendicular) $_1$✓ measure *x* at two <u>different</u> points [at each end of M] **<u>and</u>** adjust until [make sure] both <u>distances are the same</u> $_2$✓ OR use of set square to align M with the perpendicular line earns $_2$✓ if method used does not allow <u>continuous</u> variation in *x* then award maximum 1 mark OR align <u>graph paper</u> with TR $_1$✓ align M with grid lines on graph paper $_2$✓	both marks can be earned for suitable sketch showing a viable procedure involving one or more recognisable set squares or protractors; the sketch may also show a recognisable ruler, eg  allow use of scale on set square to measure the perpendicular distances don’t penalise incorrect reference to the set square, eg as ‘triangular ruler’, as long as the sketch shows a recognisable set square	2

01.4	G_{max} line ruled through bottom of $n = 3$ error bar and through top of $n = 11$ error bar $_1$✓ G_{min} line ruled through top of $n = 5$ error bar and through bottom of $n = 13$ error bar $_2$✓ G_{max} and G_{min} calculated from valid y step divided by valid x step; both n steps ≥ 6 $_3$✓	allow 1 mm tolerance when judging intersection of gradient lines with error bars ignore any unit given with G_{max} or G_{min}; penalise power of ten error in 01.5 Figure 4  $_{12}$✓= 1 MAX if (either) line is thicker than half a grid square or of variable width or not continuous; expect $G_{max} = 3.2(1) \times 10^{-2}$ and $G_{min} = 2.5\ (2.49) \times 10^{-2}$	3

01.5	λ (from $\frac{G_{max} + G_{min}}{2}$) AND result in range 2.8(0) to 2.9(0) × 10^{-2} (m) ${}_1$✓${}_2$✓ OR award one mark for 2.7(0) to 3.0(0) × 10^{-2} (m) ${}_{12}$✓	penalise 1 mark for a power of ten error reject 1 sf 3 × 10^{-2} (m) if a best fit line is drawn between the G_{max} and G_{min} lines and the gradient of this is calculated award 1 mark for λ in range 2.8(0) to 3.0(0) × 10^{-2}(m)	2
01.6	uncertainty in λ = $G_{\text{max}} - \lambda$ OR $\lambda - G_{\text{min}}$ OR $\left(\frac{G_{\text{max}} - G_{\text{min}}}{2}\right)$ ${}_1$✓ percentage uncertainty = (uncertainty/λ)×100 ${}_2$✓ result in range 11(.0) % to 14(.0) % ${}_3$✓	${}_1$✓ can be earned by showing a valid uncertainty then dividing by λ ecf their λ, G_{max} and G_{min} for ${}_1$✓ and ${}_2$✓ allow λ found from best fit line accept $\left(\frac{G_{\text{max}} - \lambda}{\lambda}\right)\times 100$ or $\left(\frac{G_{\text{max}} - G_{\text{min}}}{G_{\text{max}} + G_{\text{min}}}\right)\times 100$ etc for ${}_{12}$✓✓ allow $\left(\frac{\Delta\lambda}{\lambda}\right)\times 100$ where $\Delta\lambda$ is any plausible uncertainty for ${}_2$✓ numerical answer without valid working can only earn ${}_3$✓	3

<table>
<tr><td>01.7</td><td>(states) <u>calculate</u> the (vertical) intercept $_1$✓
OR
outlines a valid calculation method to calculate y $_1$✓
determine the intercept for <u>both lines</u> and calculate average value $_2$✓
OR
determine the (vertical) intercept of the line of best fit (between G_{max} and G_{min}) $_2$✓</td><td>draw the line of best fit (between G_{max} and G_{min}); perform calculation to find intercept earns $_{12}$✓✓</td><td>2</td></tr>
<tr><td>01.8</td><td><table><tr><th>result</th><th>reduced</th><th>not affected</th><th>increased</th></tr><tr><td>G_{max}</td><td></td><td>✓</td><td></td></tr><tr><td>G_{min}</td><td>✓</td><td></td><td></td></tr><tr><td>λ</td><td>✓</td><td></td><td></td></tr><tr><td>y</td><td></td><td></td><td>✓</td></tr></table></td><td>general marker question
allow any distinguishing mark as long as only one per row
for ✓ and × in same row ignore ×
for ✓ and ✓ in same row give no mark
ignore any crossed-out response</td><td>4</td></tr>
</table>

alternative approach: single best fit line drawn on **Figure 4**			
01.4	G calculated from y step divided by x step; n step ≥ 6 $_3$✓		MAX 1
01.5	λ in range 2.8(0) to 2.9(0) × 10^{-2} ✓		MAX 1
01.6	percentage uncertainty in $\lambda = \frac{\Delta\lambda}{\lambda} \times 100$ AND result in range 11(.0) % to 14(.0) % ✓		MAX 1
01.7	<u>calculate</u> intercept OR outlines a valid calculation method to find y ✓		MAX 1
01.8	as main scheme	no ecf possible	4
alternative approach: non-crossing lines for G_{max} and G_{min} on **Figure 4**: includes lines that meet but do not cross			
01.4	G_{max} and G_{min} calculated from y step divided by x step; both n steps ≥ 6 $_3$✓		MAX 1
01.5 to 01.8	as main scheme		11

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

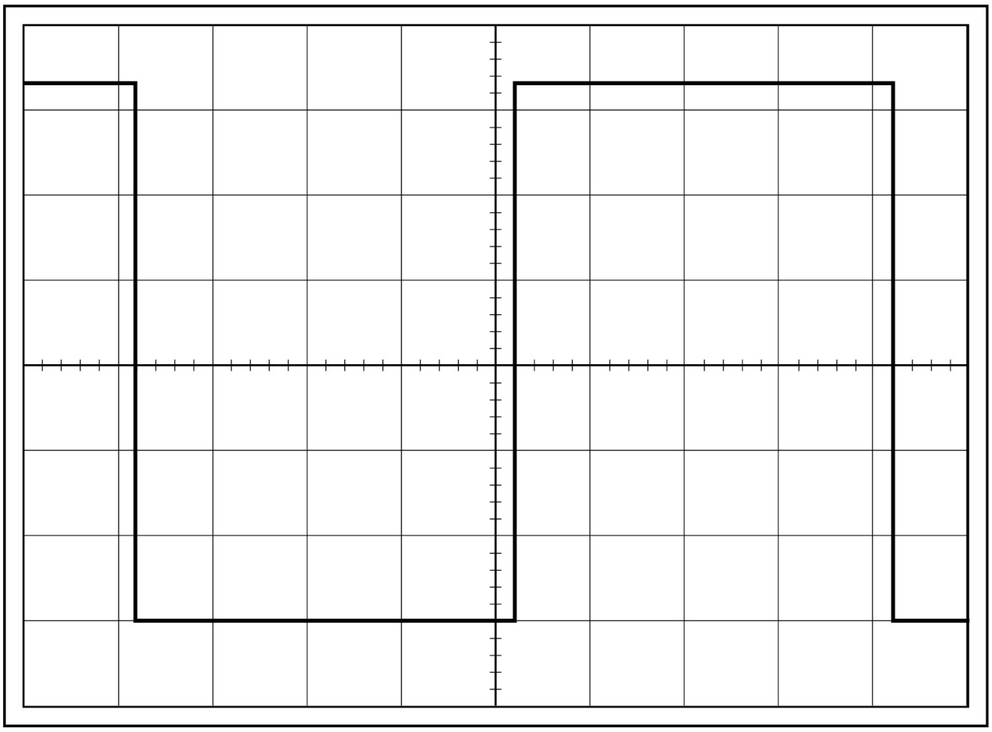
0 2 . 2 Determine the frequency f of the waveform shown in **Figure 8**.

[2 marks]

f = ___________________________ Hz

Figure 7

Figure 8



Question 2 continues on the next page

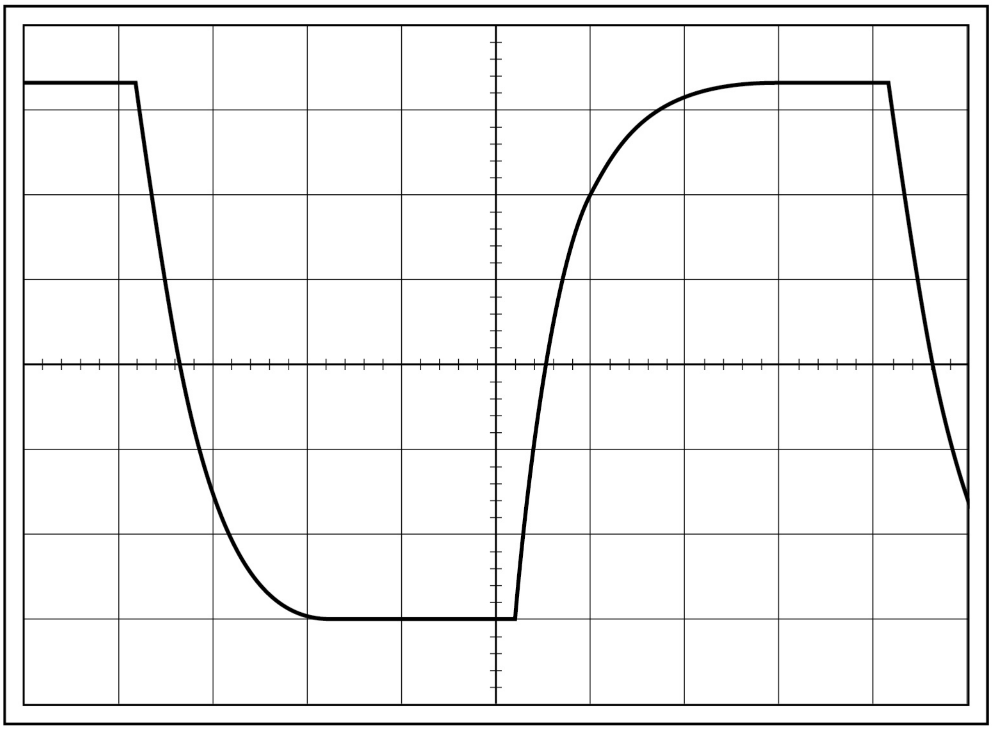
0 2 . 3 **Figure 9** shows the signal generator connected in series with a resistor **R** and a capacitor **C**.

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

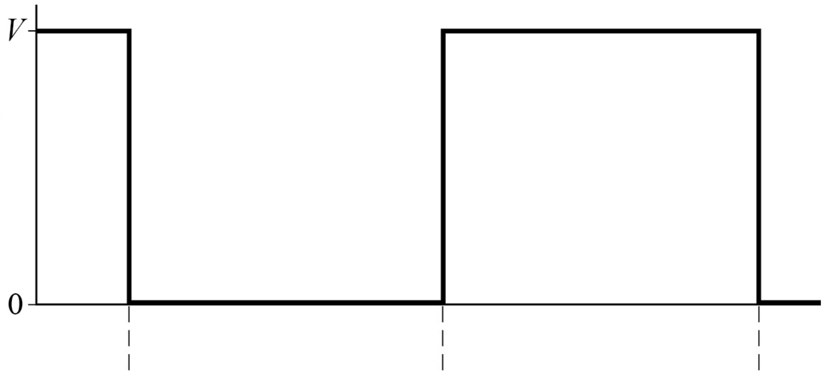


Figure 12b

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

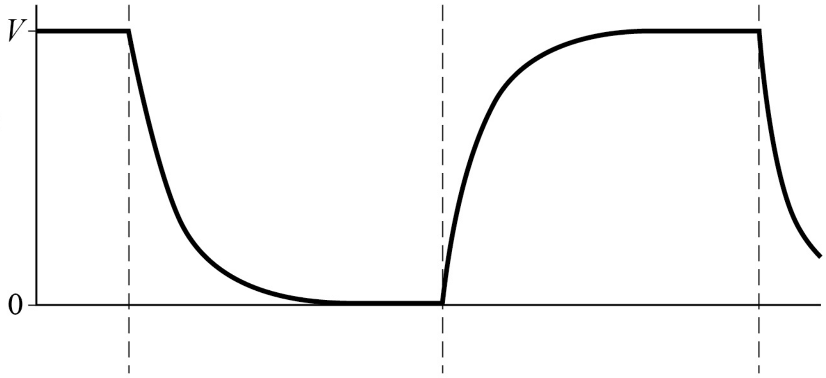
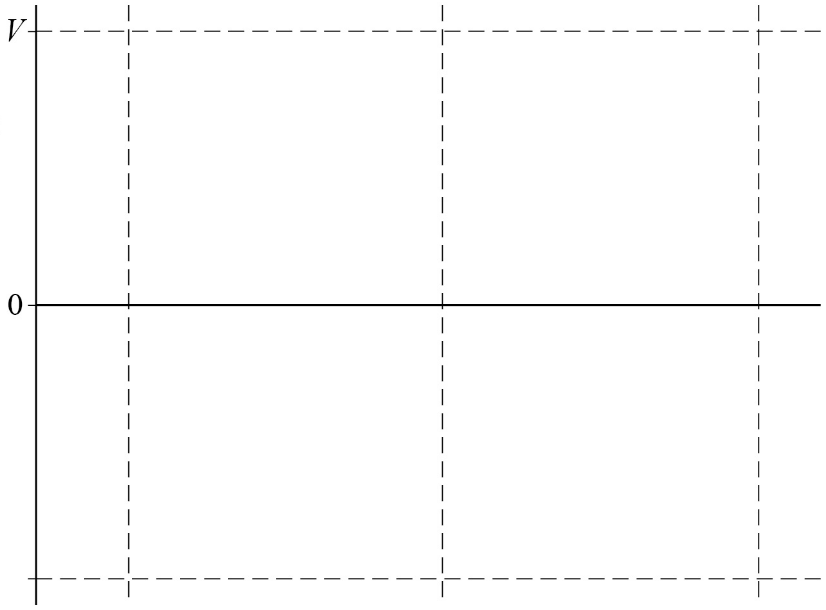


Figure 12c

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



Question 2 continues on the next page

0 2 . 7 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]

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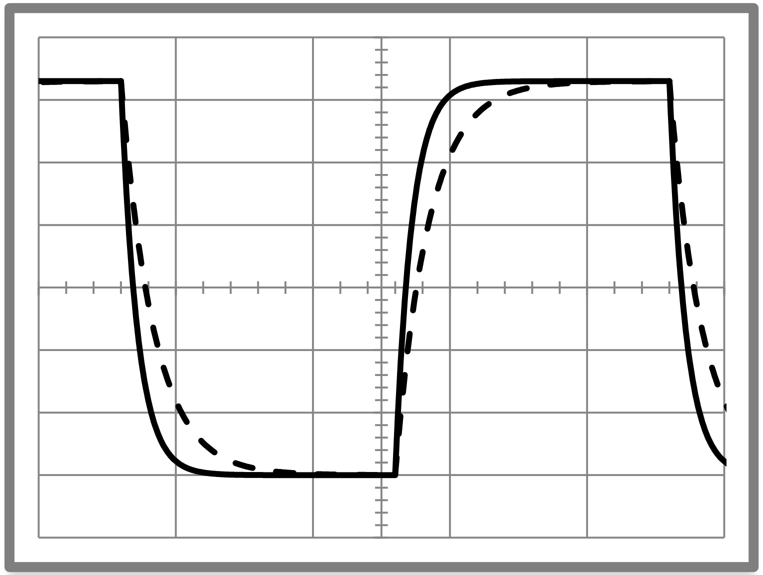
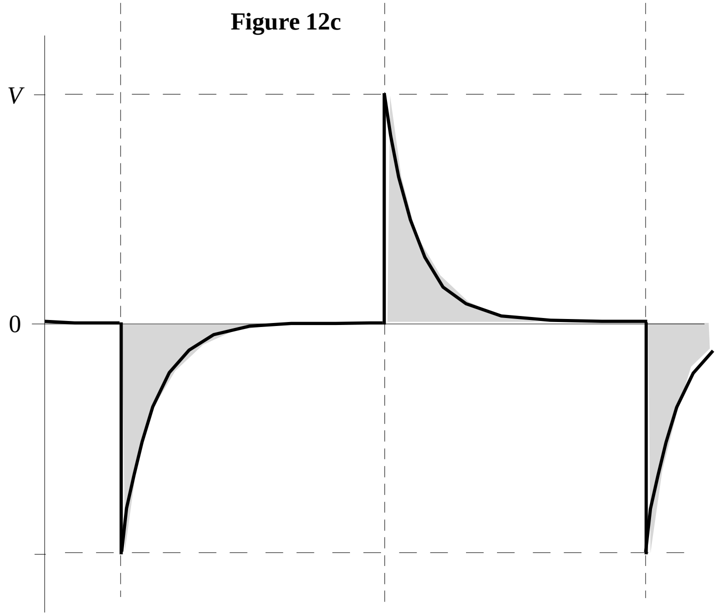
Question	Answer	Additional Comments/Guidance	Mark
02.1	peak (to peak) voltage = 6.3(0) (V) ✓	accept any answer that rounds to 6.3 V do not allow power of ten errors, eg 0.0063 V	1
02.2	period = 8 divisions (= 8 × 0.5 × 10^{-3} (s)) = 4 ms $_1$✓ $\left(f = \frac{1}{T} = \frac{1}{0.004} \right)$ = 250 (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 02.2 × 0.069 ± 10 % $_{12}$✓✓ 1 mark can be awarded for use of any valid approach in which *RC* is seen with substitutions or with rearranged equations, eg $0.5 = 6.3e^{\frac{-6\times10^{-3}}{RC}}$ or $RC = \frac{-t}{\ln\left(\frac{V}{V_0}\right)}$ or $RC = \frac{t}{\ln\left(\frac{V_0}{V}\right)}$ OR $1.75\times10^{-4} = RC\times\ln 2$ 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*: rearranges $V = V_0 e^{\frac{-\Delta t}{RC}}$ to calculate *RC* for ecf $_2$✓ 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*: rearranges $V = V_0\left(1 - e^{\frac{-\Delta t}{RC}}\right)$ to calculate *RC* etc OR determines half-life $t_{0.5}$ and finds *RC* from $\frac{t_{0.5}}{\ln(2)}$ for ecf $_2$✓ $t_{0.5}$ 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 $_2$✓ 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 5*RC*	2

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

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 ± *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	reduce the (sensitivity of) (Y-voltage)) gain $_1$✓ (change) to 2 V division^{-1} $_2$✓ (and earns $_1$✓) adjust the Y (vertical) shift $_3$✓	'make (Y-) gain smaller' or 'increase the volts per division' or 'reduce the Y-resolution' are acceptable substitutes for 'reduce the (Y-)gain' increase the (Y-) gain to 2 V division^{-1} $_2$✓ not $_1$✓ reduce the (Y-) gain to 0.5 V 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

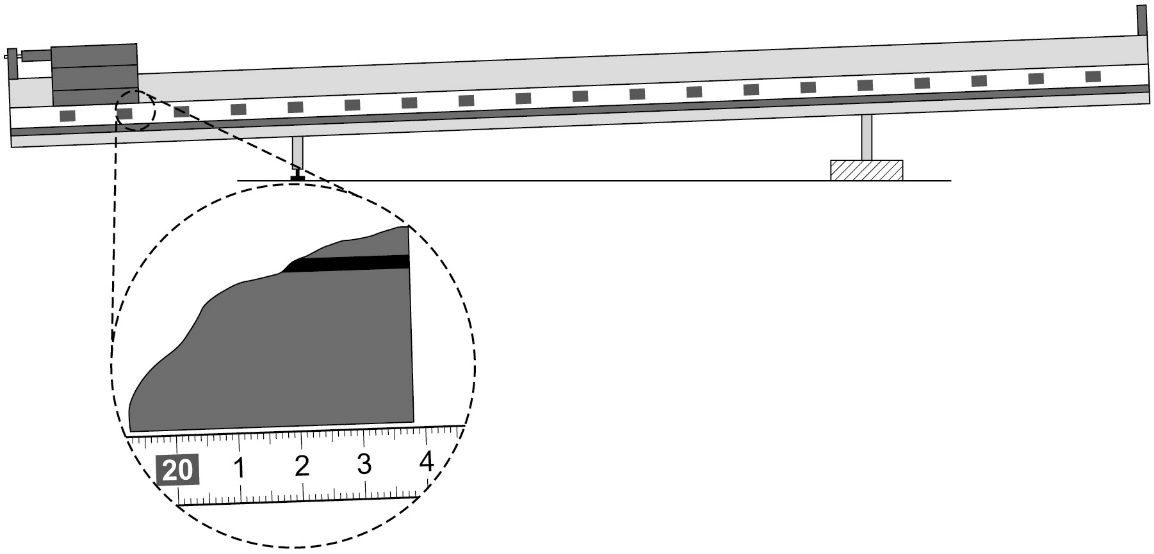
0 3 This question is about an experiment with a linear air track.

A block is used to raise one end of the track.
A bumper fitted with a rubber cord is attached at the lower end of the track.
The air track has a length of 2 m and there is a scale with major divisions marked in centimetres along the side; the zero of the scale is at the lower end, as shown in **Figure 13**.

Figure 13

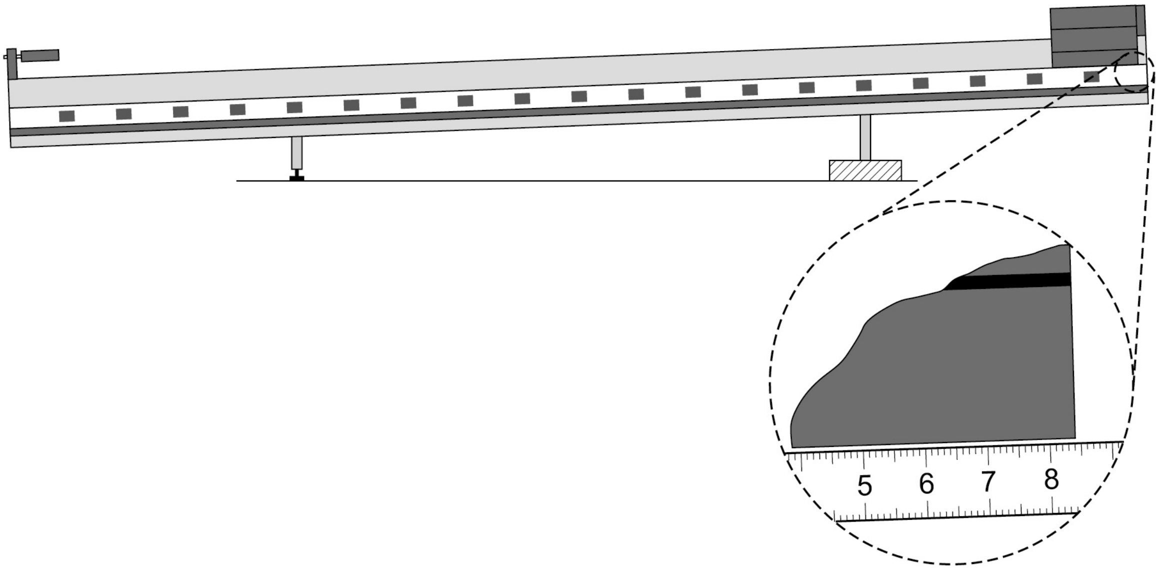
A glider is placed in contact with the rubber cord on the bumper at the lower end of the track. The position of the glider relative to the fixed scale can be determined using **Figure 14**.

Figure 14



The glider is then moved to the position shown in **Figure 15**.

Figure 15



The air supply to the track is turned on and the glider is released.
The glider accelerates down the track, strikes the rubber cord on the bumper and rebounds back up the track.
The glider is allowed to bounce off the rubber band 20 times before it is stopped.

A student reads and records the highest position p of the glider after each rebound n.
Some of the student's data are shown in **Table 2**.
Additional columns have been provided to allow you to complete question **03.2** and question **03.3**.

Question 3 continues on the next page

Table 2

n	p/cm	x/cm	ln(x/cm)
0			
2	157.0		
4	125.4		
6	101.3		
9	75.4		
13	53.8		

0 3 . 1 The value of p corresponding to $n = 0$ is the glider's initial position at the top of the track.

Deduce this value of p using **Figure 13** and **Figure 15**.
Write this result in **Table 2**.

[1 mark]

0 3 . 2 As it travels from the lower end of the track to each position p the glider moves through a distance x.

Deduce x for **all** the values of n using **Figure 14**.
Write these results in **Table 2**.

[1 mark]

0 3 . 3 Plot on **Figure 16** a graph of $\ln(x/\text{cm})$ against n.

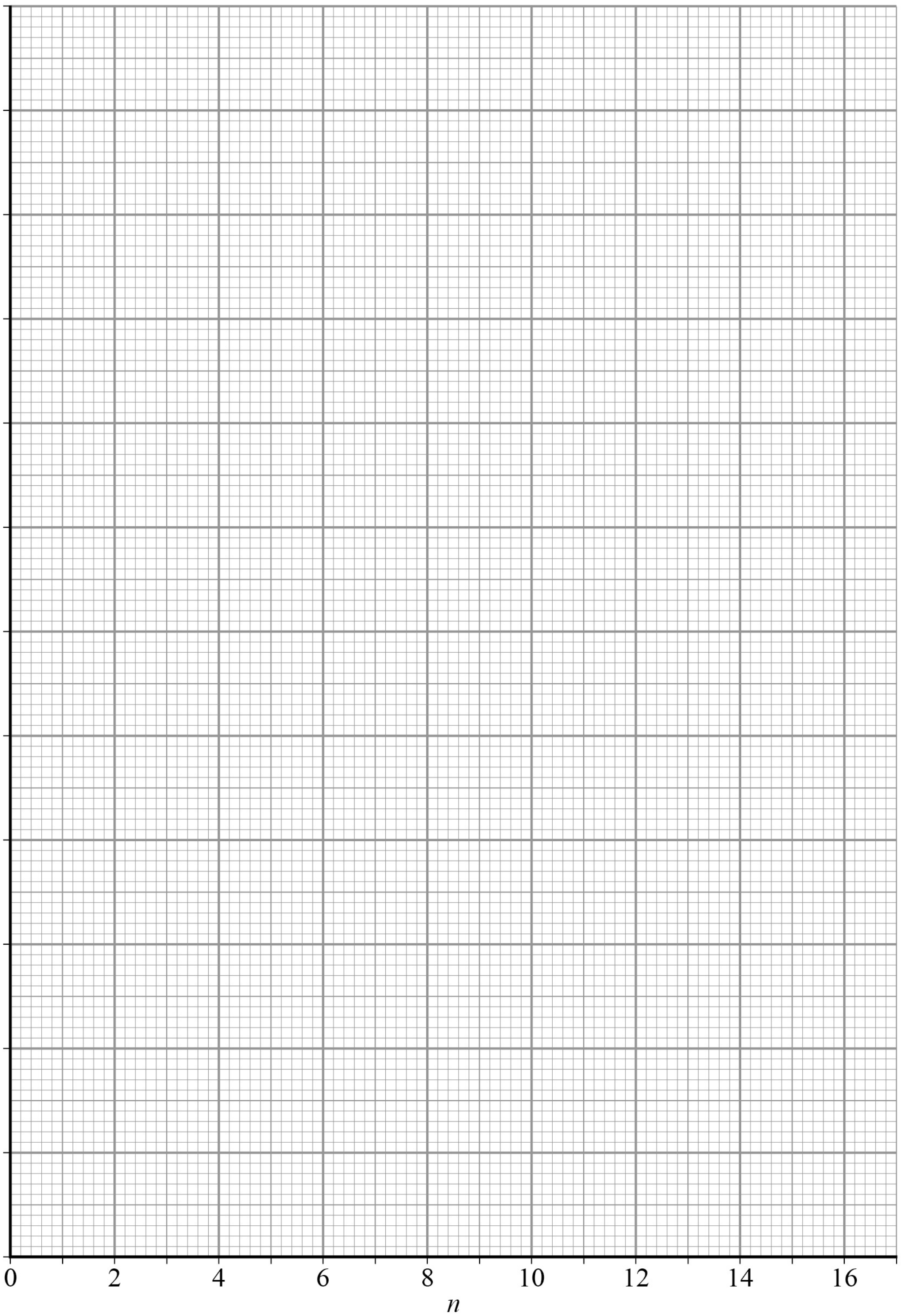
Record your values of $\ln(x/\text{cm})$ in **Table 2**.

[3 marks]

0 3 . 4 Explain why the graph you plotted confirms that x decreases exponentially with n.

[1 mark]

Figure 16



Question 3 continues on the next page

0 3 . 5 Determine, using your graph in **Figure 16**, the value of x when n is 20.

[3 marks]

x when n is 20 = ____________________ cm

0 3 . 6 Describe and explain **two** procedures the student should take to reduce uncertainty in the measurements of p.

[4 marks]

procedure 1 ____________________

procedure 2 ____________________

END OF QUESTIONS

13

<table>
<tr><th>Question</th><th>Answer</th><th>Additional Comments/Guidance</th><th>Mark</th></tr>
<tr><td>03.1</td><td>p_0 = 198.4 (cm) ✓</td><td>only acceptable answer</td><td>1</td></tr>
<tr><td>03.2</td><td>all x values correct and recorded to nearest mm ✓</td><td>
<table>
<tr><th>n</th><th>p/cm</th><th>x/cm</th></tr>
<tr><td>0</td><td>198.4</td><td>174.6</td></tr>
<tr><td>2</td><td>157.0</td><td>133.2</td></tr>
<tr><td>4</td><td>125.4</td><td>101.6</td></tr>
<tr><td>6</td><td>101.3</td><td>77.5</td></tr>
<tr><td>9</td><td>75.4</td><td>51.6</td></tr>
<tr><td>13</td><td>53.8</td><td>30.0</td></tr>
</table>
allow ecf for $x = p - 23.8$ if $p_0 \neq 198.4$
penalise 2 sf $x = 30$ for $n = 13$</td><td>1</td></tr>
</table>

03.3	six values of ln(x/cm) recorded consistently ie all to (minimum) 2 dp; confirm that value of ln(x) for n = 6 corresponds to tabulated value of x $_1$✓ vertical axis labelled ln(x/cm) ie bracket required; suitable vertical scale (points should cover at least half the grid with a frequency of not less than 5 cm) $_2$✓ points plotted for n = 0, 2, 4, 6, 9 and 13; check n = 6 point is plotted within half a grid square of tabulated position; suitable continuous ruled line of negative gradient from n = 0 to (at least) n = 13 $_3$✓	expected data: n p/cm x/cm ln(x/cm) 0 198.4 174.6 5.162 6 101.3 77.5 4.350 for n = 0, x = 0, ignore missing or incorrect ln(x) and ignore missing/wrongly-plotted point for $_2$✓ vertical axis should be labelled ln(x/cm) (note that bracket is essential); expect vertical scale to start at 3 with major divisions of 0.2 for $_3$✓ a suitable line must pass through all points if these have been correctly calculated; for any errant plotted points the line must be the best line in the opinion of the marker; line must not be thicker than half a grid square and width must not vary; points must not be thicker than half a grid square (reject any dots or blobs)	3

03.4	graph is linear and has negative gradient ✓	allow 'straight line' for 'linear'; statement must be confirmed by **Figure 18** allow 'negative slope' or 'slopes downwards' for 'negative gradient' no ecf for non-linear graph	1
03.5	gradient triangle for **Figure 16**; correct read offs (± 1 mm) for all points or for both steps in triangle $_{1}$✓ expected gradient result is –0.135 for gradient between –0.139 to –0.133 (allow this intermediate answer shown as a fraction) award two marks for minimum 3 sf *x* when *n* = 20 in range 11.2 to 12.2 (cm) $_{23}$✓✓ OR one mark for *x* when *n* = 20 in range 10.8 to 12.7 (cm) $_{23}$✓ OR (if gradient out of range) marker uses candidate's gradient (which must be negative) and (marker must read off) intercept on **Figure 16** to calculate *x* when *n* = 20 minimum 3 sf result in range ± 4% $_{23}$✓✓ OR 1 mark minimum 3 sf result in range ± 8% $_{23}$✓ (theoretical result for *x* when *n* = 20 is 11.7(3) cm)	for $_{1}$✓ allow 1 mark for sufficient evidence of working and a valid calculation of the gradient of a linear graph even if graph has a positive gradient for $_{2}$✓ and $_{3}$✓ give no credit if graph drawn has a positive gradient allow 1 mark for using a positive value for the (negative) gradient in the calculation for *x* when *n* = 20 (this leads to 2592 cm); result must be in range ± 4% $_{23}$✓ allow 'similar triangles' method; eg $\frac{5.16-3}{16}=\frac{5.16-\ln x_{20}}{20}$ $_{1}$✓ ln x_{20} = 2.46 $_{2}$✓; x_{20} = 11.7(0) cm $_{3}$✓ allow ecf *x* when *n* = 20 based on **Figure 16** if scales used enable value to be read directly using an extrapolated line; do not allow such working to extend beyond the grid into the margin $_{1}$✓; value in range 11.2 to 12.1 cm $_{23}$✓ = 1 MAX	3

03.6	valid procedure 1 described $_1$✓ explained $_2$✓; valid procedure 2 described $_3$✓ explained $_4$✓	explanation mark ($_2$✓) is only awarded when it is relevant to a correct procedure ($_1$✓); one procedure/explanation allowed per response no credit for conflicting statements or wrong physics any two from: repeat experiment and average calculated (*p*) $_1$✓ to reduce (impact of) random [human] error $_2$✓ and/or repeat readings to detect anomalies $_1$✓ so these can be discarded (before averaging) $_2$✓ and/or view air track at right angles [at eye level] $_1$✓ to reduce [eliminate] (impact of) parallax error $_2$✓ and/or repeat experiment with track direction reversed and average calculated (*p*) $_1$✓ to account for the effect of non-level bench $_2$✓ and/or use video (camera) technology [or a motion sensor linked to a data logger or laser ranger] to view [record] the position of the glider as it reaches the top of the track $_1$✓ to reduce (impact of) random [human] error [to identify and eliminate anomalous results] $_2$✓ reject any suggestion that involves changing the glider, its initial position on the track or the air track itself including the position of the scale	4

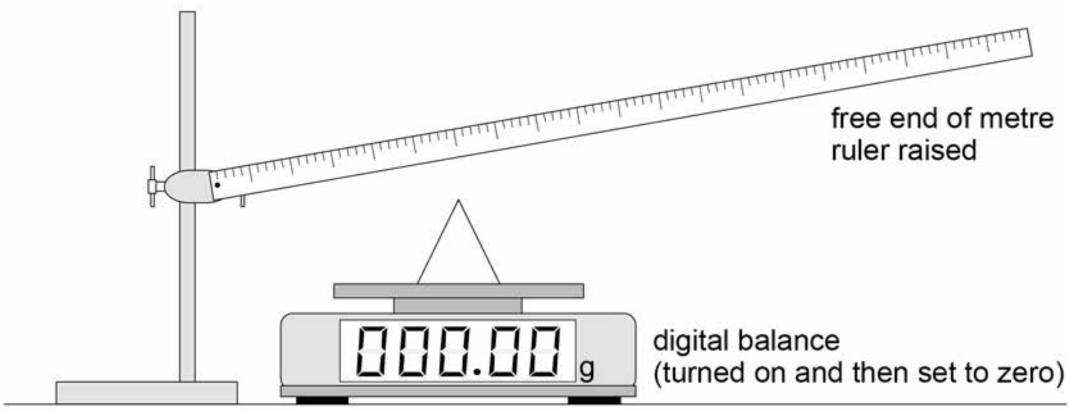
Section A

Answer **all** questions in this section.

0 1 This question is about using a digital balance to investigate the force on a wire placed in a magnetic field when there is an electric current in the wire.

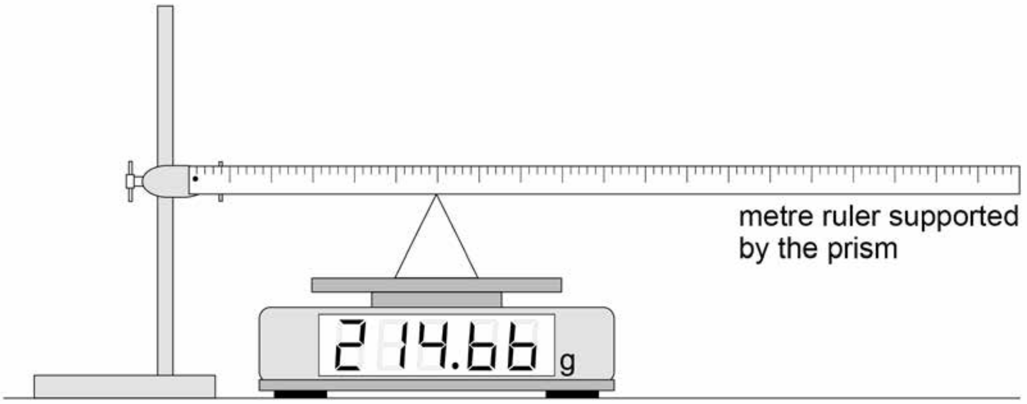
A student carries out the procedure shown in **Figure 1** and **Figure 2**.
A metre ruler is pivoted at the 1.0 cm mark and a prism is placed on a digital balance. The free end of the ruler is raised and the balance is turned on and then set to zero, as shown in **Figure 1**.

Figure 1



The ruler is then supported by the prism with the apex of the prism at the 30.0 cm mark as shown in **Figure 2**. The height of the pivot is adjusted so that the ruler is horizontal.

Figure 2



0 1 . 1 Deduce the mass of the ruler.
State **one** assumption you make.

[3 marks]

mass of ruler = ____________________ g

assumption ____________________

____

Question 1 continues on the next page

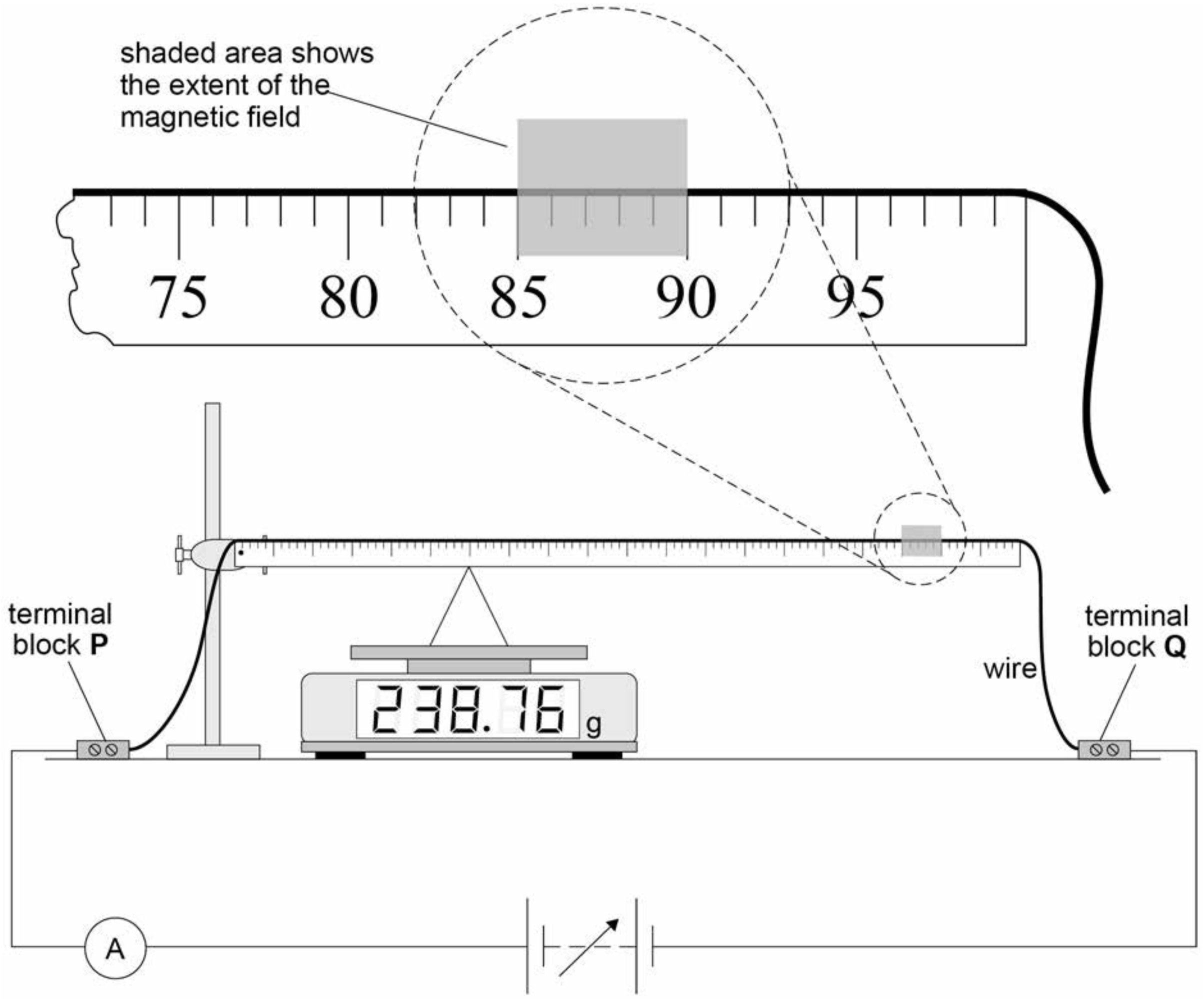
0 1 . 2 The student attaches a uniform wire to the upper edge of the ruler, as shown in **Figure 3**.

The ends of the wire are connected to terminal blocks **P** and **Q** which are fixed firmly to the bench. A power supply and an ammeter are connected between **P** and **Q**.

These modifications cause the balance reading to increase slightly.

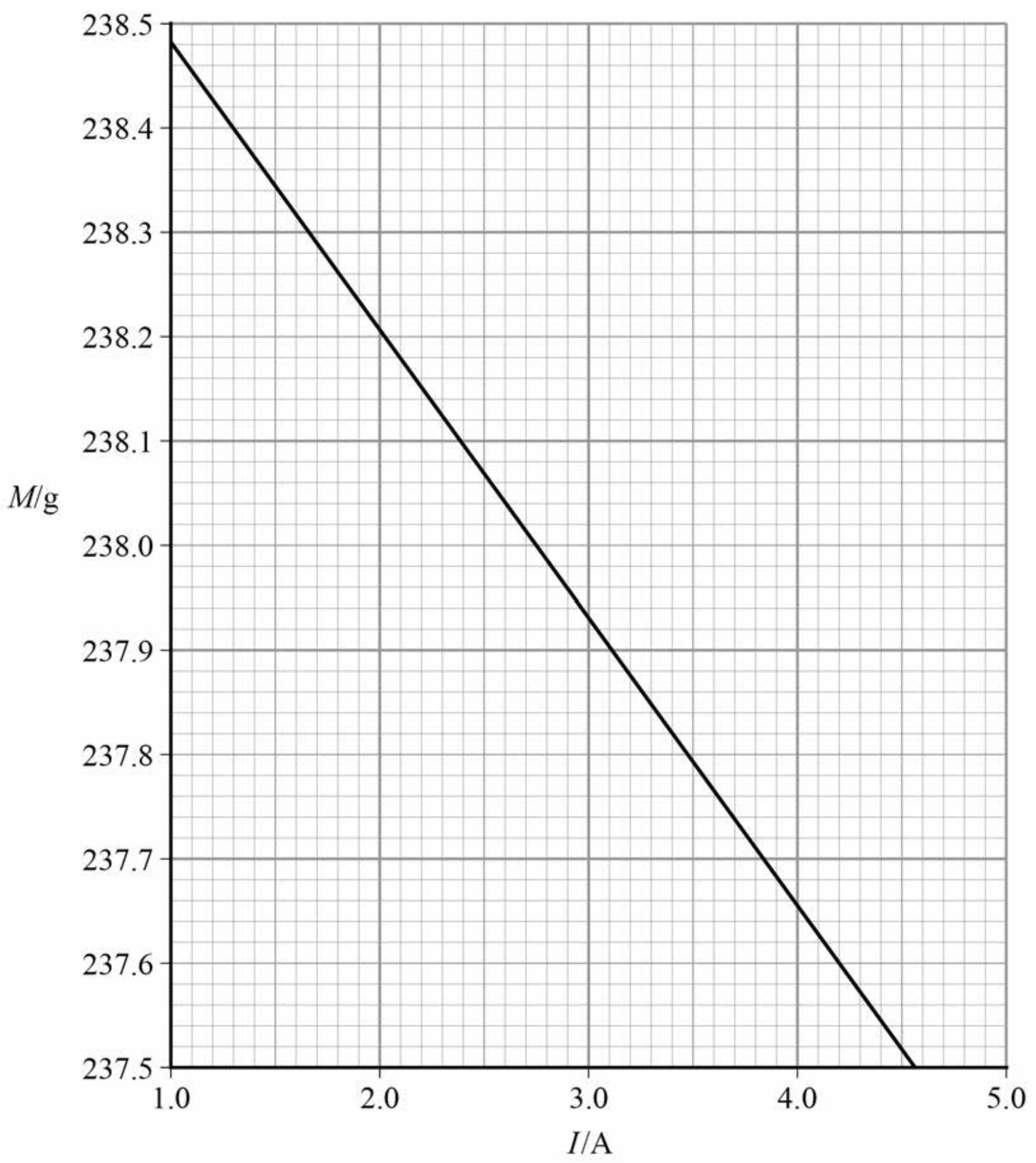
A horizontal uniform magnetic field is applied, perpendicular to the wire, between the 85 cm and 90 cm marks, as shown in the close-up diagram in **Figure 3**.

Figure 3



The balance reading M is recorded for increasing values of current I.
A graph of these data is shown in **Figure 4**.

Figure 4



State and explain the direction of the horizontal uniform magnetic field.

[3 marks]

Question 1 continues on the next page

0 1 . 3 It can be shown that B, the magnitude of the magnetic flux density of the horizontal uniform magnetic field, is given by

$$B = \frac{\sigma}{3L}$$

where σ = change in force acting on the prism per unit current in the wire
L = length of the region where the magnetic field cuts through the wire.

Determine B.

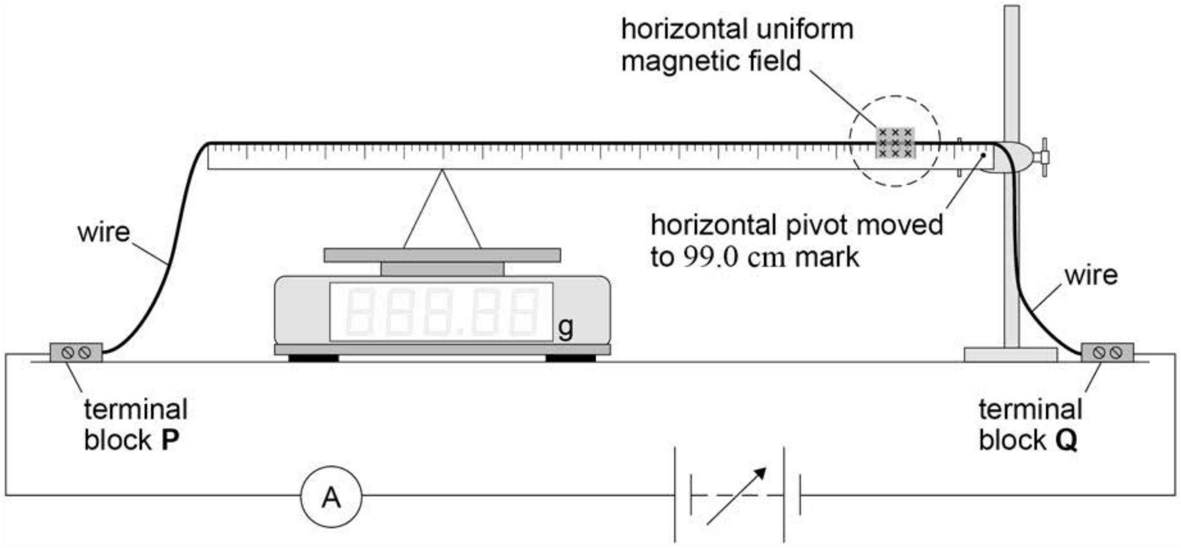
[3 marks]

B = ____________________ T

0 1 . 4 The experiment is repeated with the ruler pivoted at the 99.0 cm mark.
Nothing else is changed from **Figure 3**.

This arrangement is shown in **Figure 5**.

Figure 5



Tick (✓) **one** box in row 1 and **one** box in row 2 of **Table 1** to identify the effect, if any, on the magnitude of the forces acting on the apparatus as a certain current is passed through the wire.

Tick (✓) **one** box in row 3 and **one** box in row 4 of **Table 1** to identify the effect, if any, on the graph produced for this modified experiment compared with the graph in **Figure 4**.

[3 marks]

Table 1

		Reduced	**No effect**	**Increased**
1	Force acting on the current-carrying wire due to the horizontal uniform magnetic field			
2	Force acting on the prism due to the pivoted ruler			
3	Gradient of the graph			
4	Vertical intercept of the graph			

Question 1 continues on the next page

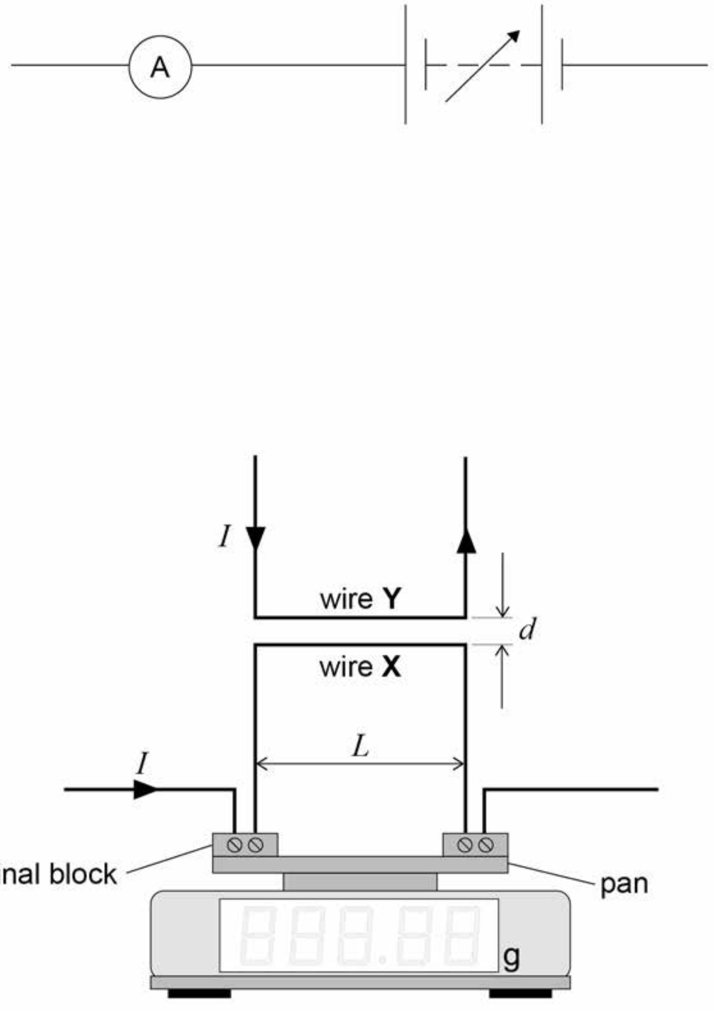
0 1 . 5 **Figure 6** shows the balance being used to measure the forces between two wires. The connections joining these wires to the power supply are not shown.

The pan of the balance moves a negligible amount during use and it supports a straight conducting wire **X** of horizontal length L.
Terminal blocks are used to connect **X** into the circuit. The weight of these does not affect the balance reading.
A second conducting wire **Y** is firmly supported a distance d above **X**.

Show, by adding detail to **Figure 6**, the wire connections that complete the circuit. The currents in **X** and **Y** must have the same magnitude and be in the directions indicated.

[2 marks]

Figure 6



0 1 . 6 The vertical force F on wire **X** due to the magnetic field produced by wire **Y** is given by

$$F = \frac{kI^2L}{d}$$

where k is a constant
d is the perpendicular distance between **X** and **Y**
I is the current in the wires
and L is the horizontal length of wire **X**.

A student wants to measure k using the arrangement in **Figure 6**.

The student is told that the following restrictions must apply:

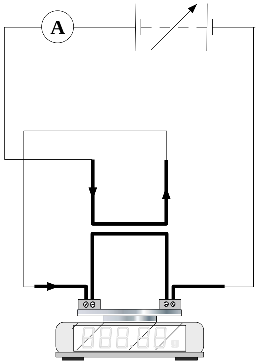
- L is fixed
- I must not exceed 5.0 A
- the result for k must be obtained using a **graphical method**
- the experimental procedure must involve **only one** independent variable.

Explain what the student could do to find k.

[5 marks]

19

Question	Answers	Additional Comments/Guidelines	Mark
01.1	attempt to apply principle of moments either about pivot or (LH) end of ruler $_1$✓ mass = 127(.04) (g) $_2$✓ assumption is that ruler is uniform / mass evenly distributed **OR** weight acts at the centre/mid-point/middle **OR** centre of mass / gravity is at the centre/mid-point/middle $_3$✓	for $_1$✓ for evidence of moments taken expect clockwise and anticlockwise moment; for moment about pivot expect to see either 29 or 49; for use of LH end of ruler expect 30 or 50 don't insist on seeing masses in kg, distances in m or the inclusion of 9.81 or g in the working; condone g seen on one side only rounding to 127 g earns $_1$✓ and $_2$✓	**3**
01.2	force on wire is upwards **OR** ↑ $_1$✓ current is from **P** to **Q** **OR** rightwards **OR** (left) to (the) right **OR** →$_2$✓ states direction of force and direction of current (or $_3$✓= 0) and makes a suitably justified deduction, eg using left-hand rule **OR** LH rule **AND** B is into the page **OR** into plane of **Figure 3** **OR** ⊗$_3$✓	for $_1$✓ condone 'motion is upwards' for $_2$✓ 'towards Q' **OR** 'positive to negative' are not enough allow logically correct (using LH rule) $_3$✓ for either downwards force with correct current **AND/OR** upwards force with wrong current increased flux density below wire is acceptable alternative to LH rule	**3**
01.3	gradient calculated from ΔM divided by ΔI, condone read off errors of ± 1 division; minimum I step ≥ 2.0 A $_1$✓ evidence of g = 9.81 or 9.8 correctly used in working for σ or B $_2$✓ $\lvert B \rvert$ in range 1.76×10^{-2} to 1.87×10^{-2} or 1.8×10^{-2} (T) $_3$✓	for $_1$✓ expect (–)0.28 (g A^{-1}); do not penalise for missing – sign for $_2$✓ look for σ = their gradient × 9.81 (× 10^{-3} N) **OR** $B = \frac{\text{their gradient} \times 9.81(\times 10^{-3})}{15(\times 10^{-2})}$; condone POT errors for $_3$✓CAO by correct method only; ignore – sign if provided; no limit on maximum sf	**3**

<table>
<tr><th>Question</th><th>Answers</th><th>Additional Comments/Guidelines</th><th>Mark</th></tr>
<tr><td>01.4</td><td>
<table>
<tr><th></th><th>Reduced</th><th>No effect</th><th>Increased</th></tr>
<tr><td>Force acting on wire</td><td></td><td>$_1$✓</td><td></td></tr>
<tr><td>Force acting on prism</td><td>$_2$✓</td><td></td><td></td></tr>
<tr><td>Gradient of graph</td><td>$_3$✓</td><td></td><td></td></tr>
<tr><td>Vertical intercept</td><td>$_4$✓</td><td></td><td></td></tr>
</table>
</td><td>$_1$✓ = 1 mark
$_2$✓ = 1 mark
$_3$✓<u>and</u> $_4$✓= 1 mark
allow any distinguishing mark as long as only one per row
for ✓ and × in same row ignore ×
for ✓ and ✓ in same row give no mark
ignore any crossed-out response unless only distinguishing mark on row</td><td>3</td></tr>
<tr><td>01.5</td><td>any complete circuit connecting the power supply in Figure 6 to X and to Y that produces currents in X and in Y that travel left to right $_1$✓
wiring correct so that X and Y are in series (see below) $_2$✓

</td><td>allow parallel circuit for $_1$✓ but reject use of additional power supply
if X and/or Y is/are short-circuited award no marks;
for impractical circuits eg voltmeter added in series, award no marks
ignore any current arrows added to diagram</td><td>2</td></tr>
</table>

Question	Answers	Additional Comments/Guidelines	Mark
01.6	strategy: states that readings of M (as the dependent variable) will be measured for different values of independent variable, I or d only $_1$✓ clearly identifies the correct control variable, d or I only; condone $\frac{d}{L}$ = constant if I varied **OR** I^2L **OR** IL = constant if d varied; it must be clear how the value of the control variable is known $_2$✓ states that L will be measured or gives value eg L = 5.0 cm $_3$✓ use of g to convert M reading to F; evidence may be found in expression for k $_4$✓	for $_1$✓ condone F identified as the dependent variable or as the balance reading; reject 'measure change in mass / change in F' failure to make M or F the dependent variable cannot score $_1$✓ or $_2$✓ for $_2$✓if d is being varied and I = 5.0 A is stated, this can be taken to mean I is the control variable and the value is known for $_1$✓ and for $_3$✓ insist that M and L are being read **OR** measured **OR** recorded for $_4$✓ 'work out force' is not enough; reject 'acceleration' for g	**MAX 3**
	analysis: suggests a plot with M or F [by itself or combined with another factor] on the vertical axis and some valid manipulation of their independent variable on the horizontal axis $_5$✓ identifies correctly how k can be found using the gradient of their graph; k must be the subject of the expression given $_6$✓ **OR** if suggesting a plot with log M or log F on the vertical axis etc identifying correctly how k can be found from the graph intercept $_6$✓ **OR** suggesting a plot with M or F on the vertical axis etc and identifying correctly how k is found using the area under the line $_{56}$✓ = 1 MAX	the intention to plot M against I^2 is taken to mean that M is the dependent variable and is plotted on the vertical axis examples: plot M against I^2 will earn $_5$✓ and then $k = \frac{g \times d \times \text{gradient}}{L}$ will earn $_6$✓ or plot F against $\frac{1}{d}$ will earn $_5$✓ and then $k = \frac{\text{gradient}}{I^2 \times L}$ will earn $_6$✓ (note that when F is the dependent variable g will not appear in the expression for k)	2
Total			**19**

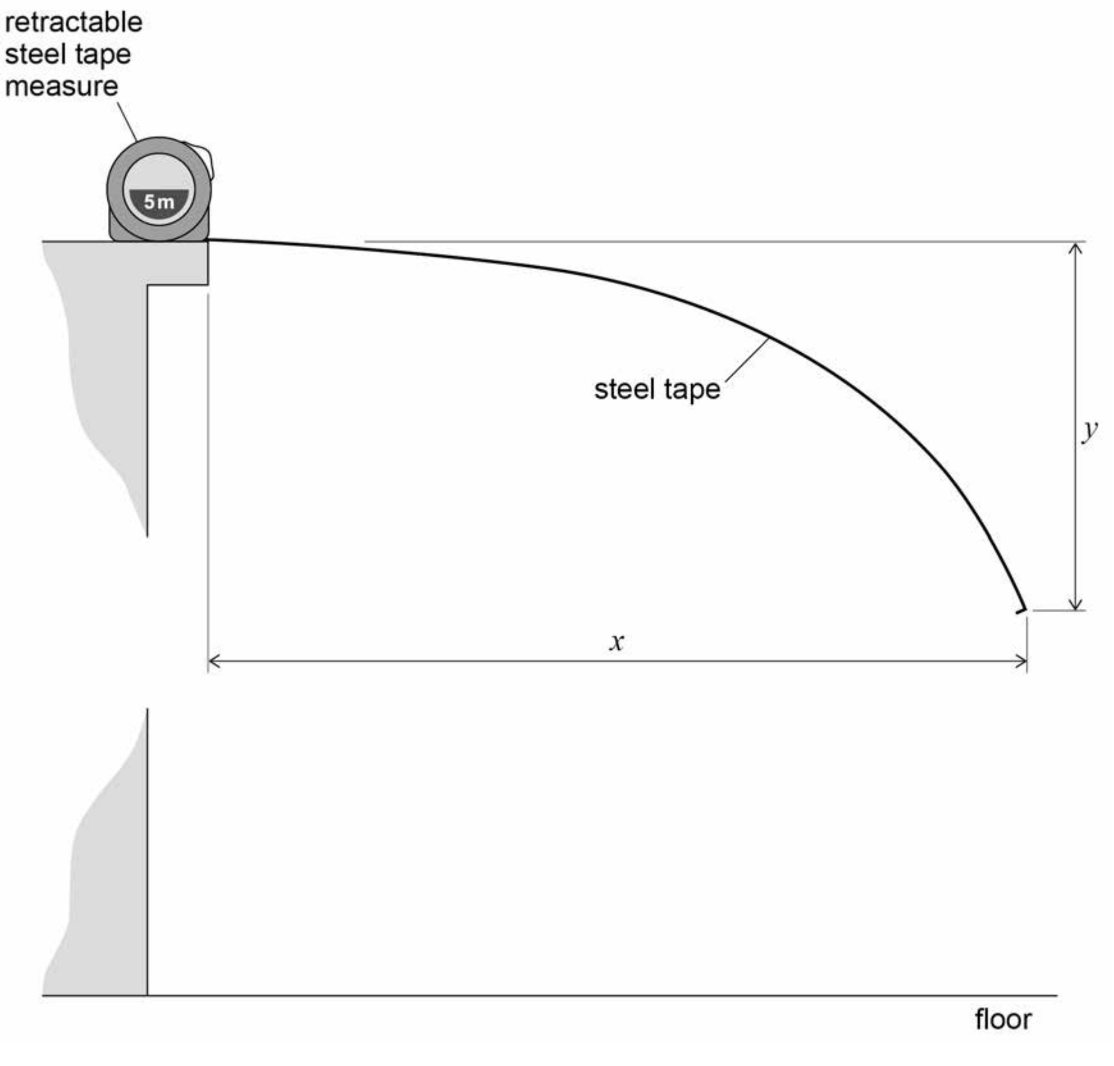
0 2 This question is about an experiment with a retractable steel tape measure.

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



0 2 . 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]

0 2 . 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.

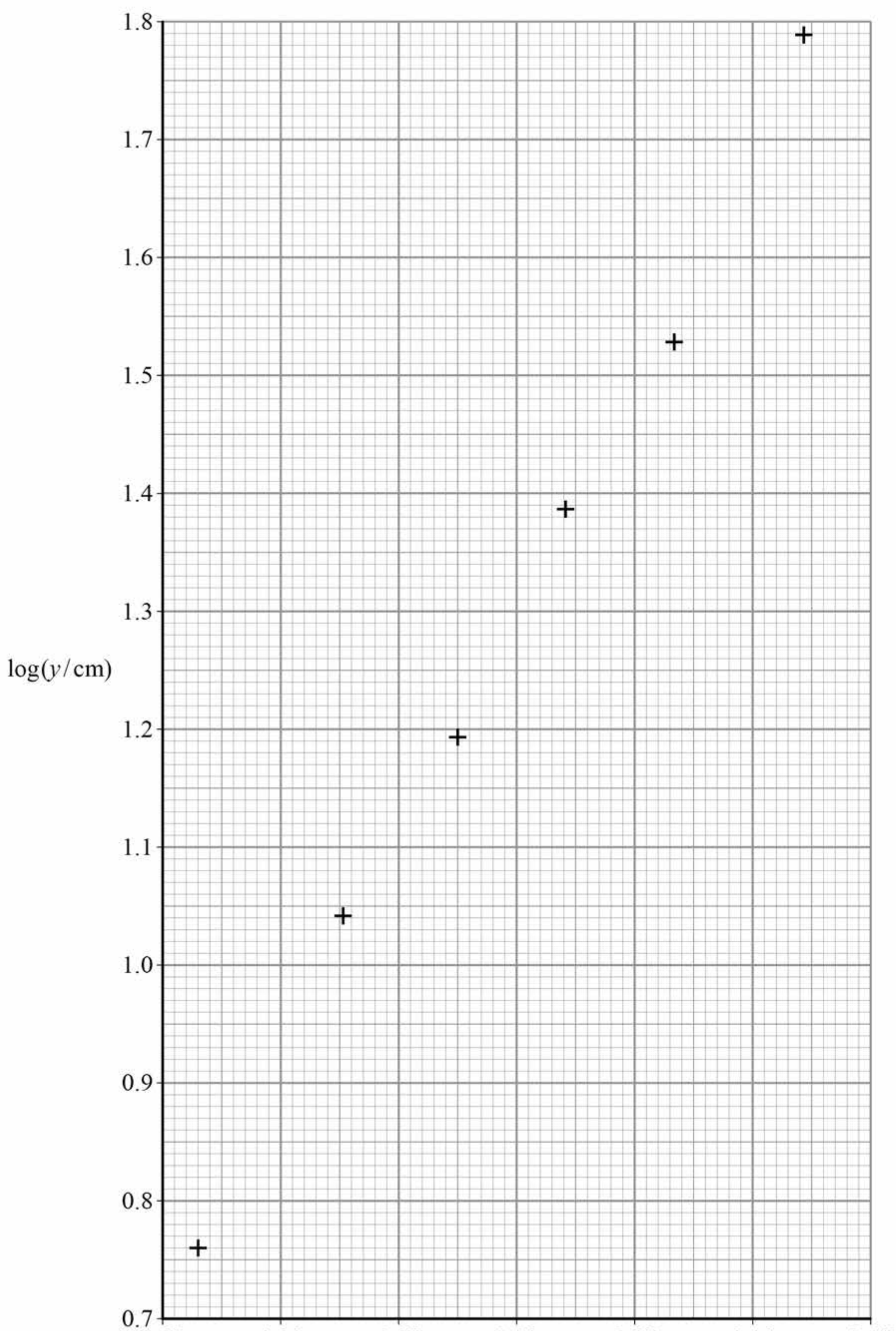
These data are used to plot the graph in **Figure 8**.

Determine n using **Figure 8**.

[3 marks]

$n =$ ____________________

Figure 8



Question 2 continues on the next page

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

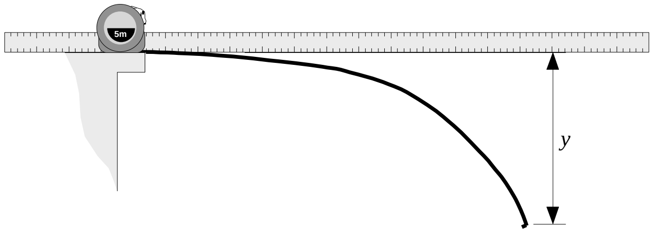
[3 marks]

0 2 . 5 Estimate 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 ________

12

Question	Answers	Additional Comments/Guidelines	Mark
02.1	technique: at least one instance seen where a metre ruler is made vertical using a set-square in contact with the floor $_1$✓ strategy: (use a metre ruler to) measure the height of the free end of the tape (above the floor) and the height of the tape at the bench [height of the bench]; y = <u>difference</u> between these heights $_2$✓ **OR** 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** ruler $_1$✓ using **additional** ruler made vertical (as before) or using set-square placed against horizontal ruler $_2$✓	for $_1$✓ allow use of plumb line or spirit level; don't insist on the set-square being used against two mutually perpendicular faces of the metre ruler the floor is assumed to be horizontal if the deflection is found from the difference between two vertical measurements for $_2$✓ allow metre ruler B made horizontal by use of set-square against vertical ruler A; ruler B establishes vertical position of free end of tape; ruler A is used to measure y directly either or both marks can be earned for suitable annotation to **Figure 7** reject suggestions that y can be found without making at least one vertical measurement	2
02.2	(for $x \le 70$ cm y is small so) <u>percentage</u>/<u>fractional</u> uncertainty in y is (too) large **OR** (for $x > 70$ cm) <u>percentage</u>/<u>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) between1st 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) intercept seen **OR** log A = log y when log $x = 0$ **OR** log y = n log x + log A (or correctly rearranged) seen ${}_1$✓ indirect method to find (vertical) intercept described, eg using (values for) a point on line; substitute into equation (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) 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 point on line find log x, log y; anti-log 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 different point on line; calculate average (A) ${}_3$✓ reject averaging of x and y or of log x and log y	**3**

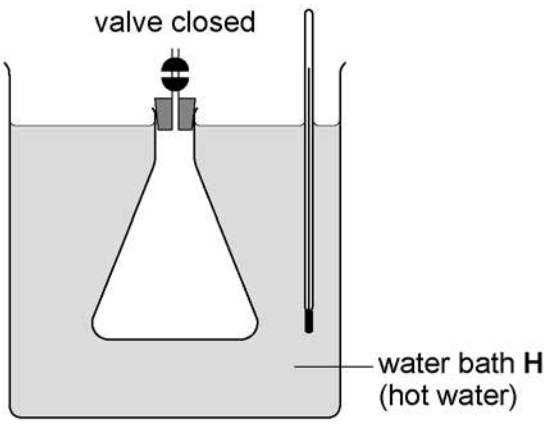
<table>
<tr><th>Question</th><th>Answers</th><th>Additional Comments/Guidelines</th><th>Mark</th></tr>
<tr>
<td>02.5</td>
<td>
<p><i>A</i> evaluated using $A = \frac{y}{x^n}$ OR using $A = 10^{(\log y - n \log x)}$;</p>
<p>correct substitution of n (from 02.3) and of y and x in cm from any row in Table 2 (likely values shown opposite),</p>
<p><i>A</i> evaluated correctly to minimum 2 sf and correct POT $_{1}$✓</p>
<p>order of magnitude of A = –7 OR 10^{-7} (accept index or of power of ten) $_{2}$✓</p>
<p>cm^{-3} $_{3}$✓</p>
<p>OR</p>
<p>$\mathrm{cm}^{(1-n)}$ where n is result given for 02.3</p>
</td>
<td>
<p>for $_{1}$✓ ECF for non-integer n</p>
<p>values that may be seen in working:</p>
<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>
<p>*equation of best-fit line gives vertical intercept = 3.879</p>
<p>for $_{2}$✓ accept 1×10^{-7} (cm^{-3}) but reject 1.0×10^{-7} or 2×10^{-7} etc;</p>
<p>ECF order of magnitude correct for their value of A;</p>
<p>POT must be consistent with unit given eg if cm^{-3} is converted into m^{-3};</p>
<p>for $_{3}$✓ CAO;</p>
<p>use of non-integer, eg n = 3.6 requires A in $\mathrm{cm}^{-2.6}$</p>
<p>withhold $_{2}$✓ and $_{3}$✓ if A is not evaluated</p>
</td>
<td>3</td>
</tr>
<tr><td>Total</td><td></td><td></td><td>12</td></tr>
</table>

0 3 This question is about an experiment to estimate absolute zero.

Figures 9a to **9d** show the stages in the procedure carried out by a student.

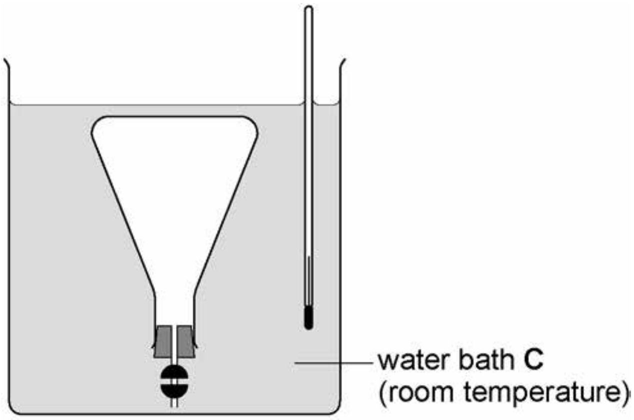
An empty flask fitted with a tube and an open valve is placed in water bath **H** containing hot water. The air inside the flask is allowed to come into thermal equilibrium with the water.
The valve is then closed, trapping a certain volume of air, as shown in **Figure 9a**.

Figure 9a



The flask is inverted and placed in water bath **C** in which the water is at room temperature.
The air inside the flask is again allowed to come into thermal equilibrium with the water, as shown in **Figure 9b**.

Figure 9b



Question 3 continues on the next page

The valve is opened and some water enters the flask, as shown in **Figure 9c**.

Figure 9c

The depth of the inverted flask is adjusted until the level of water inside the flask is the same as the level in the water bath.
The valve is then closed, trapping the air and the water inside the flask, as shown in **Figure 9d**.

Figure 9d

0 3 . 1 Explain why the volume of the air in the flask in **Figure 9c** is less than the volume of the air in the flask in **Figure 9d**.

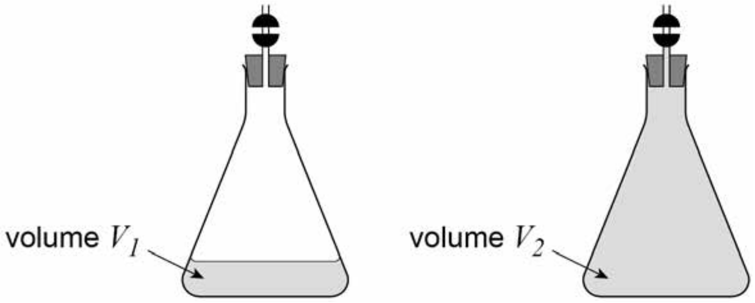
[2 marks]

0 3 . 2 Explain why Charles's Law can be applied to compare the air in the flask in **Figure 9a** with the air in the flask in **Figure 9d**.

[2 marks]

0 3 . 3 The flask is removed from water bath **C** and the valve and stopper are removed.
The volume of the water in the flask is V_1
The flask is then completely refilled with water and the valve and stopper replaced.
The volume of the water now in the flask is V_2
The volumes V_1 and V_2 are shown by the shaded parts in **Figure 10**.

Figure 10



Explain how V_1 and V_2 can be determined.

In your answer you should

- identify a suitable measuring instrument
- explain a suitable procedure to eliminate possible systematic error.

[3 marks]

Question 3 continues on the next page

0 3 . 4 Plot on **Figure 11** points to show the volume V and the temperature θ of the air in the flask when

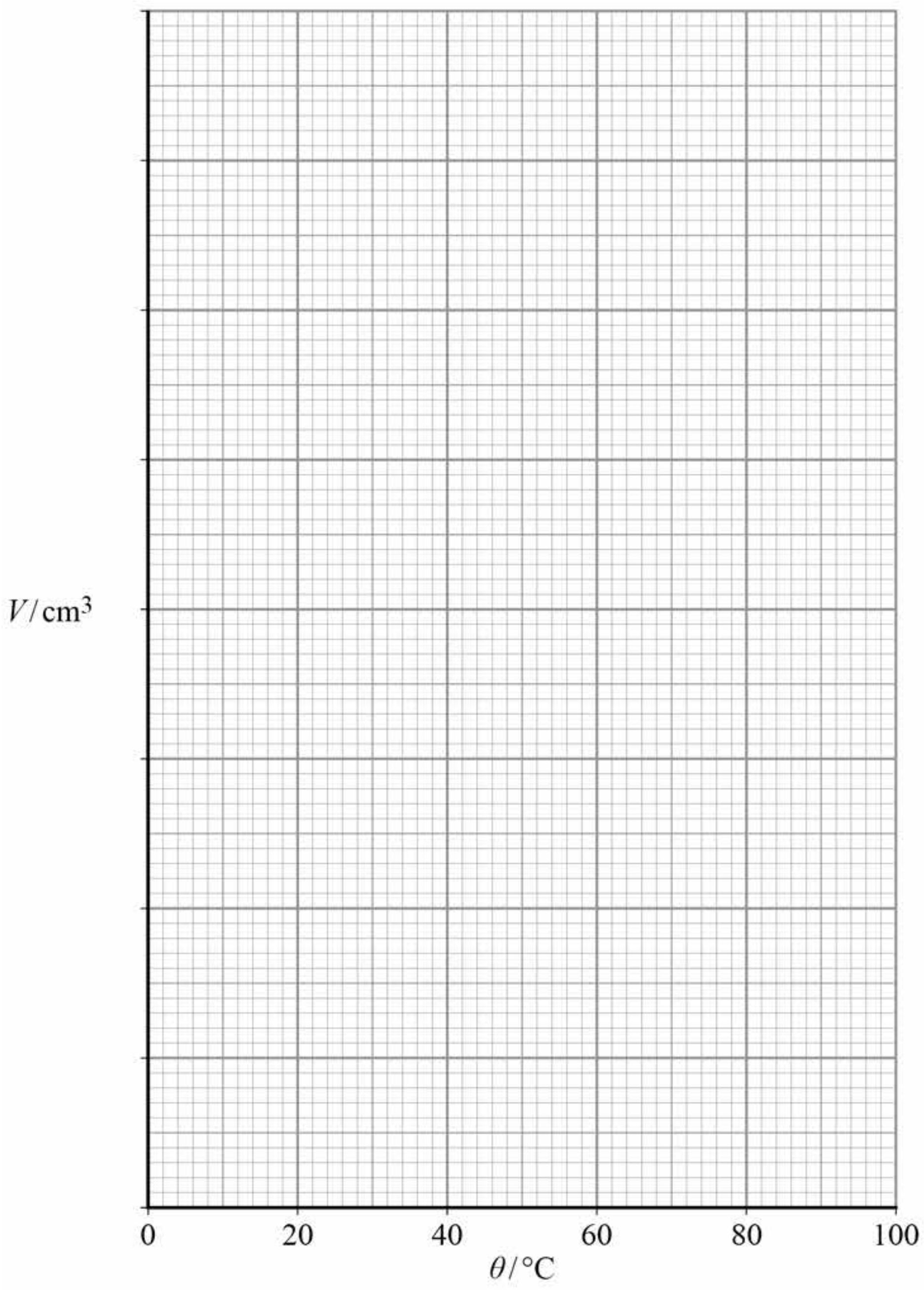
- the flask is as shown in **Figure 9a**
- the flask is as shown in **Figure 9d**.

The temperature of the hot water bath is 86 °C
Room temperature is 19 °C

$V_1 = 48\ \text{cm}^3$
$V_2 = 255\ \text{cm}^3$

[3 marks]

Figure 11



0 3 . 5 Add a best fit line to your graph in **Figure 11** to show how V should vary with θ according to Charles's Law.

[1 mark]

0 3 . 6 Determine the value of absolute zero in °C using your graph in **Figure 11**.

[3 marks]

value of absolute zero = ____________________ °C

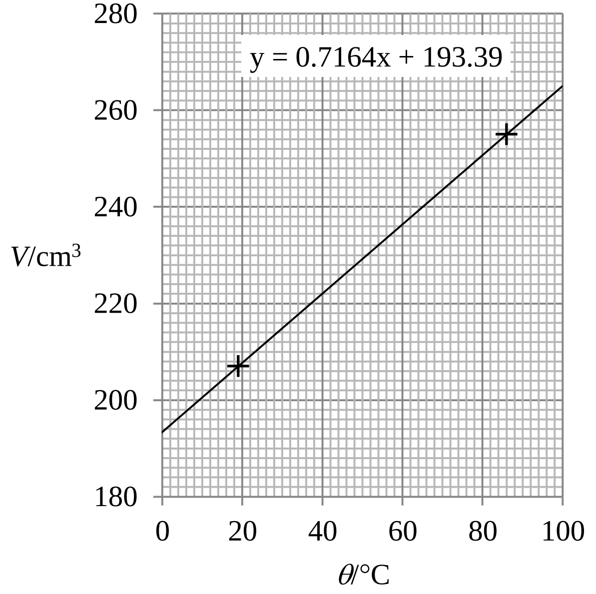
14

END OF QUESTIONS

Question	Answers	Additional Comments/Guidelines	Mark
03.1	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** Boyle's Law applies **OR** PV = constant; $_2$✓ any suggestion that pressure is constant **OR** the volume is constant **OR** the temperature changes **OR** the amount of air in the flask increases as flask is raised loses both marks	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 reject 'pressure released (in **9d**)' for $_2$✓ allow mean KE of molecules is the same accept $P \propto \frac{1}{V}$; allow nRT = constant; reject $PV = k$ (unless k = constant is also seen)	**2**

Question	Answers	Additional Comments/Guidelines	Mark
03.2	same (air) pressure $_1$✓ same mass of air $_2$✓ any suggestion that temperature is constant **OR** that volume is constant **OR** that pressure has changed **OR** the amount of air in the flask decreases as flask is moved from H to C loses both marks	for $_1$✓ and $_2$✓ accept constant/unchanged = same and condone 'assume same pressure/mass of gas' for $_2$✓accept same (number of) moles or same amount of gas no credit for stating 'volume increases as temperature increases' 'temperature is in equilibrium' is neutral	**2**

Question	Answers	Additional Comments/Guidelines	Mark
03.3	relevant quantity and instrument seen: volume(s) (of liquid) measured using a measuring cylinder **OR** graduated beaker $_1$✓ reject 'measuring beaker' and 'burette' eye level with the bottom of the meniscus (allow suitable sketch showing eye) $_2$✓ 'measure at eye level' **OR** 'eye level with graduation' **OR** 'eye perpendicular to graduation' are not enough to avoid parallax error $_3$✓ see alternative opposite; if both approaches are given record the mark to whichever scores most	alternative for $_1$✓mass (of liquid/flask) measured using a balance reject 'scales' and reject 'weigh/find weight/weigh the mass' for $_2$✓valid method to account for the mass of flask eg tare/zero balance (ECF 'scales') with (same) empty flask on balance and then measure mass of flask with liquid **OR** subtract mass of empty flask from mass of flask containing liquid; don't penalise 'weigh' twice **OR** ensure the balance is on a horizontal surface for $_3$✓find volume(s) using $V = \frac{m}{\rho}$; V must be subject	**3**
03.4	suitable vertical scale for their data points covering at least half the grid; false origin on the vertical scale correctly marked; vertical scale marked at sensible intervals, based around intervals of 1, 2, 4 or 5 etc; graduations no further than 2 major divisions apart $_1$✓ $19, 207$ plotted to nearest ½ grid square $_2$✓ $86, 255$ plotted to nearest ½ grid square $_3$✓	for $_1$✓ the two correct data points a suitable scale is 10 cm^3 for each major division an unmarked origin is be assumed to be (0, 0); if a broken scale symbol is not used and the V scale becomes non-linear, withhold the mark award $_{23}$✓ = 1 MAX for thick or poorly-marked points eg thicker than half a grid square; reject blobs, dots and circles	**3**
03.5	**continuous ruled** best-fit line of positive gradient through intersection of cross-hairs of their points ✓	apply same criteria for judging line quality as in **02.3**; don't penalise thick line if thick points are penalised in **03.4**	**1**

Question	Answers	Additional Comments/Guidelines	Mark
03.6	legitimate method to <u>calculate</u> horizontal intercept eg gradient calculated from ΔV divided by $\Delta\theta$ ie <u>numerical</u> evidence of 2 steps required; don't penalise read off errors or small steps reads (to within 1 grid square) **OR** uses a point on the line to calculate (with correct use of $y = mx + c$) the vertical intercept; sensible values are shown on the right $_1$✓ correct use of their vertical intercept and their gradient to calculate the horizontal intercept using –1 × vertical intercept divided by gradient $_2$✓ **OR** similar triangles, eg $\frac{255-207}{86-19}=\frac{207-0}{19-\theta}$ or similar seen $_1$✓ minimum $\Delta\theta$ = 86 – 19 (= 67as in example above) $_2$✓ result in range –260°C to –285°C $_3$✓ withhold mark for missing sign; no credit for unsupported answer	 in $_1$✓ condone V changed to m^3 when calculating gradient and finding intercept values for a graph with a negative gradient allow credit for $_1$✓ only = 1 MAX no credit for non-linear graph = 0 MAX data which may be seen in working include V = 193 cm^3, θ = 0 °C; V = 265 cm^3, θ = 100 °C; V = 207 cm^3, θ = 19 °C; V = 255 cm^3, θ = 86° C	**3**
Total			**14**

Do not write outside the box

Section A

Answer **all** questions in this section.

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

Figure 1

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

[2 marks]

Safety procedure 1 ____________________

Safety procedure 2 ____________________

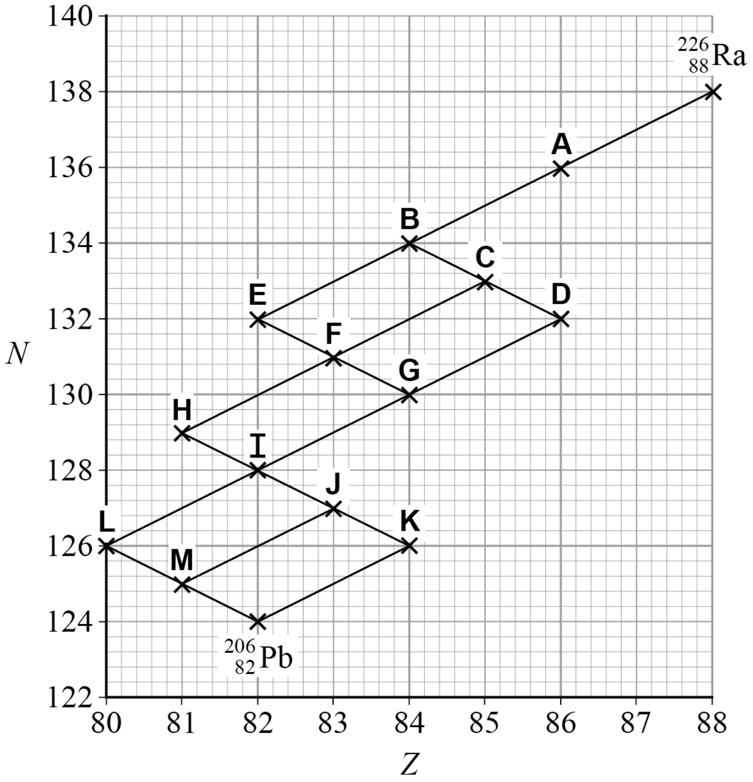
0 1 . 2 A sealed source contains radium-226 ($^{226}_{88}\text{Ra}$).

$^{226}_{88}\text{Ra}$ 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

0 1 . 4 The sealed source emits γ radiation in addition to α and β^- particles.
A student uses the sealed source to investigate the inverse-square law for γ radiation.
The student begins by making measurements to find the count rate A_b for the background radiation.

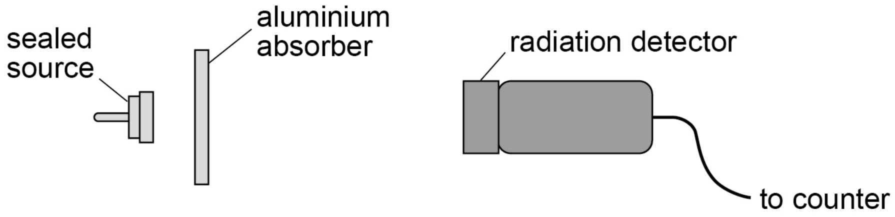
State and explain procedures

- to eliminate systematic error in the measurements used to find A_b
- to reduce the percentage uncertainty in A_b.

[3 marks]

0 1 . 5 **Figure 3** shows an aluminium absorber placed between the sealed source and a radiation detector. This is to make sure that only γ radiation from the source reaches the detector.

Figure 3

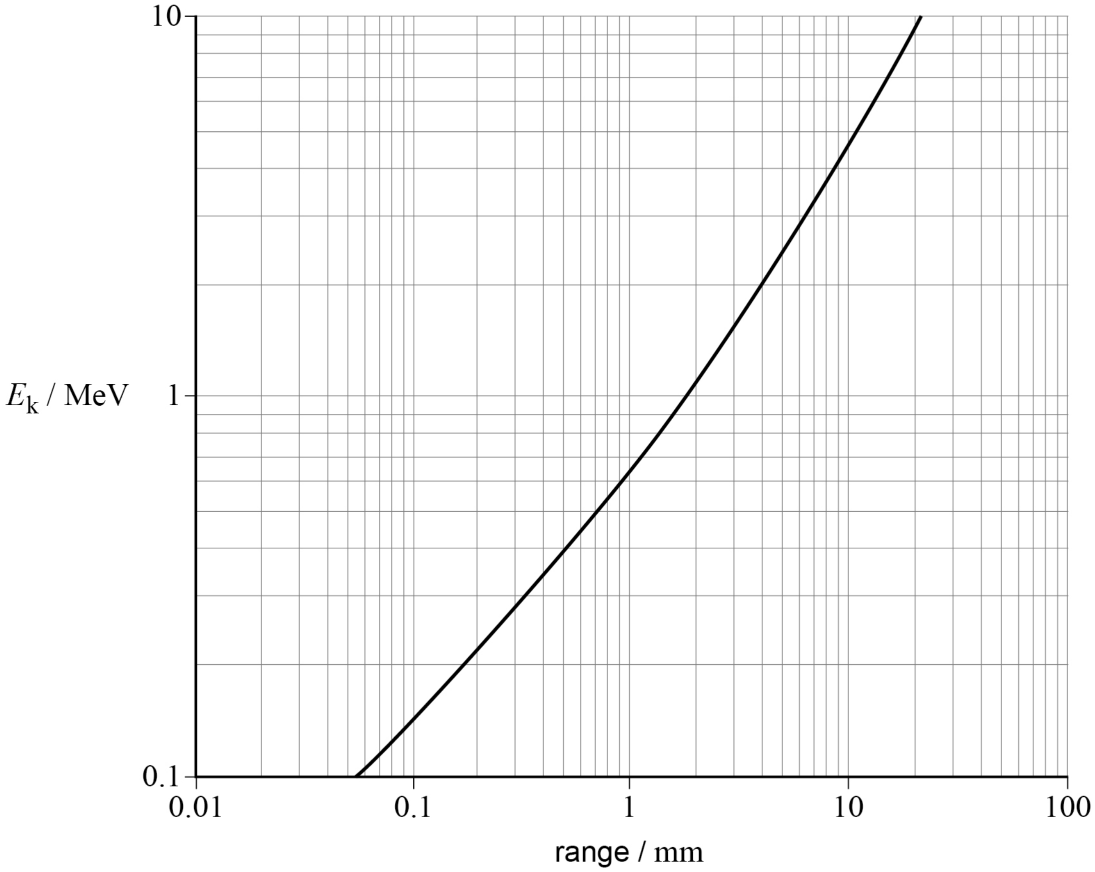


The sealed source emits:

- 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.

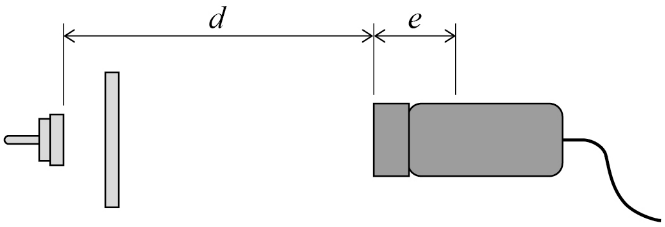
[3 marks]

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.

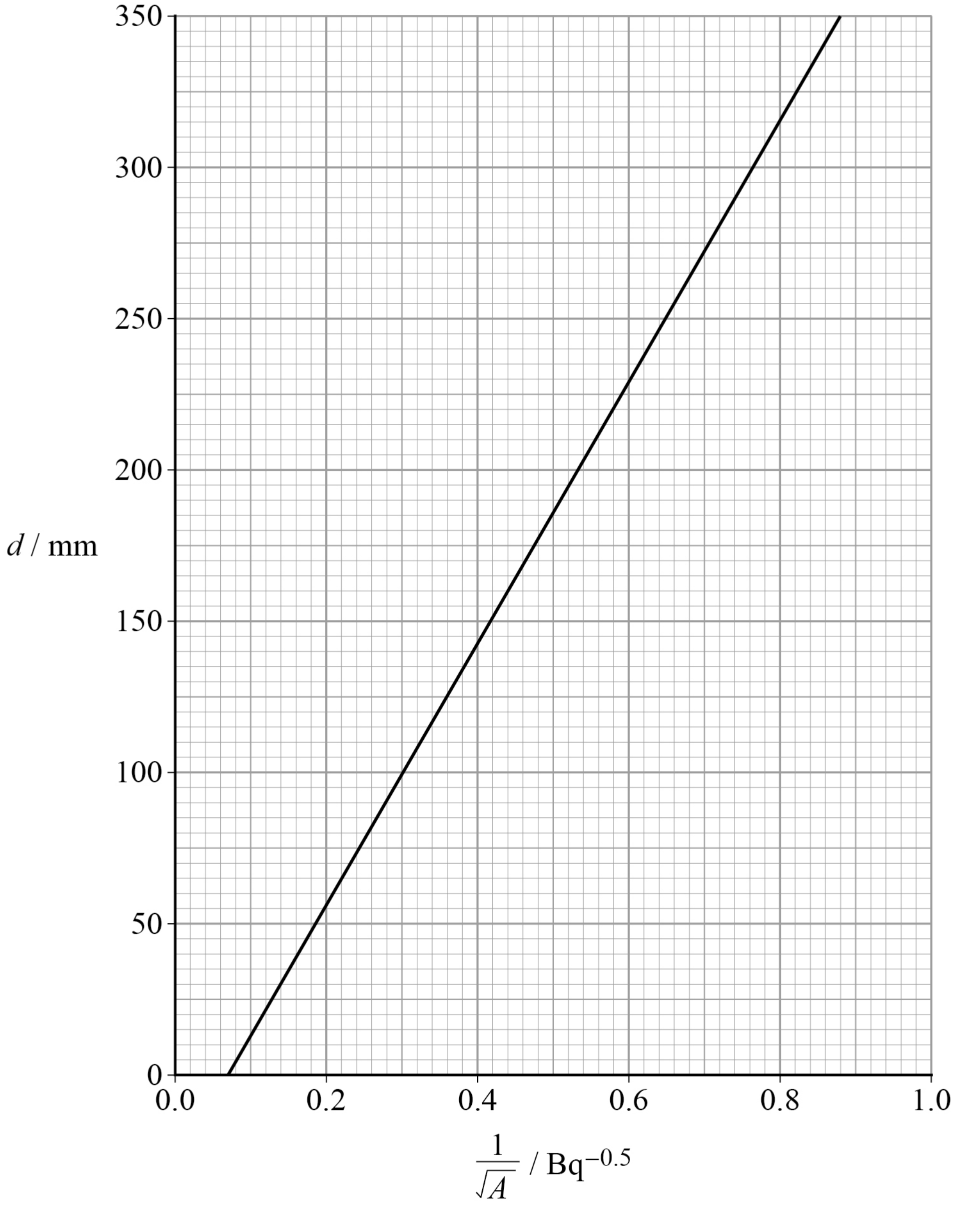
The student plots the graph of d against $\frac{1}{\sqrt{A}}$ shown in **Figure 6**.

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

19

Question	Answers	Additional Comments/Guidelines	Mark
01.1	₁✓ idea of **maximising distance** use <u>tongs</u> / <u>tweezers</u> / <u>handling tool</u> (when handling source to keep as far away from source as possible) OR keep at least 2 metres away (if observing) ₂✓ idea of **limiting exposure time during** experiment remove source from <u>lab</u> / <u>room</u> when not in use / after experiment OR idea of put / replace / keep source in a castle / container when not in use / in the open / after experiment or wtte 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	award 1 mark for each valid <u>procedure</u> (unless contradicted) do not award more than 1 mark for safety procedure 1 and do not award more than 1 mark for safety procedure 2 do **not** credit the same marking point for **different** do not award more than 1 mark for safety procedure 1 procedures for ₁✓ treat as neutral: 'keep source at arm's length / far away' / 'use pliers' / don't go close (to the source) for ₂✓ do not insist on 'lead' treat as neutral: 'use a lead container' treat as neutral: 'limit time of exposure' / 'work as quickly as possible' / 'don't keep source out of box for too long' / 'keep 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

01.2	5 ✓	correct answer only	AO3-1a = 1

01.3	**A** OR $^{222}_{86}$Rn / radon 222 / Rn 222 ✓ **B** OR $^{218}_{84}$Po / polonium 218 / Po 218 ✓ **I** OR $^{210}_{82}$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 $^{222}_{86}$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) source(s) (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 counter AND/OR stopwatch (before use) OR check the counter AND/OR stopwatch 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 total 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

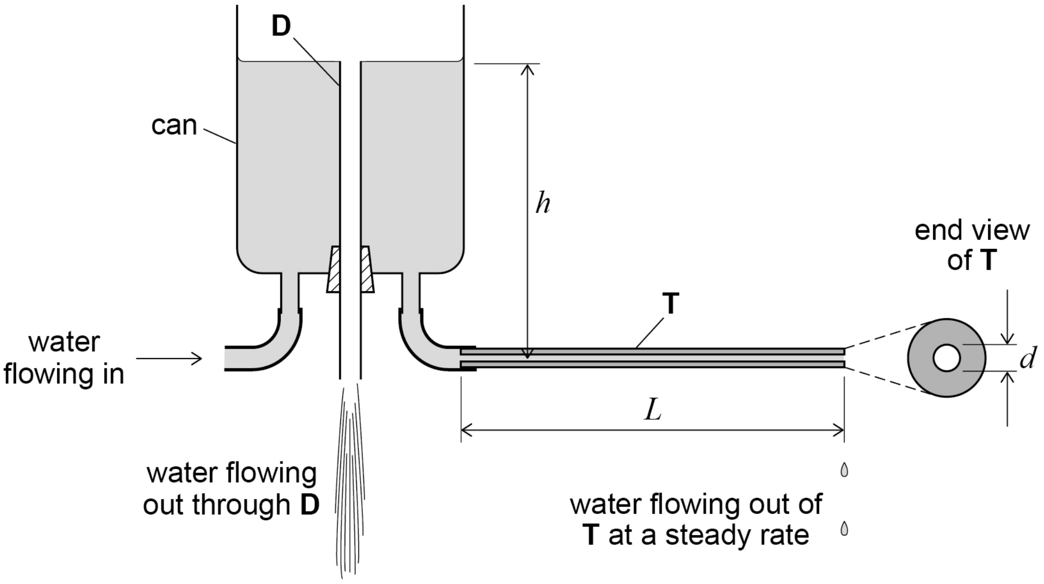
01.5	use of 5.5 MeV shown by **working** on **Figure 4** $_1$✓ minimum thickness MAX 3sf that rounds to 12 mm $_2$✓$_3$✓ OR minimum thickness MAX 3sf that rounds to 11 mm / MAX 3sf that rounds to 13 mm $_{23}$✓	for $_1$✓ use of 5.5 MeV can be inferred from **Figure 4** as a (horizontal) **line**, **a 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 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 = gradient^2 $_2$✓ 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 $1.7(0)\times10^5$ to $1.9(5)\times10^5$ $_4$✓ unit for k = mm^2 Bq or mm^2 s^{-1} $_5$✓	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 10^5 required for $_5$✓ the unit given for k must be consistent with the POT of the result for k / gradient^2 order not important Bq mm^2 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 $_5$✓ m^2 Bq or m^2 s^{-1} if for $_4$✓ gradient based on d in cm (expected ≈ 43 cm Bq$^{0.5}$) k in range $1.7(0)\times10^3$ to $1.9(5)\times10^3$ then for $_5$✓ cm^2 Bq or cm^2 s^{-1}	AO2-1d = 2 AO2-1h = 1 AO3-1b = 2
	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$^{-0.5}$		

01.7	second mark ($_2$✓) **is contingent on** award of first ($_1$✓) 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* $_1$✓ ≥ 2 sf result in range ≥ 28(.0) and ≤ 32(.0) (mm) $_2$✓	for $_1$✓ use of *y* = *mx* + *c* with recognisable data **correctly** substituted, eg $e =$ 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* = gradient × 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 $_2$✓ answer in range only (no ecf from 01.6) allow negative answer	AO2-1d = 1 AO3-1b = 1
Total			**19**

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 $\mathrm{m^3\,s^{-1}}$.
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]

$\mathrm{N\ m^{-1}\ s}$ ☐

$\mathrm{N\ m^{-2}\ s}$ ☐

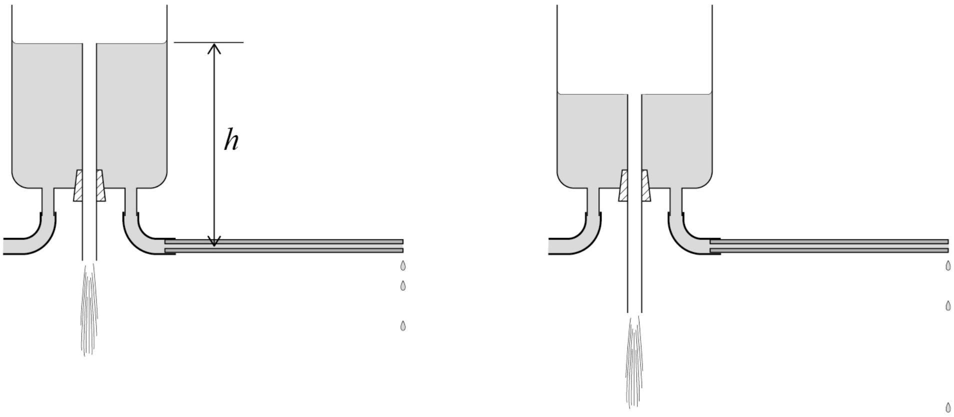
$\mathrm{N\ m^{-1}\ s^{-1}}$ ☐

$\mathrm{N\ m^{-2}\ s^{-1}}$ ☐

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.

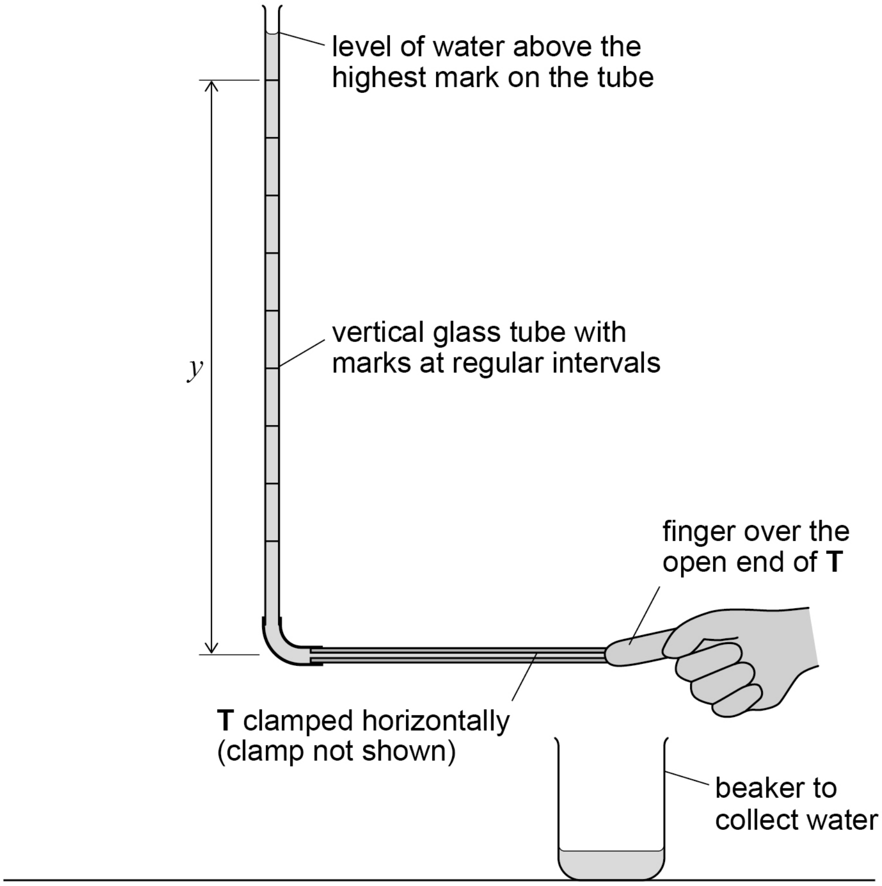
[2 marks]

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.

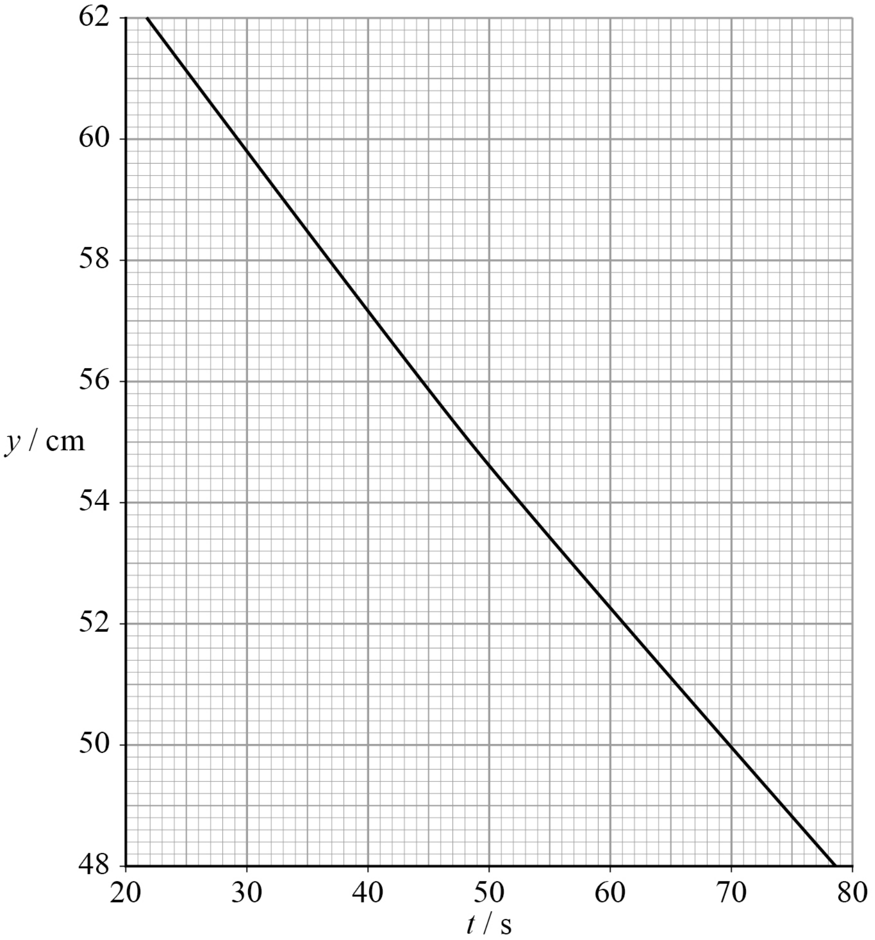
Explain how the student could check that the glass tube was vertical.
You may wish to add detail to **Figure 9** to illustrate your answer.

[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.

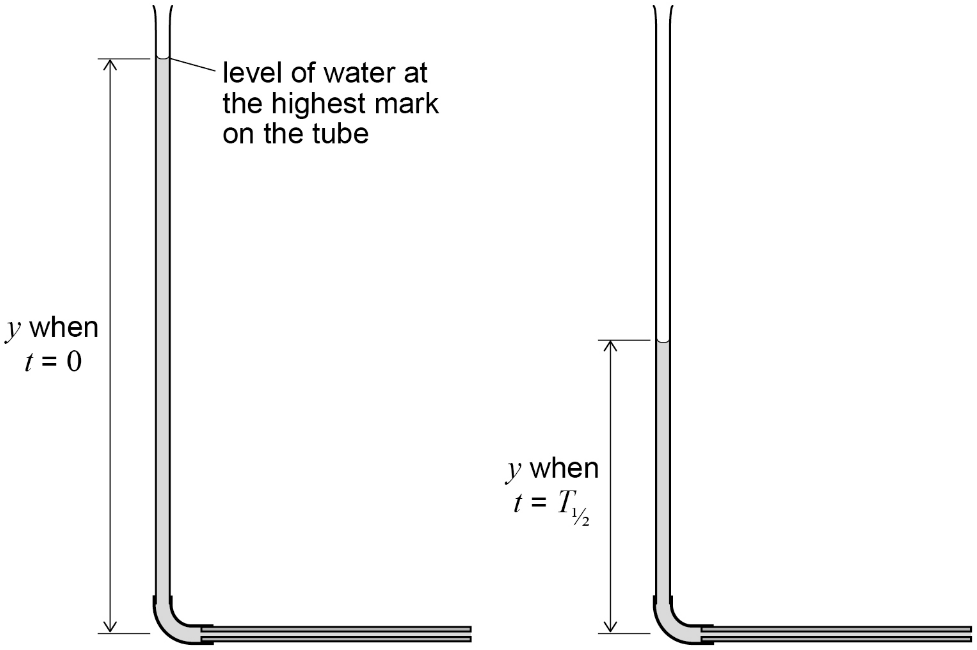
Show that λ, the decay constant for this process, is about $4.5 \times 10^{-3}\ \text{s}^{-1}$.

[2 marks]

λ = ______________________ 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 $T_{1/2}$.

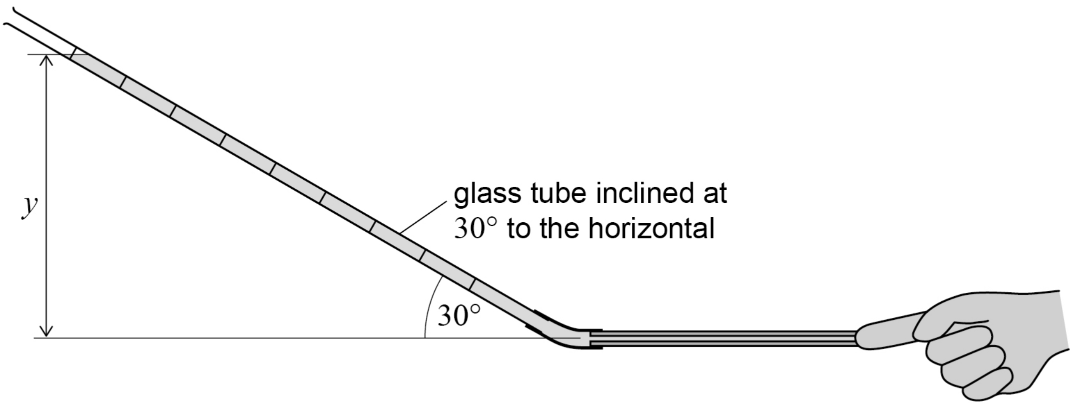
[1 mark]

$T_{1/2}$ = ______________________ 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

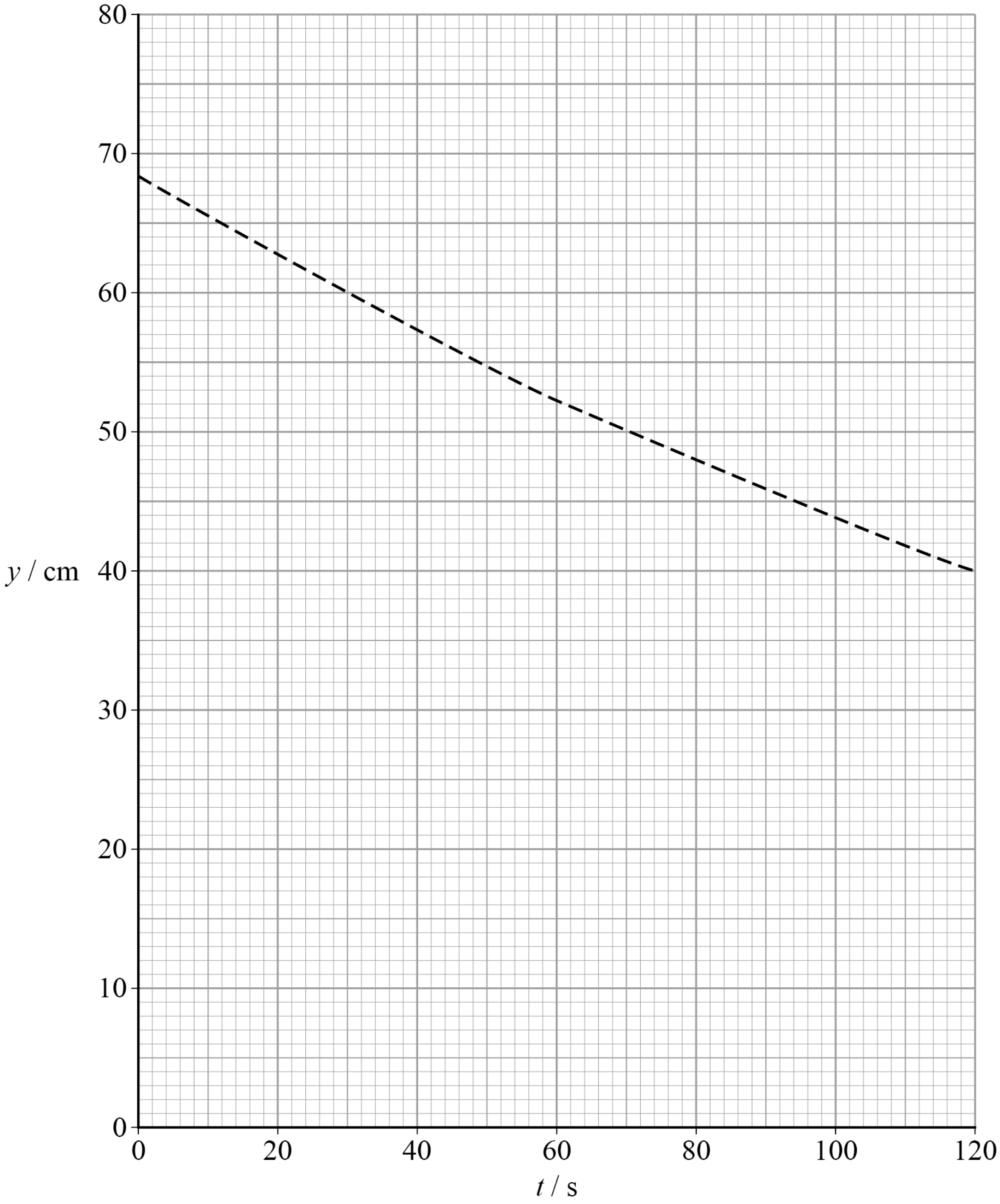


The student measures and records the new values of y, the mean vertical distance between each of the marks and the centre of **T**.
She then carries out the experiment as before, recording new values of t corresponding to each new value of y.

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



13

Turn over for the next question

Question	Answers	Additional Comments/Guidelines	Mark
02.1	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 stopwatch or stopclock; treat as neutral: 'timer' or 'light gate / data logger' for volume use measuring cylinder / graduated beaker; treat as neutral: 'measuring beaker' / 'burette' OR for mass use balance; use of $V = \frac{m}{\rho}$ (any subject) condone 'volume of 1 g is 1 cm^3'; reject 'weigh'/'weighed'	AO2-1g = 1
	method to reduce uncertainty in volume $_3$✓	read water level at bottom of the meniscus (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 horizontal 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) volume / for long(er) time / ≥ 60 s $_5$✓ this reduces percentage / fractional uncertainty $_6$✓ read at eye level or wtte, to reduce parallax $_7$✓	

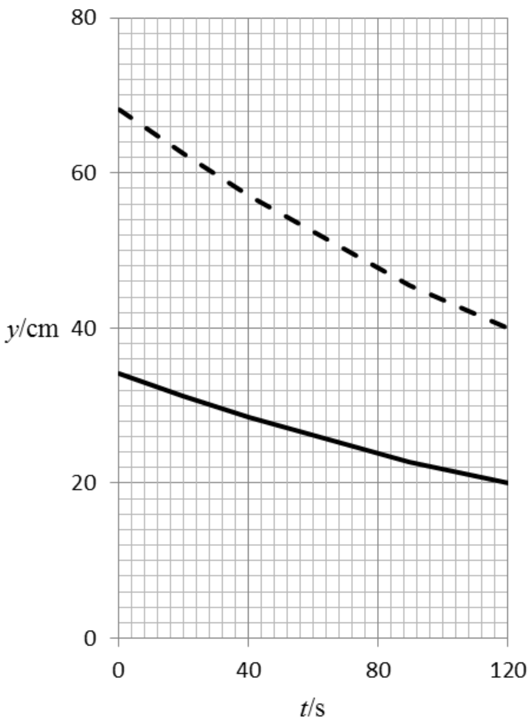
02.2	sensible mark identifying second box indicating ($\mathrm{N\ m^{-2}\ s}$) only	**auto marked question**	AO3-1a = 1

02.3	19.8% (from 4 × 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 × 2.9% / 11.6% / 12% seen in working but wrong final answer OR missing × 4 eg 2.9% + 1.8% + 6.4% = 11(.1)% OR incorrect multiplier applied to 2.9 eg 2 × 2.9% OR with × 4 applied wrongly eg 2.9 + (1.8 x 4) + 6.4 = 16.5 % or 17 % / 2.9 + 1.8 + (6.4 x 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</u> / <u>floor</u> / (flat) <u>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 $_1$✓ valid calculation **seen** leading to a result for λ that rounds to 3 sf in range 4.45 to 4.55×10^{-3} (s^{-1}); award if seen in body of answer $_2$✓	for $_1$✓ 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 $_2$✓ allow use of **Figure 13** $y_0 = 60.0$ cm, $y = 52.2$ cm; $\Delta t = 60 - 29 = 31$ s $52.2 = 60 e^{-31\lambda}$; $\therefore \lambda = 4.49 \times 10^{-3}\ \mathrm{s}^{-1}$ 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 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 $_2$✓ 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)	AO2-1h = 1 AO3-1b = 1
	variation on use of use of $y = y_0 e^{-\lambda\Delta t}$ for $_1$✓: 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 $_2$✓		

<table>
<tr>
<td>02.6</td>
<td>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 ✓</td>
<td>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}</td>
<td>AO3-1a = 1</td>
</tr>
<tr>
<td>02.7</td>
<td>(mostly) continuous line drawn on Figure 13;
below dashed line and with negative gradient between <i>t</i> = 0 and <i>t</i> = 120;
do not penalise linear line or shaky / thick / hairy line or slight discontinuities; accept ≈ horizontal after 100 s $_1$✓

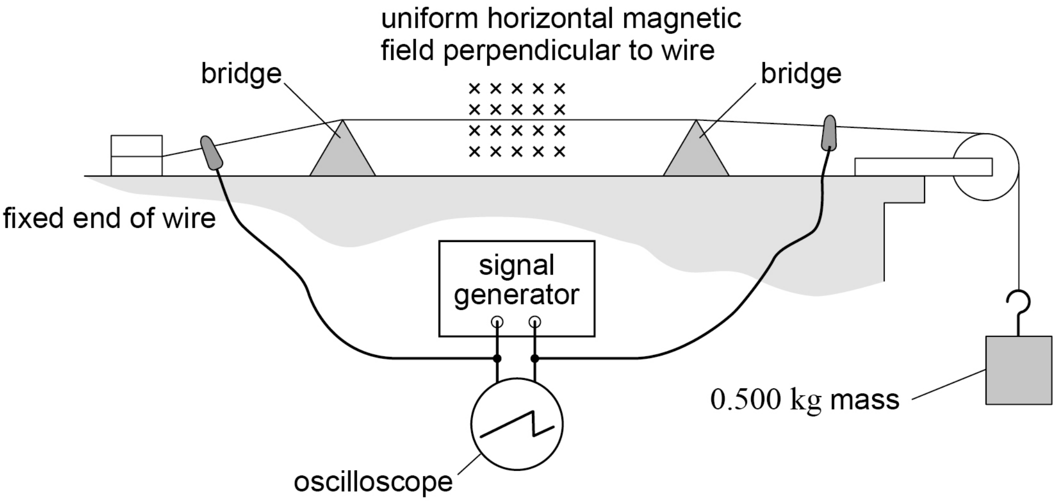
line passes through:
<table>
<tr><td><i>t</i>/s</td><td colspan="2"><i>y</i>/cm</td></tr>
<tr><td></td><td>min</td><td>max</td></tr>
<tr><td>0</td><td>33</td><td>35</td></tr>
</table>
AND through EITHER of
<table>
<tr><td><i>t</i>/s</td><td colspan="2"><i>y</i>/cm</td></tr>
<tr><td></td><td>min</td><td>max</td></tr>
<tr><td>60</td><td>24</td><td>28</td></tr>
<tr><td>120</td><td>17</td><td>23</td></tr>
</table>
$_2$✓</td>
<td>
</td>
<td>AO2-1d = 2</td>
</tr>
</table>

Total			**13**

0 3 A stationary wave is formed on a stretched wire.

Figure 14 shows the wire, fixed at one end, supported by two bridges and passing over a pulley.

Figure 14

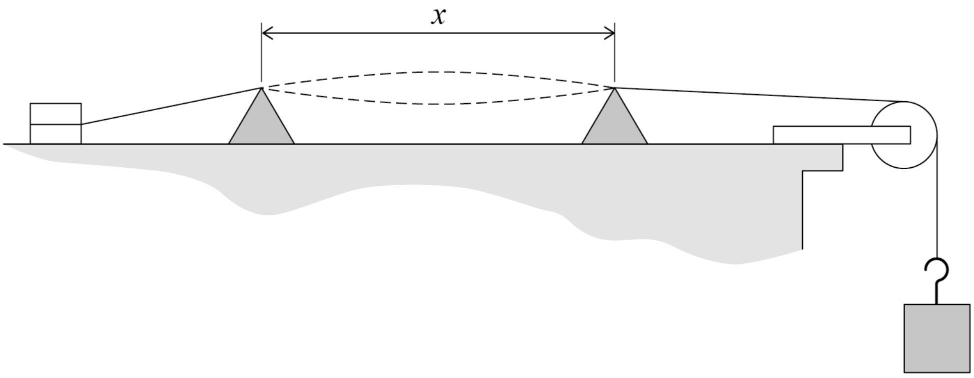


A 0.500 kg mass is attached to the free end of the wire.
A uniform horizontal magnetic field is applied perpendicular to the wire between the bridges.
A signal generator is connected to each end of the wire.

The oscilloscope shown is used to determine the frequency of the output of the signal generator. The wire oscillates because the alternating current in the wire interacts with the magnetic field.

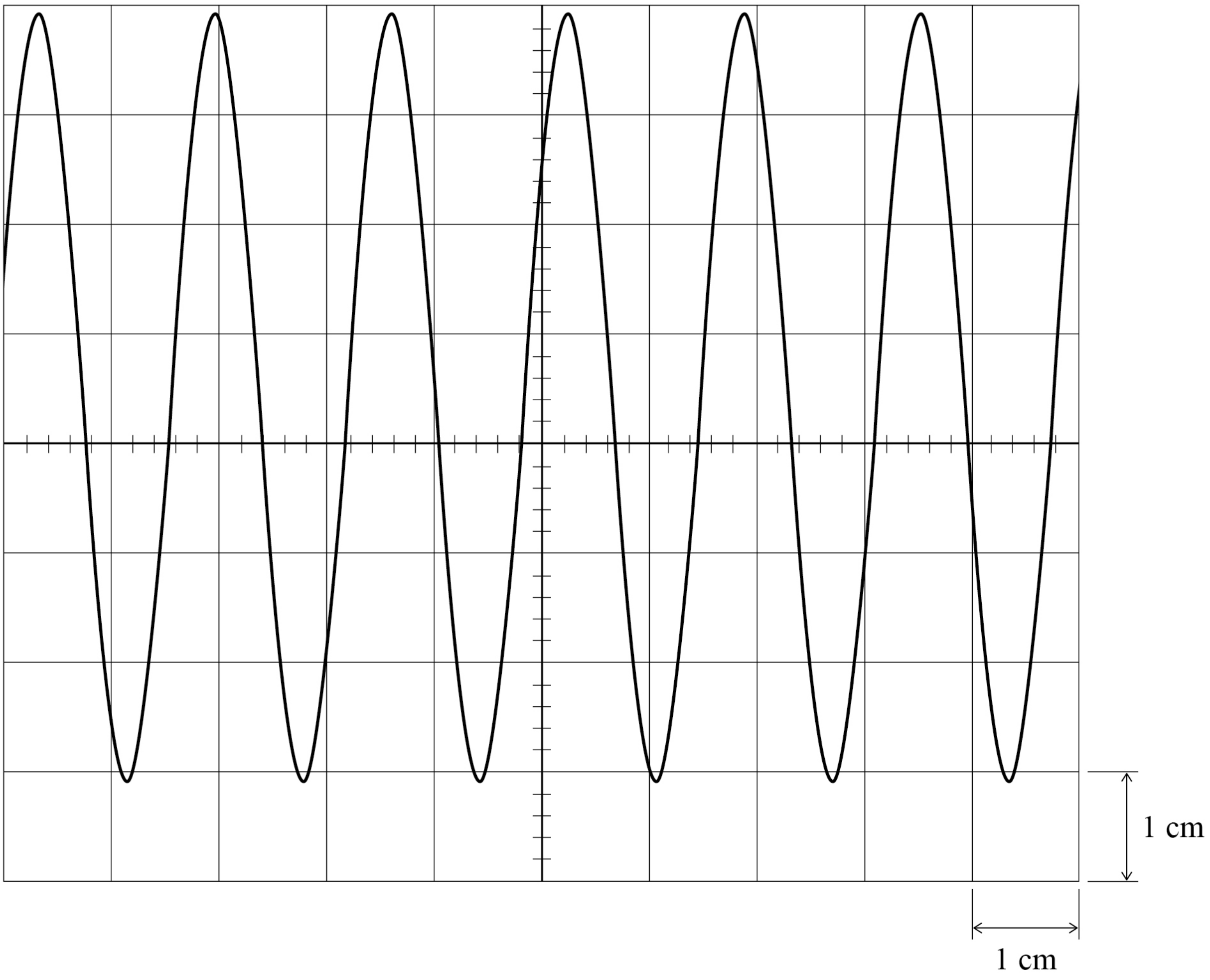
Figure 15 shows the first harmonic stationary wave produced when the distance x between the bridges is adjusted.

Figure 15



0 3 . 1 The output potential difference (pd) of the signal generator is displayed on the oscilloscope, as shown in **Figure 16**.

Figure 16



The time-base setting of the oscilloscope is $10\ \text{ms cm}^{-1}$.

Determine f, the frequency of the alternating pd.

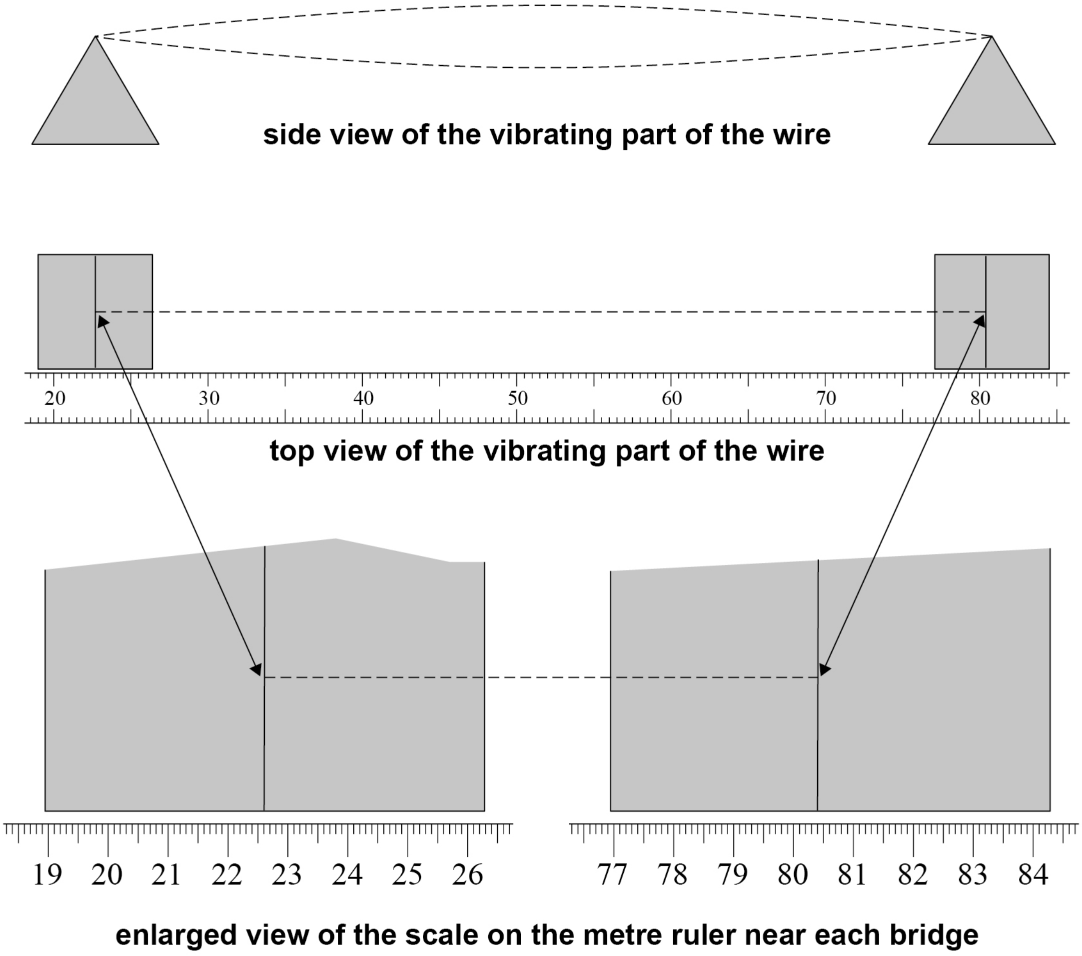
[2 marks]

f = ________________________ Hz

Question 3 continues on the next page

0 3 . 2 A metre ruler is placed next to the bridges supporting the wire, as shown in **Figure 17**.

Figure 17



Determine the wavelength λ of the stationary wave shown in **Figure 17**.

[2 marks]

λ = ______________________ m

0 3 . 3 The stationary wave is formed by two waves of frequency f and wavelength λ travelling with speed c in opposite directions.

Determine c.

[1 mark]

c = ________________________ m s^{-1}

0 3 . 4 Determine, in kg m^{-1}, the mass per unit length of the wire.

[2 marks]

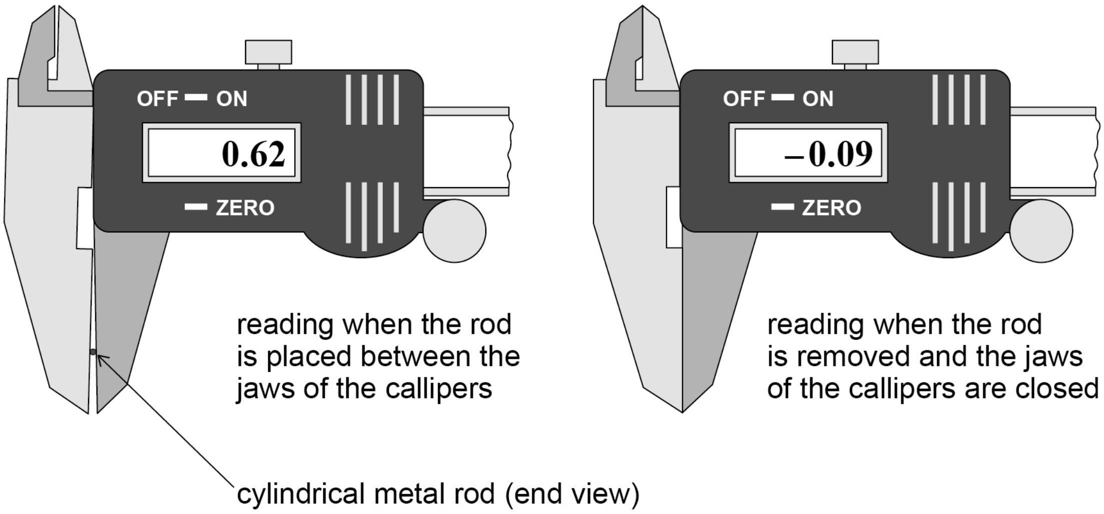
mass per unit length = ________________________ kg m^{-1}

Question 3 continues on the next page

0 3 . 5 A student uses digital vernier callipers to measure the diameter of a cylindrical metal rod. The student places the rod between the jaws of the callipers and records the reading indicated. Without pressing the zero button, the student removes the rod and closes the jaws.

Figure 18 shows the calliper readings in millimetres, before and after the jaws are closed.

Figure 18



Calculate the diameter d of the rod.

[1 mark]

d = ____________________ mm

0 3 . 6 Describe relevant procedures to limit the effect of random error in the result for d.

[2 marks]

____

____

____

____

____

Do not write outside the box

0 3 . 7 Determine the density of the rod.
The mass per unit length of the rod is 3.54×10^{-3} kg m^{-1}.

[3 marks]

density = ______________________ kg m^{-3}

13

END OF QUESTIONS

Question	Answers	Additional Comments/Guidelines	Mark
03.1	f (from $\frac{1}{T}$) in range 61 ± 1 Hz $_1$✓$_2$✓ OR 61 ± 3 Hz $_{12}$✓ maximum 1 mark for POT error OR incorrect rounding no credit for 1 sf; treat 60 as 2 sf unless clearly rounded to 6×10^1	for $_1$✓$_2$✓ **require ≥ 2 sf** that rounds to not less than 60 and not more than 62 for $_{12}$✓ **require ≥ 2 sf** that rounds to not less than 58 but less than 60 OR for $_{12}$✓ **require ≥ 2 sf** that rounds to more than 62 but not more than 64 if incorrect rounding leads to 60 treat this as 1 sf and give no credit use of $\frac{1}{T}$ does not have to be seen; marks are for final answer seen	AO3-1a = 2
03.2	(figures) 804 and 226 seen in working $_1$✓ λ = difference between their readings × 2; given to nearest mm; expect 1.156 (m) OR to nearest cm; expect 1.16 (m) $_2$✓	for $_1$✓ 578 is not enough for $_2$✓ range is based on $x = (804 - 226 =)\ 578 \pm 2$ mm; give no credit for POT errors eg 115.6 / 116 etc accept 1156 mm etc if unit on answer line is amended	AO3-1b = 2
03.3	c correctly evaluated to ≥ 2 sf from their f × their λ ✓	substituted data may be from 03.1/2 final answers or unrounded (intermediate) data from working expected answer = $61 \times 0.578 \times 2 = 70.5$ m s^{-1}	AO2-1d = 1

03.4	μ correct to 2 sf based on their *f* and their λ earns both marks $_1$✓$_2$✓ for incorrect / missing μ EITHER use of $c = \sqrt{\frac{T}{\mu}}$ OR use of $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ $_{12}$✓	for $_1$✓ their value of μ can be given to ≥ 2 sf but must agree with $\frac{0.5 \times g}{(\text{their } f \times \lambda)^2}$ OR $\frac{0.5 \times g}{(\text{their } c)^2}$ **when rounded to 2 sf**; use of g = 9.81 or 9.8 only; no ecf for mixed units expected answer $\mu = 9.9 \times 10^{-4}$ (kg m^{-1}): be wary of which approach has been taken by the candidate for $_{12}$✓ 'use of' means allow **either** rearranges so that μ is the subject eg $\mu = \frac{T}{c^2}$ (accept $\mu = \frac{mg}{c^2}, \frac{T}{c^2} = \mu$ etc) **or** substitution of all relevant data including their *c* into a correct expression with μ as the only unknown for T allow 4.9 / 4.91 / 4.905 (accept 0.5 × 9.81 or 0.5 × 9.8); allow mixed units; allow 0.5g OR 'use of' means allow **either** rearranges to $\mu = \frac{T}{(2 \times l \times f)^2}$ OR $\frac{T}{4 \times l^2 \times f^2}$ **or** substitution of all relevant data including their l and *f* leaving μ as the unknown; allow sub of λ for $2l$ watch for possible error $\lambda = L$	AO2-1d = 2

03.5	0.71 (mm) ✓	only answer that gets mark	AO3-1b = 1

03.6	ANY TWO FROM repeat readings at different points along the rod and calculate an average / mean $_1$✓ repeat readings in different directions (perpendicular to the rod) and calculate an average / mean $_2$✓ reject / discard anomalous readings before calculating an average / mean $_3$✓ award $_{123}$✓= 1 MAX for checking at different points / in different directions to confirm that the rod is uniform / that there are no anomalies	allow 'cylinder' / 'wire' etc for rod for $_1$✓ $_2$✓ and $_3$✓ averaging idea only needs to be seen once; if averaging idea missing then allow 'repeat at different points and in different directions, then remove anomalies' $_{123}$✓= 1 MAX if 'calculate' is not seen allow 'work out' / /'determine' / 'compute'; anything that sounds like a mathematical process is ok; 'find' / 'obtain' / 'take' / 'do an average' are just ok; 'get' is not ok for $_1$✓ allow repeat at 'different positions' / 'down / along the rod' for $_2$✓ allow (repeat in different directions) 'around the rod' / 'different orientations' / 'angles' / 'planes' / 'sides' for $_3$✓ allow 'ignore anomalies'; 'outlier' = 'anomaly' reject 'calculate an average to eliminate effect of anomalies' treat as neutral: 'turn the wheel to close the callipers' / suggestions about calibration treat as neutral: 'zero callipers before use' this is a procedure to eliminate a source of systematic error	AO2-1g = MAX 2

03.7	(for use of expected 0.71) $\rho = 8.9(41) \times 10^{3}$ (kg m^{-3}) OR (for use of 0.53) $\rho = 1.6(05) \times 10^{4}$ (kg m^{-3}) OR $\rho = \dfrac{4.51\times10^{-3}}{(\text{their } d \text{ from03.5})^{2}}$ $_{123}$✓✓✓ OR attempts to use μ OR $3.5(4) \times 10^{-3}$ divided by their (recognisable) cross-sectional area $_{1}$✓ AND/OR evidence showing cross-sectional area = $\dfrac{\pi d^{2}}{4}$ using their d from 03.5 (allow πr^{2} using their d) $_{2}$✓	correct answer scores $_{123}$✓✓✓ for $_{123}$✓✓✓ allow an answer that rounds to the correct 2 sf value sample results for expected d d/mm A/m^{2} ρ/kg m^{-3} 0.71 3.96×10^{-7} $8.9(41) \times 10^{3}$ 0.53 2.21×10^{-7} $1.6(05) \times 10^{4}$ for $_{1}$✓ accept use of symbols, eg $\rho = \dfrac{\mu}{A}$ / $= \dfrac{3.54\times10^{-3}}{A(\times1)}$ / $= \dfrac{4\times\mu}{\pi\times d^{2}}$ / $= \dfrac{4\times3.54\times10^{-3}}{\pi\times d^{2}(\times1)}$ / $= \dfrac{3.54\times10^{-3}}{\pi\times r^{2}(\times1)}$ for $_{2}$✓ expect correct value of A seen or correct values of A or d in working, eg $\rho = \dfrac{3.54\times10^{-3}}{3.96\times10^{-7}(\times1)}$ / $= \dfrac{4\times3.54\times10^{-3}}{\pi\times(0.71\times10^{-3})^{2}\times(1)}$ accept values $\geq$ 2 sf for A; allow ecf d and don't penalise POT error in A or d (eg missing 10^{-7}, 10^{-3})	AO3-1a = 1 / AO2-1h = 2

Total			**13**

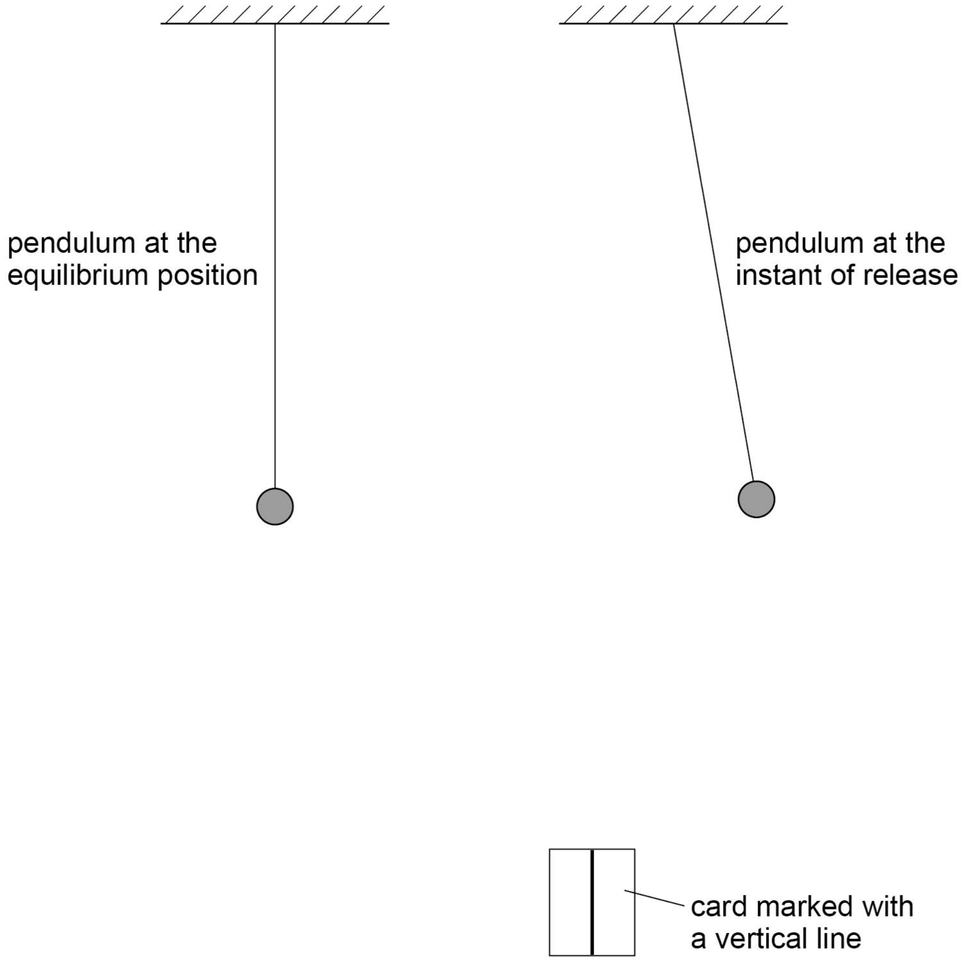
Section A

Answer **all** questions in this section.

0 1 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



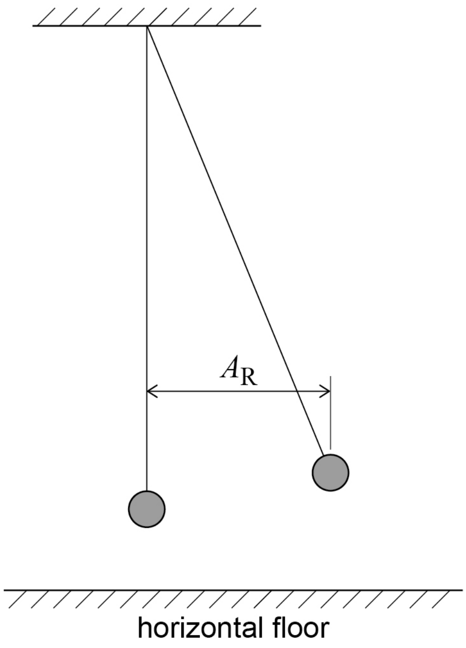
0 1 . 1 The card can be used as a fiducial mark to reduce uncertainty in the measurement of T.

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



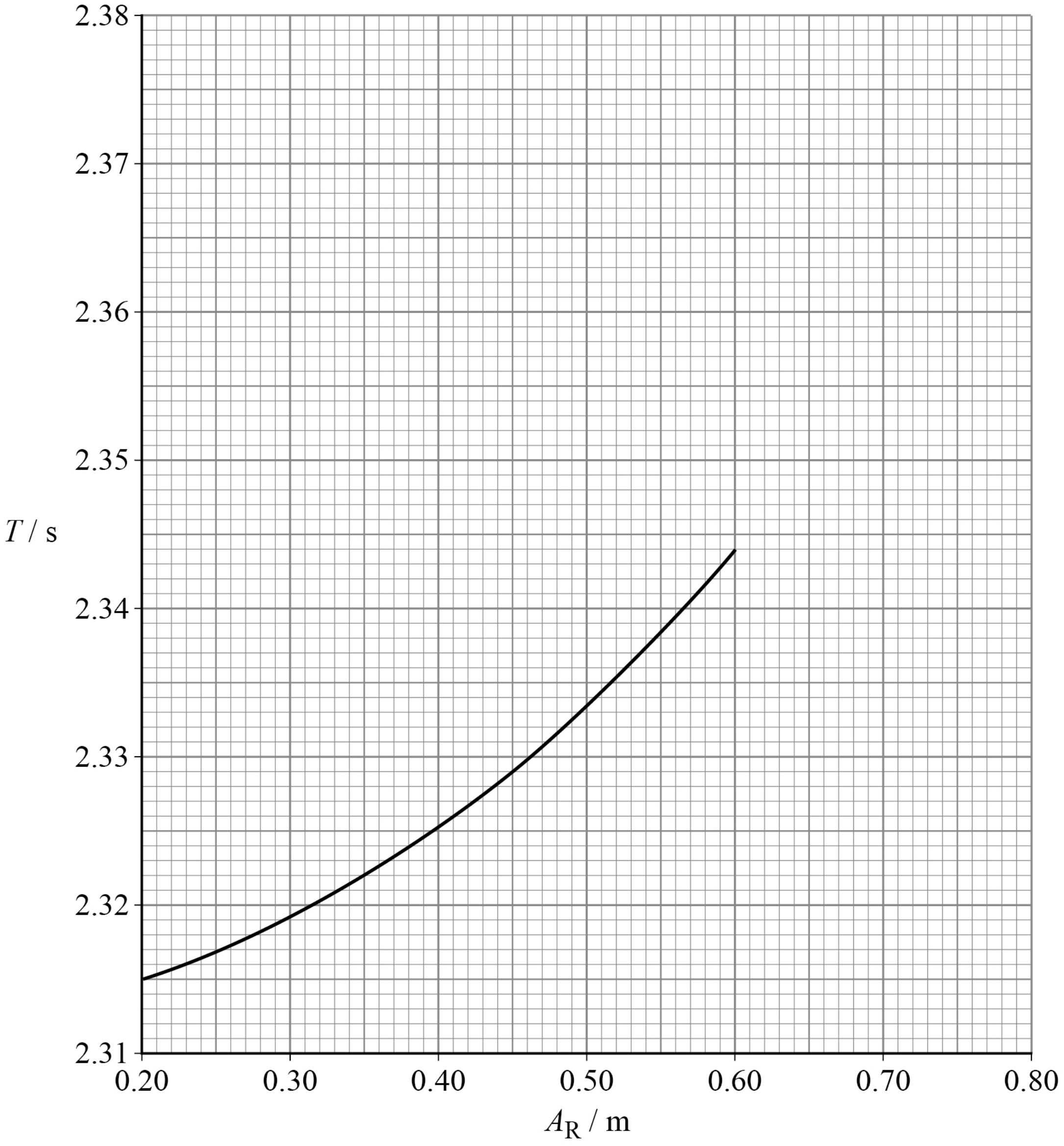
Describe a suitable procedure to determine A_R, the amplitude of the pendulum as it is released.
You may add detail to **Figure 2** to illustrate your answer.

[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 $n = 1, 2, 3, 4, 5...$.

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	$\ln(A_n$ / m)
2	0.238	−1.435
4	0.225	
7	0.212	−1.551
10	0.194	−1.640
13	0.183	−1.698

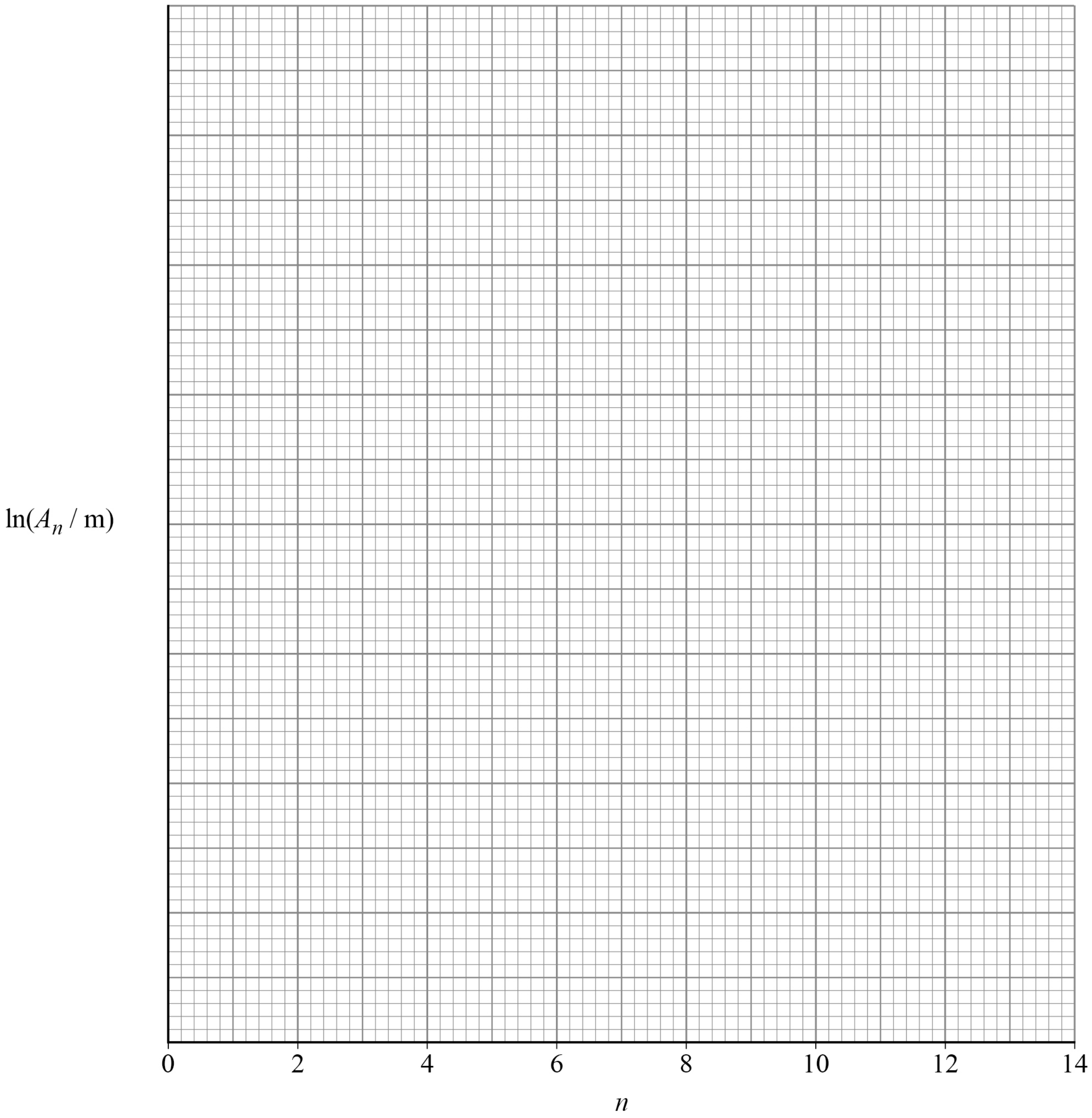
Complete **Table 2**.

[1 mark]

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

[2 marks]

Figure 4



Question 1 continues on the next page

0 1 . 7 It can be shown that

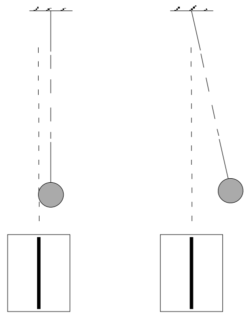
$$A_n = A_0\, \delta^{-n}$$

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]

15

Question	Answers	Additional comments/Guidelines	Mark	AO
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 ↑ ↕ etc; blobs ●✚✖ 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

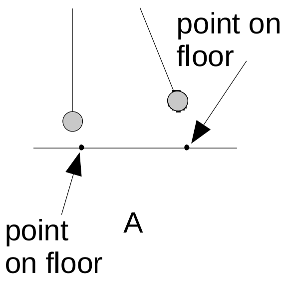
<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr>
<td>01.2</td>
<td>use of appropriate <u>horizontal</u> scale or wtte $_1$✓

use of set-square with edge made vertical or other suitable equipment to eliminate parallax error in A_R $_2$✓

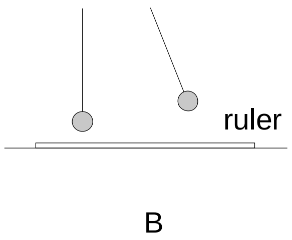
measures A_R from (either) edge of displaced bob $_3$✓</td>
<td>any of $_1$✓$_2$✓or $_3$✓can be earned by suitable annotation to Figure 2

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)



A

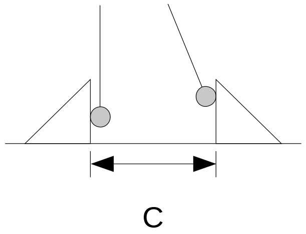


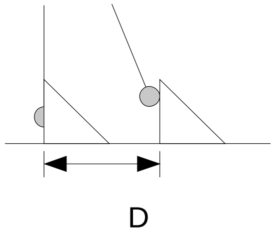
B

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

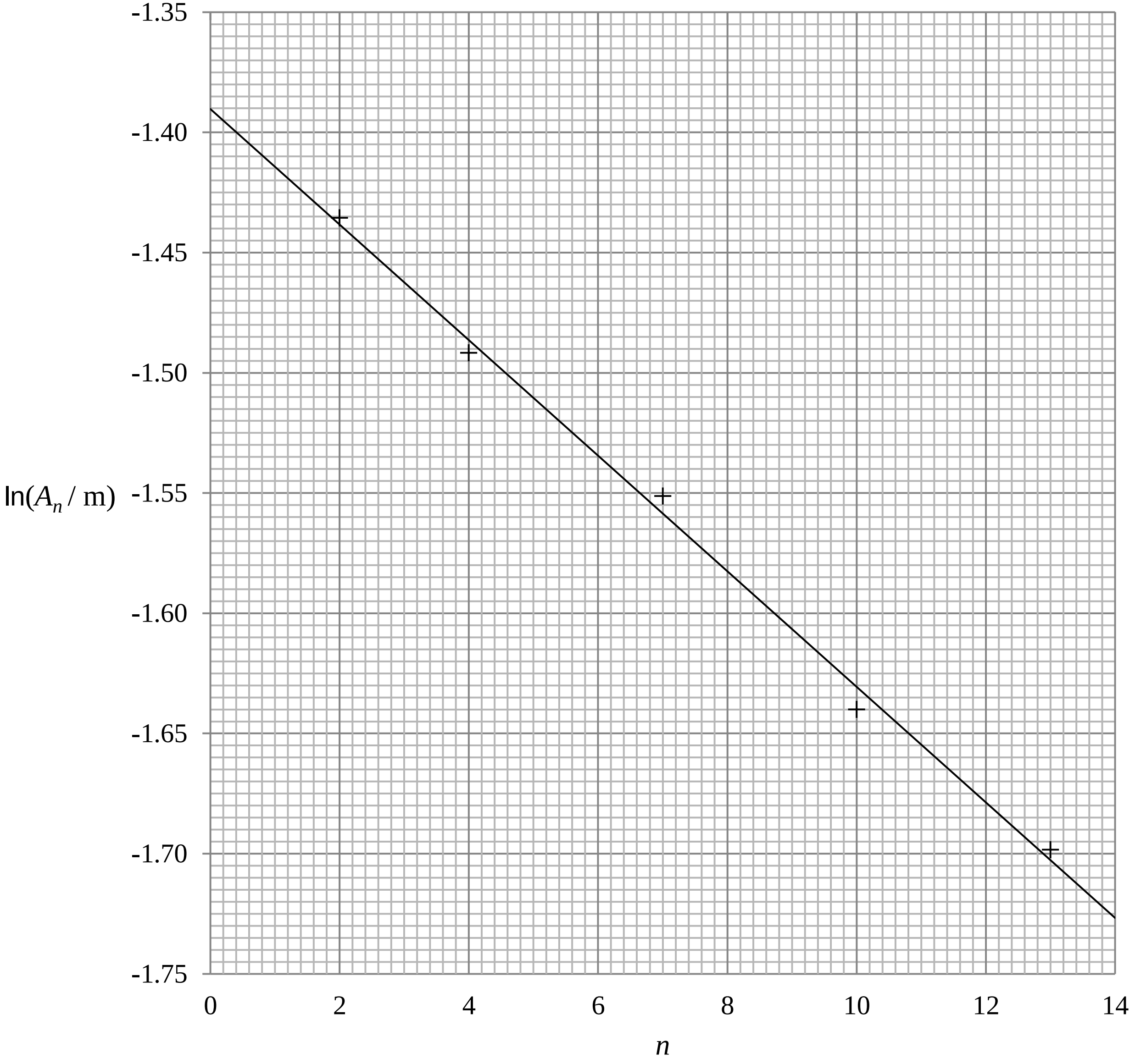
withhold $_3$✓unless candidates explains that allowance is being made for radius / diameter of bob (see C and D below)


C


D
</td>
<td>MAX 2</td>
<td>AO3.2b</td>
</tr>
</table>

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) $0.22\underline{1}$ (s) $_{1}$✓ correct uncertainty calculation or 0.004(0) (s) seen $_{2}$✓ **or** does not reject 0.247; average A_5 = (rounds to) $0.22\underline{6}$ (s); correct uncertainty calculation or $0.01\underline{5}$ (s) seen $_{12}$✓ correct % uncertainty from $\frac{\textit{their half range}}{\textit{their average}} \times 100$ ≥ 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 $6.6\underline{4}$ / $6.6\underline{5}$ % or 2 sf 6.6 / 6.7 % for $_{3}$✓ allow ECF only if uncertainty is from half range	3	AO2.1h

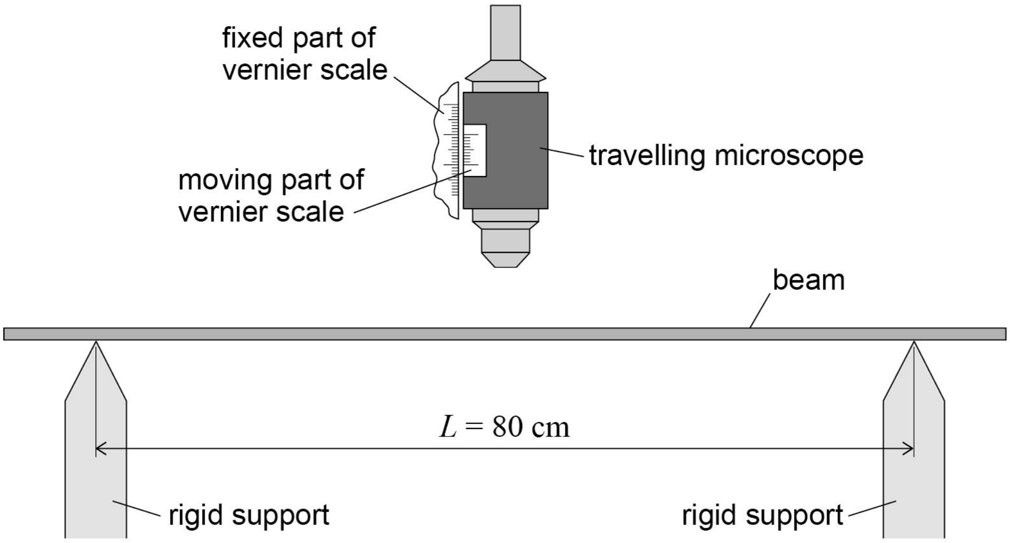
Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	$\ln(A_4 / \mathrm{m}) = -1.492$ ✓	CAO 3 dp only	1	AO1.1b
01.6	vertical scale with one major (cm) grid square = 0.02 **or** 0.025; maximum spacing of values marked on the scale = 5 cm ₁✓ points plotted for n = 2, 4, 7, 10 and 13; suitable continuous <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 $\ln(A_5 / \mathrm{m})$ based on 01.4 data; withhold mark for poor points eg blobs or for thick / faint / non-continuous line	2	AO2.1h


-1.35
-1.40
-1.45
-1.50
-1.55
-1.60
-1.65
-1.70
-1.75
ln(A_n / m)
0
2
4
6
8
10
12
14
n

Question	Answers	Additional comments/Guidelines	Mark	AO
01.7	(any) correct expression with ln A_n as subject $_1$✓ $\delta = e^{-gradient}$ or wtte $_2$✓	for $_1$✓ $y = mx + c$ idea is required **either** ln $A_n = -n$ ln δ + ln A_0 ($y = mx + c$) **or** ln A_n = ln $A_0 - n$ ln δ ($y = c + mx$) **not** ln A_n = ln A_0 – ln δ^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 $\delta = -$ 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**	

0 2 **Figure 5** shows apparatus used to investigate the bending of a beam.

Figure 5

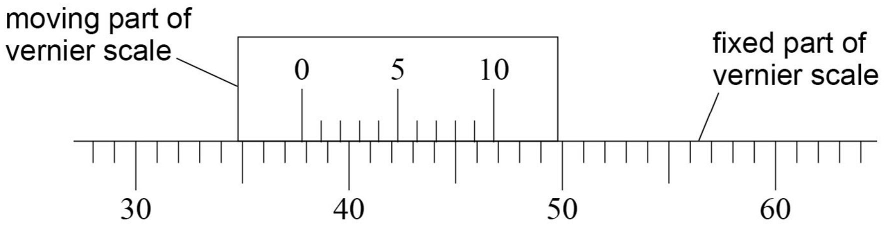


The beam is placed horizontally on rigid supports.
The distance L between the supports is $80\ \mathrm{cm}$.

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 ☐

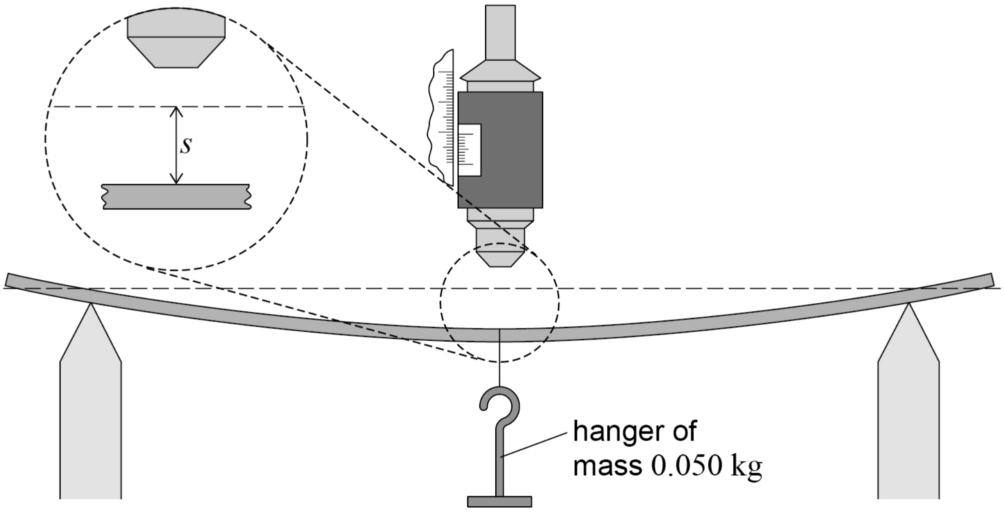
45.8 ☐

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]

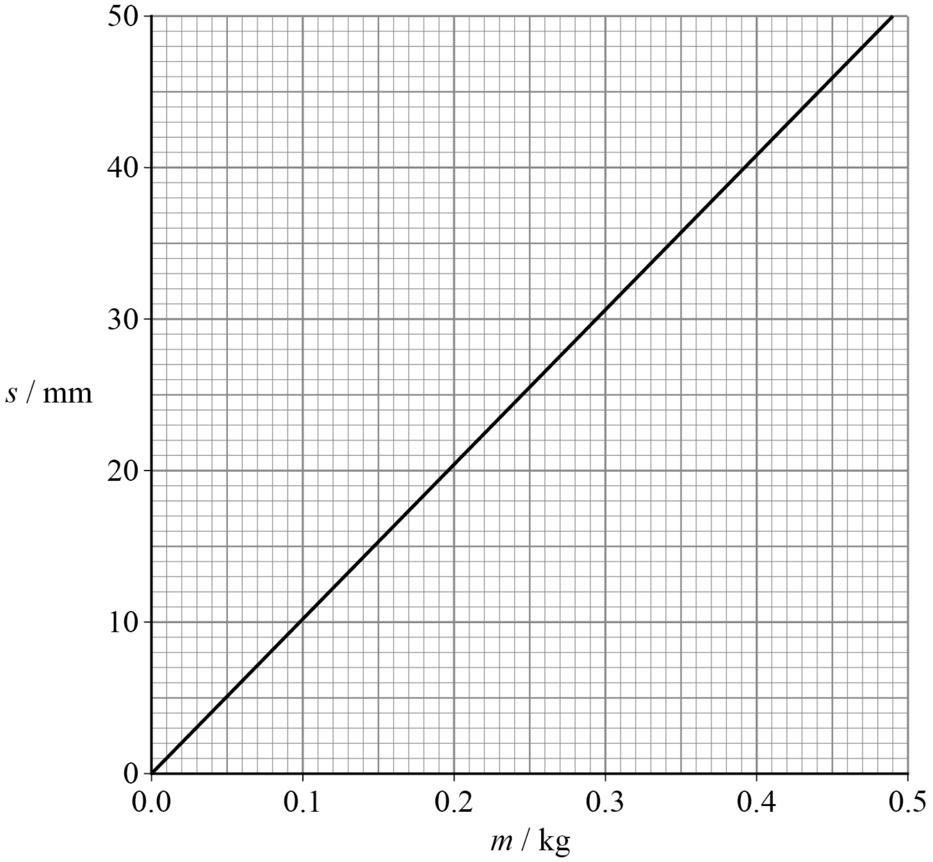
Advantage

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 η = ______________________ 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

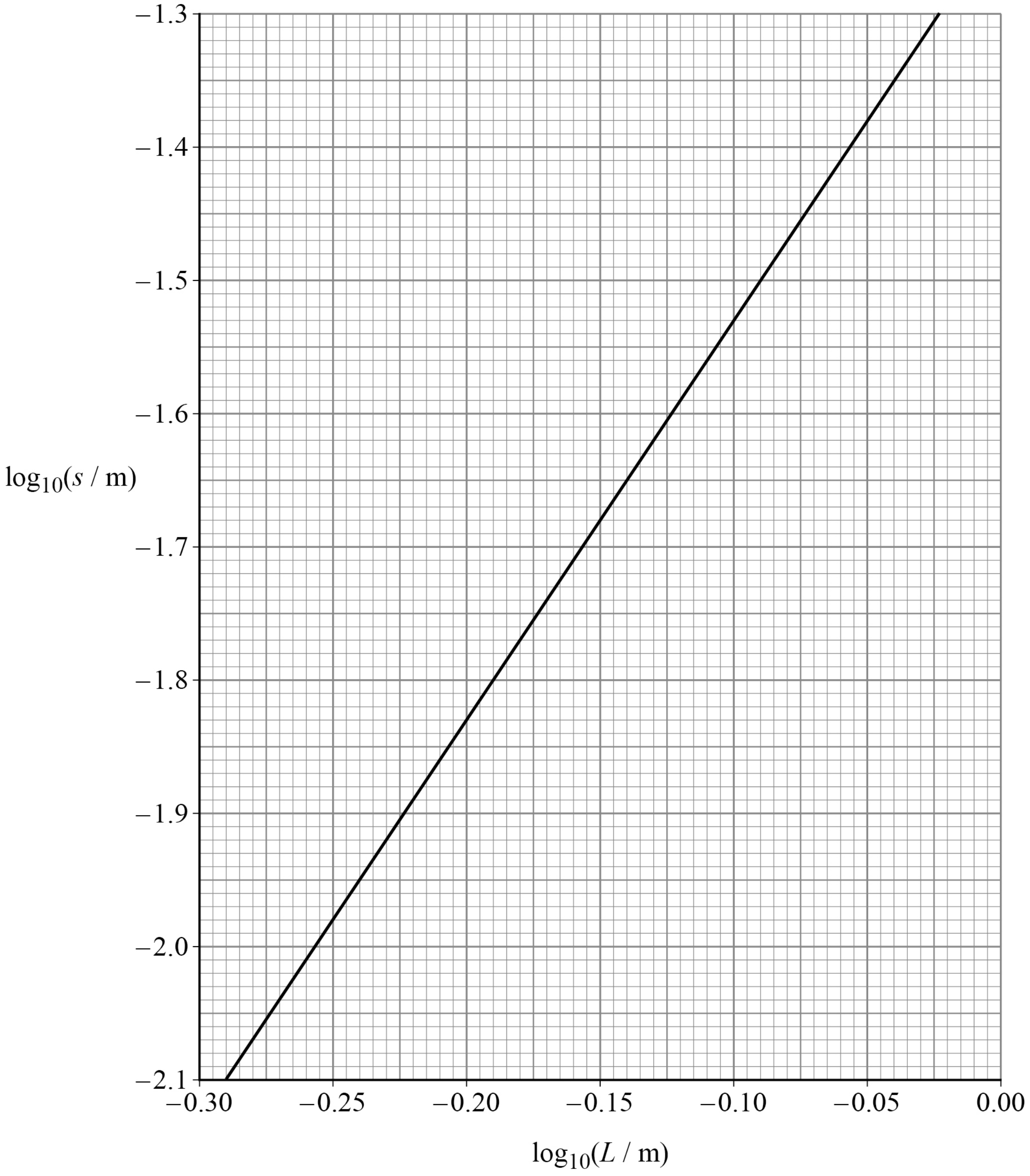


Figure 9 shows that $\log_{10}(s\ /\ \mathrm{m})$ varies linearly with $\log_{10}(L\ /\ \mathrm{m})$.

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 $L = 80\ \mathrm{cm}$.

[2 marks]

$s =$ ________________ m

0 2 . 7 Determine M using **Figure 8**.

[1 mark]

$M =$ ________________ kg

13

Question	Answers	Additional comments/Guidelines	Mark	AO
02.1	37.8 ✓	CAO	1	AO2.1h
02.2	random (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 wtte 1✓ so the percentage 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 wtte 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 wtte **and** relevant comment about the effect on the graph, eg increase scatter 34✓= 1 MAX	for 3✓accept / 'beam may become permanently deformed' or wtte / '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 $\eta = \frac{\text{their } E \times 25.5\left(\times 10^{-3}\right)}{0.25}$ **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 $s \propto L^3$ $s = kL^n$ $\log s = n \log L + (\log)\ k$ $\log s = 3 \log L + (\log)\ k$ $\log s = \log L^3 + (\log)\ k$	1	AO3.1b
		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'		

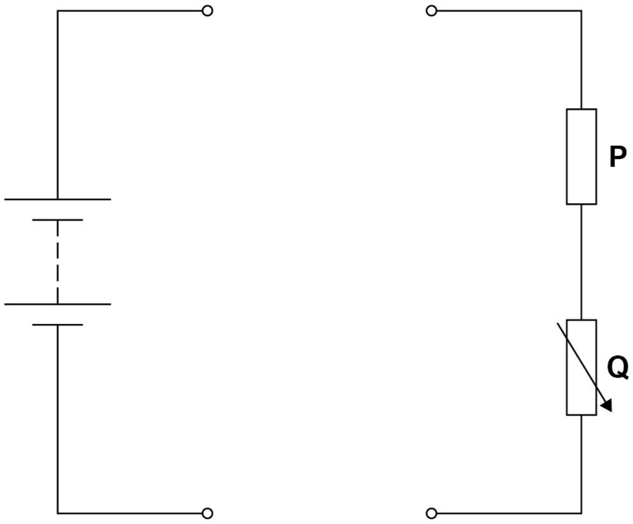
Question	Answers	Additional comments/Guidelines	Mark	AO
02.6	(log L =) -0.097 seen **or** working on **Figure 9** confirming a value of log L between -0.095 and -0.100 $_1$✓ uses **Figure 9** to obtain s in range 2.9 to 3.1×10^{-2} (m) $_2$✓	for $_1$✓accept any log L rounding to -0.097; working can be 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** × gradient of **Figure 8** ($9.8 \pm 2.5\%$) minimum 2sf condone use of 1sf s	1	AO3.1a

Total			**13**	

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

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

Figure 10



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

[1 mark]

0 3 . 2 Describe

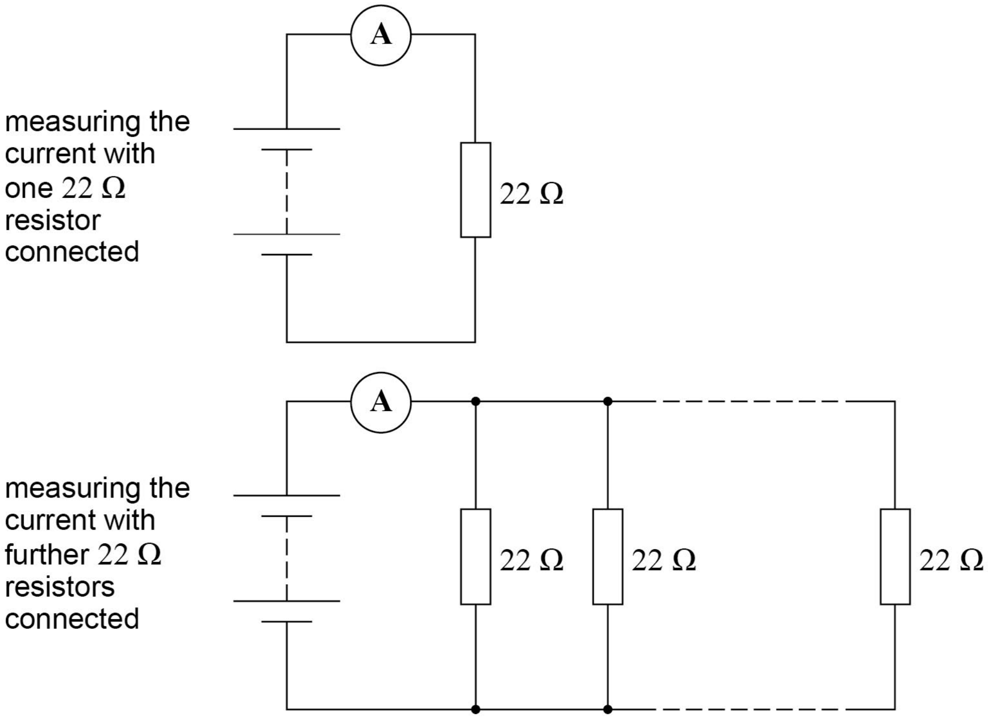
- a procedure to obtain valid experimental data using your circuit
- how these data are processed to obtain ε and r by a graphical method.

[4 marks]

Question 3 continues on the next page

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

Figure 11



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

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

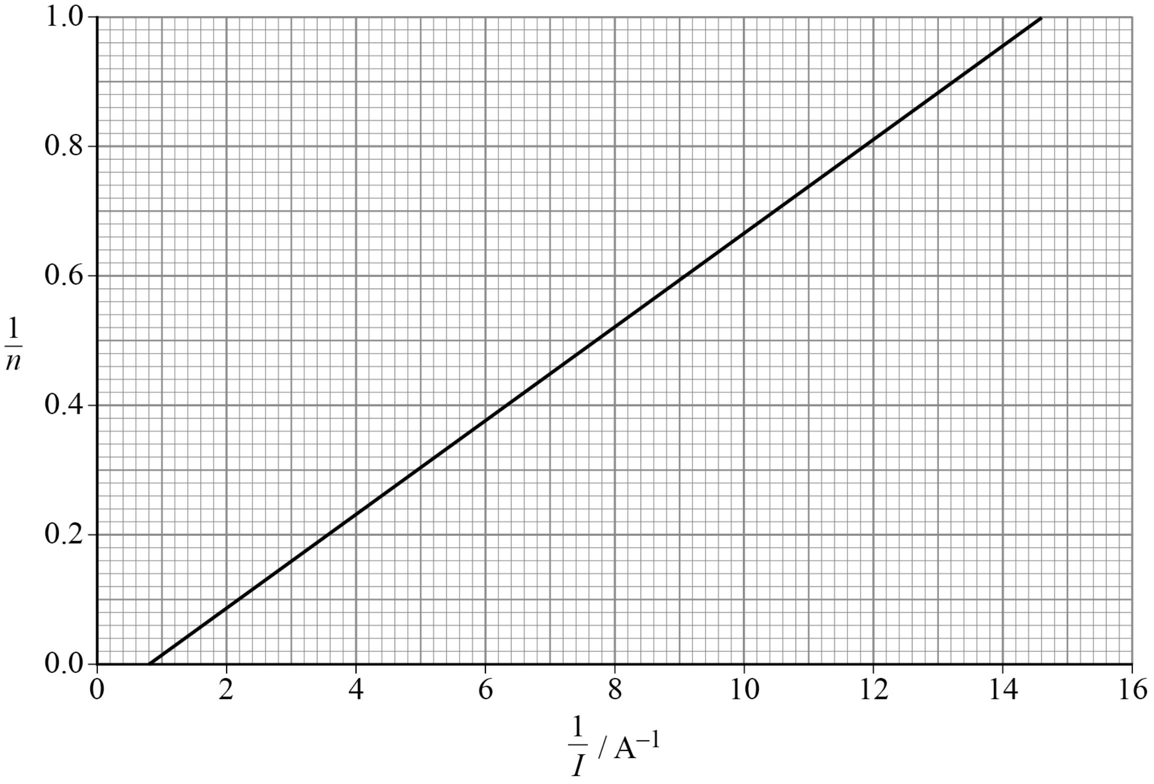
It can be shown that

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

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

Question 3 continues on the next page

Figure 12

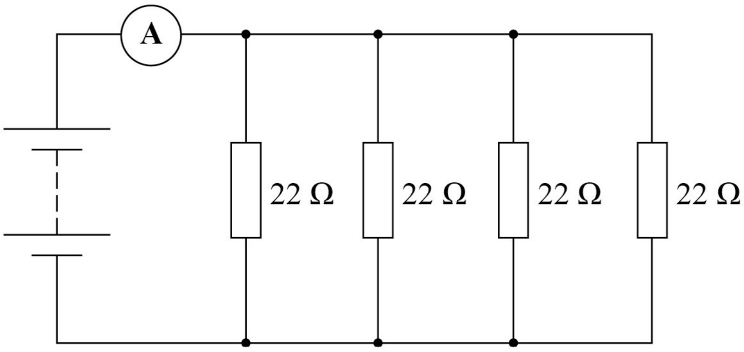


0 3 . 3 Show that ε is about 1.6 V.

[2 marks]

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

Figure 13



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

[1 mark]

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

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

[4 marks]

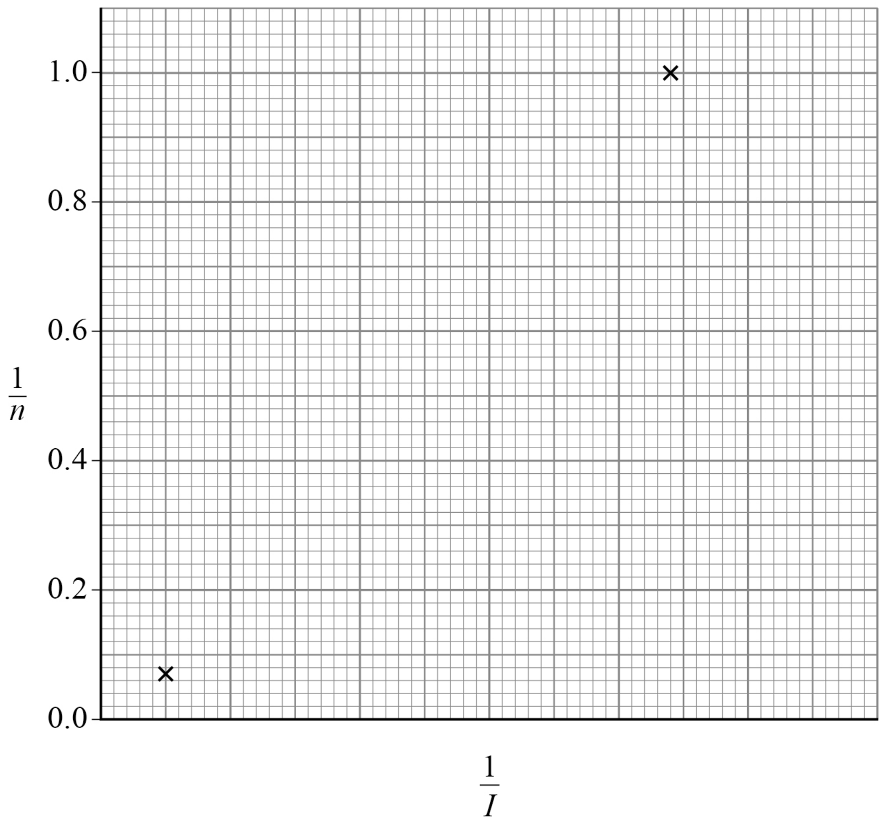
pd = ______________________ V

r = ______________________ Ω

Question 3 continues on the next page

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

Figure 14



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

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

[3 marks]

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

The relationship between n and I is now

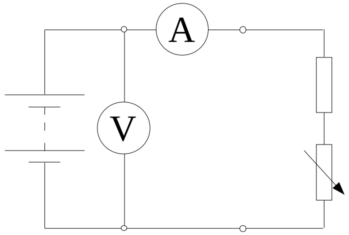
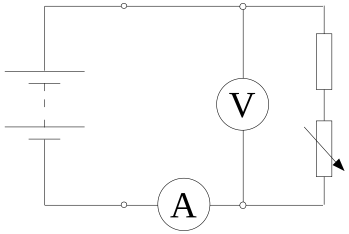
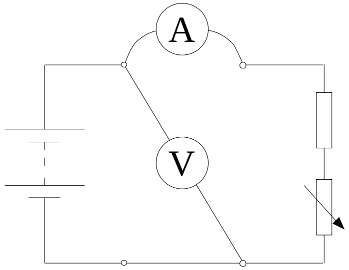
$$\frac{27}{n} = \frac{\varepsilon}{I} - r$$

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

[2 marks]

17

END OF QUESTIONS

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

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	(with any switch closed) read ammeter and voltmeter **or** record / measure I and V; adjust / vary / change resistance / (setting of) variable resistor / Q and repeat (readings) $_1$✓ plot V (against) I $_2$✓ ε = (vertical / y-axis) intercept $_3$✓ r = –gradient $_4$✓ $_2$✓$_3$✓and $_4$✓ can be awarded for a suitable sketch graph	for $_1$✓must produce a range of I, V values (>2 sets) and identify how this is achieved; it is not necessary to suggest range or number of sets condone 'use the (variable) resistor to vary current and read I, V' idea that R can be read from Q is neutral mark $_2$✓ independently of $_1$✓ for $_2$✓(and further credit in $_3$✓and $_4$✓) the ordinate and the abscissa must be identified; allow 'plot V over I ' or 'plot V/I ' allow $_2$✓for reverse plot 'I (against) V' then $_4$✓ for $r = \frac{-1}{\text{gradient}}$ and $_3$✓ intercept = $\frac{\varepsilon}{r}$ for $_3$✓open circuit methods involving ε read directly using voltmeter are neutral for $_4$✓ any subject but minus sign essential	2 2	AO1.1a AO1.1b
	variation	$_1$✓as above; $_3$✓find R from V divided by I ; disconnect external circuit and measure ε directly; $_4$✓plot $\frac{\varepsilon}{V}$ against $\frac{1}{R}$; $_2$✓gradient = r		

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

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

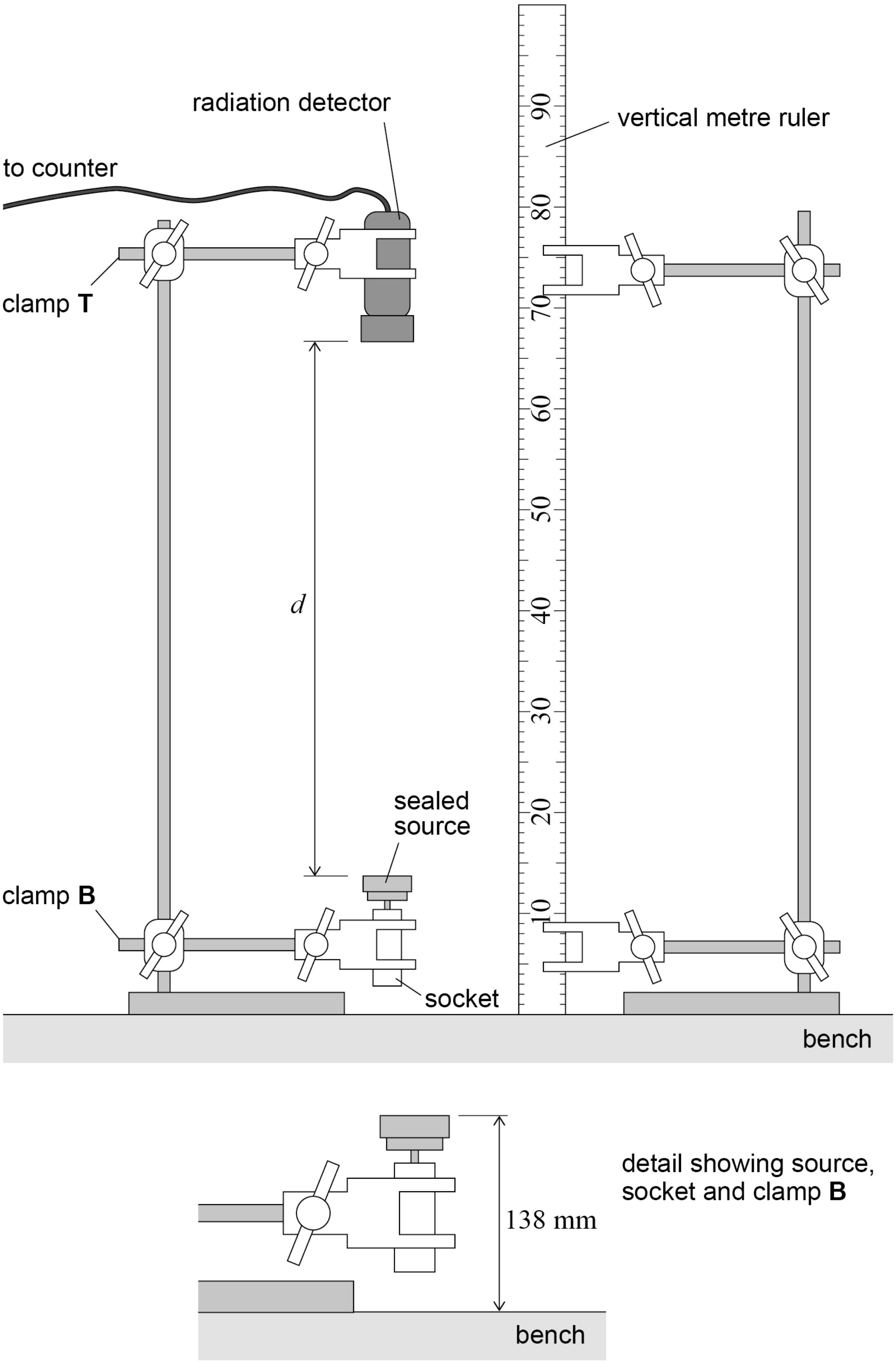
Question	Answers	Additional comments/Guidelines	Mark	AO
03.6	$n = 2$ **and** $n = 3$ 1✓ $n = 5$ **or** $n = 6$ **or** $n = 7$ 2✓ to improve distribution of points (along the line) or wtte 3✓	for 1✓ and 2✓ if suggesting more than three values for n accept only the last three for 3✓ allow: 'spread out'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

Section A

Answer **all** questions in this section.

0 1 **Figure 1** shows apparatus used to investigate the inverse-square law for gamma radiation.

Figure 1



A sealed source that emits gamma radiation is held in a socket attached to clamp **B**. The vertical distance between the open end of the source and the bench is 138 mm. A radiation detector, positioned vertically above the source, is attached to clamp **T**.

A student is told **not** to move the stands closer together.

0 1 . 1 Describe a procedure for the student to find the value of d, the vertical distance between the open end of the source and the radiation detector.

In your answer, annotate **Figure 1** to show how a set-square can be used in this procedure.

[2 marks]

Question 1 continues on the next page

0 1 . 2 Before the source was brought into the room, a background count C_b was recorded.

$C_b = 630$ counts in 15 minutes

With the source and detector in the positions shown in **Figure 1**, $d = 530$ mm.
Separate counts C_1, C_2 and C_3 are recorded.

$C_1 = 90$ counts in 100 s
$C_2 = 117$ counts in 100 s
$C_3 = 102$ counts in 100 s

R_C is the mean count rate corrected for background radiation.

Show that when $d = 530$ mm, R_C is about $0.3\ \text{s}^{-1}$.

[2 marks]

0 1 . 3 The apparatus is adjusted so that $d = 380$ mm.
Counts are made that show $R_C = 0.76\ \text{s}^{-1}$.

The student predicts that:

$$R_C = \frac{k}{d^2}$$

where k is a constant.

Explain whether the values of R_C in Questions **01.2** and **01.3** support the student's prediction.

[2 marks]

0 1 . 4 Describe a safe procedure to reduce d. Give a reason for your procedure.

[2 marks]

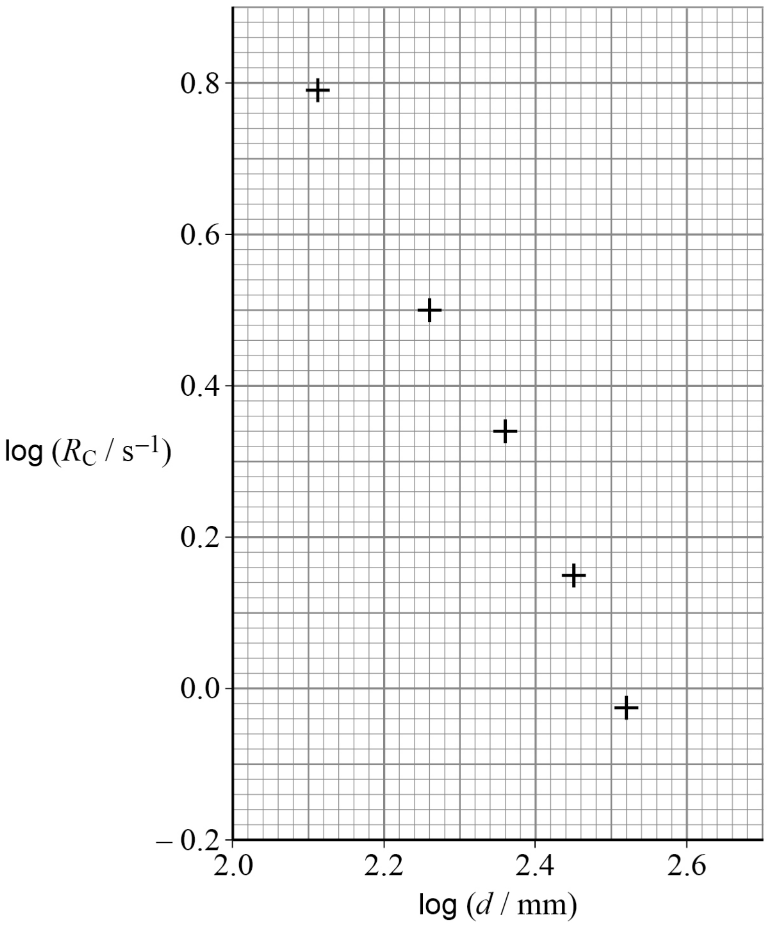
Question 1 continues on the next page

The student determines R_C for further values of d.

The values of d change by the same amount Δd between each measurement.

Figure 2 shows these data.

Figure 2



0 1 . 5 Determine Δd.

[2 marks]

Δd = ______________________ mm

0 1 . 6 Explain how the student could confirm whether **Figure 2** supports the prediction:

$$R_C = \frac{k}{d^2}$$

No calculation is required.

[3 marks]

Question 1 continues on the next page

When a gamma photon is detected by the detector, another photon cannot be detected for a time t_d called the dead time.

It can be shown that:

$$t_d = \frac{R_2 - R_1}{R_1 \times R_2}$$

where R_1 is the measured count rate
R_2 is the count rate when R_1 is corrected for dead time error.

0 1 . 7 The distance between the source and the detector is adjusted so that d is very small and R_1 is $100\ \mathrm{s}^{-1}$.
On average, two of the gamma photons that enter the detector every second are not detected.

Calculate t_d for this detector.

[1 mark]

$t_d =$ ____________________ s

0 1 . 8 A student says that if 100 gamma photons enter a detector in one second and t_d is 0.01 s, all the photons should be detected.

Explain, with reference to the nature of radioactive decay, why this idea is **not** correct.

[2 marks]

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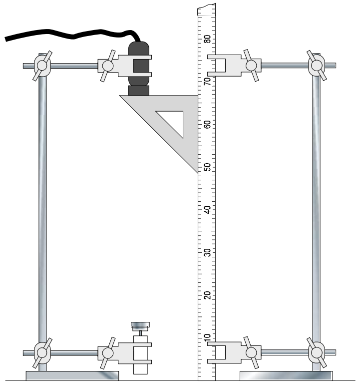
____

____

16

Question	Answers	Additional comments/Guidelines	Mark	AO
01.1	finds d by reading position of (lower end of) detector; subtracts 138 mm or wtte $_1$✓	for $_1$✓ allow 'reads / measures height of detector' / 'distance from detector to bench'; reject 'measures height of clamp **T**' if 'subtracts 138' is not seen; allow 'subtract distance from source to bench' / 'between source and bench' / 'height of source from ground' / 'position of top / open end / mouth of source'; allow 'measures height of the detector and the source and finds difference'; condone 'reversed' subtraction	2	AO2-1g
	annotates **Figure 1** to show suitable use of a recognisable set-square $_2$✓	for $_2$✓ expect a <u>triangular</u> 90° set-square in contact with a vertical edge of the ruler, top edge aligned with open end of the detector, eg 		

		~~condone use of recognisable~~ T-square in contact with vertical edge etc		

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	background count rate correct $_1$✓	for $_1$✓ accept any of: background count rate = 0.7(0) / $\frac{630}{900}$ (s^{-1}) OR background count in 100 s = 70 OR background count in 300 s = 210	1	AO1-1b
	working leading to correct R_C $_2$✓	for $_2$✓ [cao] ≥ 2 sf $R_C = 0.33$ (s^{-1}) reject $R_C = 0.30$ if their uncorrected count has been rounded to 1.0	1	AO2-1h

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	attempts two calculations that would lead to a conclusion $_1$✓ a reasoned judgement that the evidence does not support the prediction $_2$✓	for $_1$✓ the result of at least one calculation of $d^2 \times R_C$ or of $d \times \sqrt{R_C}$ must be correct to 2 sf (see table) otherwise withhold both marks; allow use of d in m but reject POT error; allow 1 sf $d^2 \times R_C$ for use of $R_C = 0.3$; allow 530^2 ×their **01.2** result for $_2$✓ two correct calculations of $d^2 \times R_C$ or of $d \times \sqrt{R_C}$, both must be correct to 2 sf OR one correct calculation of $d^2 \times R_C$ or of $d \times \sqrt{R_C}$ correct to 2 sf and an appropriate reverse-working calculation; the statement rejecting the prediction should be supported by a calculation of the percentage difference between the results of their calculations (see Δ% in table); condone weaker 'large' / 'significant differences' (between calculation results); reject 'prediction not correct' because 'values are different' / 'not constant' / 'not close enough'	2	AO3-1a

d / mm	380	530	Δ%
R_C / s^{-1}	0.76	0.33	
$d^2 \times R_C$	1.1(0)×10^5	9.27×10^4	18%
$d \times \sqrt{R_C}$	331 / 330	305 / 310	8.4%

d / mm	380	530	Δ%
R_C / s^{-1}	0.76	0.3 (1 sf)	
$d^2 \times R_C$	1.1(0)×10^5	8(.43)×10^4	29%
$d \times \sqrt{R_C}$	331 / 330	3.(0)×10^2	14%

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	lower / adjust the position of the detector / clamp **T** $_1$✓	for $_1$✓condone ‘lower clamp’ (this implies clamp **T** since **B** cannot be lowered further) allow ‘remove source using tongs while adjusting detector / clamp **T**’ otherwise $_2$✗	1	AO3-1b
	to maximise distance between the experimenter and the source or wtte OR to reduce (limit) exposure (time) of the experimenter to radiation or wtte $_2$✓	for $_2$✓ allow ‘not going (too) close (to source)’ reject ‘don’t touch / make contact with source’ suggesting using lead shielding is neutral allow $_{12}$✓ for ‘remove source or wtte using tongs to maximise distance etc before moving **B** upwards’ changes to the position of source / clamp **B** without the use of tongs loses both marks	1	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	determines $10^a - 10^b$ where a and b are (any) plotted values of log $(d\ /\ \text{mm})$ $_1$✓ use of $\Delta d = \dfrac{10^a - 10^b}{n}$ where n is 1, 2, 3 or 4; Δd in range 47(.0) to 53(.0) (mm) $_2$✓	insist on a and $b \geq 2$ dp; allow read-off errors ± one square; expect $\dfrac{10^{2.52} - 10^{2.11}}{4} = 50(.6)\ (\text{mm});$ allow $_{12}$✓for $\dfrac{e^a - e^b}{n}$ leading to Δd correct for their values $_2$✓is contingent on $_1$✓ie there is no credit for an unsupported answer	2	AO3-1a

Question	Answers	Additional comments/Guidelines	Mark	AO
01.6	suitable analysis $_1$✓ appropriate use of **Figure 2** $_2$✓ processing and conclusion $_3$✓	for $_1$✓ $\log R_C = -2 \log d + \log k$ seen; minus sign essential for $_2$✓ draw best-fit line **and** measure gradient; allow implication that a (linear) best-fit line is drawn and the gradient is being measured, eg ‘check gradient of best-fit line’; condone m = gradient for $_3$✓ states that the prediction is confirmed if the gradient / m is ≈ -2 OR prediction is **not** confirmed if the gradient is $\neq -2$ condone ‘the gradient should be -2 (to confirm prediction)’l (**no** ECF for $m = (+)2$ if denied in $_1$✓ for missing – sign) allow $_{123}$✓ prediction is **not** confirmed if the best-fit line is a curve reject ‘prediction is confirmed if the best-fit line is straight’ / ‘there is a negative gradient’ / ‘because ‘k is constant’	3	AO3-2a

Question	Answers	Additional comments/Guidelines	Mark	AO
01.7	$t_d = 1.96 \times 10^{-4}$ (s) ✓	minimum 2 sf; accept 196 μs; calculation should be $\frac{102 - 100}{102 \times 100}$ so only accept 2.0×10^{-4} (s) / 200 μs only if **rounding up** ($\frac{100 - 98}{100 \times 98}$ gives $t_d = 2.04 \times 10^{-4}$ (s))	1	AO2-1h

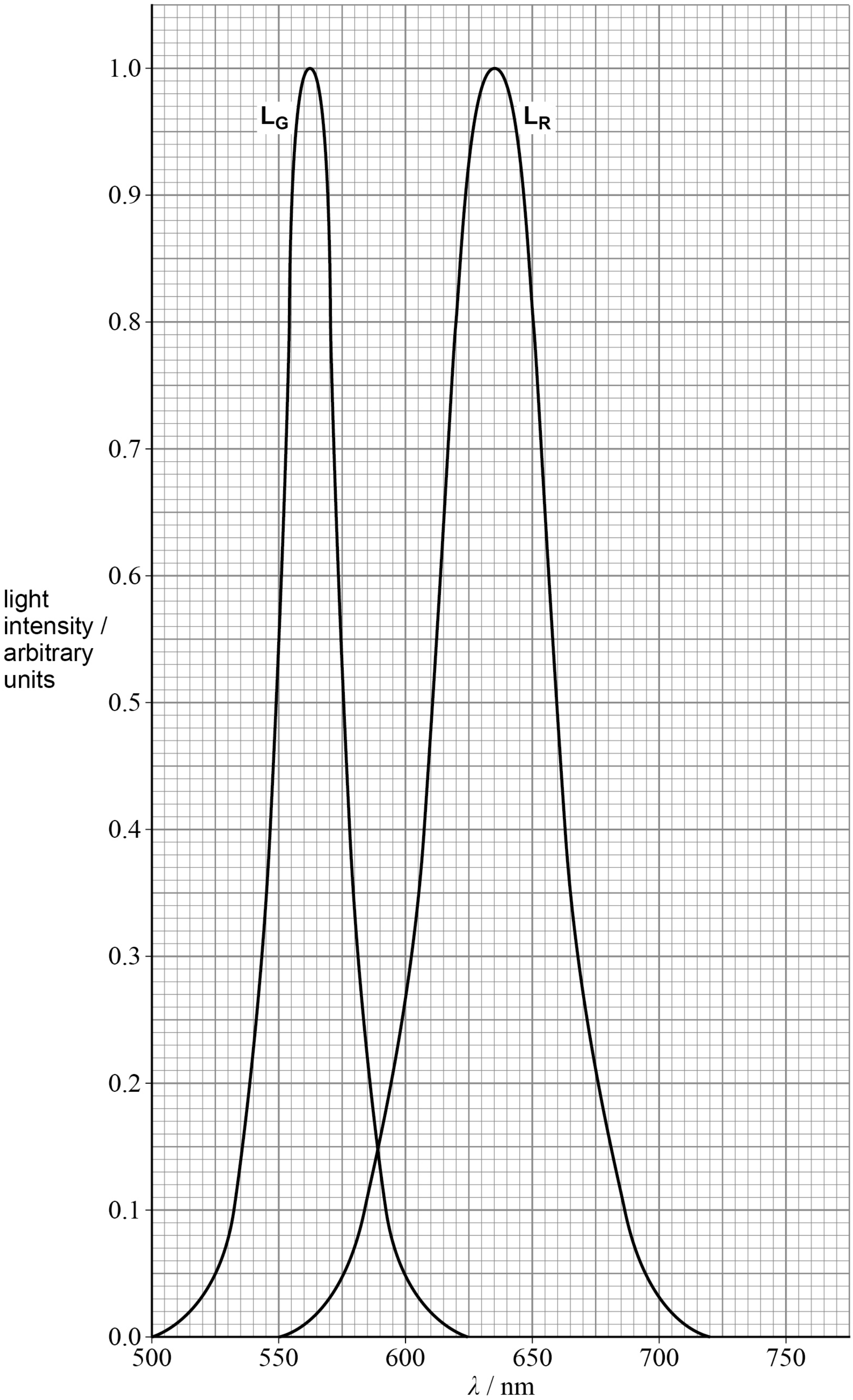
Question	Answers	Additional comments/Guidelines	Mark	AO
01.8	random nature of decay or wtte $_1$✓	for $_1$✓ condone 'the source emits (photons) sporadically' / 'unpredictably'; reject explanation based on exponential decay reject 'decay occurs by chance' / 'source does not emit photons at a constant rate' / 'photons decay' / 'decay is spontaneous / inconsistent'	1	AO1-1a
	idea that more than one photon may arrive per 0.01 s interval OR idea that no photon may arrive during per 0.01 s interval OR photons 'arrive randomly' / 'do not arrive at a steady rate or wtte $_2$✓	$_2$✓ is contingent on $_1$✓ (if no other answer given) allow $_{12}$✓ for: 'only counts 50 since detector still 'dead' at 0.01 s so only 'sees' odd-numbered photons'; use of formula to show $R_1 = 50$ is neutral	1	AO1-1b

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

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

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

Figure 3



Question 2 continues on the next page

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

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

[3 marks]

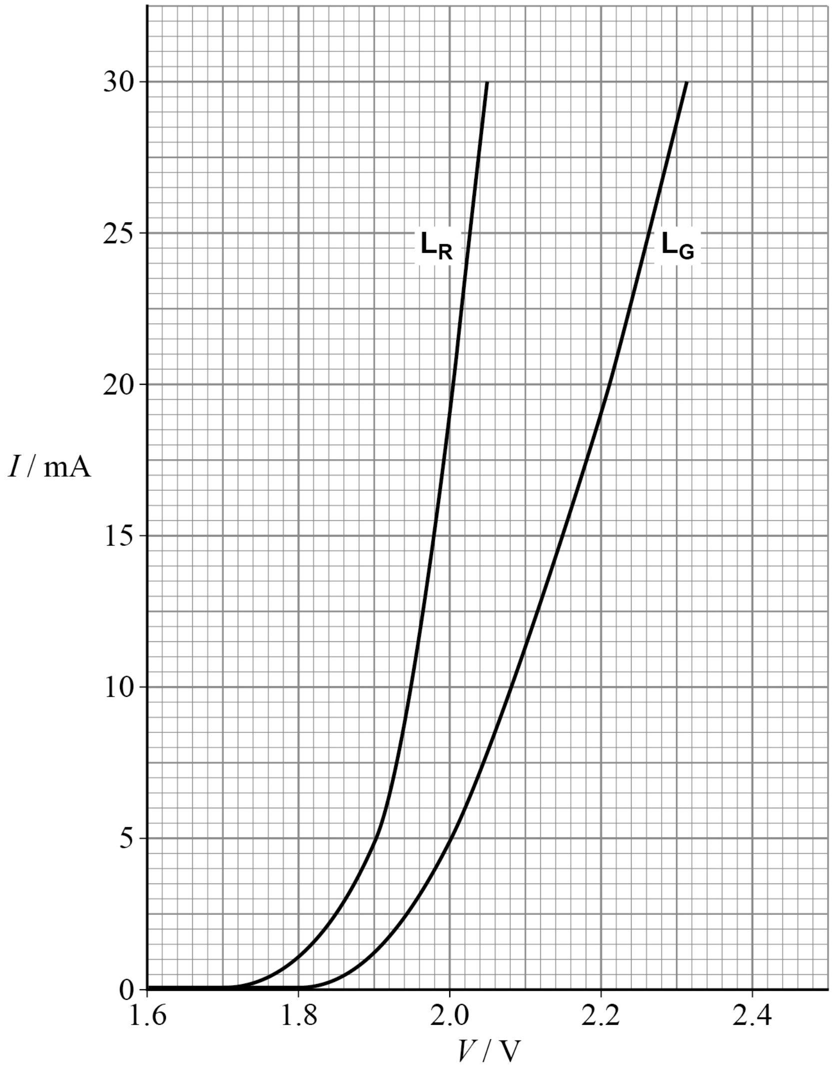
$N =$ ______________________ m^{-1}

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

[1 mark]

0 2 . 3 **Figure 4** shows part of the current−voltage characteristics for $\mathbf{L_R}$ and $\mathbf{L_G}$.

Figure 4



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

Determine, using **Figure 4**, V_A for $\mathbf{L_R}$.

[2 marks]

V_A for $\mathbf{L_R}$ = ______________________ V

Question 2 continues on the next page

0 2 . 4 It can be shown that:

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

where h = the Planck constant.

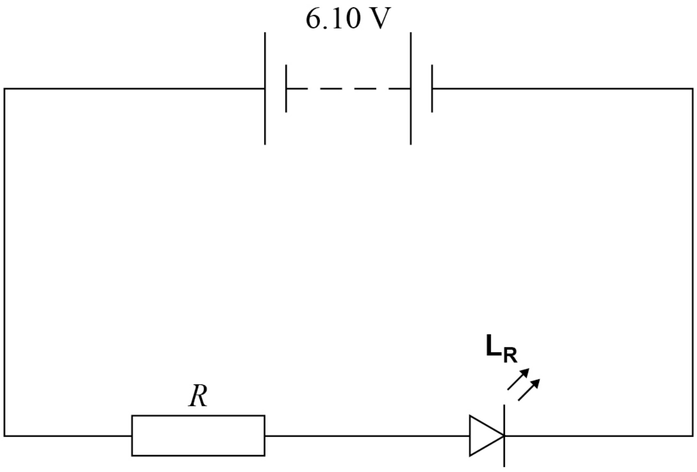
Deduce a value for the Planck constant based on the data given about the LEDs.

[2 marks]

h = ______________________ J s

0 2 . 5 **Figure 5** shows a circuit with **L$_R$** connected to a resistor of resistance R.

Figure 5



The power supply has emf 6.10 V and negligible internal resistance.
The current in **L$_R$** must not exceed 21.0 mA.

Deduce the minimum value of R.

[2 marks]

minimum value of R = ______________________ Ω

10

Total			**16**

Question	Answers	Additional comments/Guidelines	Mark	AO
02.1	reads off λ_{p} $_1$✓	for $_1$✓ condone POT; expect $\lambda_{\mathrm{p}} = 635 \pm 2$ (nm) / $635 \pm 0.02 \times 10^{-9}$ / $6.35 \pm 0.02 \times 10^{-7}$ (m) allow evidence of working on **Figure 3**	1	AO1-1a
	use of $n \times$ their $\lambda_{\mathrm{p}} = d \sin \theta$ $_2$✓	for $_2$✓ accept subject N with no / incomplete substitution, eg $N = \dfrac{\sin \theta}{n \times \lambda_{\mathrm{p}}}$ OR subject d and <u>full</u> substitution, eg $d = \dfrac{5 \times \text{their } \lambda_{\mathrm{p}}}{\sin 76.3}$ / $5.15 \times$ their λ_{p} OR correct result $d = 3.27$ ($\times 10^{-6}$ (m)); allow ECF in λ_{p} including POT; allow recognisable d / 2 sf intermediate result	1	AO2-1h
	$N = \left(= \dfrac{1}{d} = \dfrac{1}{3.27 \times 10^{-6}} \right) = 3.06 \times 10^{5}$ $_3$✓	for $_3$✓ accept ≥ 3 sf in range 3.05 to 3.07×10^{5} OR	1	AO3-1b

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

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

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

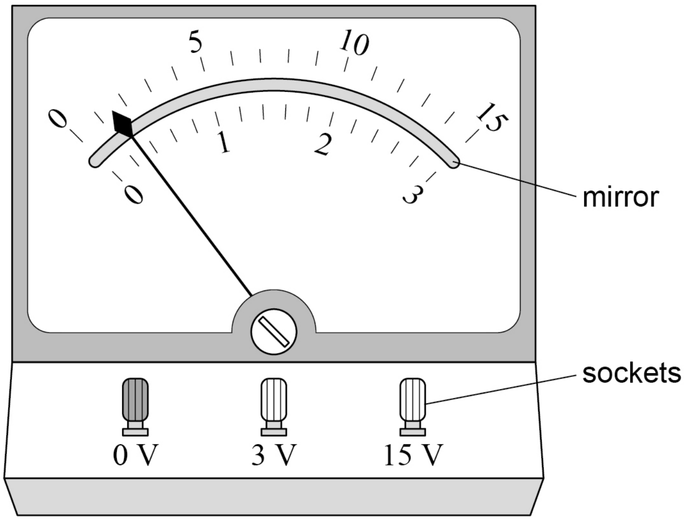
Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	any fully correct calculation of the Planck constant $_1$✓	for $_1$✓ allow 2 sf use of $c = 3(.00) \times 10^8$ AND $e = 1.6(0) \times 10^{-19}$ AND EITHER V_A from **02.3** AND λ_p in range 620 to 650 nm / ECF their λ_p from **02.1** OR $V_A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

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

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

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

Figure 6



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

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

Tick (✓) **one** box.

[1 mark]

2.7 V ☐

3.3 V ☐

13.5 V ☐

16.5 V ☐

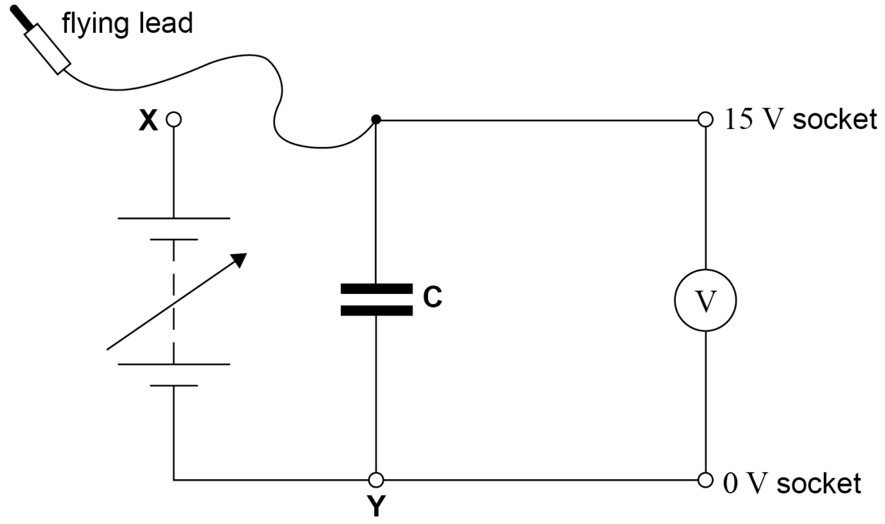
0 3 . 2 Explain the use of the mirror when reading the meter.

[2 marks]

Question 3 continues on the next page

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

Figure 7



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

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

She repeats this process several times.

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

Table 1

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

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

[2 marks]

percentage uncertainty = ______________ %

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

[1 mark]

Question 3 continues on the next page

0 3 . 5 The student thinks that the time constant of the circuit in **Figure 7** is directly proportional to the range of the meter.
To test her theory, she repeats the experiment with the voltmeter set to the 3 V range.
She expects $T_{½}$ 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 μF capacitor and charges it to 15 V.
She discharges the capacitor through the voltmeter, starting a stopwatch when *V* is 14 V.
She records the stopwatch reading *t* at other values of *V* as the capacitor discharges.

Table 2 shows her results.

Table 2

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

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

[4 marks]

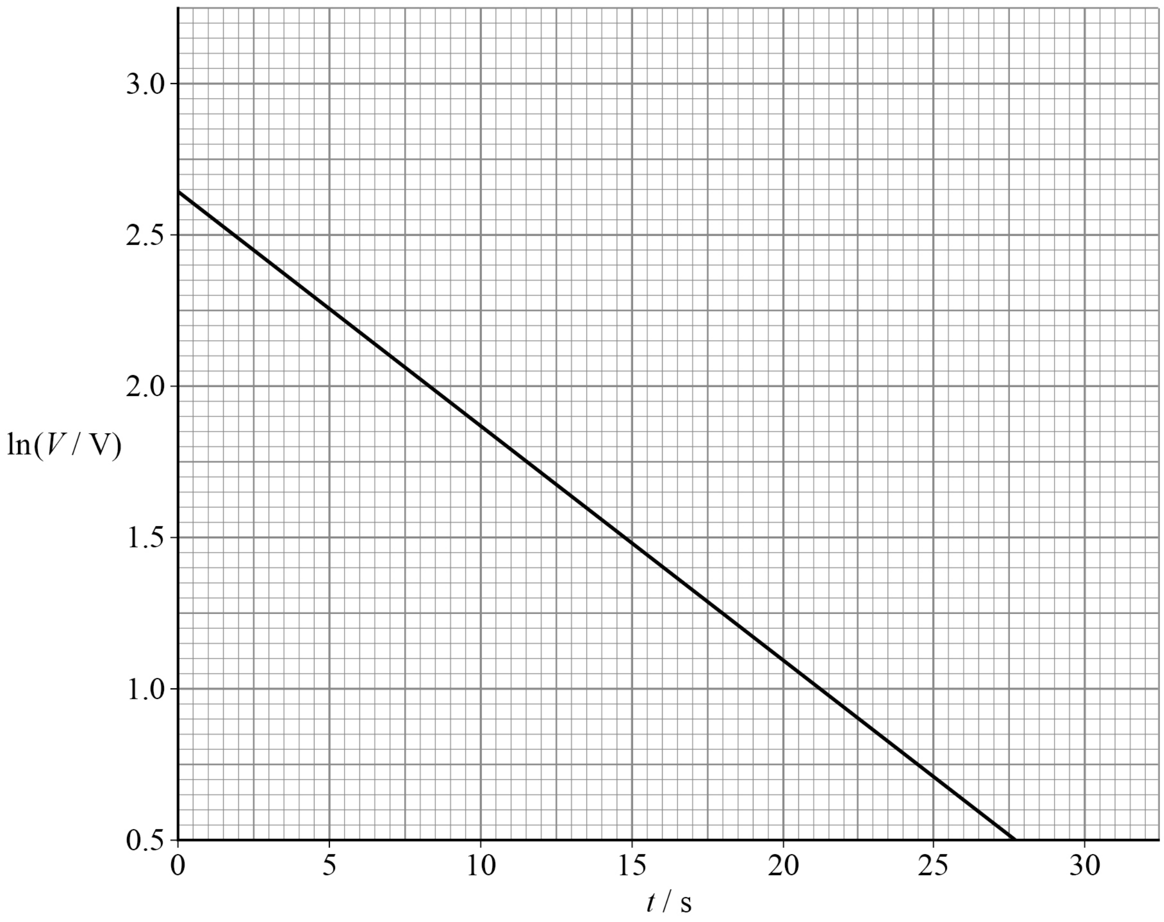
1

2

Question 3 continues on the next page

Figure 8 shows a graph of the experimental data.

Figure 8



0 3 . 7 Show, using **Figure 8**, that the resistance of the voltmeter is about 16 kΩ.

[3 marks]

0 3 . 8 Determine the current in the voltmeter at $t = 10$ s.

[2 marks]

current = ______________ A

19

END OF QUESTIONS

Question	Answers	Additional comments/Guidelines	Mark	AO
03.1	tick in **first** box (2.7 V) ✓	[cao]	1	AO2-1d

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

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	average $T_{1/2}$ correct OR uncertainty in $T_{1/2}$ correct $_1$✓	for $_1$✓ 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 $_2$✓	for $_2$✓ minimum 2 sf; correct answer rounds to 0.91(4)%	1	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO

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

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	ways ensure pd across **C** doesn't exceed $3\ \mathrm{V}$ before connecting **C** to **X** $_1$✓ as **X** is connected $_2$✓	for $_1$✓ discharge **C** / connect flying lead to **Y** / 'reset to $0\ \mathrm{V}$' (before reconnecting); reject 'reset equipment' for $_2$✓ reduce the <u>output pd</u> / socket **X** (or wtte) to $\leq 3\ \mathrm{V}$ (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 $T_{½}$ or time constant); any valid processing eg calculate an average value / reject anomalies / check results are concordant or wtte $_{3b}$✓ check / correct / compensate for any <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 $T_{½}$ 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 $15\ \text{V}$ range $_5$✓	(theory will be correct if) half-life / time constant is one fifth / 20% (of previous value) / about $3.5\ \text{s}$ / time constant reduced by 80% / ratio of time constant to range / ratio of half-life to range is same / similar reject ‘plot ln V against t, find (–gradient^{-1})’	1	AO2-1d

Question	Answers	Additional comments/Guidelines	Mark	AO
03.6	in answer space 1:	give credit for any good physics, eg	4	AO2-1g
	any valid comment about the values of V in **Table 2** $_1$✓	V recorded to nearest volt $_1$✓		
	corresponding explanation $_2$✓ (contingent on $_1$✓)	because of (low) scale resolution / hard to interpolate between markings; reject ‘values easier to plot’ $_2$✓		
	in answer space 2:			
	different valid comment about the values of V in **Table 2** $_3$✓	different / decreasing intervals between values of V / more lower values of V $_3$✓		
	corresponding explanation $_4$✓ (contingent on $_3$✓)	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 $_4$✓		
	only credit one comment and explanation per answer space			
	comments about the number of data sets are neutral			
		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 $\underline{14\ \text{to}\ 2}$ (V) $_7$✓		

		to maximise evidence available (for graph / **Figure 8**) or wtte $_8$✓ no readings for $V > 14$ V / largest $V = 14$ V $_9$✓ can begin discharge **C** before starting stopwatch $_{10}$✓		

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

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

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

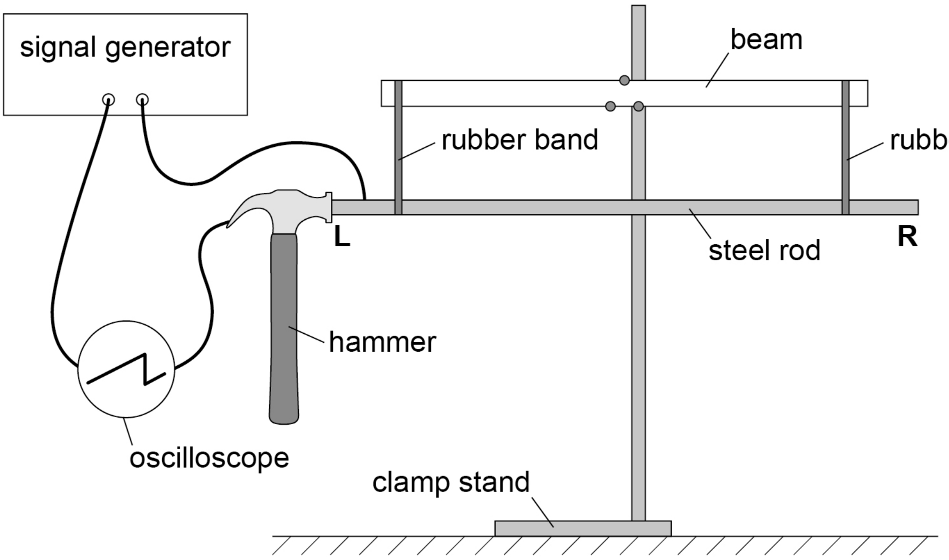
Total			**19**

Section A

Answer **all** questions in this section.

0 1 **Figure 1** shows apparatus used to measure the speed of sound in a steel rod.

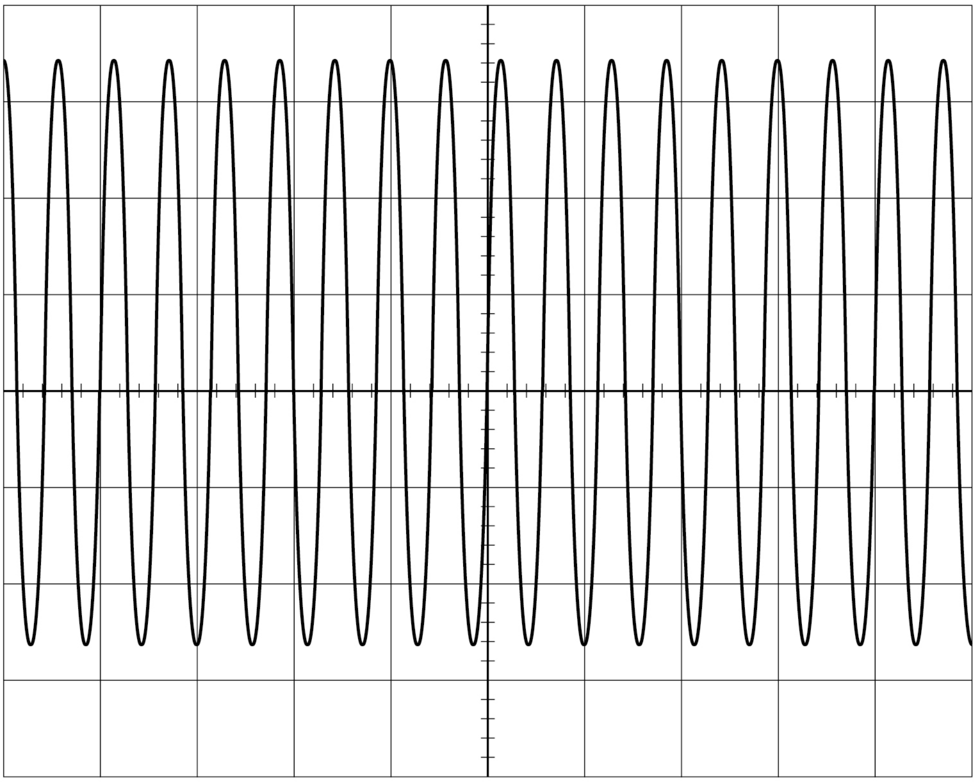
Figure 1



The steel rod is suspended from a beam using rubber bands.
When the hammer is in contact with the end **L** of the steel rod, a circuit is completed and the signal generator is connected to the oscilloscope.

Figure 2 shows the waveform then displayed on the oscilloscope.

Figure 2



0 1 . 1 Which control on the oscilloscope should be used to centre the trace vertically on the screen?
Tick (✓) **one** box.

[1 mark]

X-shift ☐

Y-gain ☐

Y-shift ☐

Question 1 continues on the next page

When the hammer hits end **L**, a sound wave travels along the steel rod and is reflected at end **R**.
When the wave returns to **L** the rod bounces away from the hammer and the circuit is broken.

Figure 3 shows the waveform produced by the brief contact between the hammer and **L**.
Note that the waveform has now been centred vertically.

Figure 3

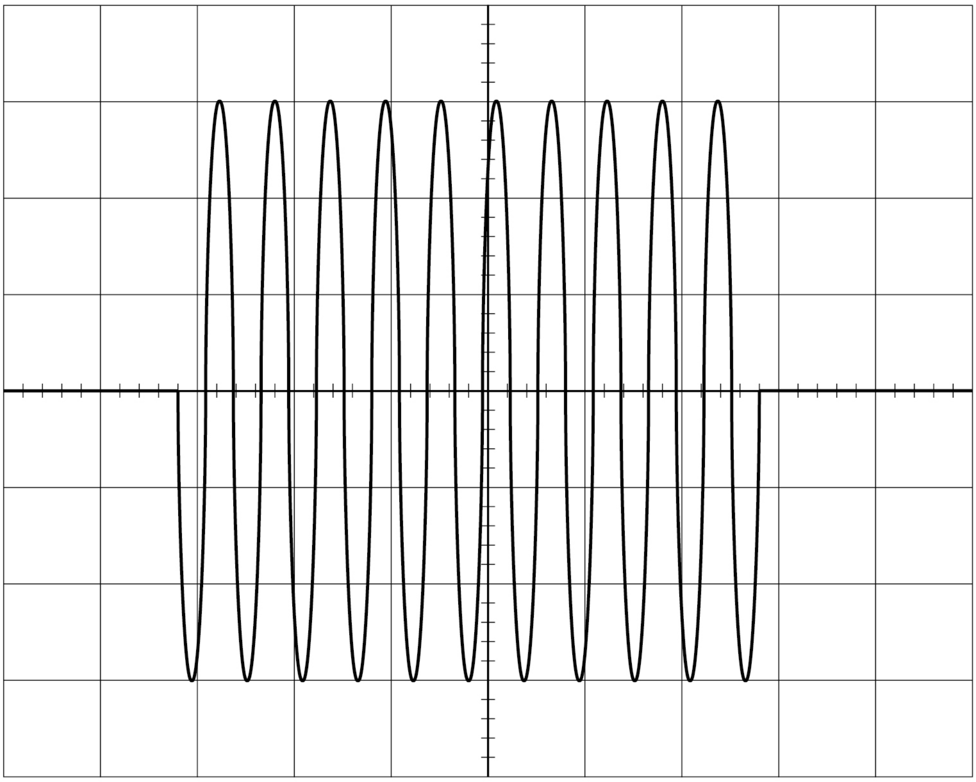
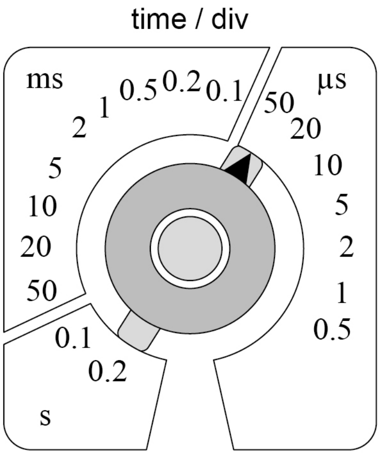


Figure 4 shows the time-base setting of the oscilloscope.

Figure 4



0 1 . 2 The distance between **L** and **R** in **Figure 1** is 0.870 m.

Deduce the speed of sound in the steel rod.

[3 marks]

speed of sound = ____________________ m s^{-1}

0 1 . 3 A student repeats the experiment using a steel rod of twice the length.

Explain:

- how using the longer rod affects the waveform displayed
- any changes needed to get an accurate result for the speed.

You should include numerical detail.

[4 marks]

8

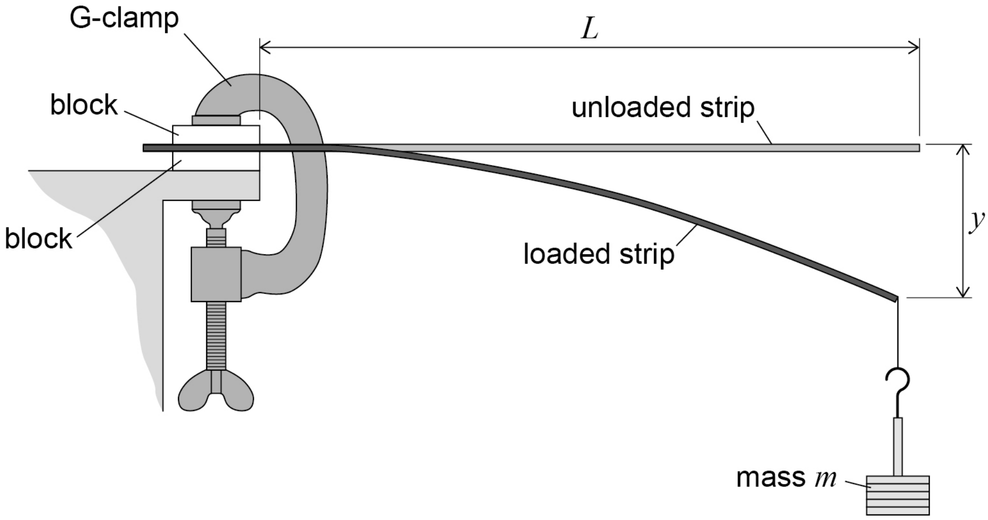
Question	Answers	Additional comments/Guidelines	Mark	AO
01.1	Y-shift ✓	auto-marked: CAO	1	AO1

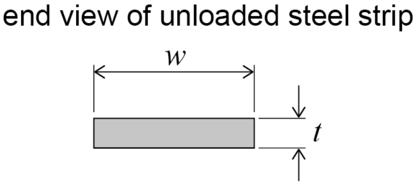
Question	Answers	Additional comments/Guidelines	Mark	AO
01.2		speed correct from valid calculation earns $_1$✓$_2$✓$_3$✓		3 x AO2
	use of (transit distance) = 2×0.870 $_1$✓	for $_1$✓ allow 1.74	1	
	use of (contact time) = 6 ± 0.2 major divisions $\times$ 50×10^{-6} $_2$✓	for $_2$✓ allow POT error in time-base value; allow 2.9, $3(.0)$ or 3.1 ($\times 10^{-4}$ s) seen in working	1	
	speed in range 5600 to 6000 ($\mathrm{m\ s^{-1}}$) using valid speed calculation $_3$✓	for $_3$✓ no credit for $c = f \times \lambda$ approach; speed in range 2800 to 3000 ($\mathrm{m\ s^{-1}}$) from valid calculation eg $\frac{0.870}{3\times10^{-4}}$ award $_2$✓$_{13}$✓ $= 2$; speed in range 1120 to 1200 ($\mathrm{m\ s^{-1}}$) from valid calculation (using minor divisions) eg $\frac{2\times0.870}{5\times3\times10^{-4}}$ award $_1$✓$_{23}$✓ $= 2$; for speed = length of rod ÷ (0.5 × time-base) $_1$✓$_2$✗$_3$✗ no credit for speed = length of rod ÷ time-base	1	

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	quantitative effect on (contact) time $_1$✓	for $_1$✓ expect '(contact) time is doubled' / '600 μs'	Max 2	2 x AO1
	quantitative effect on waveform $_2$✓	for $_2$✓ expect 'double the number of cycles would be produced' / 'would require 12 divisions'; accept 'waveform extended horizontally × 2' 'waveform is twice as long' or wtte; condone 'number of wave(length)s doubled'; reject 'trace is twice as long' / 'wavelength doubled' / 'waveform stretched'; allow 'increased (contact) time so more waves / longer waveform seen' for $_{12}$✓ = 1 MAX		
	waveform extends beyond screen / scale or wtte $_3$✓	for $_3$✓ consequences eg waveform could not be (fully) displayed / would not fit; only penalise 'trace' once		
	adjustment to time-base control $_4$✓	for $_4$✓ allow (any) change time-base; allow 'time (per) div'; condone 'X-scale'	1	2 x AO3
	to 0.1 ms (div^{-1}) $_5$✓	for $_5$✓ CAO	1	
Total			**8**	

0 2 **Figure 5** shows a strip of steel of rectangular cross-section clamped at one end. The strip extends horizontally over the edge of a bench.

Figure 5

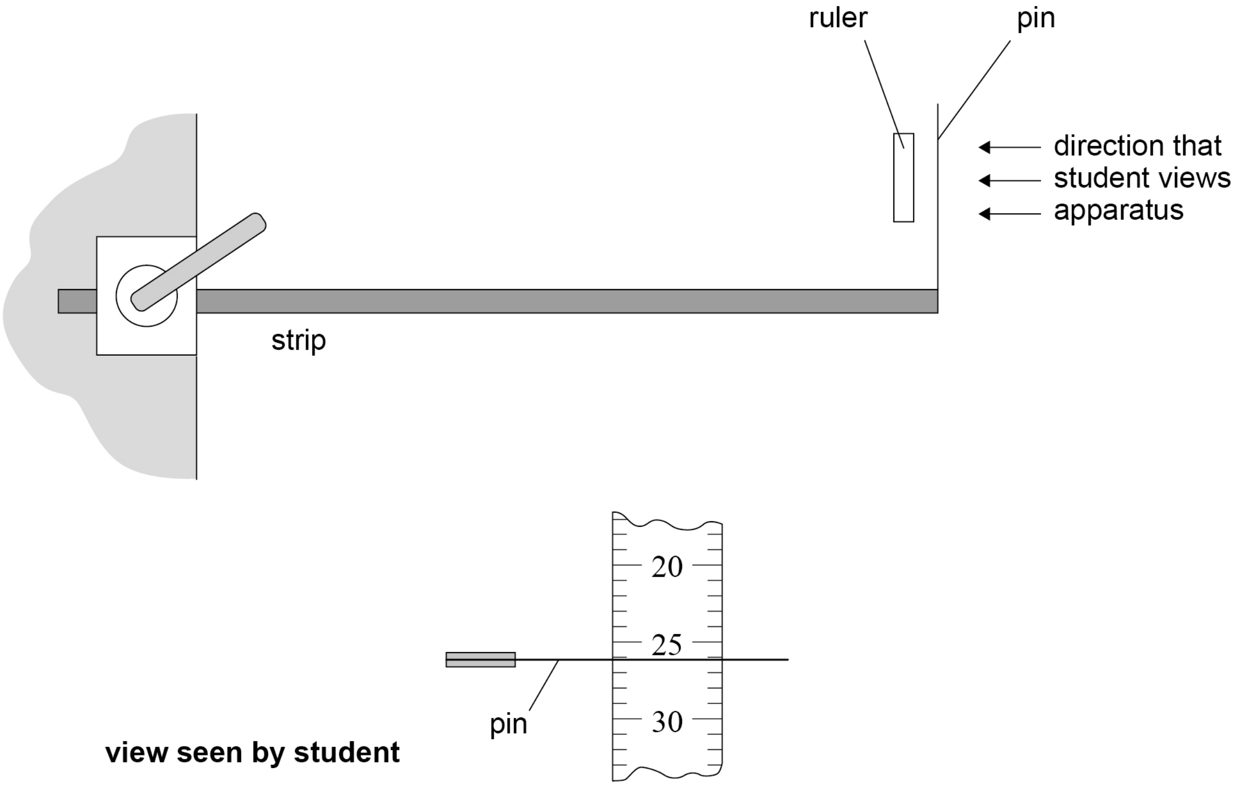




0 2 . 1 A mass m is suspended from the free end of the strip.
This produces a vertical displacement y.
A student intends to measure y with the aid of a horizontal pin fixed to the free end of the steel strip.
She positions a clamped vertical ruler behind the pin, as shown in **Figure 6**.

Figure 6

plan view



Explain a procedure to avoid parallax error when judging the reading indicated by the position of the pin on the ruler.
You may add detail to **Figure 6** to illustrate your answer.

[2 marks]

Question 2 continues on the next page

0 2 . 2 It can be shown that

$$y = \frac{4mgL^3}{Ewt^3}$$

where:

L is the distance between the free end of the **unloaded** strip and the blocks
w is the width of the strip and is approximately 1 cm
t is the thickness of the strip and is approximately 1 mm
E is the Young modulus of the steel.

A student is asked to determine E using the arrangement shown in **Figure 5** with the following restrictions:

- only one steel strip of approximate length 30 cm is available
- m must be made using a 50 g mass hanger and up to four additional 50 g slotted masses
- the experimental procedure must involve only **one** independent variable
- a graphical method must be used to get the result for E.

Explain what the student must do to determine E.

[5 marks]

Question	**Answers**	**Additional comments/Guidelines**	**Mark**	**AO**
02.1		give credit for any relevant annotation to Figure 6 or in additional sketch		2 x AO3
	place mirror behind ruler $_1$✓	for $_1$✓ do not insist on contact between mirror and ruler	1	
	adjust position (of eye / head) until pin hides / lines up with its own reflection / image $_2$✓	condone use of (non-hypotenuse) edge of set-square to define horizontal plane $_1$✓ adjust position until horizontal edge of set square meets/is touching pin or wtte $_2$✓ if no other mark given award $_{12}$✓= 1 max for ‘read value at eye level’ OR move (clamped) ruler closer to pin	1	

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	valid strategy using apparatus in **Figure 5**: y (as the dependent variable) measured (or wtte) for different values of <u>one</u> independent variable (only L or m are acceptable) $_1$✓	for $_1$✓ must refer to variables only using the symbols and/or terms given on page 8; accept 'weight' / mg as independent variable condone mock table as intent / y = 'extension'	1	2 x AO1
	identifies the correct control variable (besides w and t) $_2$✓	for $_2$✓ L = control variable if m = independent variable OR m = control variable if L = independent variable; if L is being varied and $m = 250$ g is stated, this can be taken as m = control variable and therefore known; take a similar approach if m is being varied but in this case L must have a **quoted value** that is ≤ 30 cm; for more than one independent variable, eg variation of both m and L $_{12}$✗✗ but allow ECF for $_4$✓ as long as plot is valid, eg y against mL^3	1	
	suitable measuring instruments for L OR w OR t $_3$✓	ANY ONE of the following (for more than one response mark as LIST) for L: use ruler; for w: use (any type of vernier) callipers; accept micrometer (screw gauge); for t: use micrometer (screw gauge); accept digital / electronic (vernier) callipers	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2 continued	analysis: suggests valid plot $_4$✓ identifies correctly how E can be found from a valid plot $_5$✓	for $_4$✓ plot must involve y [by itself or combined with another factor] on one axis and their independent variable [by itself or combined with another factor] on the other axis; do not insist on y as ordinate for $_5$✓ E must be the subject; some examples include:	1 1	2 x AO3

ordinate	abscissa	$E =$
y	m	$\frac{4\times L^3\times g}{w\times t^3\times \text{gradient}}$
mg	y	$\frac{4\times L^3\times \text{gradient}}{w\times t^3}$
y	L^3	$\frac{4\times m\times g}{w\times t^3\times \text{gradient}}$
y	$\frac{4\times L^3}{w\times t^3}$	$\frac{m\times g}{\text{gradient}}$
$\log y$	$\log m$	$\frac{4\times g\times L^3}{w\times t^3\times 10^{\text{intercept}}}$
$\log y$	$\log L$	$\frac{4\times m\times g}{w\times t^3\times 10^{\text{intercept}}}$

Total			**7**

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

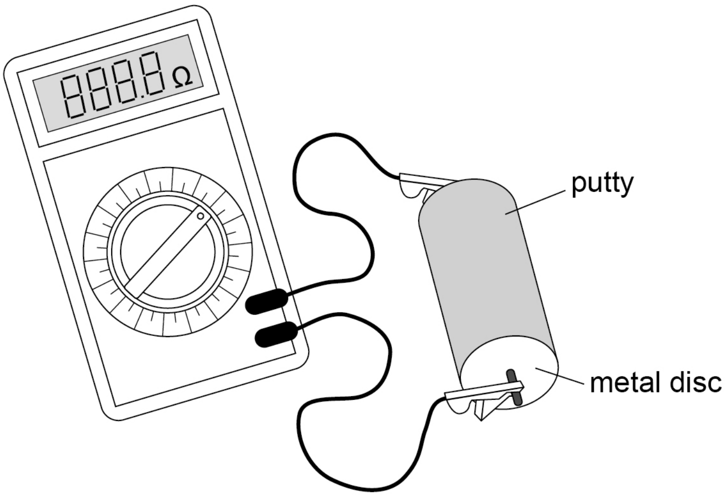
Question 3 continues on the next page

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

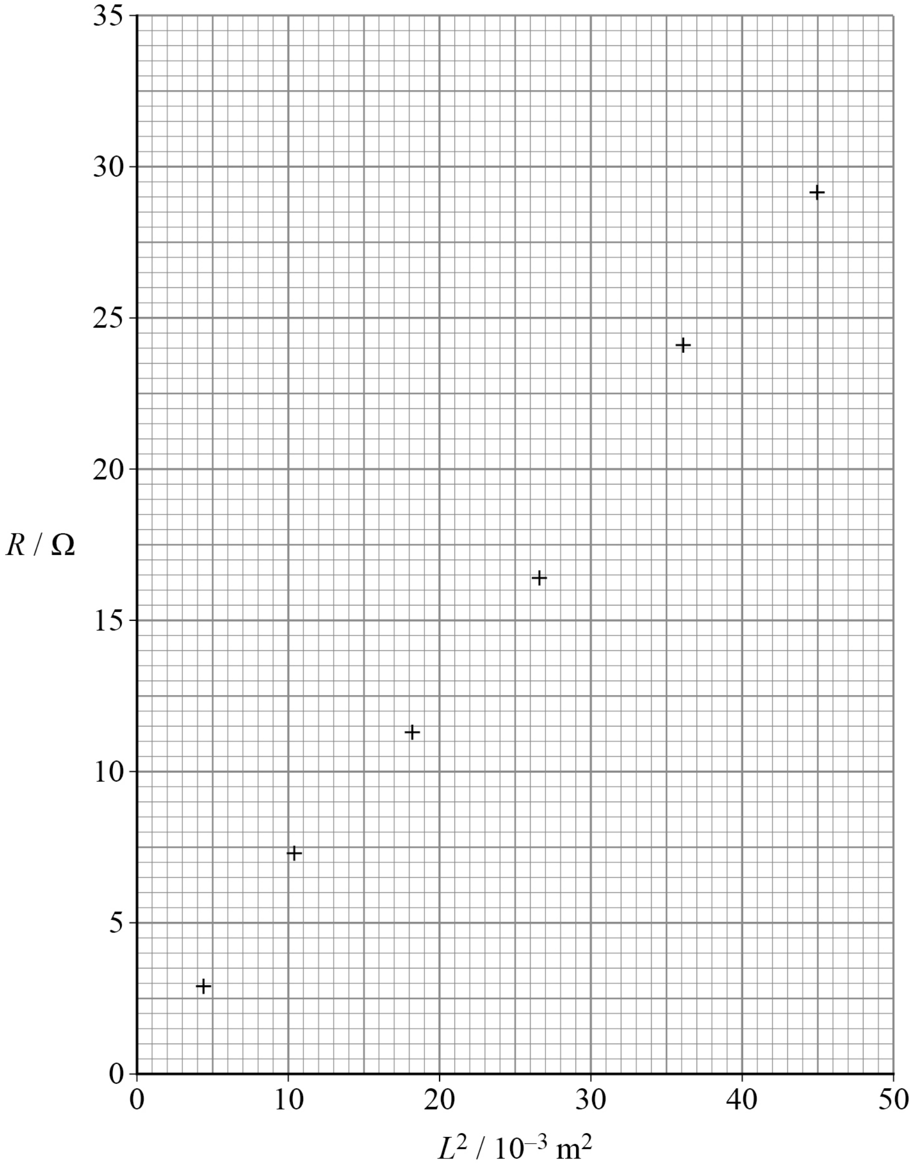
The student plots the graph shown in **Figure 8**.

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

[4 marks]

ρ = ______________________ unit = ______________________

Figure 8



Turn over for the next question

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

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

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

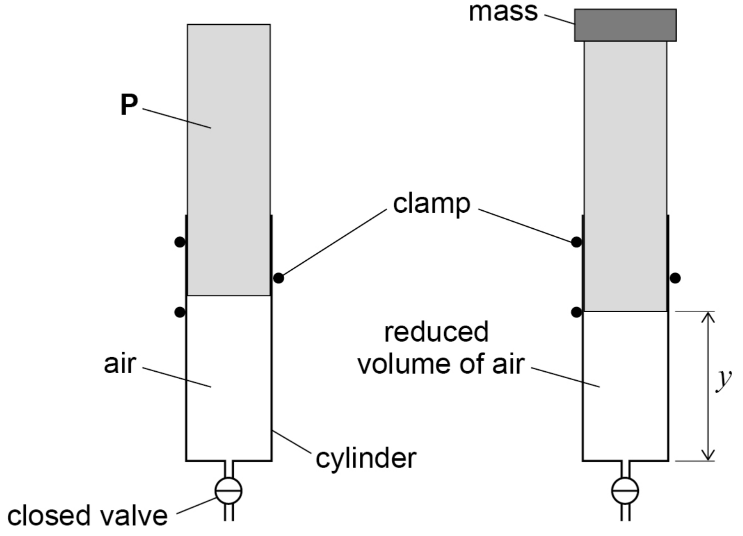
Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	<u>ruled</u> line $_1$✓	for $_1$✓ line passing below 5th AND above 4th ie <u>no overlap between line and either **+**;</u> line passing through or extrapolated to $(0, 0)$ to half a minor grid square; withhold this mark if line is poorly-marked (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 $\Delta L^2 = 25$ $(\times 10^{-3}\ \mathrm{m}^2)$; 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 $0.0378\ \Omega\ \mathrm{m}$ as equally acceptable; allow alternative valid answer, eg $37.8\ \Omega\ \mathrm{mm}$	1	

Total			**11**

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

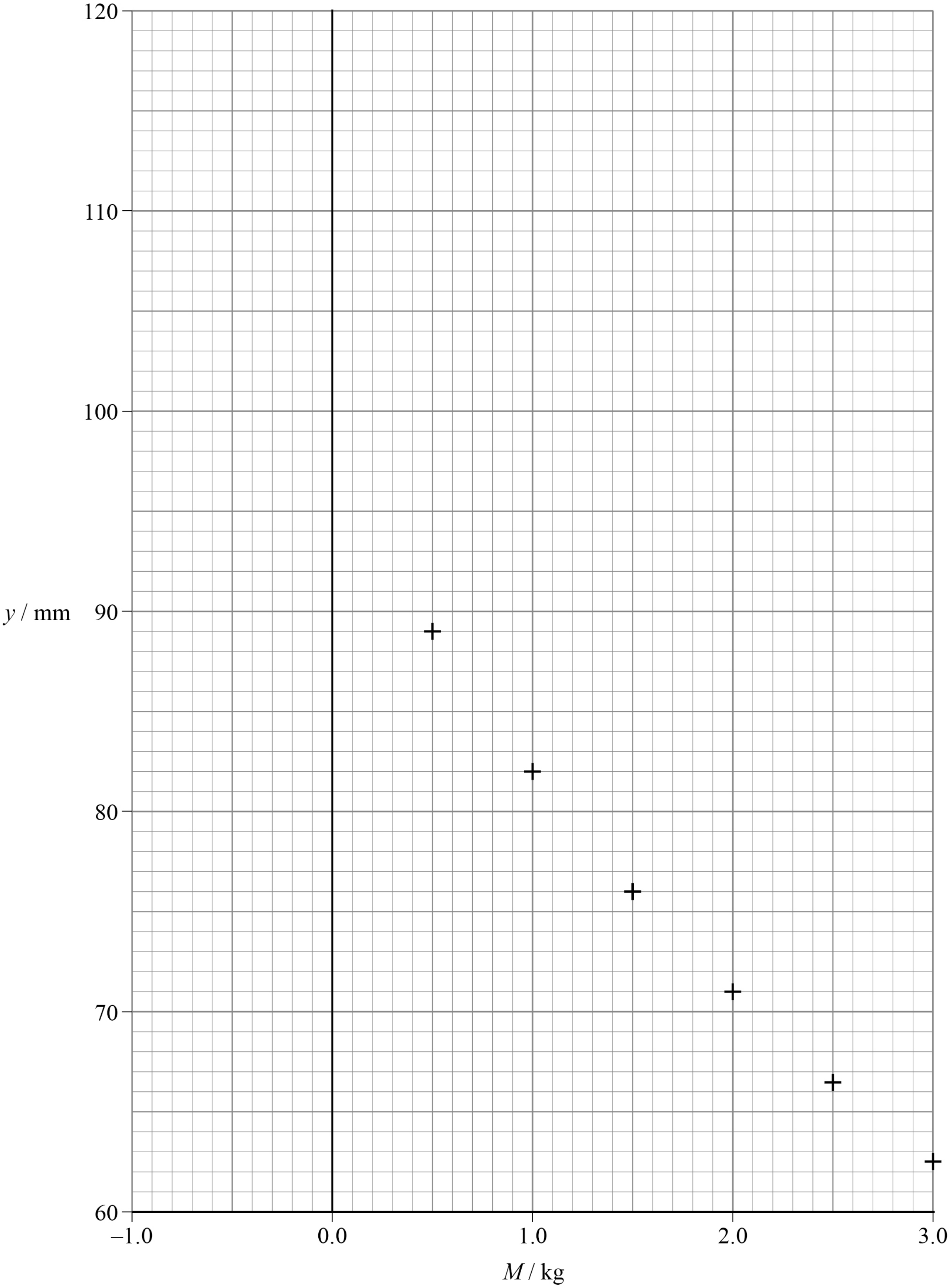


The vertical distance y between the end of **P** and the closed end of the cylinder is measured.
Additional masses are used to find out how y depends on the total mass M placed on top of **P**.
Figure 10 shows a graph of these data.

0 4 . 1 Show that y is **not** inversely proportional to M.
Use data points from **Figure 10**.

[2 marks]

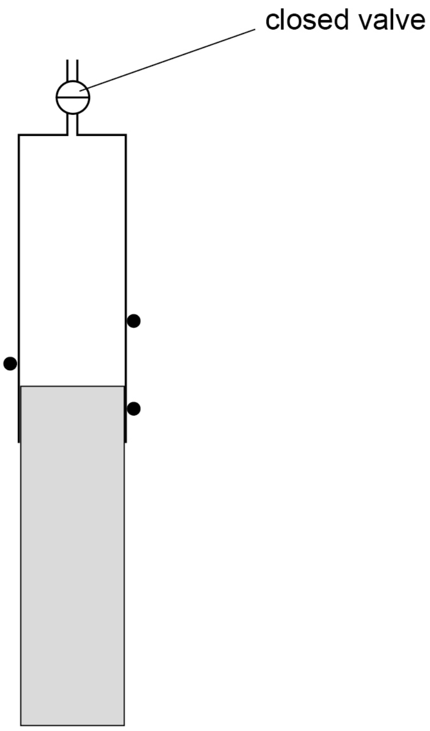
Figure 10



Question 4 continues on the next page

0 4 . 2 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.

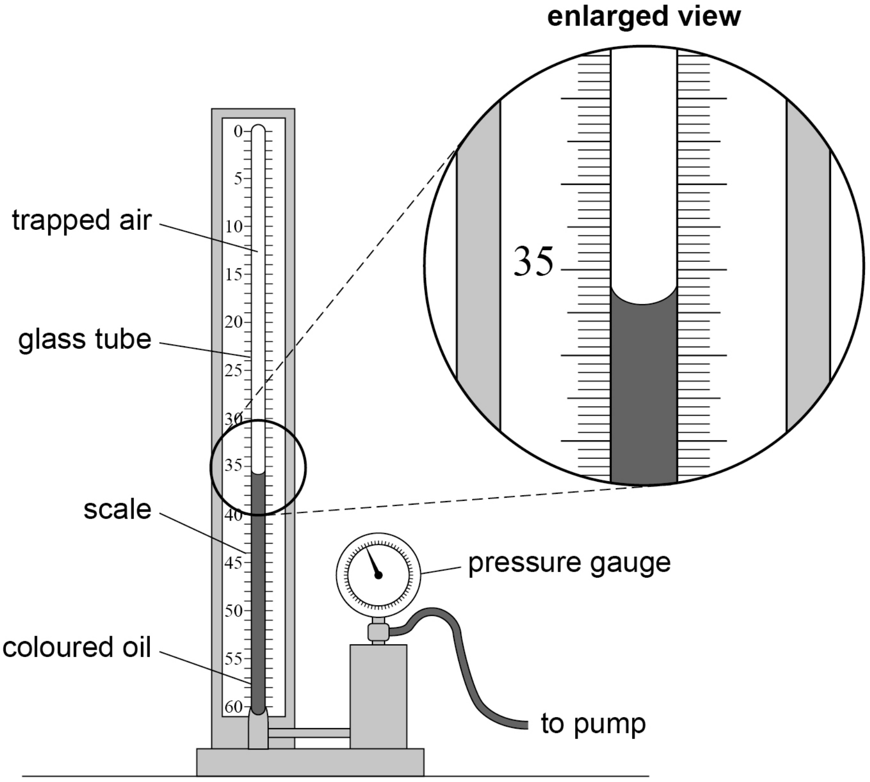
[4 marks]

$y =$ ______________________ 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 A scale, marked in $0.2\ \text{cm}^3$ intervals, is used to measure the volume V of the air.
A student says that the reading for V shown in **Figure 12** is $35.4\ \text{cm}^3$.

State:

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

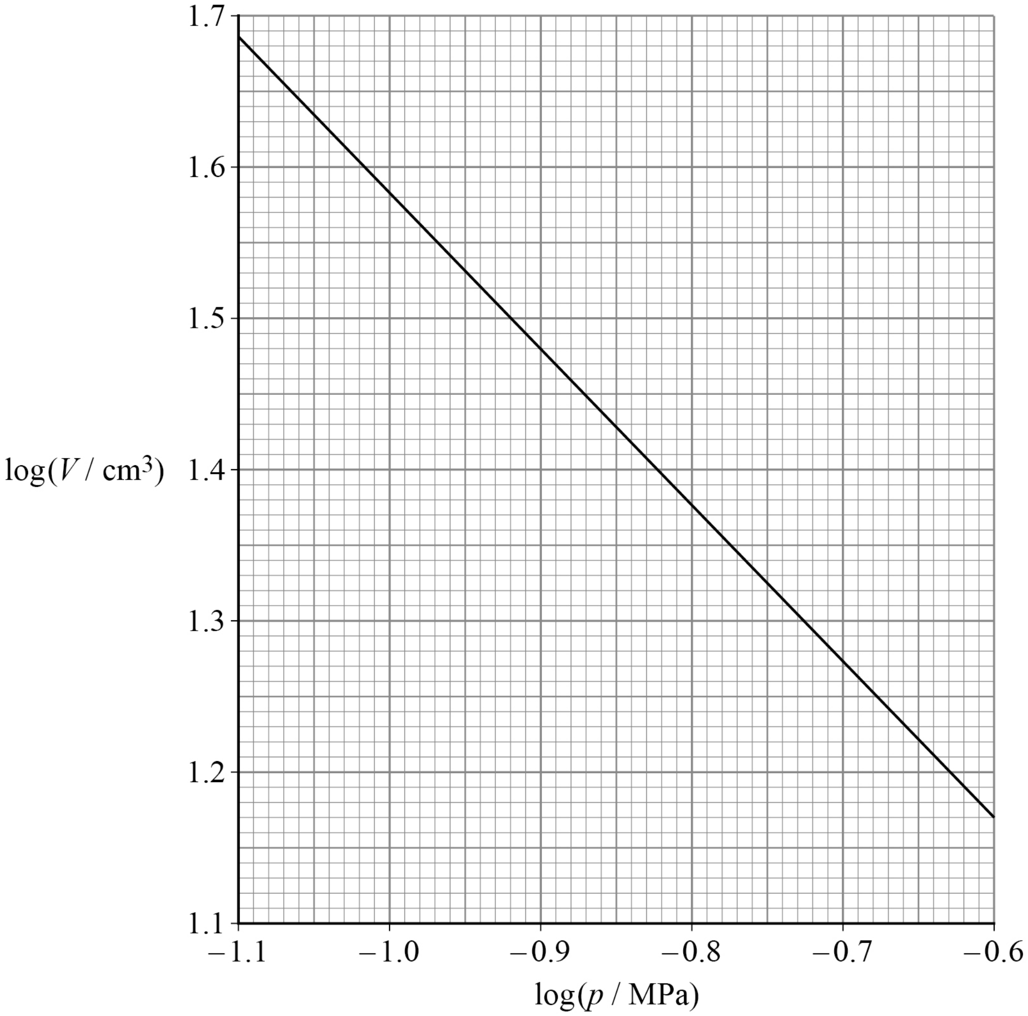
[2 marks]

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]

____

____

____

____

____

____

19

END OF QUESTIONS

Question	Answers	Additional comments/Guidelines	Mark	AO
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;	1	1 x AO1 1 x AO2
	a reasoned judgement explaining why y not inversely proportional to M $_2$✓	award of $_2$✓ is contingent on valid $_1$✓ 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 $_1$✓	must address situation in Figure 11 for $_1$✓ allow 'pressure reaches lower value' reject 'pressure is low'	Max 3	3 x AO3
	pressure less than atmospheric pressure $_2$✓	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''		
	this leads to an upwards force balancing the weight of **P** OR pressure difference across **P** × area of piston = weight of piston $_3$✓	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		
	why **P** falls when the valve is opened $_4$✓	for $_4$✓ idea of external and internal pressures equalising; reject 'pressure released / returns to normal'		

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 **+**; condone poorly-marked line (note that poor line quality may only be penalised in **Question 03.4**)	1	1 × AO1 2 × AO2 1 × AO3
	line with negative gradient extrapolated (backwards) to $M \leq -0.35$ $_2$✓	for $_2$✓ condone linear extension of curve with negative gradient for $M < +0.5$	1	
	records y corresponding to $M = -0.7$ $_3$✓	for $_3$✓ curve must extend to where read off is being made	1	
	y in range 108 mm to 116 mm $_4$✓	award of $_4$✓ is contingent on valid $_3$✓ for $_4$✓ answers that round to nearest mm are acceptable	1	
	OR for incorrect M (3 MAX) smooth curve etc $_1$✓ line with negative gradient extrapolated (backwards) to $M \leq -0.35$ $_2$✓ records y corresponding to $M = -0.35$; 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 $0.1\ \text{cm}^3$ and not (as question states) $0.2\ \text{cm}^3$’ 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 Δ log(V / cm^3) divided by Δ log(p / MPa); evaluated to ≥ 3 sf result between -1.05 and -1.01 $_1$✓	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 $y = mx + c$ $_2$✓	for $_2$✓ (eg Boyle's Law written as) log V = – log p + 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 = gradient × log p + 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 $\approx \underline{-1}$ confirms Boyle's Law $_3$✓	for $_3$✓ allow gradient is / equals / should be -1 if $_2$✓ not given accept 'gradient $\approx \underline{-1}$ demonstrates inverse proportion or wtte	1	

Question	Answers	Additional comments/Guidelines	Mark	AO
04.6		V_2 in range 10.5 to 11.5 (cm^3) earns ${}_1$✓${}_2$✓${}_3$✓		1 x AO2 2 x AO3
	reads off and attempts to make use of log p_1 AND log V_1 for any point on the line ${}_1$✓	for ${}_1$✓ 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	
	applies a workable method ${}_2$✓	for ${}_2$✓ creditworthy examples are a calculation of the intercept in **Figure 13** eg log V + log $p = 0.585$ OR use of gradient = $\dfrac{\Delta \log V}{\Delta \log p}$ (eg similar triangles idea) OR a calculation of $p \times V$ (by any means) OR use of log $V = -1 \times$ log 0.34 + their intercept no credit for claiming 1.685 (or 1.170) are intercepts; this cannot earn ${}_2$✓	1	
	further manipulation to determine unknown V_2 ${}_3$✓	for ${}_3$✓ 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 of air' '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**	

Section A

Answer **all** questions in this section.

0 1 A stroboscope emits bright flashes of white light.
The duration of each flash and the frequency of the flashes can be varied.

Table 1 shows information about the stroboscope.

Table 1

	Minimum	**Maximum**
Duration of each flash / µs	60	300
Frequency of flashes / Hz	1	150

The duration of each flash is T_1.
The time from the start of a flash to the start of the next flash is T_2.

The duty cycle of a stroboscope is defined as $\frac{T_1}{T_2}$.

0 1 . 1 What is the maximum duty cycle of the stroboscope?

Tick (✓) **one** box.

[1 mark]

6.0×10^{-5} ☐

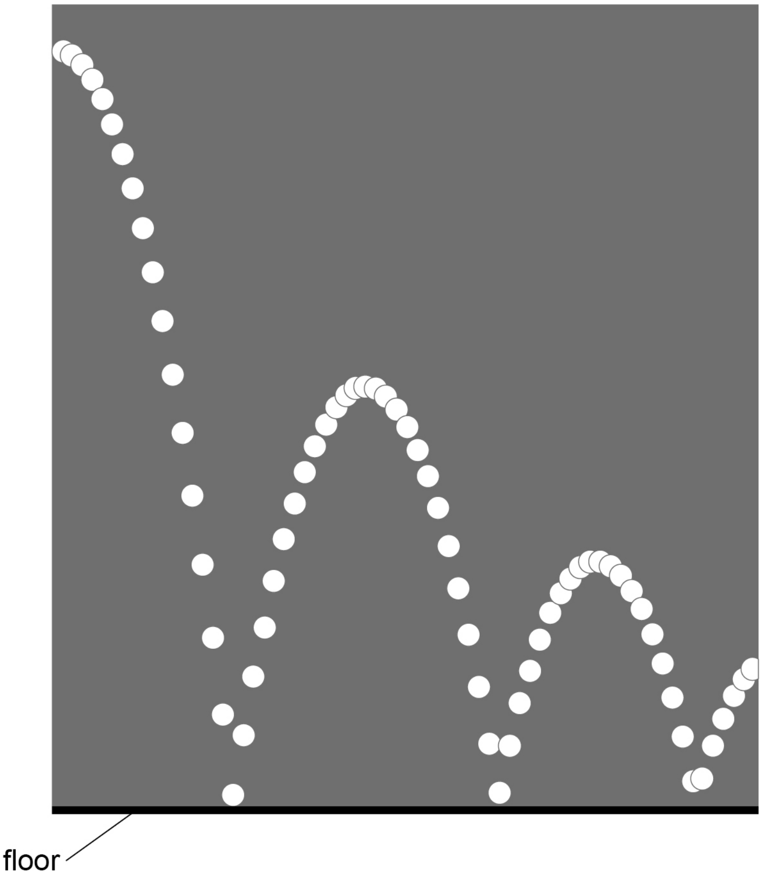
3.0×10^{-4} ☐

9.0×10^{-3} ☐

4.5×10^{-2} ☐

0 1 . 2 **Figure 1** shows images produced in an experiment in which a bouncing ball is illuminated by a stroboscope.
The stroboscope flashes at a constant frequency.

Figure 1



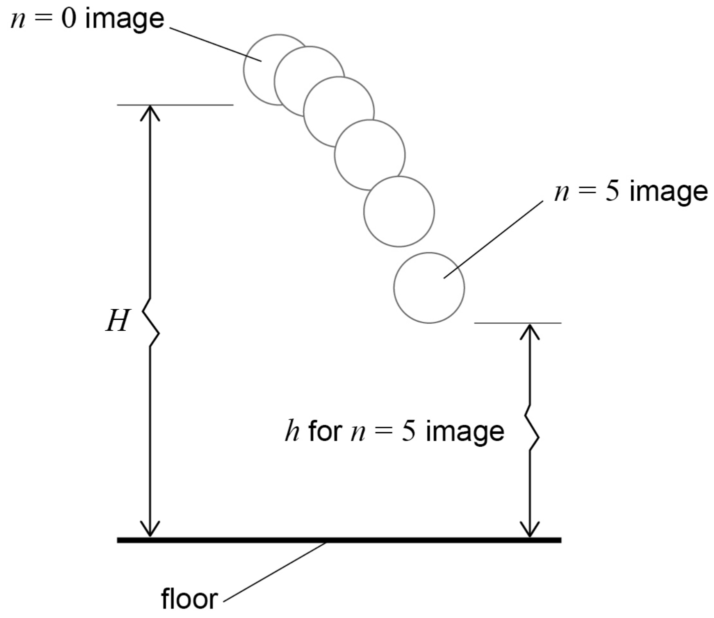
Suggest why T_1 must be very short for this experiment.

[1 mark]

Question 1 continues on the next page

Figure 2 shows the first six images starting with $n = 0$, where n is the image number.

Figure 2



The images are used to determine:

H, the vertical distance from the bottom of the ball to the floor when $n = 0$

h, the vertical distance from the bottom of the ball to the floor for each non-zero value of n.

The $n = N$ image is produced at the instant that the ball hits the floor for the first time. For n between 0 and N it can be shown that

$$H - h = \frac{u_0 n}{f} + \frac{g}{2}\left(\frac{n}{f}\right)^2$$

where

u_0 is the vertical velocity of the ball when $n = 0$

g is the acceleration due to gravity

f is the frequency of the flashes.

0 1 . 3 In order to find g, a graph is plotted with values of $\frac{H-h}{n}$ on the y-axis.

Suggest what is plotted on the x-axis.
Go on to explain how g is determined from this graph.

[3 marks]

The following data are recorded.

$H = 1550$ mm
$f = 31.0$ Hz

The graphical analysis of data from **Figure 1** gives g as 9.79 m s^{-2}.

0 1 . 4 Determine u_0.

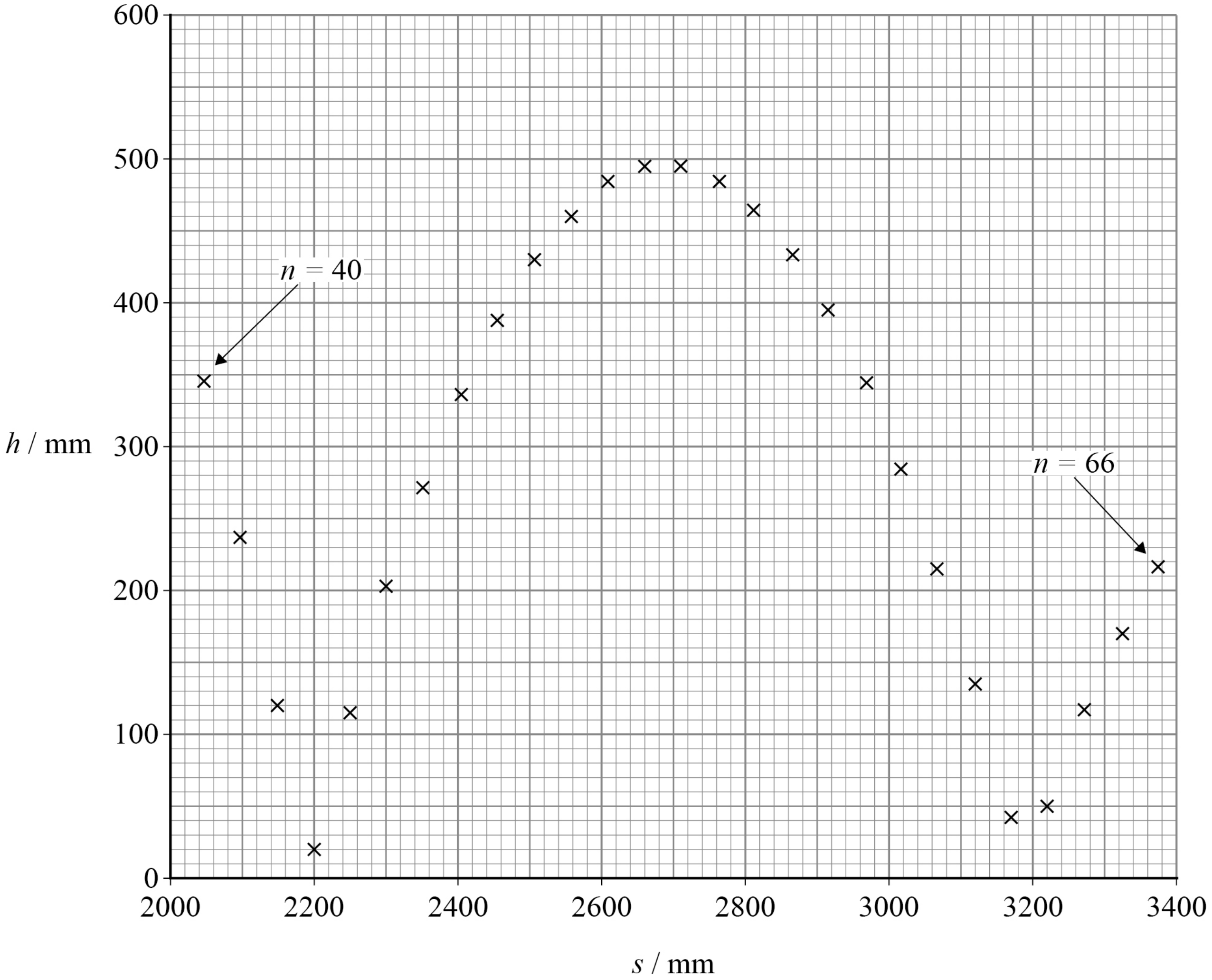
[3 marks]

$u_0 =$ ______________ m s^{-1}

Question 1 continues on the next page

Figure 3 shows positions of the bottom of the ball for $n = 40$ to $n = 66$
In this range of positions, the ball makes contact with the floor for the second and third times.
Values of h, the vertical distance from the bottom of the ball to the floor, are plotted on the y-axis.
Values of s, the horizontal displacement from a point on the floor below the centre of the $n = 0$ image, are plotted on the x-axis.

Figure 3



0 1 . 5 Determine, in mm s^{-1}, the horizontal velocity of the ball between the second and third contacts of the ball with the floor.

[2 marks]

horizontal velocity = ____________________ mm s^{-1}

0 1 . 6 Determine the time between the second and third contacts.
Annotate **Figure 3** to show your method.

[3 marks]

time = ____________________ s

13

Question	Answers	Additional comments/Guidelines	Mark	AO
01.1	4.5×10^{-2} ✓	CAO	1	AO2-1h

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	(short T_1) so images are not blurred (or wtte) OR to determine position of the ball (in each image or wtte) ✓	must refer to quality / property of images, eg 'images are sharp' / 'focused' / ‘clear’ / ‘defined’; allow ‘(images of) ball are circular’ / ‘spherical’ / ‘not elongated’ or wtte: accept sketch ‘increasing distance between images’ / ‘image is accurate’ are neutral allow ‘to see (point) where ball is’ / idea that (centre of) ball needs to be a ‘single point’ / ‘ball does not move during each flash (T_1)’ comments about the motion / trajectory of ball eg ‘see a clear pattern’ are neutral comments about the duty cycle / flash rate are neutral	1	AO2-1c

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr>
<td>01.3</td>
<td>correct rearrangement to a three-term equation;
$\frac{H-h}{n}$ as the subject eg $\frac{H-h}{n}=\frac{u_0}{f}+\frac{gn}{2f^2}$ $_{1}$✓

valid suggestion for quantity plotted on x-axis;
allow use of $y = mx + c$ aligned with $\frac{H-h}{n}=\frac{u_0}{f}+\frac{gn}{2f^2}$
suitably annotated to identify x $_{2}$✓

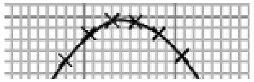
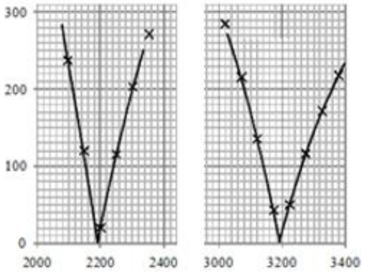
explains how g found using the gradient for their x-axis;
insist on g as subject whether explanation is in words or expressed as an equation $_{3}$✓</td>
<td>for $_{1}$✓ condone $\frac{H-h}{n}=\frac{u_0}{f}+\frac{g}{2n}\left(\frac{n}{f}\right)^2$
$_{3}$✓ is contingent on $_{2}$✓;
for a correct equation or if no equation is seen mark $_{2}$✓ and $_{3}$✓ as below:
<table>
<tr><th>for $_{2}$✓</th><th>for $_{3}$✓</th></tr>
<tr><td>n</td><td>g = gradient × $2f^2$</td></tr>
<tr><td>$\frac{n}{2}$</td><td>g = gradient × f^2</td></tr>
<tr><td>$\frac{n}{f}$</td><td>g = gradient × $2f$</td></tr>
<tr><td>$\frac{n}{2f}$</td><td>g = gradient × f</td></tr>
<tr><td>$\frac{n}{f^2}$</td><td>g = gradient × 2</td></tr>
<tr><td>$\frac{n}{2f^2}$</td><td>g = gradient</td></tr>
</table>
for an incorrect equation with n in the ‘mx’ term allow ECF for $_{2}$✓ and $_{3}$✓</td>
<td>1

2</td>
<td>AO1-1b

AO2-1g</td>
</tr>
</table>

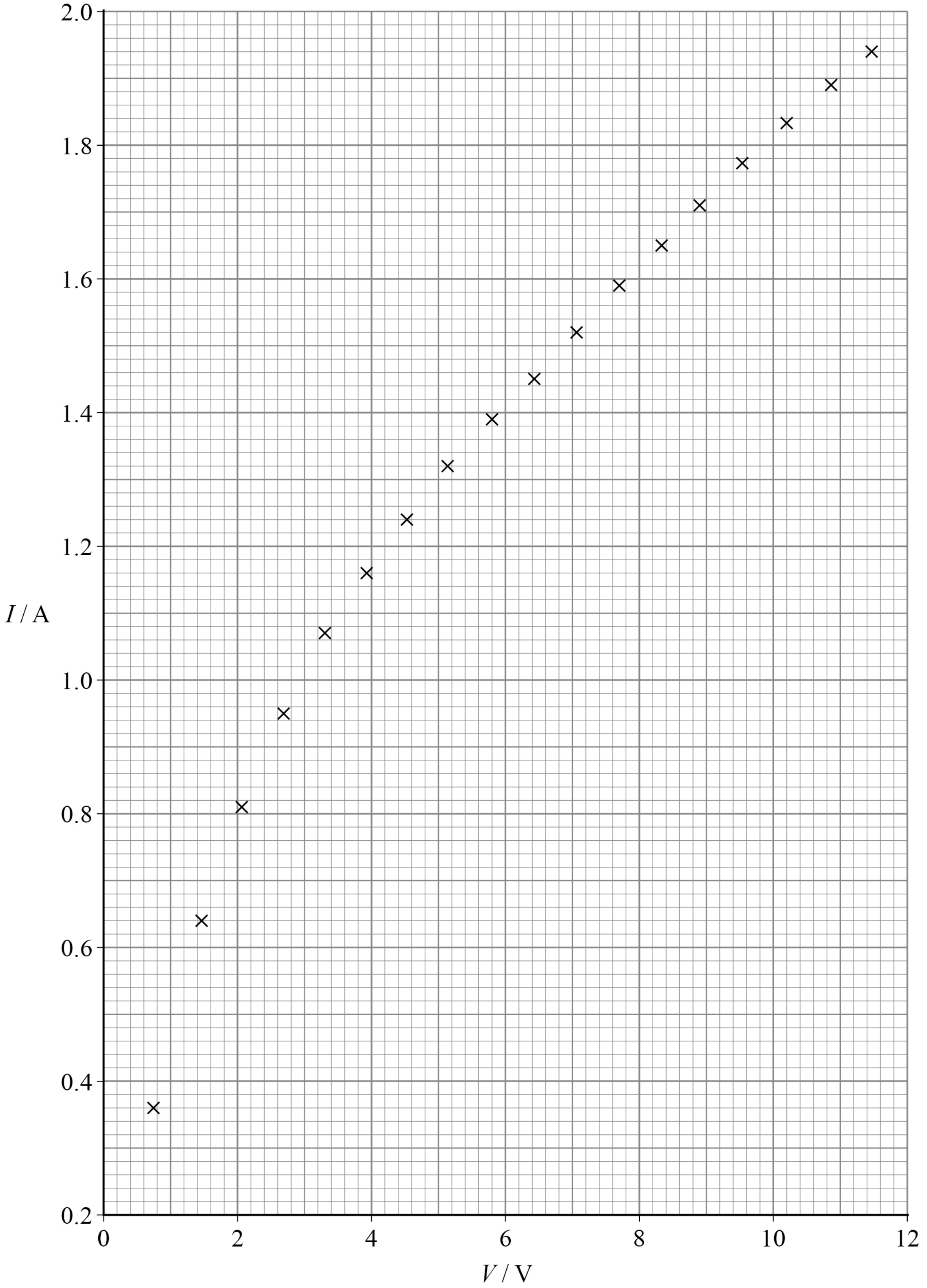
<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr>
<td>01.4</td>
<td>$n = 17 \pm 1$ ${}_1$✓
use of $H = \frac{u_0 n}{f} + \frac{g}{2}\left(\frac{n}{f}\right)^2$
OR
use of $H = u_0 t + \frac{1}{2}gt^2$ (eg with t from $\frac{n}{31}$) ${}_2$✓
u_0 correctly evaluated to (minimum) 2 sf ${}_3$✓
valid alternative method:
use of Figure 1 to determine non-zero h for integer $n > 0$
for ${}_1$✓ a valid h for their integer n (≤ 16)
eg when $n = 5$, $h = \frac{89\,(\text{mm})}{99\,(\text{mm})} \times 1550\,(\text{mm}) = 1393\,(\text{mm})$
for ${}_2$✓ full sub including a valid h for their n
for ${}_3$✓ u_0 correct for their n and h
eg for $n = 5$ and $h = 1393$, $u_0 = 0.18(4)\ (\text{m s}^{-1})$ ${}_3$✓</td>
<td>${}_1$✓ expect integer $n = 17 \pm 1$ but see valid unusual approach below left
for ${}_2$✓ either approach ‘use of’ means full substitution without error (with $h = 0$ shown or implied by omission) so that u_0 is the only unknown;
condone $g = \pm 9.79$ OR $\pm 9.8(1)$;
condone POT error / mixed units for H and g
for ${}_3$✓ see table for u_0 with n = 16 OR 18 AND/OR for the (intermediate) rounding of t;
accept > 3 sf that rounds to values in table:
<table>
<tr><td></td><td>subs n, f</td><td colspan="2">truncates t</td></tr>
<tr><td>expected</td><td>$t = 17/31$</td><td>3 sf</td><td>2 sf</td></tr>
<tr><td>t / s</td><td>(0.548387)</td><td>0.548</td><td>0.55</td></tr>
<tr><td>u_0 / m s^{-1}</td><td>0.14</td><td>0.15</td><td>0.13</td></tr>
</table>
<table>
<tr><td>ECF</td><td>$t = 16/31$</td><td>3 sf</td><td>2 sf</td></tr>
<tr><td>t / s</td><td>(0.516129)</td><td>0.516</td><td>0.52</td></tr>
<tr><td>u_0 / m s^{-1}</td><td>0.48</td><td>0.48</td><td>0.44</td></tr>
</table>
<table>
<tr><td>ECF</td><td>$t = 18/31$</td><td>3 sf</td><td>2 sf</td></tr>
<tr><td>t / s</td><td>(0.580645)</td><td>0.581</td><td>0.58</td></tr>
<tr><td>u_0 / m s^{-1}</td><td>–0.17</td><td>–0.18</td><td>–0.17</td></tr>
</table>
</td>
<td>1
1
1</td>
<td>AO1-1b
AO2-1h
AO3-1b</td>
</tr>
</table>

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	calculates the horizontal velocity; divides a valid horizontal displacement $s_2 - s_1$ by a time $_1$✓	for $_1$✓ $s_2 - s_1$ in range 490 to 1000 (mm); expect time to be found from counting intervals between flashes but allow use of **their 01.6** result; condone use of distance between contacts with time of $\frac{19}{31}$ and $\frac{20}{31}$;	2	AO2-1h
	horizontal velocity in range 1550 and 1650 (mm s^{-1}) $_2$✓	$_2$✓ is not contingent on $_1$✓ allow 2 sf 1.6×10^3 (mm s^{-1})		

Question	Answers	Additional comments/Guidelines	Mark	AO
01.6	determines $h_{\max}$ (at top of bounce) using an annotation to **Figure 3** $_1$✓ eg  valid attempt to find time t between contacts by using *suvat* with $u = 0$, eg $\text{time} = (2\times)\sqrt{\dfrac{2\times \text{their } h_{\max}}{9.81 \text{ OR } 9.79}}$ $_2$✓ OR determines s for both contacts OR determines $s_2 - s_1$ using annotations to **Figure 3** $_1$✓ eg  valid attempt to find t by $= \dfrac{\text{their } s_2 - s_1}{\text{their horizontal velocity in 01.5}}$ $_2$✓ time in range $0.61(0)$ to $0.65(0)$ (s) $_3$✓	for $_1$✓ annotation should be a smooth curve through (at least) top 4 points, $n = 51$ to 54; don't insist on seeing a horizontal line to the h axis for $_2$✓ accept mixed units / POT in substitution / time to maximum height calculated / valid working in **01.5** OR for $_1$✓ annotation should be at least one smooth (allow straight) line to define each contact; eg (at least) through $n = 41/42$ OR $43/44$ to $h = 0$ AND through $n = 61/62$ OR $63/64$ to $h = 0$ for $_1$✓or $_2$✓ accept valid working in **01.5**; accept use of horizontal distance = 1000 (mm) for $_2$✓do not condone use of integer number of intervals, eg $t = \dfrac{19}{31} = 0.61(3)$ OR $t = \dfrac{20}{31} = 0.645$ $_3$✓ is contingent on $_2$✓; exception: award $_3$✓ for t in range if obtained by estimating a **non-**integer number of intervals, eg $t = \dfrac{19.5}{31}$	3	AO2-1h
Total			**13**	

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

Figure 4



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

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

[2 marks]

rate of increase of V = ______________________ $\mathrm{V\ s^{-1}}$

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

[2 marks]

1 ____

____

____

2 ____

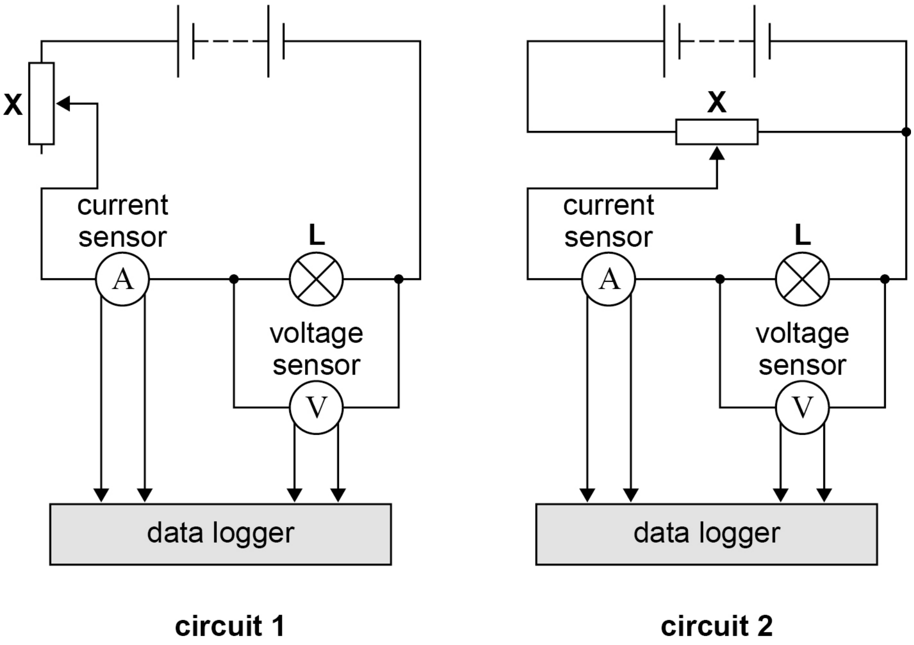
____

____

Question 2 continues on the next page

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

Figure 5



circuit 1 **circuit 2**

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

In circuit **1**:

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

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

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

[4 marks]

Question 2 continues on the next page

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

Table 2

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

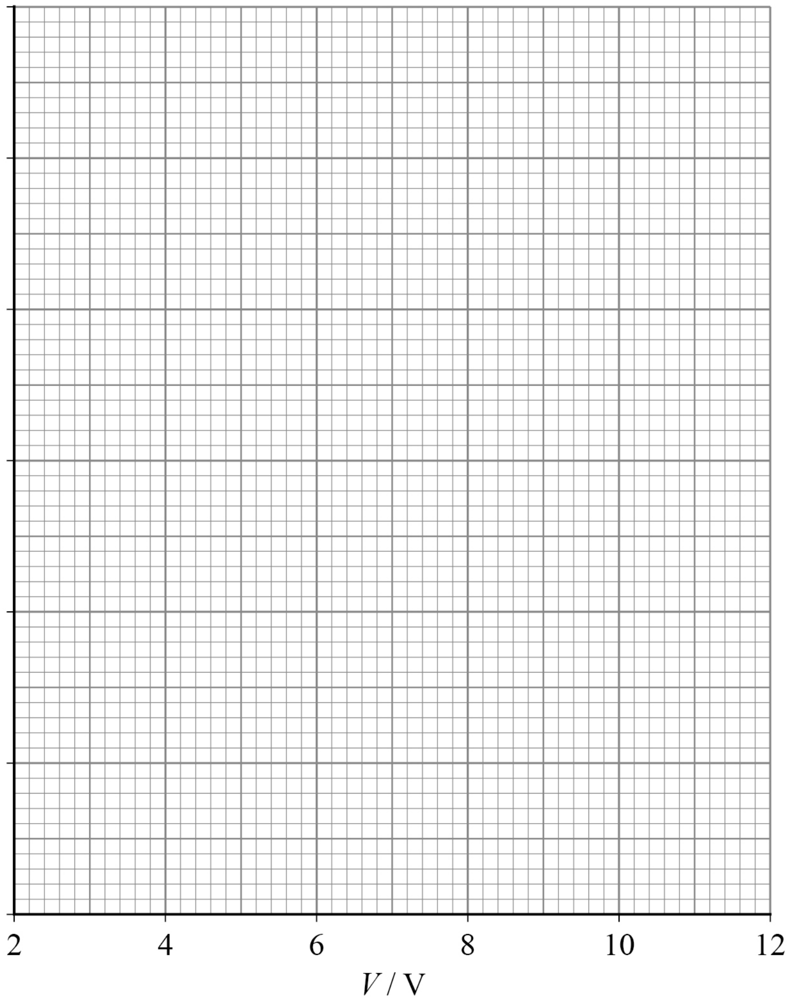
0 2 . 4 Complete **Table 2**.

[3 marks]

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

[3 marks]

Figure 6



Question 2 continues on the next page

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

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

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

[2 marks]

percentage = ____________________ %

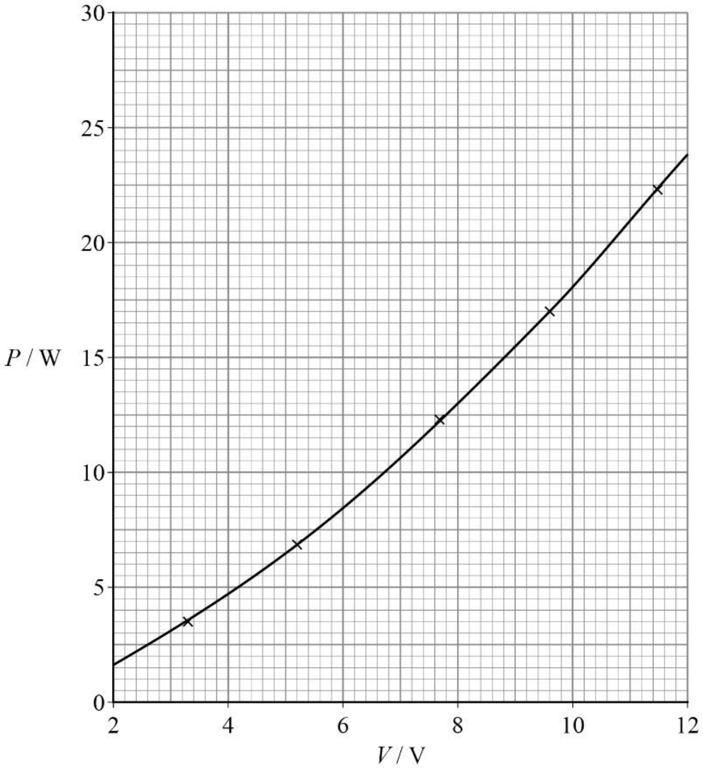
16

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

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

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

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr>
<td>02.4</td>
<td>P = 6.82 in row 2 $_{1}$✓
I = 1.77 in row 4 $_{2}$✓
P = 17.0 in row 4 $_{3}$✓</td>
<td>
<table>
<tr><th></th><th>V / V</th><th>I / A</th><th>P / W</th></tr>
<tr><td></td><td>3.30</td><td>1.07</td><td>3.53</td></tr>
<tr><td>$_{1}$✓</td><td>5.17</td><td>1.32</td><td>6.82</td></tr>
<tr><td></td><td>7.69</td><td>1.59</td><td>12.2</td></tr>
<tr><td>$_{2}$✓$_{3}$✓</td><td>9.58</td><td>1.77</td><td>17.0</td></tr>
<tr><td></td><td>11.47</td><td>1.94</td><td>22.3</td></tr>
</table>
for $_{1}$✓ CAO
for $_{2}$✓ allow 1.77 ± 0.01
for $_{3}$✓ ECF for their (incorrect) $I \times 9.58$;
deduct MAX 1 mark if any are not to 3 sf
</td>
<td>3</td>
<td>AO2-1h</td>
</tr>
</table>

Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	vertical axis labelled P / W $_1$✓ suitable vertical scale for their data $_2$✓	for $_1$✓allow P (W), P in W; reject comma separator, eg P, W; allow words, eg power for P / watt(s) for W for $_2$✓ expect 1 cm interval = 2 W OR 2 cm intervals = 5 W vertical scale must • be linear • be marked in integer values • be marked with a frequency of not less than 4 cm intervals • cover the range of plotted points assume $P = 0$ at unmarked origin	2	AO1-1b
	5 points plotted AND smooth curve of increasing gradient $_3$✓  	for $_3$✓ check the plotting of any obviously suspect point; points must **not** be thick / faint / dots / blobs; line must • be a continuous **curve** • be neither thick or faint • (at least) extend from the first to the fifth point • be a reasonable best-fit for their data; withhold mark if line deviates by ≥ 2 minor squares from examiner's best line (by eye) if I / A is plotted award $_2$✓ if the effective range of vertical scale is ≥ half height of grid	1	AO2-1h

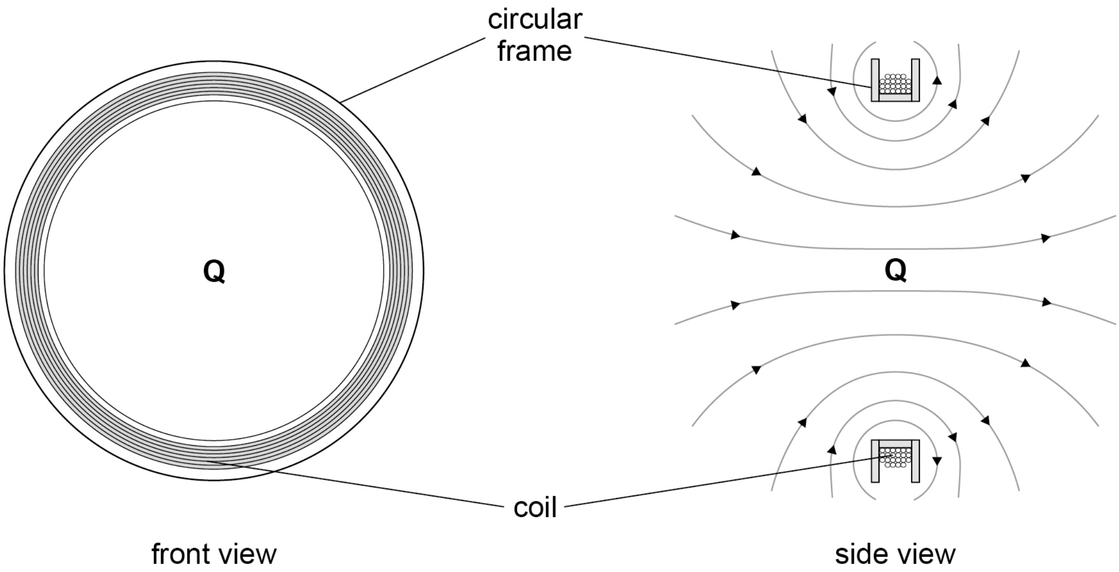
Question	Answers	Additional comments/Guidelines	Mark	AO
02.6	evidence that P_r read-off to ± 1 minor grid square $_1$✓ reads off P_2 corresponding to 6 V; evaluates $\frac{2 \times \text{their } P_2}{\text{their } P_r} \times 100$ $_2$✓	for $_1$✓ best-fit line must be extrapolated to V = 12 V (at the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

Total			**16**

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.

Figure 7a **Figure 7b**



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}.

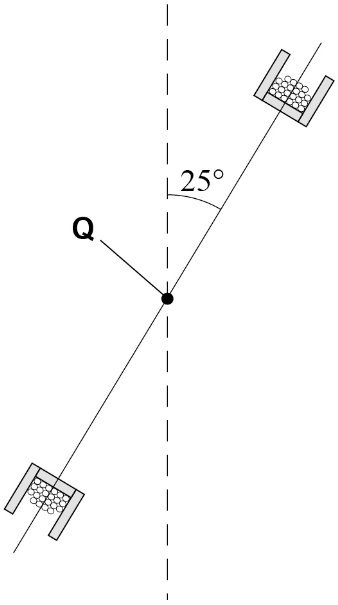
[2 marks]

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.

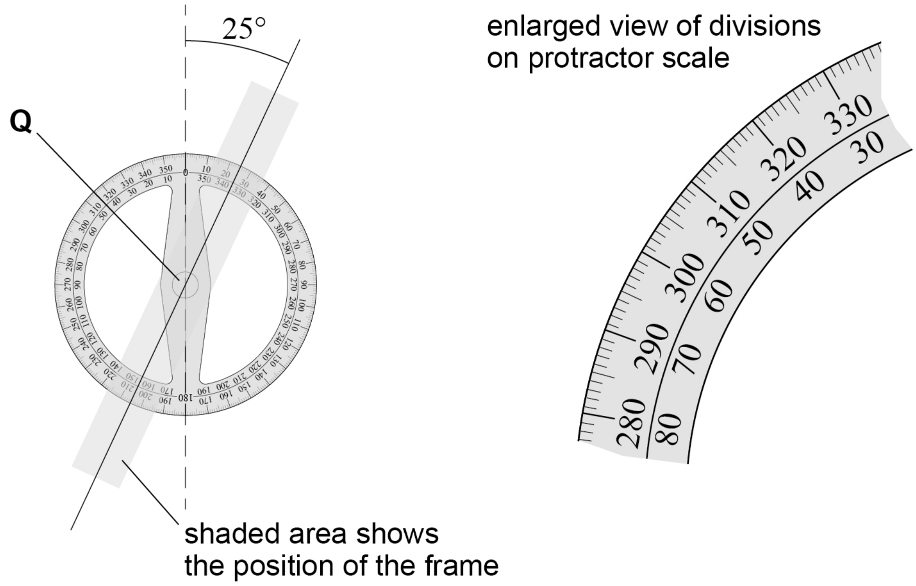
0 3 . 2 Determine the percentage change in B_H produced by this rotation of the coil.
Show your working.

[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.

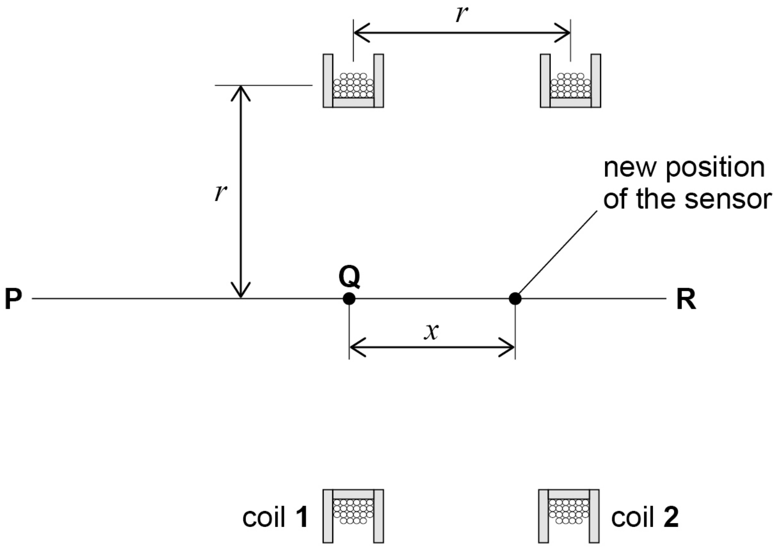
[3 marks]

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**.

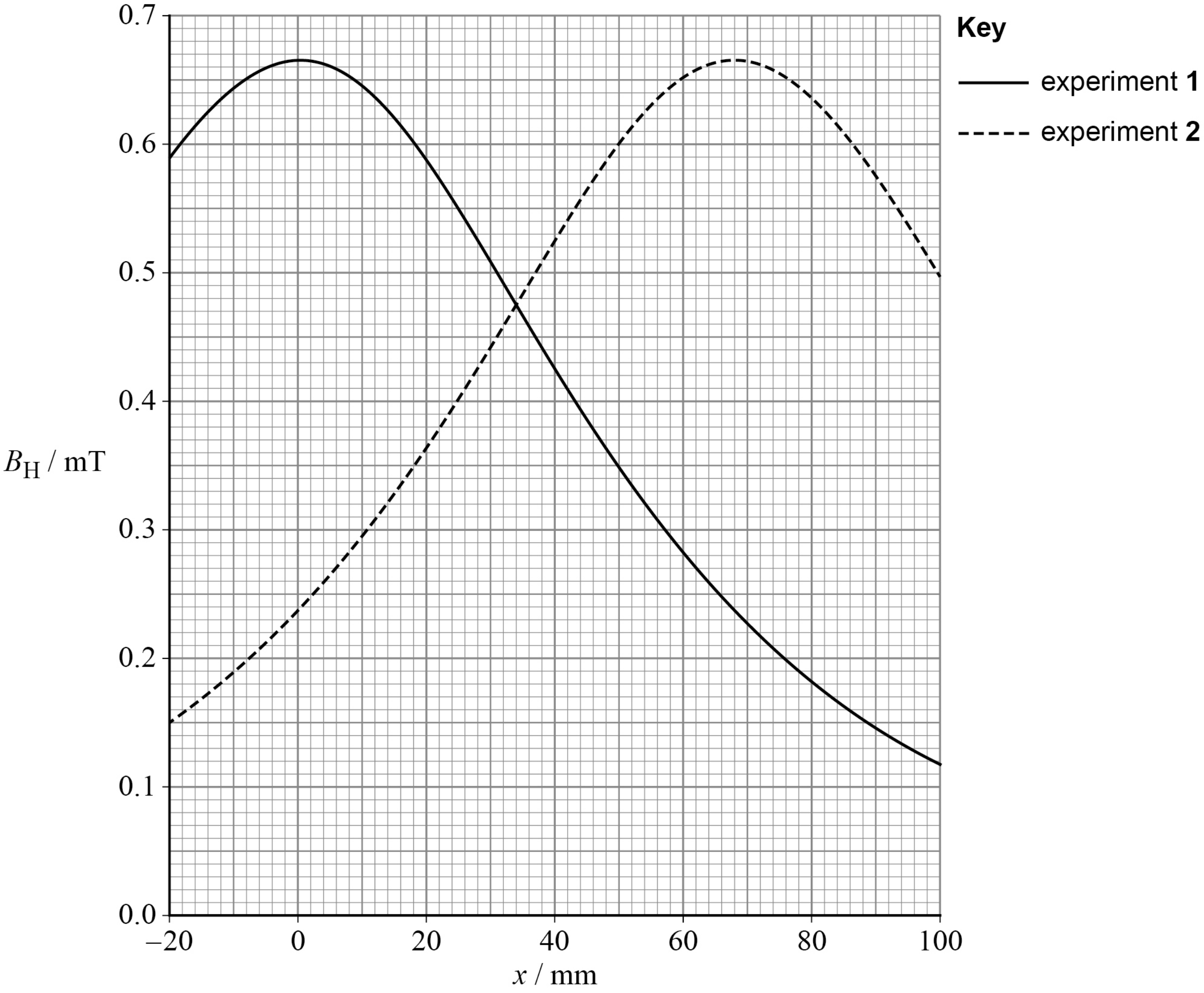
The four different experiments investigate how B_{H} varies with x, the displacement of the sensor from **Q** along **PR**.

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]

$\frac{x_{0.5}}{r}$ = ______________________________

In experiment **3**, the current in both coils is $225\ \mathrm{mA}$ 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]

$B_\mathrm{H} =$ ______________________ mT

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

[2 marks]

1 ____

____

____

2 ____

____

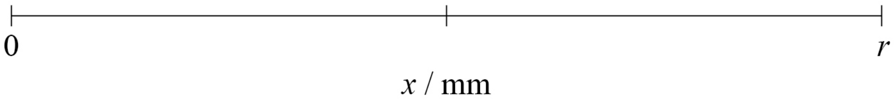
____

0 3 . 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

16

Question	Answers	Additional comments/Guidelines	Mark	AO
03.1	search coil is not suitable or wtte: no emf (would be induced in a search coil) $_{1}$✓	$_{1}$✓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	1	AO1-1a
	a search coil needs (to be cut by) changing flux OR search coil is not cut by changing flux OR flux (cutting coil) is constant or wtte $_{2}$✓	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	AO3-1b
	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 flux through search coil OR if search coil is cut by changing flux or wtte $_{2}$✓	alternative approach: $_{1}$✓and $_{2}$✓ can be earned independently but are contingent on a statement that the search coil is suitable		

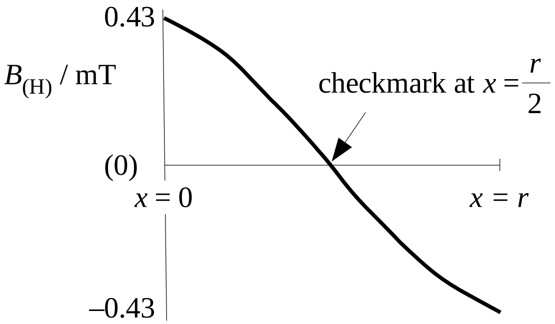
Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	use of 1 – cos 25(°) or 1 – sin 65(°) in a calculation of percentage change $_1$✓ (–) 9.4 (%) CAO $_2$✓	for $_1$✓ expect either ≥ 3 sf rounding to 1 – 0.906 OR 1 – 0.91 seen in working OR 100 – 90.6 or 100 – 91 seen in working; for $_2$✓ expect 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 $_2$✓ for unsupported answer of (–) 9.4; if no other mark is awarded allow $_{12}$✓ use of 1 – sin 25(°) or 1 – cos 65(°) 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 ½° $_1$✓ (measurement of) θ is based on (difference between) two readings / judgements OR absolute uncertainty in θ (or $\Delta\theta$) = 2 × uncertainty in each reading / judgement $_2$✓ correct percentage uncertainty calculation based on 100 × their absolute uncertainty divided by 25 $_3$✓	for $_1$✓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 for $_2$✓accept 2×0.5 OR 2 × their uncertainty in (a single) reading seen in numerator OR evidence for use of 2 × their uncertainty in result of % calculation; 'measured twice' is ambiguous for $_3$✓ allow 1 sf result; $\frac{2\times0.5}{25}\times100=4\%$ (use of 0.5°) earns $_1$✓$_2$✓$_3$✓ $\frac{0.5}{25}\times100=2\%$ (missing 2×) earns $_1$✓$_2$✗$_3$✓ $\frac{2\times1}{25}\times100=8\%$ (1° unexplained) earns $_1$✗$_2$✓$_3$✓ $\frac{1}{25}\times100=4\%$ (1° unexplained) earns $_1$✗$_2$✗$_3$✓ $_{123}$✓✓✓ for two-judgement explanation leading to 1° used in a correct % uncertainty calculation	1 2	AO1-1a 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 $x = \frac{r}{2}$ $_{1}$✓ vertical axis drawn, labelled with symbol B; negative gradient, line continuous between x = 0 and x = r; 2-quadrant graph $_{2}$✓ vertical axis drawn with symbol and unit eg $B_{(H)}$ / mT; continuous line between x = 0 and x = r; $B_{(H)}$ = 0.43 ± 0.01 at x = 0 OR $B_{(H)}$ = –0.43 ± 0.01 at x = r $_{3}$✓ 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) $_{4}$✓	for $_{1}$✓ use checkmark on axis for guidance; for $_{2}$✓ allow 'magnetic flux density' in words; condone any flat section ≤ r/4 (judge by eye); allow (always) positive gradient for $_{1}$✓ and $_{2}$✓ allow a straight line; single quadrant can score $_{1}$✓ or $_{3}$✓ for $_{3}$✓apply usual symbol-separator-unit convention / allow $B_{(H)} = 4.3 \times 10^{-4}$ etc; adjust criteria for positive gradient graph for $_{4}$✓ 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**	

Section A

Answer **all** questions in this section.

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

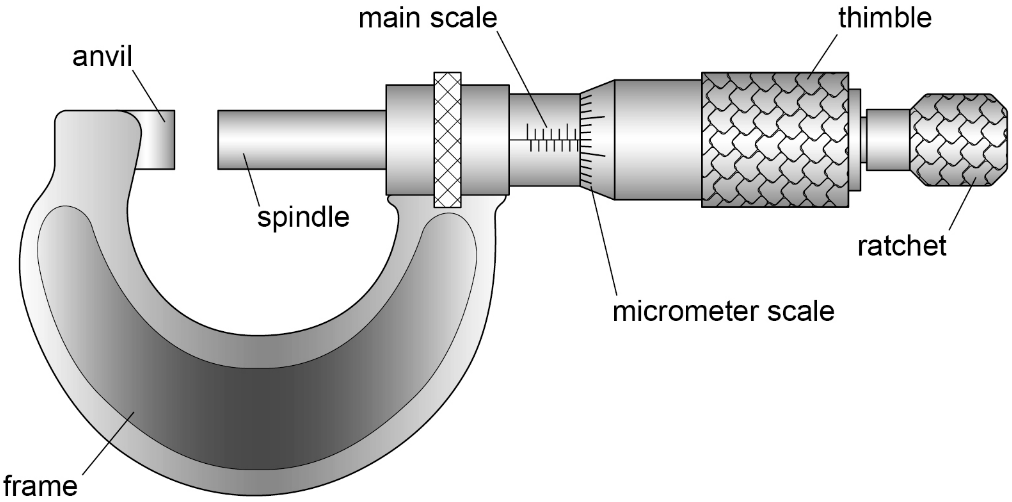
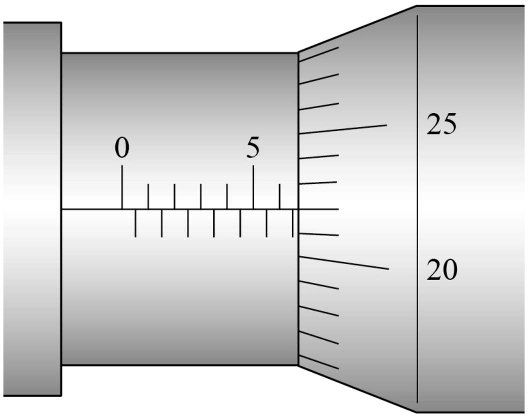


Figure 2 shows an enlarged view of the scales.

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]

____

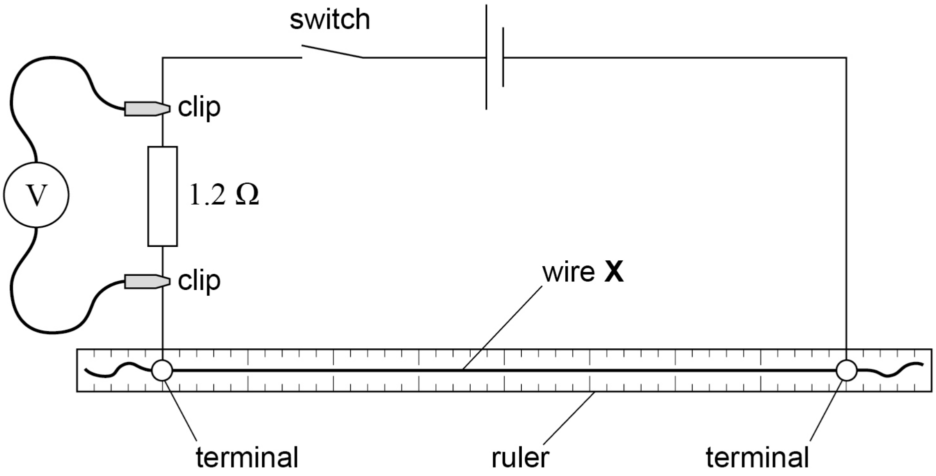
____

____

Question 1 continues on the next page

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

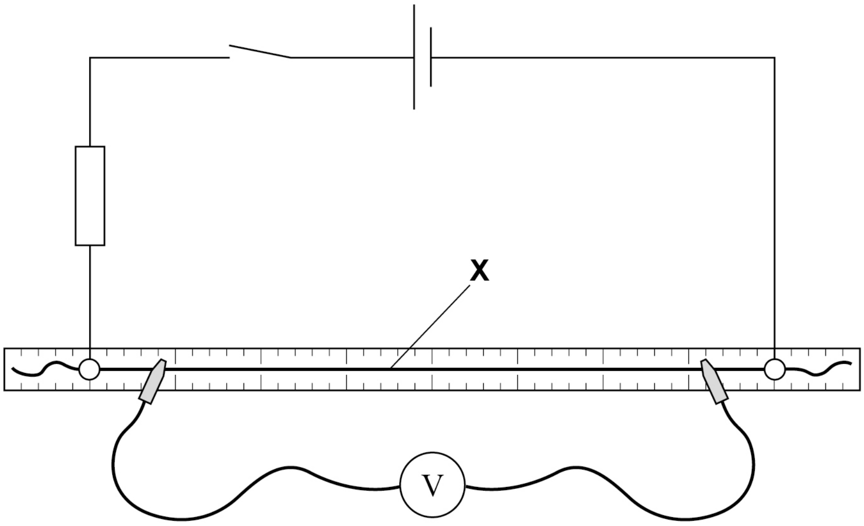
Figure 3



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 $931\ \mathrm{mV}$.

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 $397\ \mathrm{mV}$.

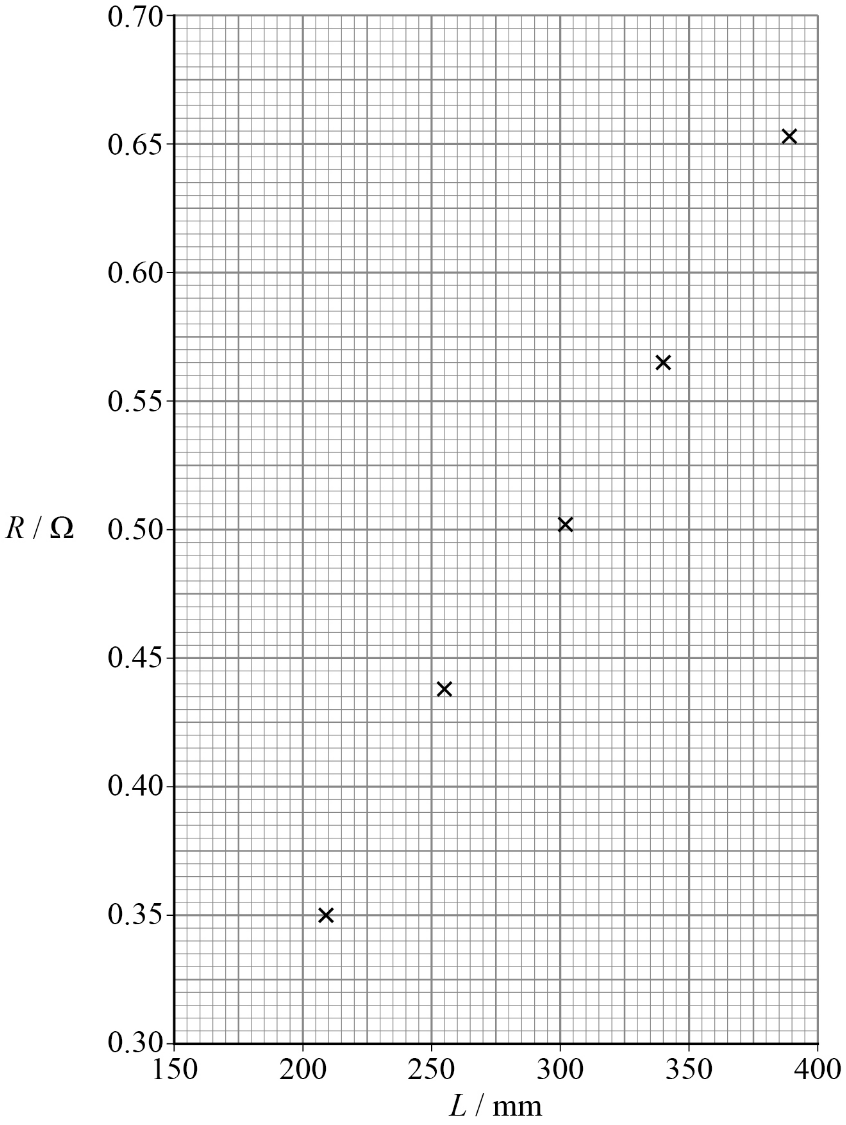
Show that, for the arrangement in **Figure 4**, the resistance R of the wire between the clips is about $0.5\ \Omega$.

[2 marks]

Question 1 continues on the next page

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

Figure 5



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

[2 marks]

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

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

Table 1

	Resistance per metre of wire / Ω 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 $5\ \text{mm}$.

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

[2 marks]

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

[2 marks]

15

Turn over for the next question

Question	Answers	Additional comments/Guidelines	Mark	AO
01.1	(±) 0.5(0) mm CAO ✓		1	AO2

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

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

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	use of $I = \frac{(0.)931}{1.2}$ OR $R = \frac{(0.)397}{\text{their } I}$ ₁✓ $R = 0.51$ (Ω) 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 ruled best-fit line drawn $_1$✓ gradient evaluated from ΔR divided by ΔL; with correct $\Delta R \geq 0.2$ (Ω) OR correct $\Delta L \geq 150$ (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 $1.66\ (\Omega\ \mathrm{m}^{-1})$ withhold both marks for no line on **Figure 5**	2	AO2

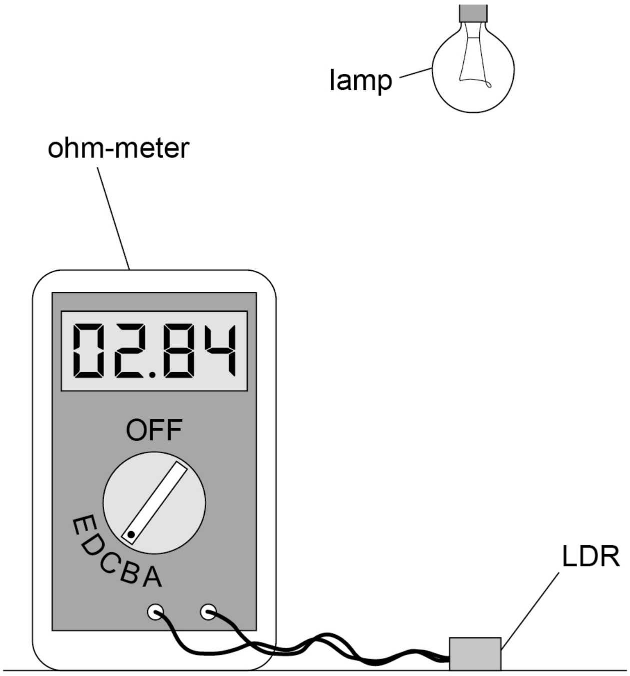
<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr><td rowspan="4">01.6</td><td>attempts to find ρ_X using $\frac{\pi d^2}{4} \times \frac{\Delta R}{\Delta L}$ $_1$✓</td><td>for $_1$✓ expect use of their $\frac{\Delta R}{\Delta L}$ OR the closest value in Table 1;
allow use of concordant $\frac{\Delta R}{\Delta L}$ and d values for the metal that is the valid choice for their $\frac{\Delta R}{\Delta L}$;
d must be correct for their $\frac{\Delta R}{\Delta L}$;
if value not seen in working, judge d from their ρ_X;
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</td><td rowspan="4">4</td><td rowspan="4">1 × AO3
3 × AO2</td></tr>
<tr><td>ρ_X in range below for their metal on the answer line $_2$✓
<table><tr><th>metal</th><th>resistivity / Ω m</th></tr><tr><td>copper</td><td>1.6 to 1.8 (× 10^{-8})</td></tr><tr><td>tungsten</td><td>5.4 to 5.9 (× 10^{-8})</td></tr><tr><td>alumel</td><td>3.3 to 3.8 (× 10^{-7})</td></tr><tr><td>nichrome</td><td>1.0 to 1.2 (× 10^{-6})</td></tr></table></td><td>for $_2$✓ ignore POT and use the most significant digits in their ρ_X to judge result, eg for alumel $\rho_X = 0.351$ scores $_2$✓$_3$✗ because this is equivalent to 3.51×10^{-1}
allow >2 sf values that round to 2 sf in range</td></tr>
<tr><td>POT correct and unit = Ω m for their metal on the answer line $_3$✓</td><td>for $_3$✓ allow alternative valid answer eg (for nichrome) 1.1×10^{-3} Ω mm</td></tr>
<tr><td>nichrome CAO $_4$✓</td><td>for $_4$✓ must be consistent with their 01.5 $\frac{\Delta R}{\Delta L}$</td></tr>
</table>

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

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

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

Figure 6



The ohm-meter

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

Table 2

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

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

[1 mark]

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

The resistance R of the LDR is given by

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

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

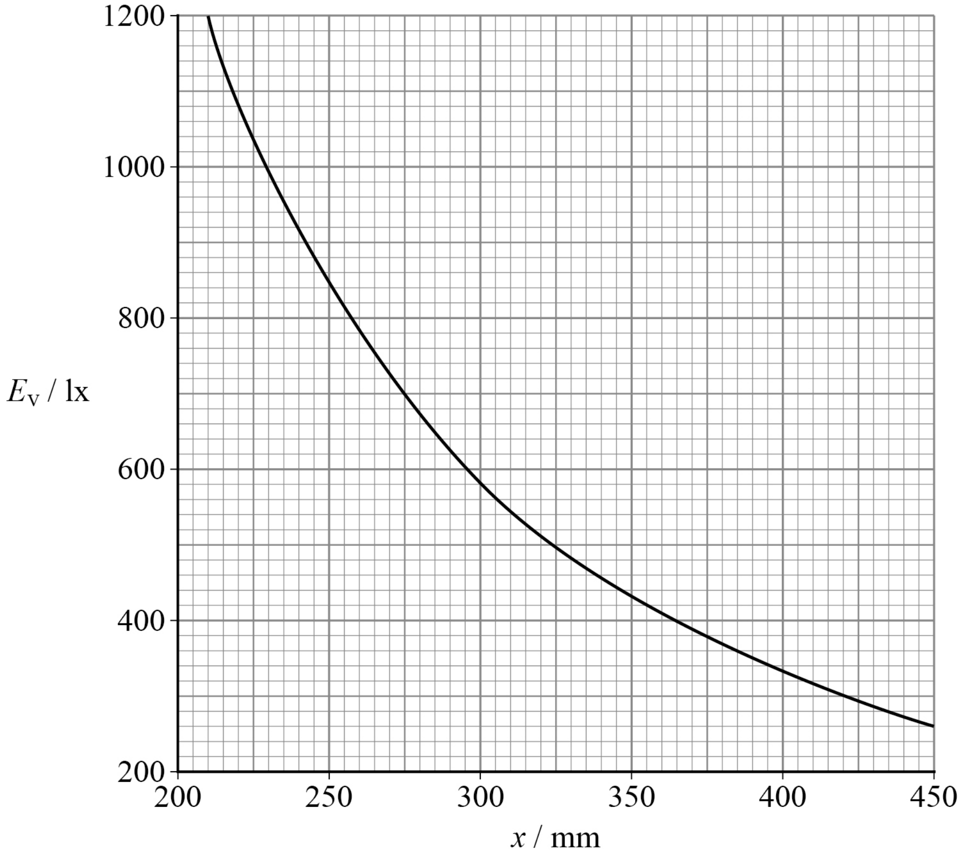
[2 marks]

Question 2 continues on the next page

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

Figure 7 shows how E_V varies with x.

Figure 7



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

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

[2 marks]

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

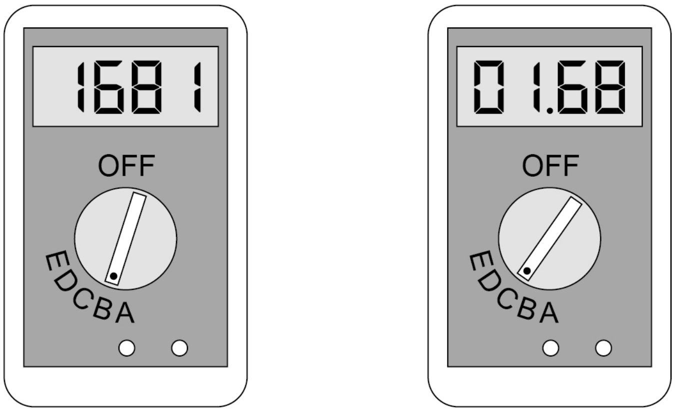
[2 marks]

$x =$ ______________________ mm

Question 2 continues on the next page

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

Figure 8



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

This means that:

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

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

[2 marks]

Table 3

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

____

____

____

____

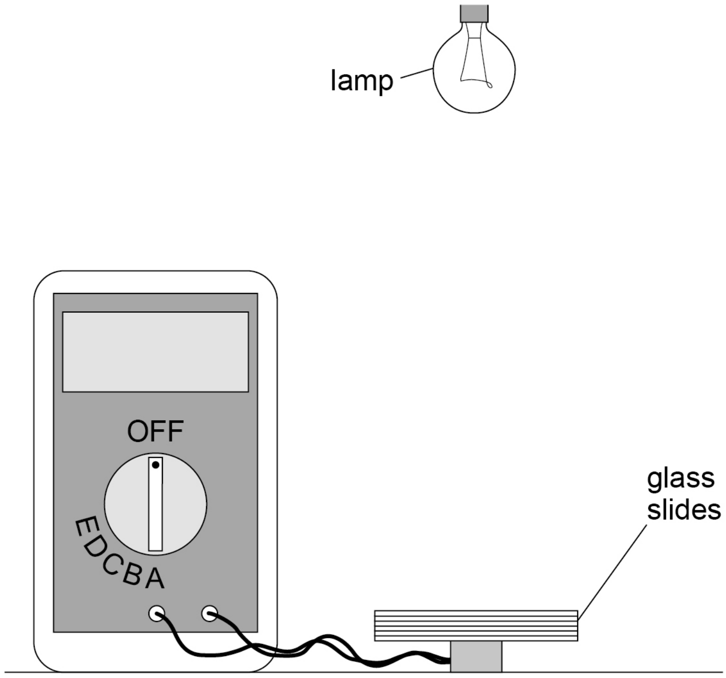
____

____

Question 2 continues on the next page

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

Figure 9



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

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

Identify **two** other control variables.

[2 marks]

1 ____

____

2 ____

____

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

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

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

Explain how μ can be determined from a linear graph.

[2 marks]

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

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

[2 marks]

number of slides = ____________________

15

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

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

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	reads off from at least **three** different points on the line / graph $_1$✓ 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

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr>
<td>02.5</td>
<td>1645 AND 1.73 correctly added to Table 3 $_{1}$✓

valid reasoned judgement to support use of range;
allow ECF for incorrect values in Table 3 $_{2}$✓</td>
<td>for $_{1}$✓ do not insist on units;
condone extra sf that round to these values
<table>
<tr><th>Setting</th><th>Min R</th><th>Max R</th></tr>
<tr><td>range B</td><td>1645 (Ω)</td><td>1717 Ω</td></tr>
<tr><td>range C</td><td>1.63 kΩ</td><td>1.73 (kΩ)</td></tr>
</table>
for $_{2}$✓ states that B should be used because
(half) range is smaller / (percentage) difference between max and min R is smaller
OR
any valid and correct quantitative comparison between both settings, eg
<table>
<tr><th></th><th>Range (/ Ω)</th><th>Uncert. (/ Ω)</th><th>% Diff.</th><th>% Uncert.</th></tr>
<tr><td>B</td><td>72</td><td>(±)36</td><td>≈ 4%</td><td>≈ 2%</td></tr>
<tr><td>C</td><td>100</td><td>(±)50</td><td>≈ 6%</td><td>≈ 3%</td></tr>
</table>
allow ‘resolution is smaller’ not ‘better’;
‘more precise’ / ‘more accurate’ / ‘(percentage) uncertainty is smaller’ are neutral</td>
<td>2</td>
<td>AO3</td>
</tr>
</table>

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

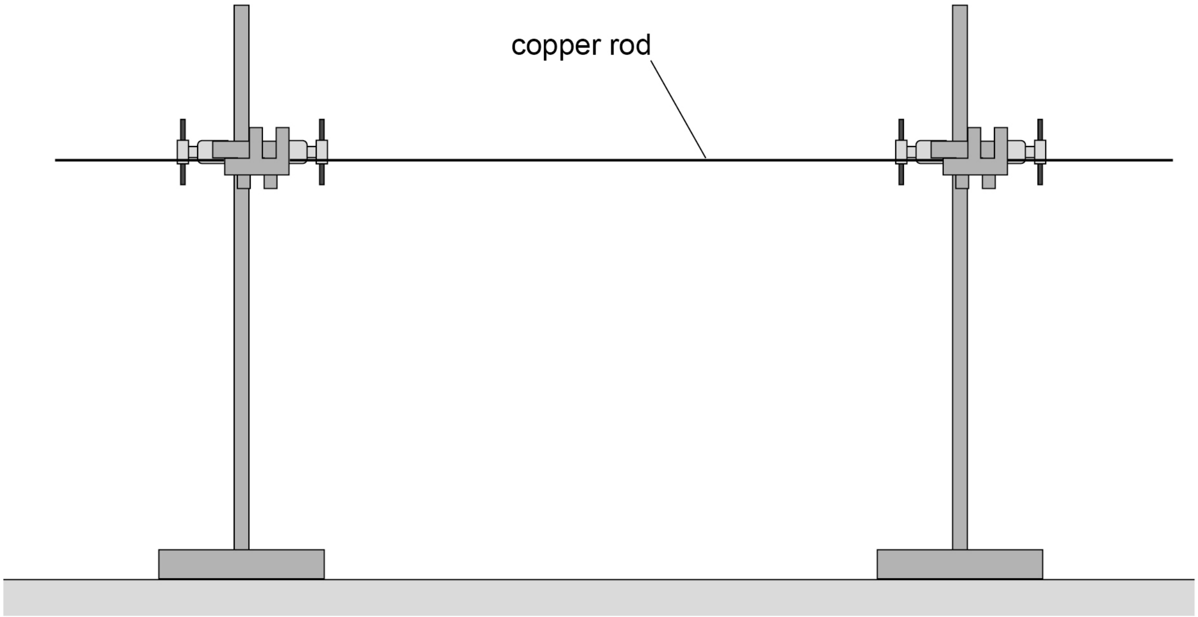
Question	Answers	Additional comments/Guidelines	Mark	AO
02.7	**plot** $\ln E_{\text{V}}$ against N OR plot **implied** by comparison between **correct algebra** $\ln E_{\text{V}} = -\mu N + \ln 400$ and $y = mx + c$ $_1$✓ μ is –gradient $_2$✓ **plot** $\ln E_{\text{V}}$ against N with incorrect algebra is talk out for $_1$✓ allow ECF if linking μ to **gradient** based on their incorrect algebra for $_2$✓	for $_1$✓ allow plot $\ln\left(\frac{E_{\text{V}}}{400}\right)$ against N; must clearly imply that N is the abscissa; allow aligned expressions eg $\begin{array}{ccccc} \ln E_{\text{V}} & = & \ln 400 \text{ OR } 5.99 & - & \mu N \\ y & (=) & c & (+) & mx \end{array}$ allow $_2$✓ for '$-\mu$ is gradient' / 'μ is absolute value of gradient' / 'μ is modulus of gradient value' where $\ln E_{\text{V}} = -\mu N + \ln 400$ 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** $\log E_{\text{V}}$ against N OR plot **implied** by $\log E_{\text{V}} = -\mu \log(e) N + \log 400$ 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 $N_{½} \approx 7.7$ OR a final integer answer that is appropriate to their calculated value $_1$✓ $N_{½}$ = 8 slides CAO $_2$✓	for $_1$✓ expect use of $\ln 0.5 = -9.0 \times 10^{-2}\, N_{½}$ or similar (including trial and improvement)	2	AO3
Total			**15**	

0 3 This question is about a method to investigate how the force on a conductor varies with flux density and current (required practical activity 10).

Figure 10 shows a copper rod clamped above a horizontal bench.

Figure 10



0 3 . 1 Describe a method to show that the copper rod is horizontal.
Your method must include the use of a metre ruler.
You may annotate **Figure 10**.

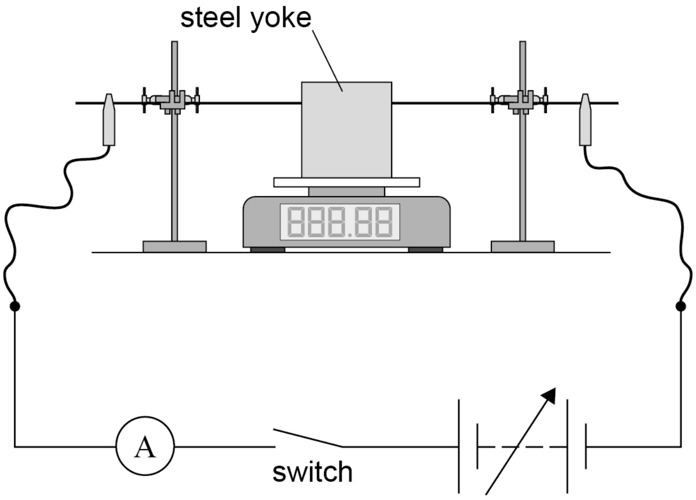
[3 marks]

Question 3 continues on the next page

Figure 11 shows the copper rod positioned above a digital balance.

Two identical magnets are mounted on a steel yoke with their opposite poles facing each other.
The balance is zeroed.
The yoke is then placed on the balance so that a horizontal uniform magnetic field is applied perpendicular to the copper rod.
The ends of the rod are connected as shown.

Figure 11



0 3 . 2 When the switch is open, the reading on the balance shows the mass of the yoke and the two magnets.
When the switch is closed, the reading on the balance decreases.

Explain, with reference to **Figure 11**, the direction of the horizontal magnetic field.

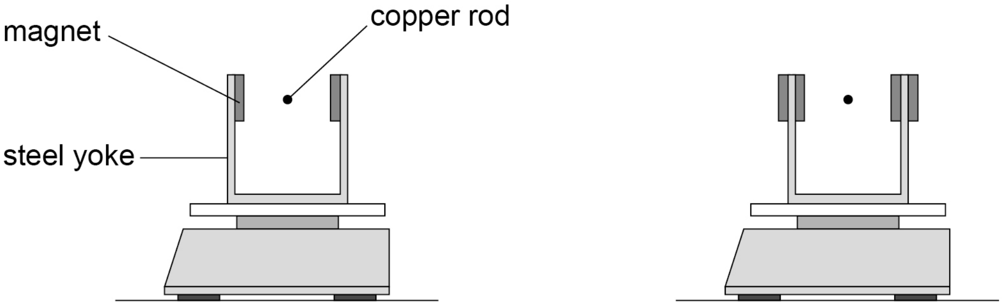
[3 marks]

The current I in the rod is varied.
The balance reading M_1 is recorded for different values of I.

The switch is now opened.
Two additional magnets, identical to those used before, are attached to the yoke.

Figure 12 shows how this new arrangement compares with the arrangement in **Figure 11**.

Figure 12



use of two magnets for the arrangement in **Figure 11**

new arrangement using four magnets

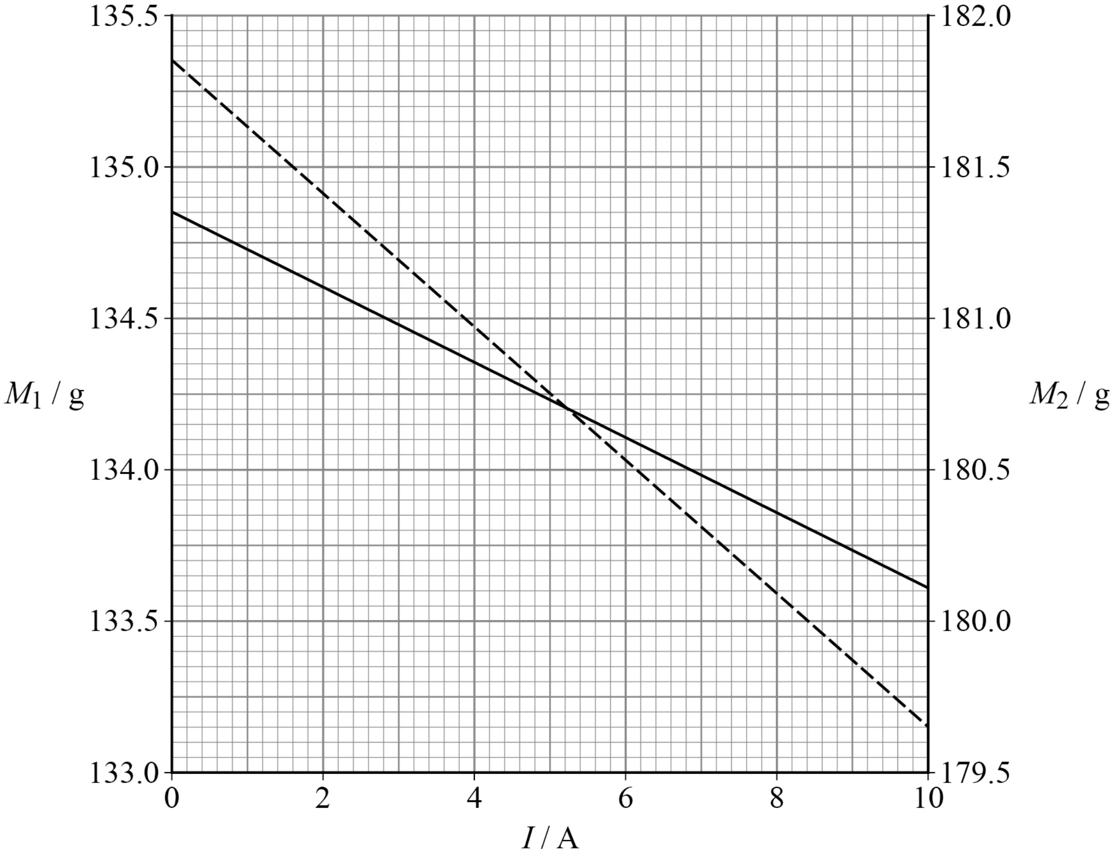
The balance reading with four magnets attached to the yoke is M_2.
With the switch open, M_2 is the mass of the yoke and the four magnets.

The switch is now closed.
M_2 is recorded for different values of I.

Question 3 continues on the next page

Figure 13 shows data from both experiments.
Values of M_1 and M_2 are plotted using different vertical axes.

Figure 13



The solid line ——— shows the variation of M_1 with I

The dashed line ----- shows the variation of M_2 with I

It can be shown that

$$M = kBI + nZ + Y$$

where

M = balance reading when the current is I
B = magnetic flux density of the horizontal uniform magnetic field
n = number of magnets attached to the yoke
Z = mass, in g, of each magnet
Y = mass, in g, of the yoke
k is a constant.

0 3 . 3 Deduce the fundamental base units for k.

[3 marks]

fundamental base units = ______________________

0 3 . 4 Determine Y.

[3 marks]

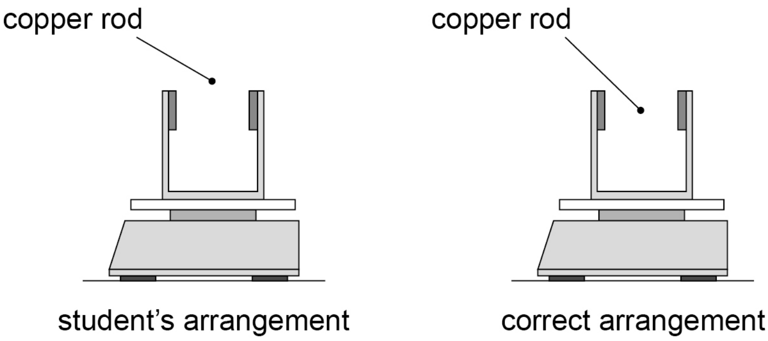
Y = ______________________ g

Question 3 continues on the next page

0 3 . 5 A student sets up the apparatus with the copper rod positioned incorrectly.

Figure 14 shows how the student's arrangement compares with the correct arrangement.

Figure 14



The student produces a graph of M_1 against I.

Compare the student's graph with the graph of M_1 against I (the solid line) in **Figure 13**.
Explain your answer.

[3 marks]

15

END OF QUESTIONS

Question	Answers	Additional comments/Guidelines	Mark	AO
03.1	(use of a ruler to) **measure** height **from bench to rod** at (minimum of two) different points $_1$✓ explains how the **ruler** is made vertical $_2$✓ checks heights are the same $_3$✓ (contingent on $_1$✓) OR use of a metre ruler placed on the rod with a spirit level placed on the ruler; check no gap between ruler and rod $_{12}$✓ check bubble is at centre $_3$✓ (contingent on $_{12}$✓) OR use of metre ruler placed with no gap on top of nested set-squares so the metre ruler can be compared with rod $_{12}$✓ lower set-square in contact with the bench (no gaps) $_3$✓ (contingent on $_{12}$✓)	for $_1$✓ points may be **anywhere** along rod; allow 'measure height of rod at each end' / 'at both clamps'/ 'measure height from ground' do not allow 'find height' / 'measure on both sides of the rod / wire' for $_2$✓ expect to see a set-square in **contact with** the bench AND in **contact with** the upright ruler; allow use of a spirit level / T-square / plumb line / **large** protractor to make ruler vertical; use of set-square between the ruler and the rod OR between stand and rod is neutral; for $_1$✓ and $_2$✓ allow annotation to **Figure 10** allow $_{12}$✓ for use of a set-square in contact with the bench that reaches the rod (ie no ruler mentioned) as long as **measuring** is being done with it for $_3$✓ allow 'compare heights to check rod is parallel to bench / level' allow 'measurements match' / 'contingent' etc 'straight' for horizontal or for vertical / 'heights are constant' is neutral	3	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2		‘force down’ & ‘current to right’ & ‘field out of page by left-hand rule’ earns ✓✓✓ = 3/3;	3	1 × AO1 2 × AO3
	force on **rod** is down(wards) $_1$✓	for $_1$✓ allow use of F ↓ for force on rod down; may be indicated on **Figure 11** allow unqualified ‘force’; condone force = ‘motion’ / rod = ‘wire’ ‘force **on balance / yoke** is up’ is neutral		
	the current (in rod) is from left / to right / rightwards $_2$✓	for $_2$✓ allow I → for current from left / to right; may be indicated on **Figure 11** condone ‘current clockwise’; ‘from positive to negative’ is neutral		
	predicts direction of field based on their force and their current using valid (left-hand) rule or WTTE $_3$✓	$_3$✓ is contingent on seeing $_1$✓ force up or down and on seeing $_2$✓current left or right etc; for $_3$✓ allow use of B for field and LHR for left-hand rule; allow B ⊙ by LHR; for reversed F OR for reversed I allow ⊗ by LHR, eg ‘force upwards’ / ‘current to right’ / ‘field into page’ etc earns ✗✓✓ = 2/3		

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	MAX 2 from: - **any** valid expression to demonstrate homogeneity of terms $_{\text{A}}$✓ - $B = \frac{F}{IL}$ OR $BI = \frac{F}{L}$ $_{\text{B}}$✓ - identifies the base units of F as $\mathrm{kg\ m\ s^{-2}}$ $_{\text{C}}$✓ the units for k are $\mathrm{s^2}$ $_{3}$✓	correct units for k earns 3 marks unless evidence of incorrect working seen for $_{\text{A}}$✓ and $_{\text{B}}$✓ allow any valid expression or statement that contains both units AND quantities for $_{\text{A}}$✓ idea that $k\ B\ I$ has units of **mass** any subject eg $k \equiv \mathrm{kg\ T^{-1}\ A^{-1}}$ allow 'M OR mass OR g $= k\ B\ I$' condone words for **units**, eg 'amps' / 'tesla'; accept use of dimensional analysis, M (mass), L (length) and T (time) for $_{\text{B}}$✓ allow T (OR B) $\equiv \frac{\mathrm{N}}{\mathrm{A\ m}} \equiv \frac{\mathrm{N\ s}}{\mathrm{C\ m}}$ for $_{\text{B}}$✓ allow TA (OR $B\ I$) $\equiv \frac{\mathrm{N}}{\mathrm{m}}$ for $_{\text{AB}}$✓✓ allow $k \equiv \mathrm{kg}\ \frac{\mathrm{(A)\,m}}{\mathrm{N}}(\mathrm{A^{-1}})$ for $_{\text{BC}}$✓✓ allow T (OR B) $\equiv \frac{\mathrm{kg\ (m)\ s^{-2}}}{\mathrm{A\ (m)}} \equiv \frac{\mathrm{kg}}{\mathrm{C\ s}}$ for $_{\text{BC}}$✓✓ allow TA (OR $B\ I$) $\equiv \frac{\mathrm{kg\ (m)\ s^{-2}}}{\mathrm{(m)}}$	3	1 × AO1 2 × AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	records **two** vertical intercepts to 2 dp with at least one intercept correct to ± 0.05 (g) OR M_1 and M_2 read off to 2 dp for the same value of I with at least one read off correct to ± 0.05 (g)₁✓	M_1 intercept $= 134.85 \pm 0.05$ (g) M_2 intercept $= 181.85 \pm 0.05$ (g) allow either value seen in working	3	AO2
	derives **two** valid equations using their M_1 and M_2 that can be solved to determine Y OR their Y min 1 dp, consistent with their intercepts to ± $0.1(0)$ (g) ₂✓	for ₂✓ mark is for method OR for their Y equations **[A]** and **[B]** seen: $134.85 = (0 +)\ 2Z + Y$ ………………**[A]** $181.85 = (0 +)\ 4Z + Y$ ………………**[B]** OR $Y = 2 \times M_1$ intercept – M_2 intercept; ₂✓ not contingent on ₁✓ so allow their Y correctly deduced using two incorrect intercepts including intercepts rounded to 1 dp		
	$Y = 87.85 \pm 0.1(0)$ (g) CAO ₃✓	₃✓ is contingent on ₁✓ for ₃✓ min 1 dp; only allow 1 dp 87.8 OR 87.9		

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	identifies that B is less $_1$✓	for $_1$✓ allow 'field' / '(magnetic) **flux density**' for B; allow 'B weaker' / 'less field lines through the rod' / '(rod) not affected by field as much'; 'B is not uniform' / '(rod) cuts less flux' / 'cutting less field lines' are neutral $_1$✓	3	1 × AO2 2 × AO3
	states and explains why the intercept is the same $_2$✓	for $_2$✓ allow intercept is the same **because** 'intercept is the mass of yoke **and** magnets' / 'intercept = $2Z$ AND Y' / 'Z AND Y don't change' / 'there is the same initial mass'		
	states and explains why the line is less steep $_3$✓	for $_3$✓ allow 'gradient is smaller' / 'gradient is **less** negative' / 'line is flatter' **because**		
	allow $_{23}$✓ for **stating** that the line is less steep **AND** that the intercept is the same without a valid explanation for either statement	'**change in** M_1 / balance reading / force is less for each (**change in**) I' OR 'force won't **change as much** with current' OR 'less force per unit current' OR gradient is kB / gradient $\propto B$		
	allow $_{13}$✓ for $B = 0$ or WTTE (reject 'rod not in field');	'less force for same current' is neutral		
	intercept same as in **Figure 13** AND gradient $= 0$ or WTTE;	take account any sketch graph that correctly compares the new graph of M_1 against I with **Figure 13**		
	then mark $_2$✓ as above			
Total			**15**	

Section A

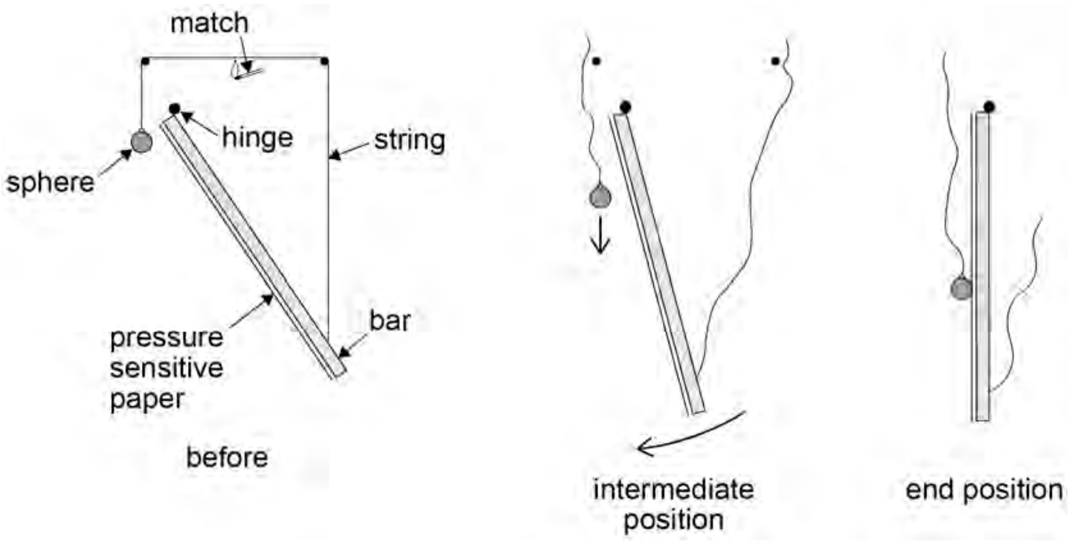
Answer **all** question(s) in this section.

0 1 This question is about measuring the acceleration of free fall g.

A student undertakes an experiment to measure the acceleration of free fall.

Figure 1 shows a steel sphere attached by a string to a steel bar. The bar is hinged at the top and acts as a pendulum. When the string is burnt through with a match, the sphere falls vertically from rest and the bar swings clockwise. As the bar reaches the vertical position, the sphere hits it and makes a mark on a sheet of pressure-sensitive paper that is attached to the bar.

Figure 1



The student needs to measure the distance d fallen by the sphere in the time t taken for the bar to reach the vertical position.

To measure d the student marks the initial position of the sphere on the paper. The student then measures the distance between the initial mark and the mark made by the sphere after falling.

To measure t the student sets the bar swinging without the string attached and determines the time for the bar to swing through 10 small-angle oscillations.

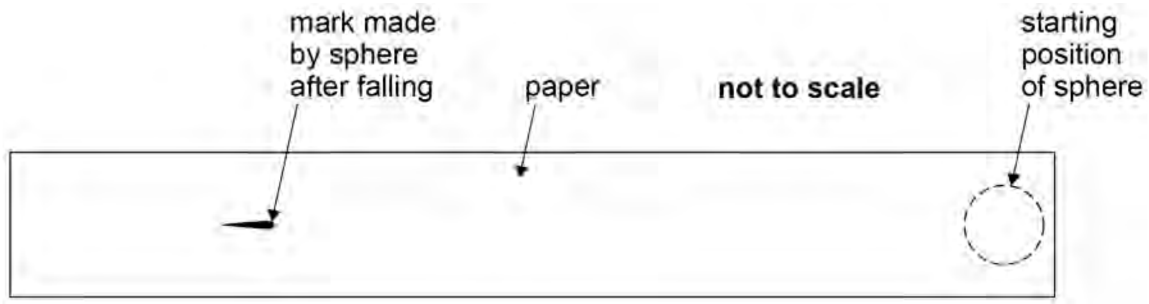
Question 1 continues on the next page

0 1 . 1 **Figure 2** shows the strip of paper after it has been removed from the bar. The initial position of the sphere and the final mark are shown.

Mark on **Figure 2** the distance that the student should measure in order to determine d.

[1 mark]

Figure 2



0 1 . 2 The student repeats the procedure several times.

Data for the experiment is shown in **Table 1**.

Table 1

d / m
0.752
0.758
0.746
0.701
0.772
0.769

Time for bar to swing through 10 oscillations as measured by a stop clock = 15.7 s

Calculate the time for one oscillation and hence the time t for the bar to reach the vertical position.

[1 mark]

time______________s

0 1 . 3 Determine the percentage uncertainty in the time t suggested by the precision of the recorded data.

[2 marks]

uncertainty = ______________%

0 1 . 4 Use the data from **Table 1** to calculate a value for d.

[2 marks]

d = ______________m

0 1 . 5 Calculate the absolute uncertainty in your value of d.

[1 mark]

uncertainty = ____________m

0 1 . 6 Determine a value for g and the absolute uncertainty in g.

[3 marks]

g = ______________________$\mathrm{m\,s^{-2}}$

uncertainty = ____________$\mathrm{m\,s^{-2}}$

0 1 . 7 Discuss **one** change that could be made to reduce the uncertainty in the experiment.

[2 marks]

0 1 . 8 The student modifies the experiment by progressively shortening the bar so that the time for an oscillation becomes shorter. The student collects data of distance fallen s and corresponding times t over a range of times.

Suggest, giving a clear explanation, how these data should be analysed to obtain a value for g.

[3 marks]

Question	Answers	Additional Comments/Guidance	Mark
01.1	Clear identification of distance from centre of sphere to right hand end of mark, or to near r.h.end of mark ✓		1
01.2	0.393 (s) ✓	Accept 0.39 (s)	1
01.3	For 10 oscillations percentage uncertainty = $\frac{0.1}{15.7}$ = 0.00637 ≡ 0.64% ✓ same for the ¼ period ✓		2
01.4	Identifies anomaly [0.701] ✓ and calculates mean distance = 0.759 (m)✓	Allow 1 max if anomaly included in calculation giving 0.750 (m)	2
01.5	Largest to smallest variation = 0.026 (m) Absolute uncertainty = 0.013 (m)✓		1
01.6	Use of $g = \frac{2d}{t^2}$ leading to 9. 83 (m s^{-2}) ✓ percentage uncertainty in distance = 1.7%✓ Total percentage uncertainty = 1.7 + 2 x 0.64 = 3.0% Absolute uncertainty = 0.30 (m s^{-2}) ✓ [g = 10.0 ± 0.3 m s^{-2}]	Allow 9.98 (m s^{-2}) if 0.39 used Ecf if anomaly included in mean in 1.4 Expressed sf must be consistent with uncertainty calculations	3

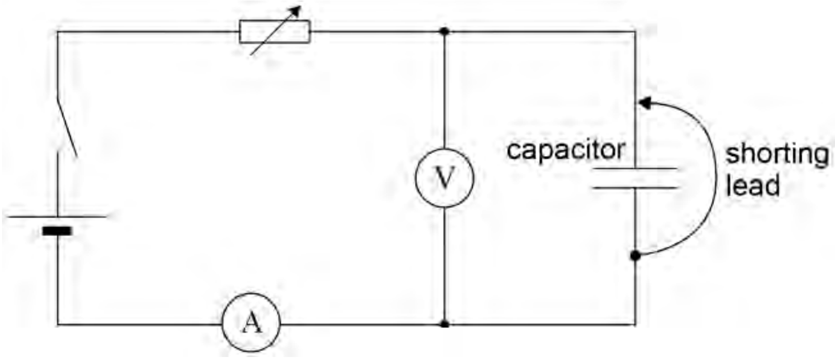
01.7	suggests one change ✓ Sensible comment about change or its impact on uncertainty ✓ eg Use pointed mass not sphere Because this will give better defined mark OR because the distance determination has most impact on uncertainty OR Time more swings/oscillations As this reduces the percentage uncertainty in timing OR longer/heavier bar would take a greater time to swing to the vertical increasing t and s and reducing the percentage uncertainty in each	If data logger proposed, it must be clear what sensors are involved and how the data are used.	2

01.8	[$s = \frac{g}{2}t^2$] plot graph of s against t^2 or $\sqrt{s}$ against t ✓ calculate the gradient ✓ the gradient is $g/2$ or $\sqrt{(g/2)}$ ✓	Accept: plot s against $t^2/2$ or plot $2s$ against t^2: calculate the gradient in both cases gradient gives g Allow 1 max for answer that evaluates g for each data point and averages	3

0 2 This question is about capacitor charging and discharging.

A student designs an experiment to charge a capacitor using a constant current. **Figure 3** shows the circuit the student designed to allow charge to flow onto a capacitor that has been initially discharged.

Figure 3



The student begins the experiment with the shorting lead connected across the capacitor as in **Figure 3**. The variable resistor is then adjusted to give a suitable ammeter reading. The shorting lead is removed so that the capacitor begins to charge. At the same instant, the stop clock is started.

The student intends to measure the potential difference (pd) across the capacitor at 10 s intervals while adjusting the variable resistor to keep the charging current constant.

The power supply has an emf of 6.0 V and negligible internal resistance. The capacitor has a capacitance of 680 μF. The variable resistor has a maximum resistance of 100 kΩ.

0 2 . 1 The student chooses a digital voltmeter for the experiment. A digital voltmeter has a very high resistance.

Explain why it is important to use a voltmeter with very high resistance.

[1 mark]

Question 2 continues on page 9

There are no questions printed on this page

DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED

0 2 . 2 Suggest **one** advantage of using an analogue ammeter rather than a digital ammeter for this experiment.

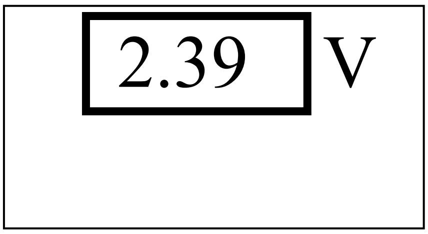
[1 mark]

0 2 . 3 Suggest a suitable full scale deflection for an analogue ammeter to be used in the experiment.

[2 marks]

full scale deflection = ______________

0 2 . 4 The diagram shows the reading on the voltmeter at one instant during the experiment. The manufacturer gives the uncertainty in the meter reading as 2%.



Calculate the absolute uncertainty in this reading.

[1 mark]

uncertainty = ___________V

Question 2 continues on the next page

0 2 . 5 Determine the number of different readings the student will be able to take before the capacitor becomes fully charged.

[3 marks]

number = ________________

0 2 . 6 The experiment is performed with a capacitor of nominal value 680 μF and a manufacturing tolerance of ± 5 %. In this experiment the charging current is maintained at 65 μA. The data from the experiment produces a straight-line graph for the variation of pd with time. This shows that the pd across the capacitor increases at a rate of 98 $\mathrm{mV\ s^{-1}}$.

Calculate the capacitance of the capacitor.

[2 marks]

capacitance = ________________ μF

0 2 . 7 Deduce whether the capacitor is within the manufacturer's tolerance.

[1 mark]

____

____

____

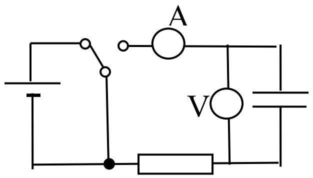
0 2 . 8 The student decides to confirm the value of the capacitance by first determining the time constant of the circuit when the capacitor **discharges** through a **fixed** resistor.

Describe an experiment to do this. Include in your answer:

- a circuit diagram
- an outline of a procedure
- an explanation of how you would use the data to determine the time constant.

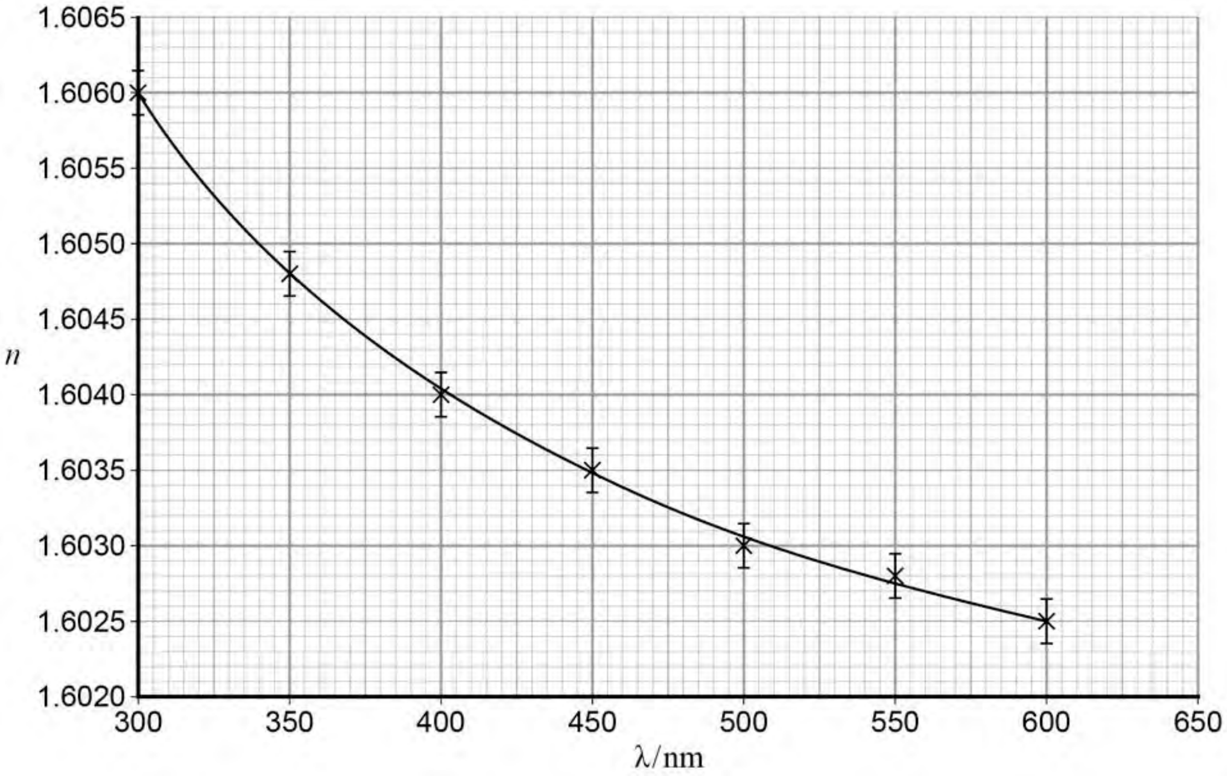
[4 marks]

02.1	Capacitor must not lose charge through the meter ✓		1
02.2	Position on scale can be marked/easier to read quickly etc ✓		1
02.3	Initial current = $\frac{6}{100000} = 60.0\ \mu\text{A}$ ✓ 100 μA or 200 μA ✓ (250 probably gives too low a reading)	Give max 1 mark if 65 μA (from 2.6) used and 100 μA meter chosen	2
02.4	0.05 V ✓		1
02.5	Total charge = 6.0 x 680 x 10^{-6} (C) (= 4.08 mC) ✓ Time = 4.08 x 10^{-3} / 60.0 x 10^{-6} = 68 s ✓ Hence 6 readings ✓		3
02.6	Recognition that total charge = $65\ t\ \mu\text{C}$ and final pd = 0.098 t so C = 65μ/0.098✓ 660 μF ✓	Allow 663 μF	2
02.7	(yes) because it could lie within 646 – 714 to be in tolerance ✓ OR it is 97.5 % of quoted value which is within 5% ✓		1

02.8	Suitable circuit drawn ✓ Charge C then discharge through R and record V or I at 5 or 10 s intervals ✓ Plot In V or In I versus time ✓ gradient is $1/RC$ ✓ OR Suitable circuit drawn ✓ Charge C then discharge through R and record V or I at 5 or 10 s intervals✓ Use V or I versus time data to deduce half-time to discharge ✓ $1/RC = \ln 2/t_{½}$ quoted ✓ OR Suitable circuit drawn ✓ Charge C then discharge through R and record V or I at 5 or 10 s intervals ✓ Plot V *or* I against t and find time T for V or I to fall to 0.37 of initial value ✓ $T = CR$ ✓	 Either A or V required For 2nd mark, credit use of datalogger for recording V or I.	4

0 3 **Figure 4** shows how the refractive index *n* of a type of glass varies with the wavelength of light λ passing through the glass. The data for plotting the graph were determined by experiment.

Figure 4



0 3 . 1 A student says that **Figure 4** resembles that of the decay of radioactive atomic nuclei with time and that it shows half-life behaviour.

Comment on whether the student is correct.

[1 mark]

0 3 . 2 The dispersion D of glass is defined as the rate of change of its refractive index with wavelength. At a particular wavelength $D = \frac{\Delta n}{\Delta \lambda}$.

Determine D at a wavelength of 400 nm. State an appropriate unit for your answer.

[3 marks]

D ____________________ unit ____________________

Question 3 continues on the next page

0 3 . 3 It is suggested that the relationship between n and λ is of the form

$$n = a + \frac{b}{\lambda^2}$$

where a and b are constants. The data plotted in **Figure 4** are given in **Table 2**.

Table 2

λ / nm	n			
300	1.6060			
350	1.6048			
400	1.6040			
450	1.6035			
500	1.6030			
550	1.6028			
600	1.6025			

You are to determine *a* using a graph of n against $\frac{1}{\lambda^2}$.

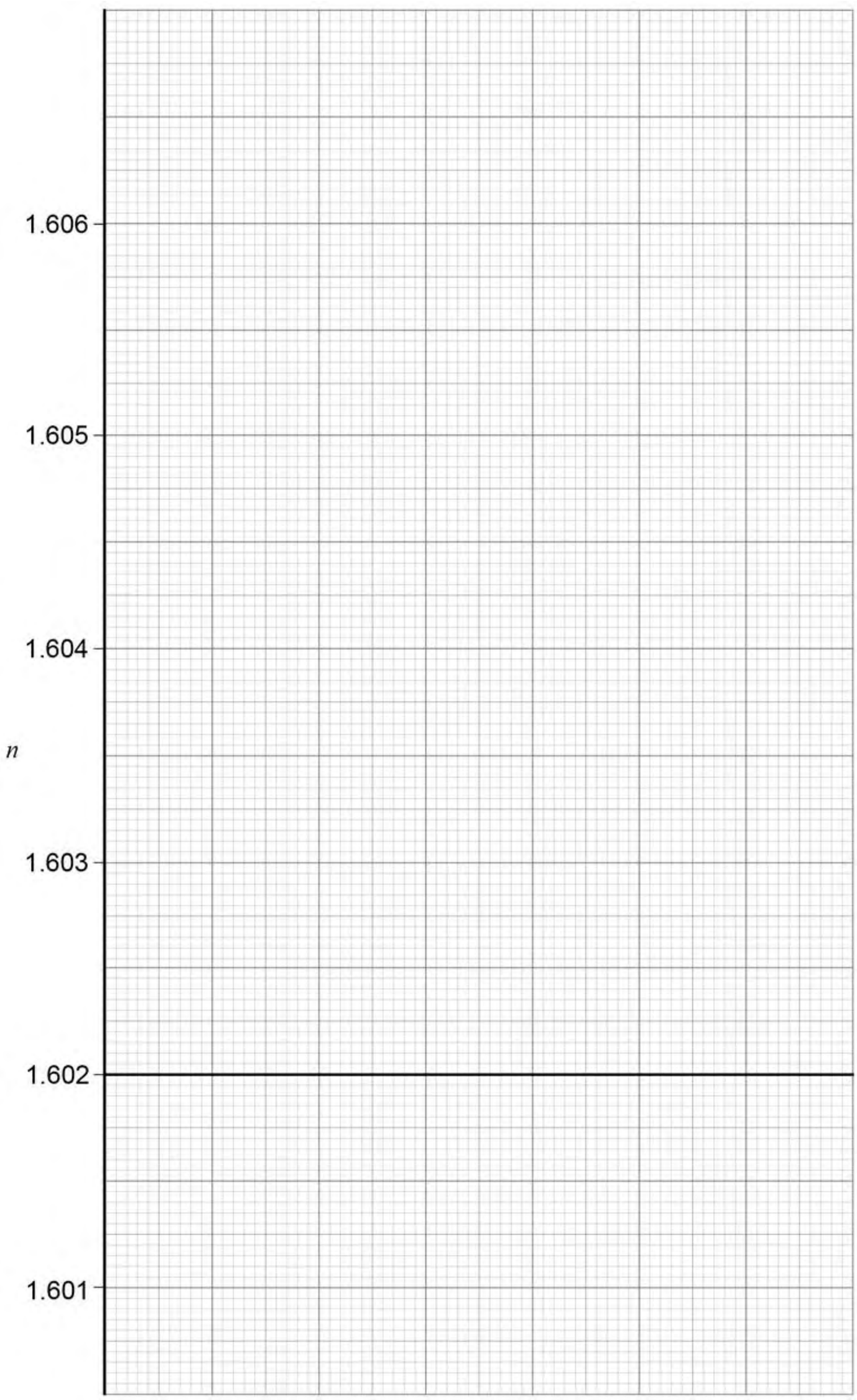
Make any calculations that you need to in order to plot your graph. The columns in **Table 2** are for you to use to calculate and tabulate the derived data that you need. You may not need all the columns.

[3 marks]

0 3 . 4 Plot your graph on **Figure 5**. The values of n are provided on the y-axis.

[3 marks]

Figure 5



Question 3 continues on the next page

0 3 . 5 Use your graph to determine a.

[1 mark]

0 3 . 6 State the significance of a.

[1 mark]

0 3 . 7 Another suggestion for the relationship between n and λ is that

$$n = c\lambda^d$$

where c and d are constants.

Explain how d can be determined graphically. Do not attempt to carry out this analysis.

[3 marks]

END OF QUESTIONS

03.1	n changes by 4 units, 2 units, 1 unit for each change in 100 nm ✓ OR this is not half-life behaviour because graph has false origin for n OR the magnitude of n does not halve every interval		1
03.2	Sensible long (> 8 cm) tangent drawn, correct read-off for points from triangle at least half length of line and readings taken ✓ Substitution correct✓ (–) $(1.5 \pm 0.2) \times 10^4$ **and** m^{-1} ✓	Condone power of ten error in first two marks	3

<table>
<tr>
<td>03.3</td>
<td>Column heading correct ✓
All calculations correct ✓
appropriate (3) sfs✓
<table>
<tr><th>$1/\lambda^2$ / 10^{-12} m^{-2}</th></tr>
<tr><td>11.1</td></tr>
<tr><td>8.16</td></tr>
<tr><td>6.25</td></tr>
<tr><td>4.94</td></tr>
<tr><td>4.00</td></tr>
<tr><td>3.31</td></tr>
<tr><td>2.78</td></tr>
</table>
</td>
<td>Accept if calculated in nm^{-2} instead of m^{-2}
11.1×10^{-6} nm^{-2} etc
Units as follows: $1/\lambda^2$ /m^{-2}. Alternative acceptable labelling includes $1/\lambda^2$ (m^{-2}), $1/\lambda^2$ in m^{-2}. The 10^{-12} can be in the body of the table or at top of column.</td>
<td>3</td>
</tr>
</table>

03.4	Graph axes labelled correctly and sensible axes✓ Plots correct to within half a square ✓ Best-fit line by eye ✓	Suitably large graph scale (do not award if scale on axis could have been doubled) Scale must be sensible divisions which can be easily read. eg scales in multiples of 3, 6, 7, 9 etc are unsatisfactory. 2nd mark is independent mark i.e. if candidates have used an unsuitable scale they can still achieve marks for accurately plotting the points. The line of best fit should have an approximately equal distribution of points on either side of the line. Check bottom 3 plots.	3
03.5	Intercept correct to within half a square ✓	[1.6014]	1
03.6	The value of refractive index at infinite/very long wavelength✓		1
03.7	states that log n = log c + d log λ✓ plot log n versus log λ ✓ d is the gradient of the graph ✓		3