IB · DP · Physics

3 hours 14 questions

Structured Questions

1.2 Uncertainties & Errors

1.2.1 Random & Systematic Errors / 1.2.2 Calculating Uncertainties / 1.2.3 Determining Uncertainties from Graphs

Easy (4 questions)	/55
Medium (5 questions)	/66
Hard (5 questions)	/42
Total Marks	**/163**

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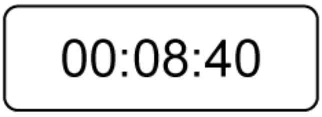
Easy Questions

1 (a) A student uses a stopwatch to measure the time taken for a pendulum to complete one swing.

The display on the stopwatch after the pendulum completes 10 swings is shown on the diagram.



For this reading, determine:

(i) The absolute uncertainty [1]

(ii) The fractional uncertainty [1]

(iii) The percentage uncertainty [1]

(3 marks)

(b) Calculate the mean time for one complete swing with its absolute uncertainty and a percentage uncertainty.

Give your answer to an appropriate number of significant figures.

(4 marks)

(c) Draw lines between the three types of error to show if the error affects the precision or accuracy of a result.

Systematic error	Precision
Random error	
Zero error	Accuracy

(2 marks)

(d) In order to reduce errors, a different student collected measurements of time over 20 cycles instead of 10.

Complete the following sentences by circling the correct word and placing a tick (✓) next to the correct explanation

Repeated measurements reduce **systematic / random** errors because...

	using a larger sample to calculate the mean value reduces the uncertainty in the final value
	these cause values to be different by the same amount each time, hence they are not influenced by repetition

Repeated measurements have no effect on **systematic / random** errors because...

	using a larger sample to calculate the mean value reduces the uncertainty in the final value
	these cause values to be different by the same amount each time, hence they are not influenced by repetition

(4 marks)

2 (a) Outline the difference between precise and accurate measurements.

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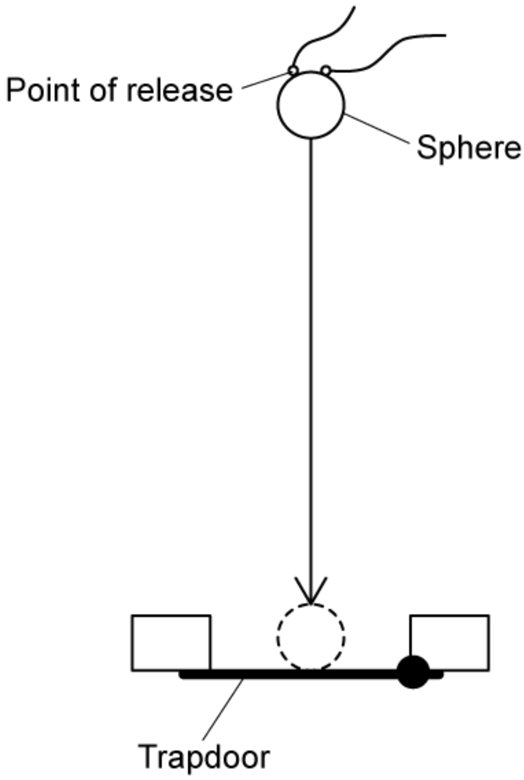
(2 marks)

(b) A student investigates the relationship between the height that a small metal sphere is dropped from and the time it takes to fall. The ball is dropped from rest through a distance of 543 ± 2 mm.



The student predicts the expected time the sphere should take to fall this distance is 0.323 s, using the following equation:

$$\text{acceleration due to gravity} = \frac{2 \times \textit{distance fallen by centre of mass of sphere}}{(\textit{measured time to fall})^2}$$

The time taken for the sphere to fall from the point of release to a trapdoor is measured. This measurement is repeated a number of times.

Time, t_1 / s	Time, t_2 / s	Time, t_3 / s	Time, t_4 / s	Time, t_5 / s	Time, t_6 / s
0.423	0.422	0.424	0.421	0.423	0.424

For the student's results:

(i) Calculate the mean value

[1]

(ii) Explain why the results are precise but not accurate

[2]

(3 marks)

(c) The student repeats the experiment and obtains the following data:

Measured time to fall	0.322 ± 0.002 s
Distance between the point of release and the trapdoor	543 ± 1 mm
Diameter of the metal sphere	10.0 ± 0.1 mm

For this data, calculate:

(i) The total distance fallen by the centre of mass of the sphere

[1]

(ii) The absolute uncertainty in this distance

[1]

(2 marks)

(d) Calculate the acceleration due to gravity, including an estimate of the absolute uncertainty in your answer.

You may use the following rules for propagating uncertainties:

Operation	Example	Propagation Rule
Addition & Subtraction	$y = a \pm b$	$\Delta y = \Delta a + \Delta b$ The sum of the absolute uncertainties
Multiplication & Division	$y = a \times b$ or $y = \frac{a}{b}$	$\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b}$ The sum of the fractional uncertainties
Power	$y = a^{\pm n}$	$\frac{\Delta y}{y} = n\left(\frac{\Delta a}{a}\right)$ The magnitude of n times the fractional uncertainty

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(5 marks)

3 (a) List the following currents from largest to smallest percentage uncertainty:

4.1 ± 0.2 A	5 ± 1 mA	7.30 ± 0.23 A	0.5 ± 0.05 mA

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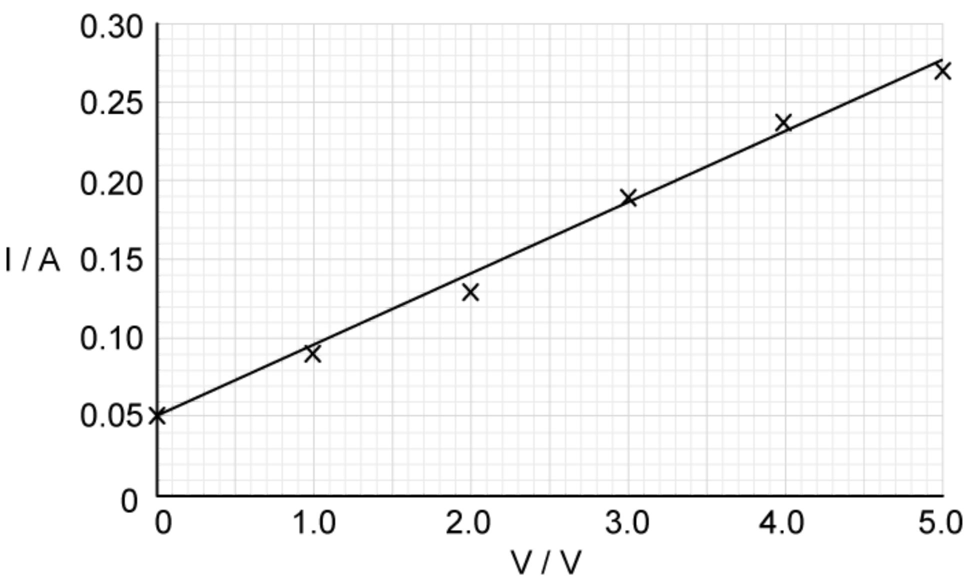
(4 marks)

(b) A circuit is set up to measure the resistance, *R*, of a resistor. The potential difference (p.d), *V*, across the resistor and the current, *I*, are related by the equation:

$$V = IR$$

The readings for the p.d, *V*, and the corresponding current, *I*, are obtained and plotted on a graph with a line of best fit drawn.



Complete the following sentences by circling the correct words:

Current and potential difference have a **directly** / **inversely** proportional relationship.

This means when one quantity is zero, the other will be **zero** / **non-zero.**

On the graph, the y-intercept is **zero** / **non-zero**, hence, this shows the readings **have** / **have not** been affected by **systematic** / **random** uncertainties.

The points on the graph are **close to** / **scattered around** the line of best fit, hence, this shows the readings **have** / **have not** been affected by **systematic** / **random** uncertainties.

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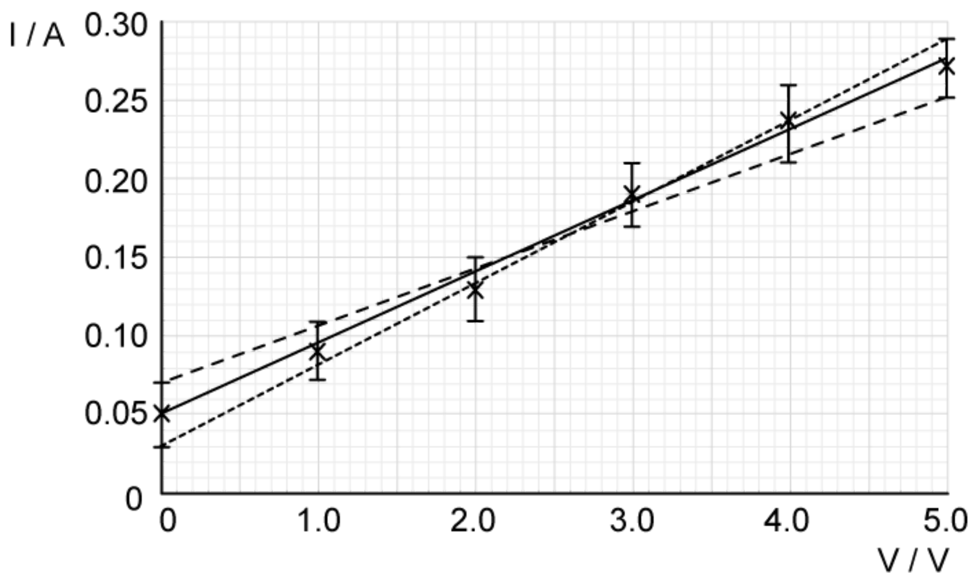
(4 marks)

(c) The student plots error bars on the graph along with lines of maximum and minimum gradient.



Black solid line = best fit line
Dashed black line = maximum fit line
Dotted black line = minimum fit line

(i) Determine the percentage uncertainty in the gradient using the following equations of the lines:

Best line	$I = 0.045V + 0.05$
Maximum line	$I = 0.052V + 0.03$
Minimum line	$I = 0.036V + 0.07$

[3]

(ii) The student suggests the analogue ammeter used to measure the current may have introduced a positive zero error. State what is meant by a zero error.

[1]

(iii) Outline **one** way a zero error could affect the results and suggest how this type of error can be fixed.

[2]

(6 marks)

(d) In another student's experiment, the resistance of the resistor, *R*, is determined using the following data:

Current, *I*	0.74 ± 0.01 A
Potential difference, *V*	6.5 ± 0.2 V

Calculate the value of *R*, together with its percentage uncertainty. Give your answer to an appropriate number of significant figures.

(5 marks)

4 (a) A vernier calliper has a positive zero error of 0.10 mm.

A student uses the vernier calliper to measure the length of a wire under various loads and records the data in a table.

Load / N	Length / mm	Corrected Length / mm
1.00	3.00	
1.50	3.54	
2.00	4.02	
2.50	4.61	
3.00	4.99	

Correct the readings of the length of wire in mm for each load.

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(2 marks)

(b) The student wants to determine the extension of the wire after each load is applied. Part of the results table is shown below.

Load / N	Length / mm
1.00	3.00
1.50	3.54

The vernier calliper scales have an uncertainty of ± 0.01 mm

Using the data, calculate the extension of the wire and its absolute uncertainty.

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(2 marks)

(c) Another student decides to use a ruler to measure the length of the wire for each load and records the data in a table.

Load / N	Length / mm
1.00	3.00
1.50	4.00
2.00	4.00
2.50	5.00
3.00	5.00

The ruler has an uncertainty of ± 1.00 mm.

Calculate the fractional uncertainty in the length of the wire using a ruler when a load of 2.50 N is applied. Quote the final value with its fractional uncertainty.

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(3 marks)

(d) The student using the vernier calliper to measure the length of the wire obtained a length of 4.61 ± 0.01 mm when a load of 2.50 N was applied.

They quoted the percentage uncertainty in this length as 0.22 %.

State and explain whether or not the student has:

(i) Calculated the percentage uncertainty correctly

[2]

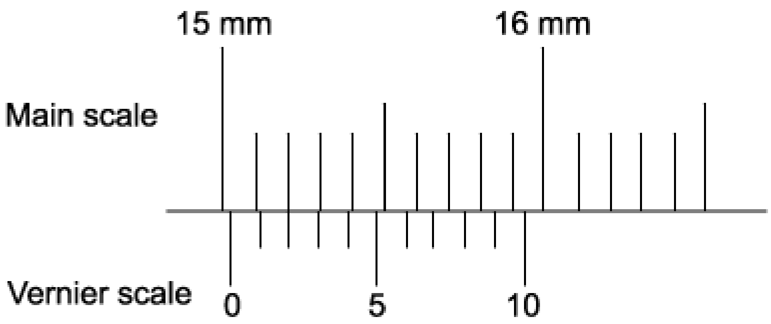
(ii) Quoted the percentage uncertainty correctly

[2]

(4 marks)

Medium Questions

1 (a) A vernier calliper is used to measure the length of a piece of copper wire.



Determine the full reading of the vernier calliper with its absolute uncertainty.

(4 marks)

(b) The reading from part (a) is taken after a mass has been added to the copper wire of length *L* and the wire extends.

The original length of the wire *L* was 14.9 ± 0.05 mm.

Calculate the extension Δ*L* of the copper wire after the mass has been added. Give the range of the uncertainty of this extension.

(3 marks)

(c) Tensile strain is a measure of the deformation of an object and is defined as the ratio between the extension of the wire and its original length.

$$\text{Tensile Strain, } \varepsilon = \frac{\Delta L}{L}$$

Deduce the tensile strain of the copper wire and its percentage uncertainty.

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(4 marks)

(d) State two ways to reduce the systematic error in this experiment.

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(2 marks)

2 (a) A student participates in an experiment to measure the Earth's gravitational field strength g. This is done using a simple pendulum.

The student suggests the period of oscillation T is related to length of the pendulum L and by the equation:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

The table shows the period T recorded ten times.

0.67	0.66	0.67	0.68	0.69	0.64	0.66	0.65	0.68	0.65

Determine the mean period of oscillation and its percentage uncertainty.

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(3 marks)

(b) In a new experiment ,the length of the pendulum L is measured with an accuracy of 1.8% and the acceleration due to free-fall g is measured with an accuracy of 1.6%.

If the time for the pendulum to complete 20 oscillations is 18.4 s, determine the time period for one oscillation and the absolute uncertainty in this value.

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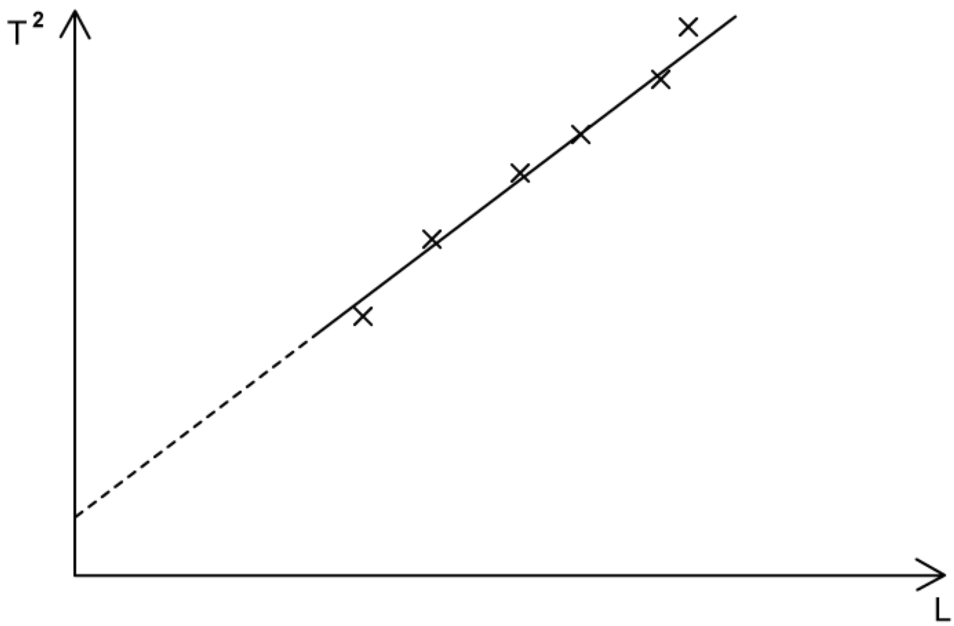
(3 marks)

(c) Measurements of time periods for different lengths of pendula were taken using a stopwatch and plotted on a graph.



Explain how the graph indicates that the readings are subject to systematic and random uncertainties.

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(2 marks)

(d) The period T for a mass m hanging on a spring performing simple harmonic motion is given by the equation:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Such a system is used to determine the spring constant k. The fractional error in the measurement of the period T is α and the fractional error in the measurement of the mass m is β.

Determine the fractional error in the calculated value of k in terms of α and β.

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(2 marks)

3 (a) An object falls off a cliff of height, *h*, above the ground. It takes 13.8 seconds to hit the ground.

It is estimated that there is a percentage uncertainty of ± 5% in measuring this time interval. A guidebook of the local area states the height of the cliff is 940 ± 10 m.

Calculate the acceleration of free-fall of the object and its fractional uncertainty.

(4 marks)

The only instrument used in this experiment was a stopwatch.

(i) Write down one possible source of systematic error and one possible source of random error in this investigation.

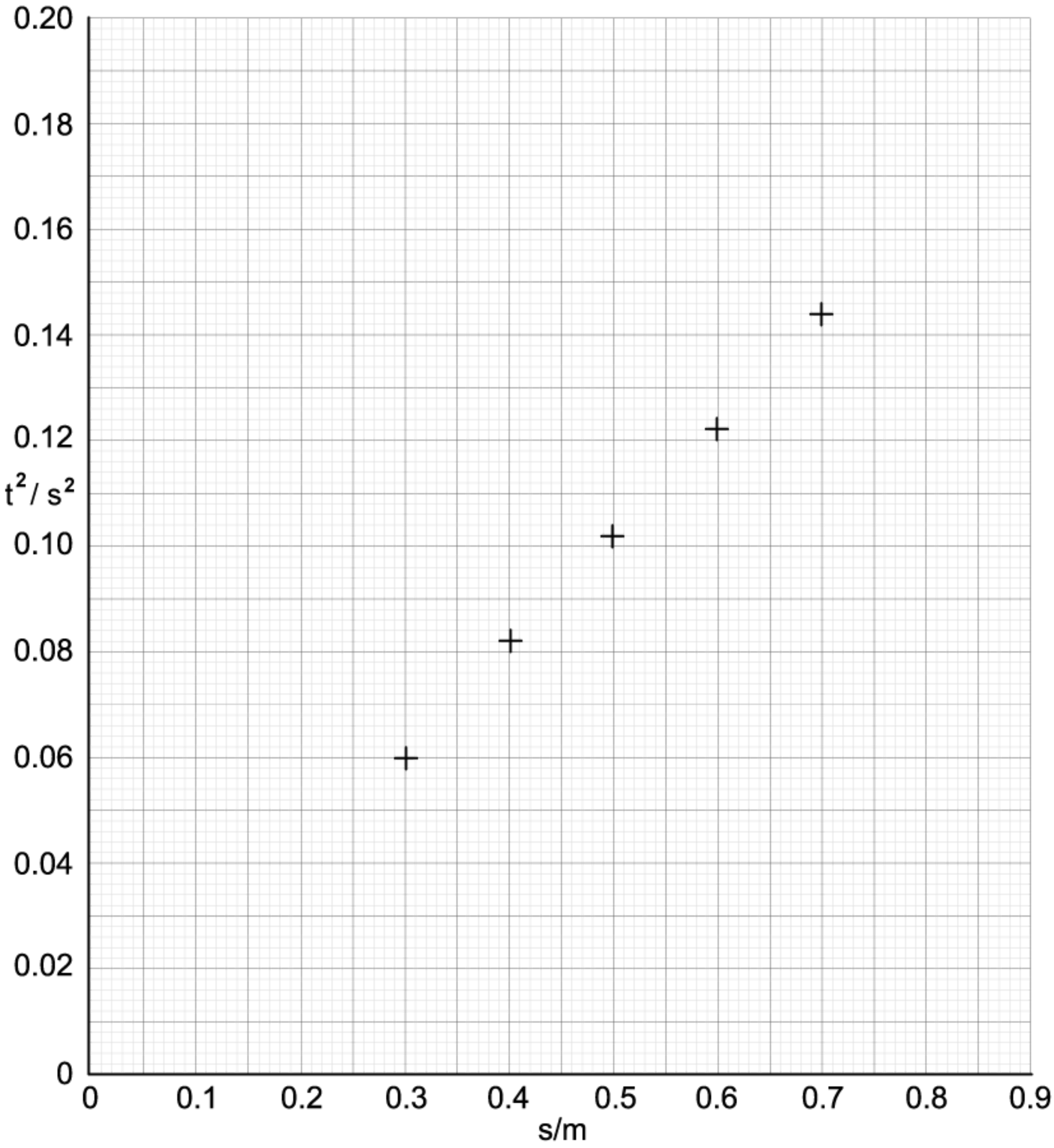
(ii) Explain how these errors could influence the value of acceleration of free-fall of the object from part (a).

(b) **(4 marks)**

(c) A student performs an experiment to find the acceleration due to gravity. A spherical object falling freely through measured vertical distances *s* for a time *t*. The experiment is repeated in a lab and the time is measured electronically.

s / **m**	t_1 / s	t_2 / s	t_3 / s	**mean time** t / s	t^2 / s^2
0.100	0.141	0.138	0.144	0.141	0.020
0.200	0.201	0.205	0.209	0.205	0.042
0.300	0.240	0.246	0.250	0.245	0.0600
0.400	0.285	0.288	0.284	0.286	0.0818
0.500	0.315	0.319	0.323	0.319	0.102
0.600	0.345	0.349	0.354	0.349	0.122
0.700	0.376	0.379	0.382	0.379	0.144
0.800	0.399	0.405	0.407	0.404	0.163
0.900	0.426	0.428	0.432	0.429	0.184

Plot the data on the graph below, including error bars and a line of best fit.



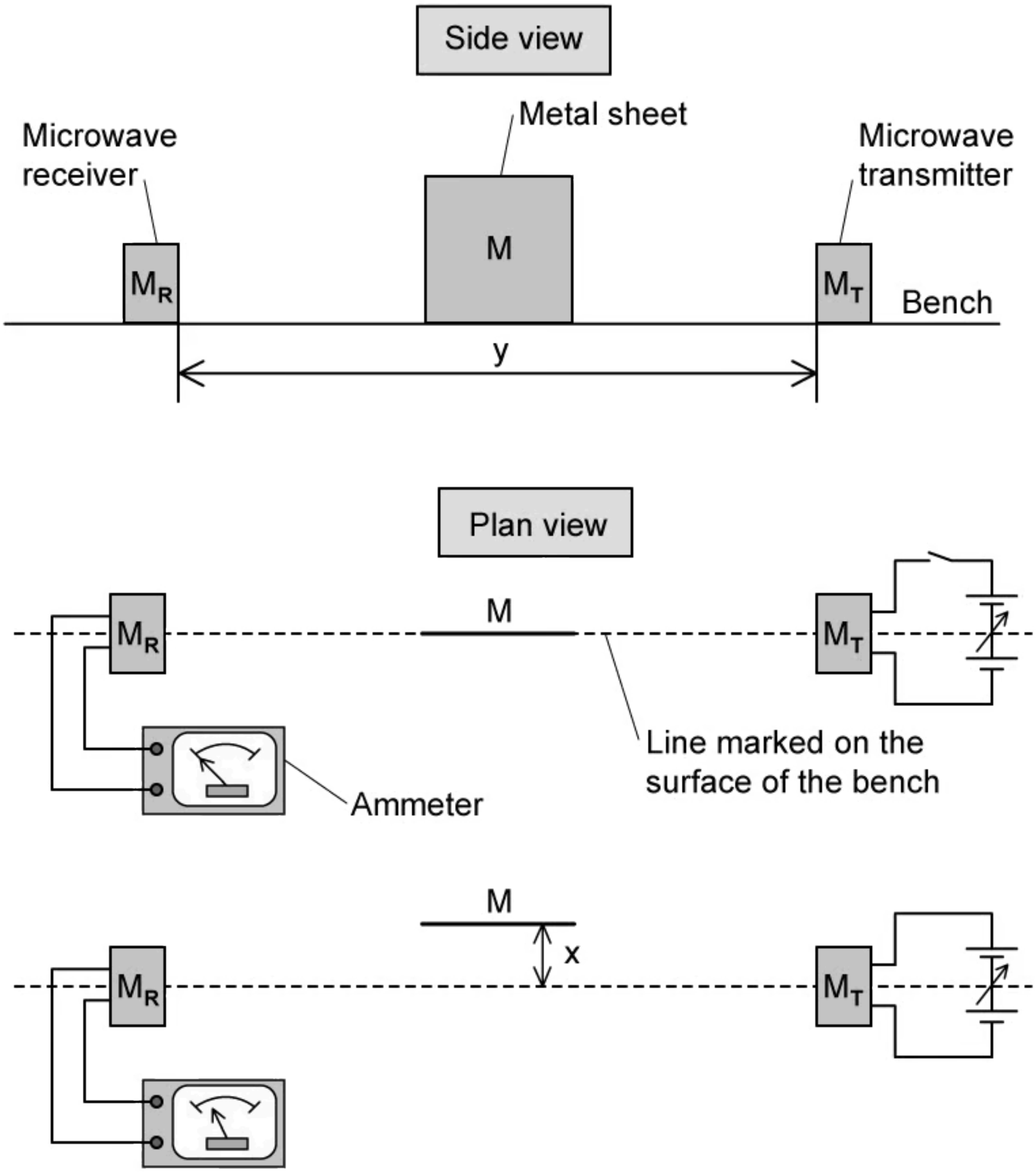
(5 marks)

(d) Calculate the value of *g* for this experiment.

(4 marks)

4 (a) The diagram shows the side and plan views of a microwave transmitter $\mathbf{M_T}$ and a receiver $\mathbf{M_R}$ arranged on a line marked on the bench.

The circuit connected to $\mathbf{M_T}$ and the ammeter connected to $\mathbf{M_R}$ are only shown in the plan view.



The distance y between $\mathbf{M_T}$ and $\mathbf{M_R}$ is recorded.

$\mathbf{M_T}$ is switched on and the output from $\mathbf{M_T}$ is adjusted so a reading is produced on the ammeter.

M is kept parallel to the marked line and moved slowly away. The perpendicular distance x between the marked line and **M** is recorded.

Describe one method to reduce systematic errors in the measurement of *x*. Use a sketch to aid your answer.

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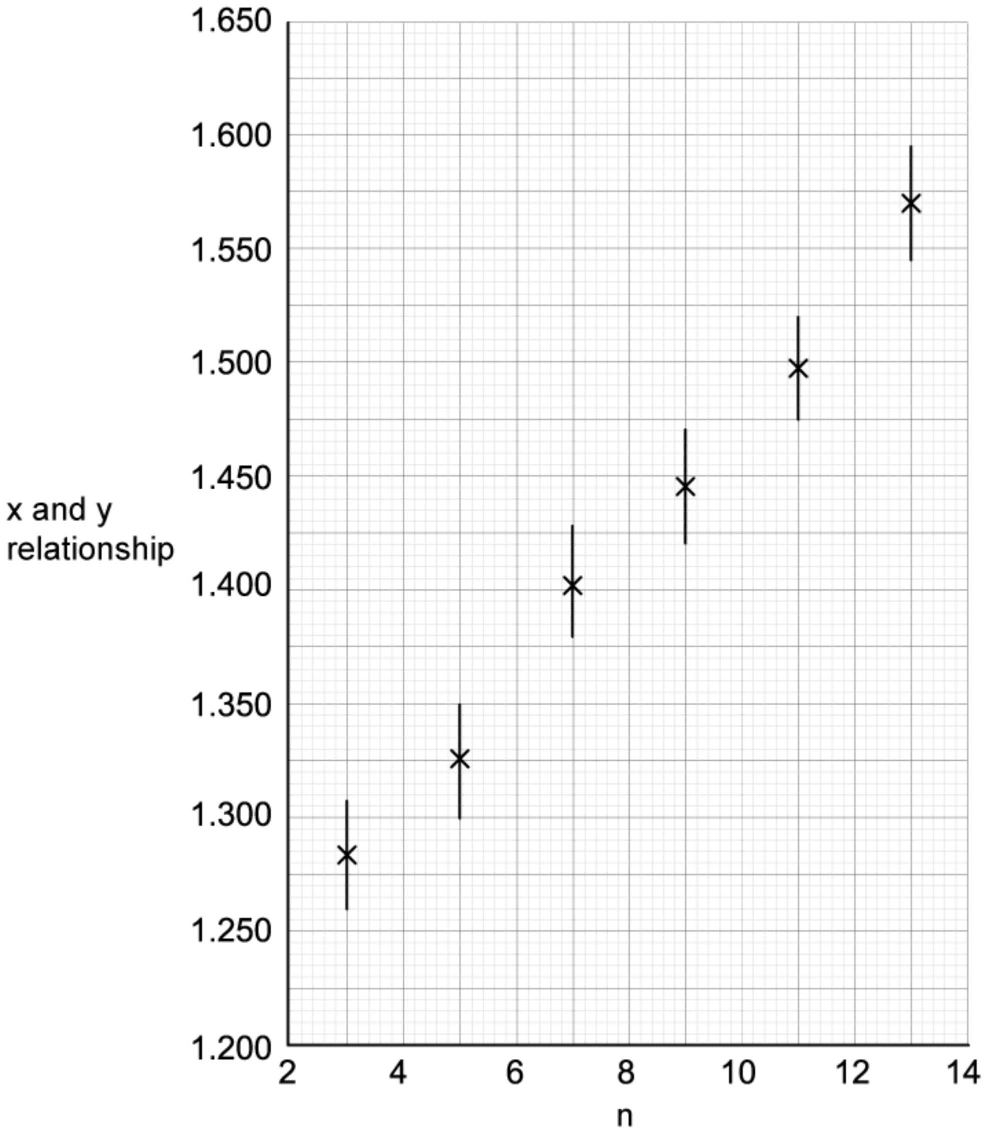
(4 marks)

(b) 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.

A relationship between x and y against n is shown on the graph. The wavelength λ is the gradient of the graph.



Determine the maximum and minimum possible values of λ.

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(3 marks)

(c) Determine:

(i) The value of λ

(ii) The percentage uncertainty in the value of λ.

(4 marks)

(d) Another student conducted a similar experiment but determined the uncertainty in the relationship of x and y to be 0.010 m for each term.

Explain the effect this would have on the uncertainty in λ.

(2 marks)

5 (a) The decay of a radioactive substance can be represented by the equation:

$$C = C_0 e^{-\lambda t}$$

where C is the count rate of the sample at time t, C_0 is the initial count rate at time $t = 0$ and λ is the decay constant.

The half-life, $t_{½}$ of the radioactive substance is given by

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

An experiment was performed to determine the half-life of a radioactive substance which was a beta emitter. The radioactive source was placed close to a detector.

The results in the table show the total count for exactly 5 minutes, repeated at 15 minute intervals.

time, t / minutes	total count, recorded in 5 minutes	Count rate, C / counts minute^{-1}	ln (C / minute^{-1})
0	1016	183	5.21
15	920	164	5.10
30	835	147	4.99
45	758	132	4.88
60	665	113	4.73
75	623	105	4.65
90	568	94	4.54
105	520	84	4.43
120	476	75	4.32
135	437	67	4.21

The uncertainty in the count rate, C, is given by

$$\Delta C = \pm\sqrt{C}$$

Calculate the uncertainty in each value of ln C.

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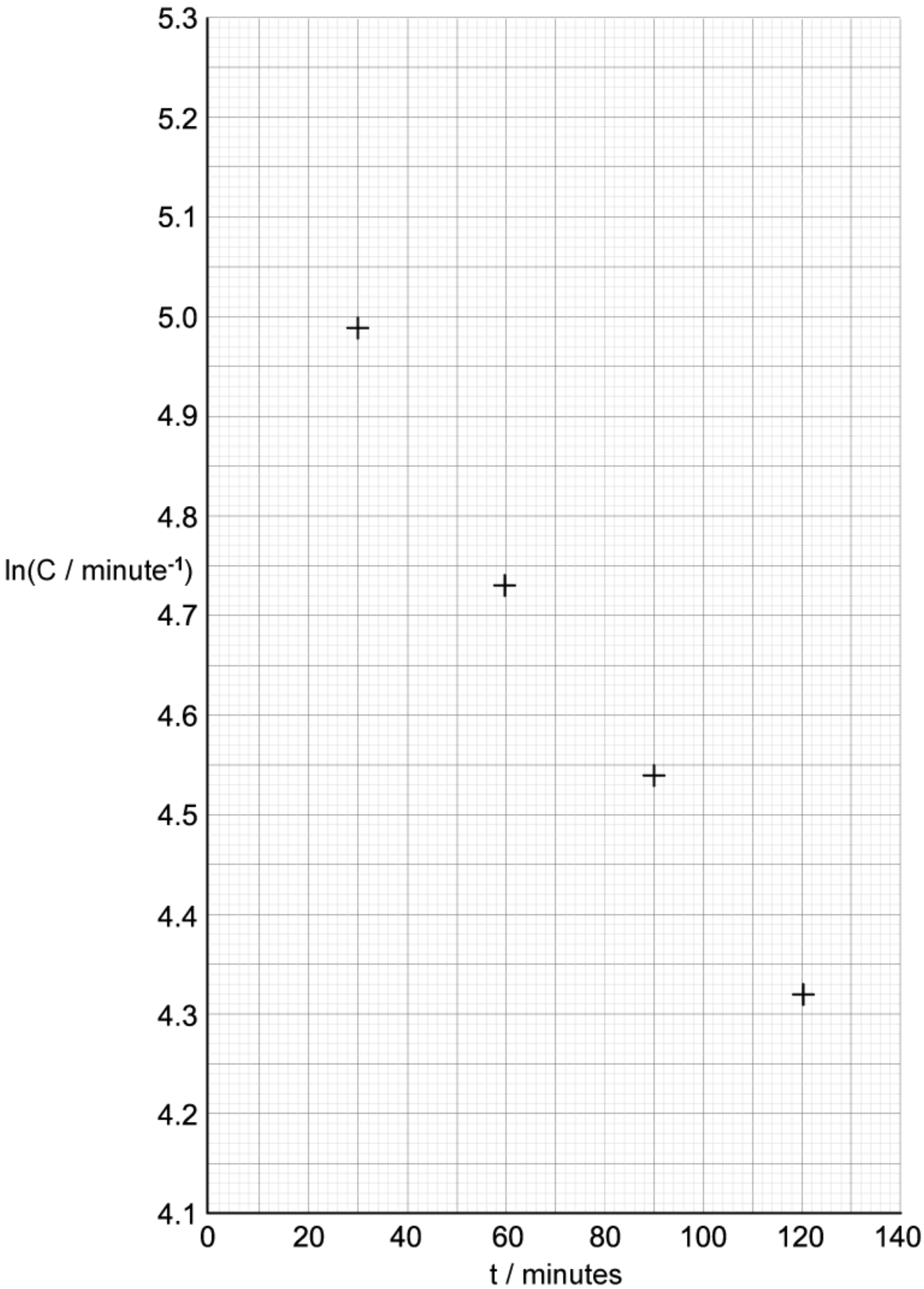
(2 marks)

(b) Draw a line of best fit and error bars for each point on the graph.



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(3 marks)

(c) The activity of the sample $\lambda = -\frac{\ln C}{t}$

Calculate the activity of the sample and its percentage uncertainty.

(5 marks)

(d) Another student performed the same experiment with identical equipment but took total counts over a 1-minute period rather than a 5-minute period. The total count, *C*, at 140 minutes was equal to 54 counts.

Use the relationship

$$\ln(x) = y \text{ so } x = e^y$$

to estimate the percentage uncertainty in this total count and explain the advantage of using a larger time.

(3 marks)

Hard Questions

1 (a) One method to determine the acceleration of free fall g involves measuring the time period of a simple pendulum T. It is related to the length of the pendulum l by the equation

$$T = 2\pi\sqrt{\frac{l}{g}}$$

In this method, l was found to be (0.500 ± 0.001) m while the period T was measured to be (1.42 ± 0.02) s.

Based on these measurements, determine the value of g and its absolute uncertainty. Give your final answer to an appropriate degree of precision.

(4 marks)

(b) Another method to determine the acceleration of free fall involves timing the descent of a small metal ball bearing, released vertically via an electromagnetic trapdoor. In one particular trial, the displacement of the ball bearing s is measured as (266 ± 1) cm and the time measured t is (0.740 ± 0.005) s.

Determine the value of g using this method, and its absolute uncertainty. Give your final answer to an appropriate degree of precision.

(4 marks)

2 (a) The length *l* of a simple pendulum is increased by 6%.

Determine the fractional increase in the pendulum's period, *T*.

You may use the relationship between period *T* and length *l* as:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where *g* is the acceleration of free fall.

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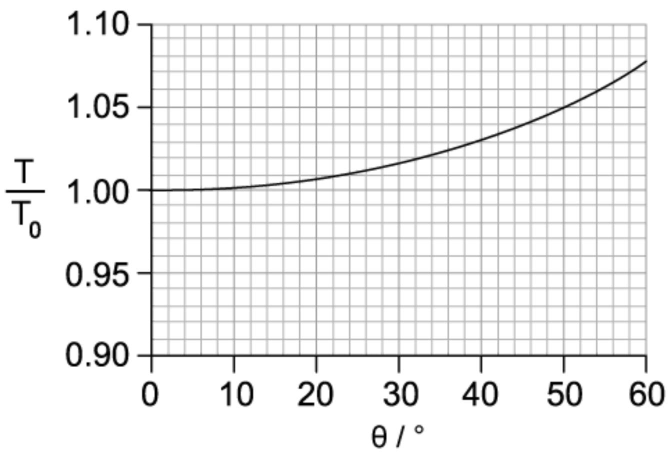
(3 marks)

(b) The time period *T* of a pendulum is also related to the amplitude of oscillations *θ*.

Measurements are taken and a graph is obtained showing the variation of $\frac{T}{T_0}$ with angular amplitude *θ*, where T_0 is the period for small amplitude oscillations:



Use the information from the graph to

(i) Deduce the condition for the time period *T* to be considered independent of angular amplitude *θ*.

[2]

(ii) Determine the maximum value of θ for which T is independent of θ.

[2]

(4 marks)

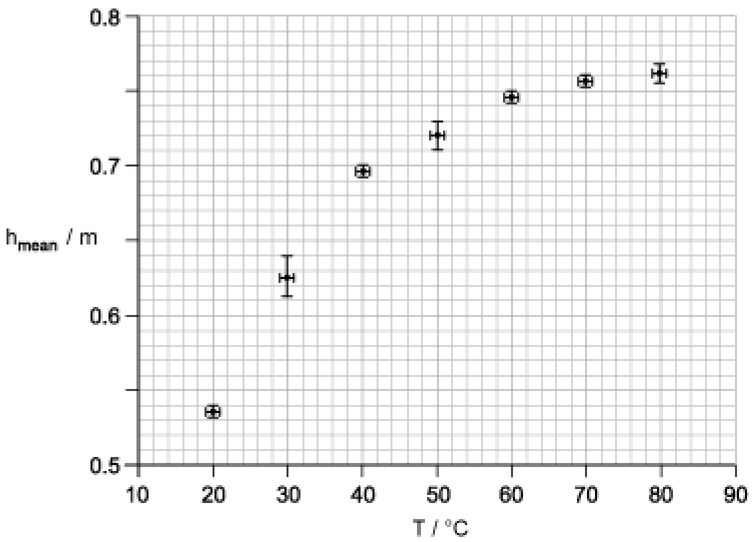
(c) Typically, using a simple pendulum to determine the acceleration of free fall g involves measuring the periodic time T and the pendulum length l.

State and explain which piece of measuring equipment is likely to have the biggest impact on the accuracy of the value determined for g.

(2 marks)

3 (a) An experiment is designed to explore the relationship between the temperature of a ball T and the maximum height to which it bounces h.

The ball is submerged in a beaker of water until thermal equilibrium is reached. The ball is then dropped from a constant height and the height of the first bounce is measured. This is repeated for different temperatures. The results are shown in the graph, which shows the variation of the mean maximum height h_{mean} with temperature T:



Compare and contrast the uncertainties in the values of h_{mean} and T.

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(3 marks)

(b) The experimenter hypothesises, from their results, that h_{mean} is proportional to T^2.

Suggest how the experimenter could use two points from the graph to validate this hypothesis.

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(2 marks)

(c) State and explain whether two points from the graph can confirm the experimenter's hypothesis.

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(3 marks)

4 (a) It is known that the energy per unit time P radiated by an object with surface area A at absolute temperature T is given by:

$$P = e\sigma AT^4$$

where e is the emissivity of the object and σ is the Stefan-Boltzmann constant.

In an experiment to determine the emissivity e of a circular surface of diameter d, the following measurements are taken:

- P = (3.0 ± 0.2) W
- d = (6.0 ± 0.1) cm
- T = (500 ± 1) K

Determine the value of the emissivity e of the surface and its uncertainty. Give your answer to an appropriate degree of precision.

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(4 marks)

(b) The power dissipated in a resistor can be investigated using a simple electrical circuit. The current in a fixed resistor, marked as 47 kΩ ± 5%, is measured to be (2.3 ± 0.1) A.

Determine the power dissipated in this resistor with its associated uncertainty. Give your answer to an appropriate degree of precision.

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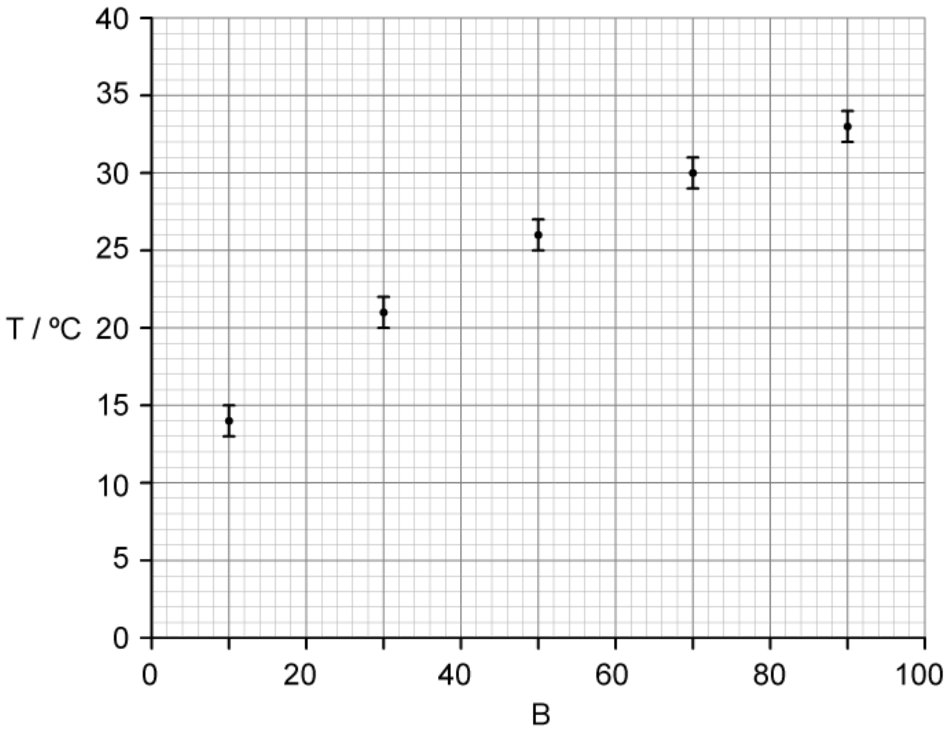
(3 marks)

5 (a) A student investigates the relationship between two variables *T* and *B*. Their results are plotted in the graph shown:



Comment on the absolute and fractional uncertainty for a pair of data points.

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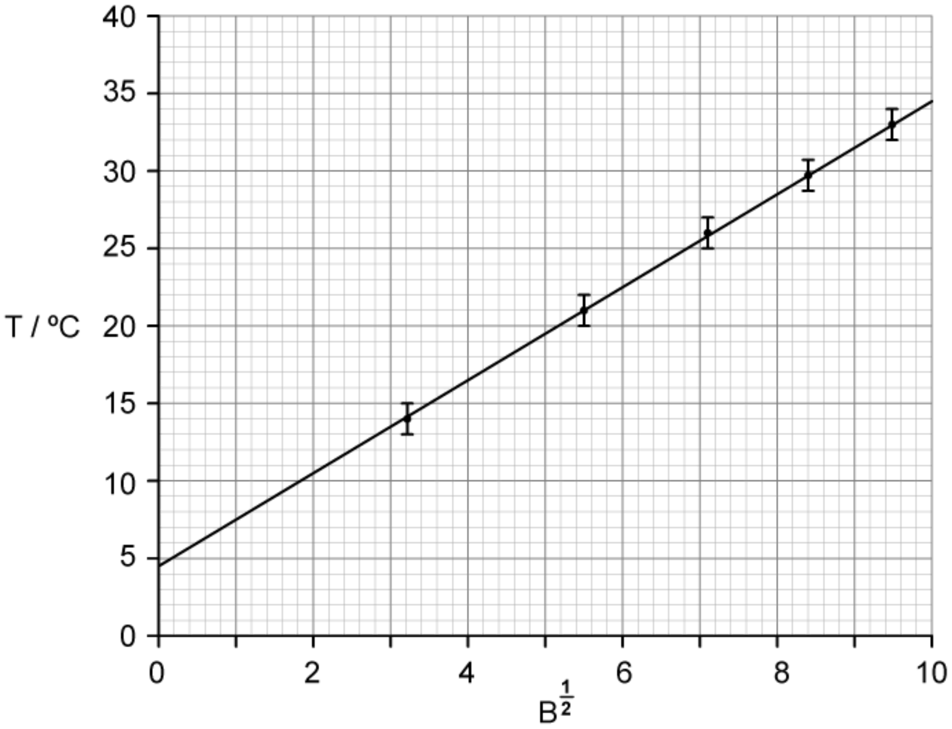
(3 marks)

(b) The student suggests that the relationship between *T* and *B* is of the form:

$$T = a\sqrt{B} + c$$

where *a* and *c* are constants. To test this suggested relationship, the following graph is drawn:



Describe a method that would determine the value of *c* and its uncertainty.

(4 marks)

(c) Comment on the student's suggestion from part (b).

(3 marks)