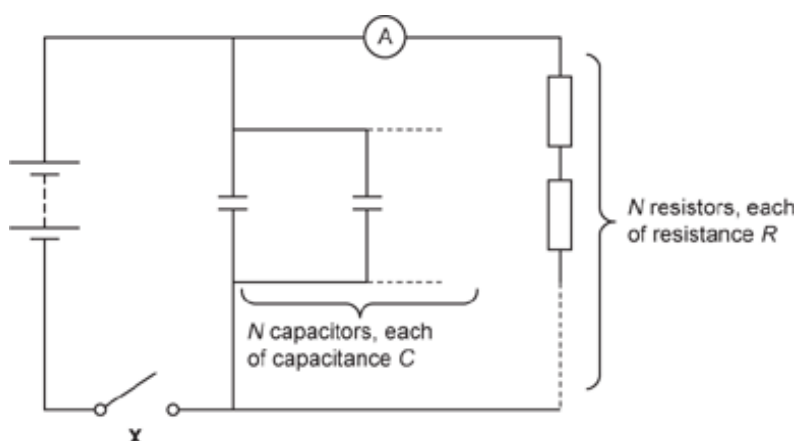


- one voltmeter
- one ammeter
- one sensitive thermistor, known to have resistance of approximately $0.1\ \Omega$ at $20\ ^\circ\text{C}$
- several connecting wires and crocodile clips.

Include how the student should:

- collect and analyse the data
- determine the uncertainties in the values of r and ε .

2(a). A group of students investigate the circuit shown in the figure below.



There are N capacitors, each of capacitance C , connected in parallel.

There are N resistors, each of resistance R , connected in series.

Initially, the students close the switch **X**. They then note the reading on the ammeter.

The students then open the switch. They record the time T for the reading on the ammeter to fall to half of its initial value.

The table below shows the students' results.

N	T/s			
	1	2	3	Mean
1	14.7	14.1	14.3	
2	50.3	49.6	50.1	
3	126.6	126.3	125.2	126.0
4	224.4	224.3	225.9	224.9
5	356.1	354.3	345.6	352.0
6	500.4	512.7	499.5	504.2

The students write in their lab books, "Our data is precise".

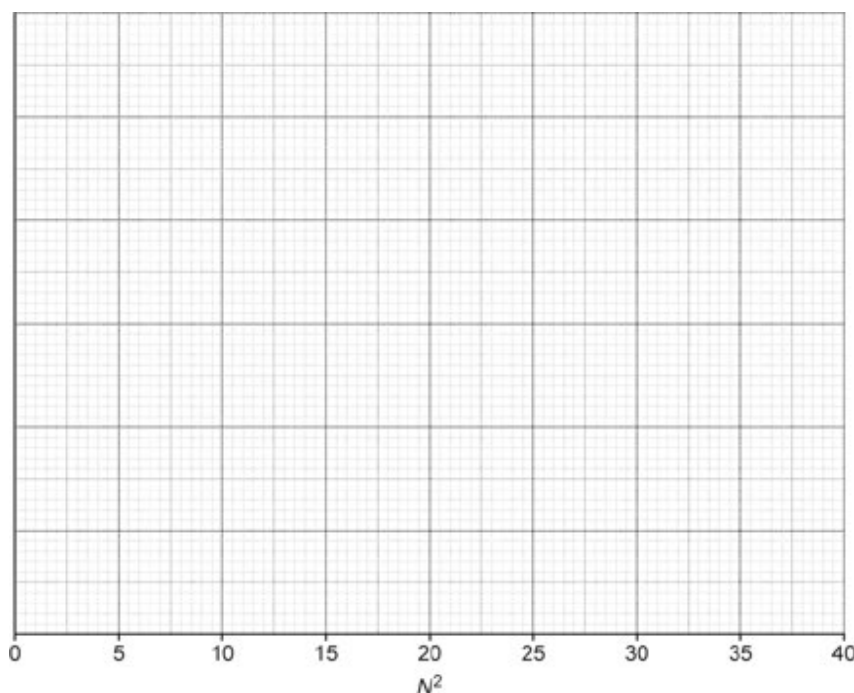
Evaluate this statement.

(b). Complete the last column for $N = 1$ and $N = 2$ in the results table.

[1]

(c). The students begin to plot a graph of T (y-axis) against N^2 (x-axis).

- i. Complete the graph below and plot the 6 results from the table. You are **not** expected to include error bars.



[4]

- ii. Draw a straight line of best fit on the graph.

[1]

- iii. Calculate the gradient of the straight line of best fit.

gradient = s [2]

- iv. The value of C is known to be $1000 \mu\text{F} \pm 5\%$.

Use your gradient value from (iii) to find a value for R , in units of $\text{k}\Omega$, including an **absolute** uncertainty.

$R = \dots\dots\dots \pm \dots\dots\dots \text{k}\Omega$ [2]

(d). Following the investigation, the students discovered that the sixth $1000\ \mu\text{F}$ capacitor connected to the circuit was actually two $470\ \mu\text{F}$ capacitors connected in parallel.

- i. State the type of error caused by this mistake.

[1]

- ii. Explain the effect that this error would have had on the calculated value of R .

[1]

3. A rubber bung is attached to a string. The bung is whirled around in a horizontal circle of radius r . The rotational period of the bung is T . The tension in the string is kept constant as the bung is whirled around at different speeds.

Which relationship is correct for this whirling bung?

- A** $T \propto r$
B $T^2 \propto r$
C $T \propto r^2$
D $T \propto \sqrt{r}$

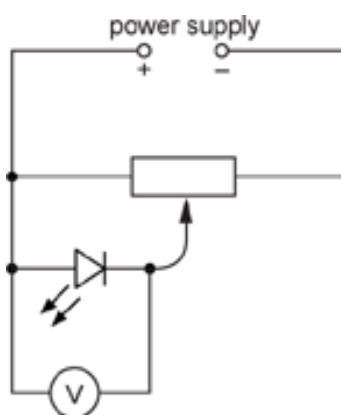
Your answer

☐

[1]

4(a). A student carries out an investigation to determine the value of the Planck constant, h .

They use the circuit shown below



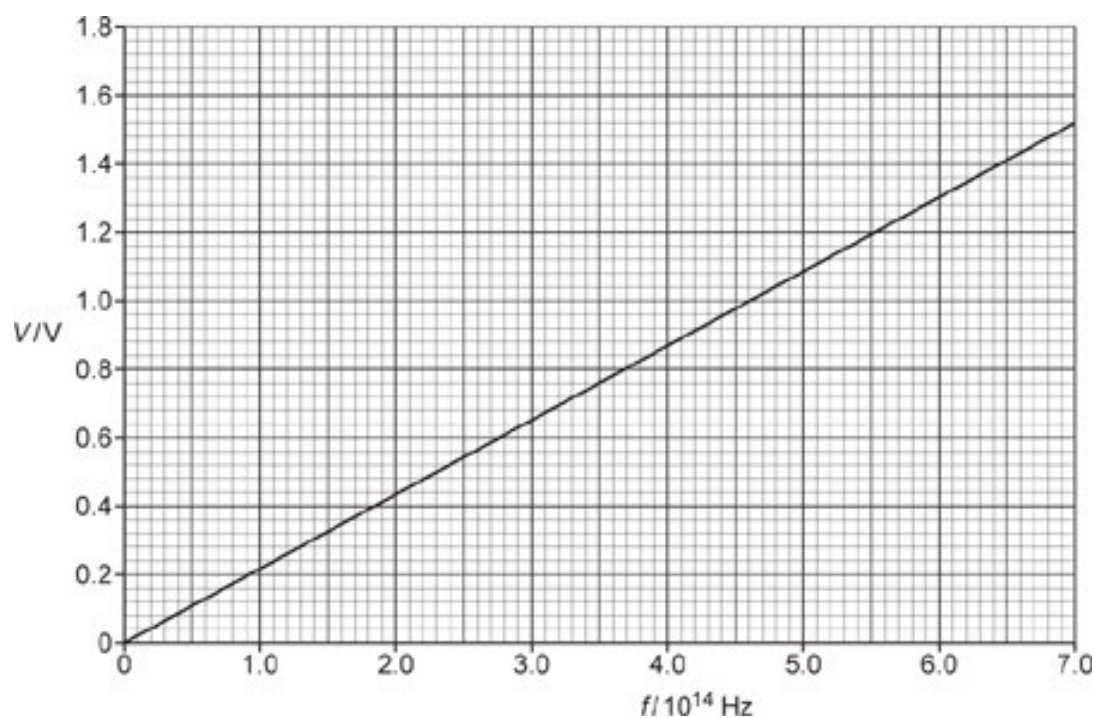
Initially the LED emits no light.

The student slowly increases the p.d. across the LED.

They record the p.d. V on the voltmeter when the LED just starts to emit light.

The measurement is repeated for LEDs that emit light with different frequencies f .

The student plots a graph of V against f , as shown below.



Calculate a value for the Planck constant using the graph.

Planck constant = J s [3]

(b). An accepted value for the Planck constant is $6.63 \times 10^{-34} \text{ J s}$.

Calculate the percentage uncertainty in the student's results.

percentage uncertainty = % [2]

5. A student makes measurements to determine the total energy W transferred by a filament lamp.

They record the measurements shown below.

Potential difference / V	12 ± 0.20
Current / mA	80 ± 1.0
Time / s	60 ± 0.01

What is the percentage uncertainty in their calculated value of W ?

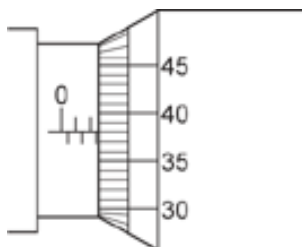
- A 0.2%
- B 1.2%
- C 2.9%
- D 7.2%

Your answer

[1]

6. The image shows a micrometer that is being used to measure the diameter of a wire.

The micrometer has a zero error of $+0.07$ mm. The measured value of the diameter from the micrometer scale is 2.88 mm.



What is the correct area of cross-section of the wire?

- A $2.21 \times 10^{-6} \text{ m}^2$
- B $6.20 \times 10^{-6} \text{ m}^2$
- C $6.51 \times 10^{-6} \text{ m}^2$
- D $6.84 \times 10^{-6} \text{ m}^2$

Your answer

[1]

7. In an experiment, a trapdoor and electromagnet are used to determine the acceleration of free fall of a ball.

The distance the ball falls is h and the time taken for the ball to fall is t .

The experiment is repeated for different values of h .

The table shows the results. Values of $\sqrt{h}$ have been included.

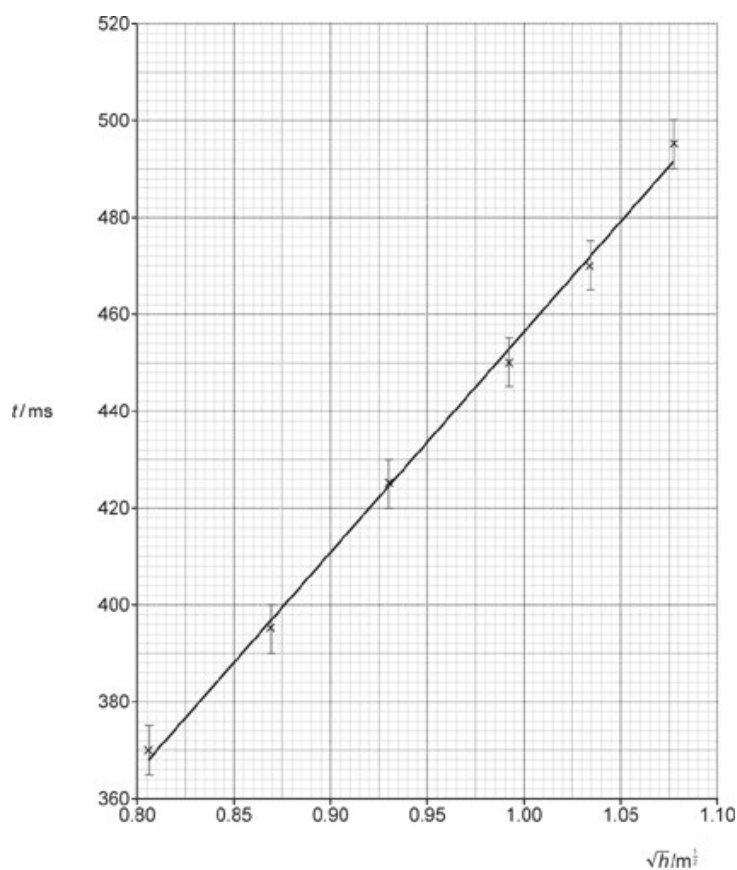
h/m	$\sqrt{h}/\text{m}^{1/2}$	t/ms
0.650	0.806	370 ± 5
0.755	0.869	395 ± 5
0.865	0.930	425 ± 5
0.985	0.992	450 ± 5
1.070	1.034	470 ± 5
1.160	1.077	495 ± 5

It is suggested that the relationship between t and h is

$$t = \sqrt{\frac{2}{g}}\sqrt{h} + k$$

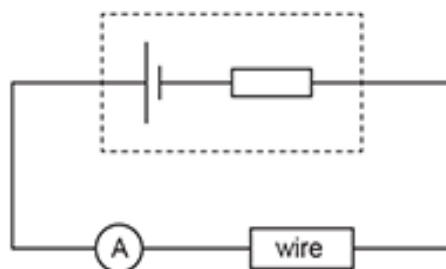
where g is the acceleration of free fall and k is a constant.

A graph of t/ms on the y-axis against $\sqrt{h}/\text{m}^{1/2}$ on the x-axis is plotted.



- [illegible]

8. A student uses the circuit below to investigate the resistivity of a wire.



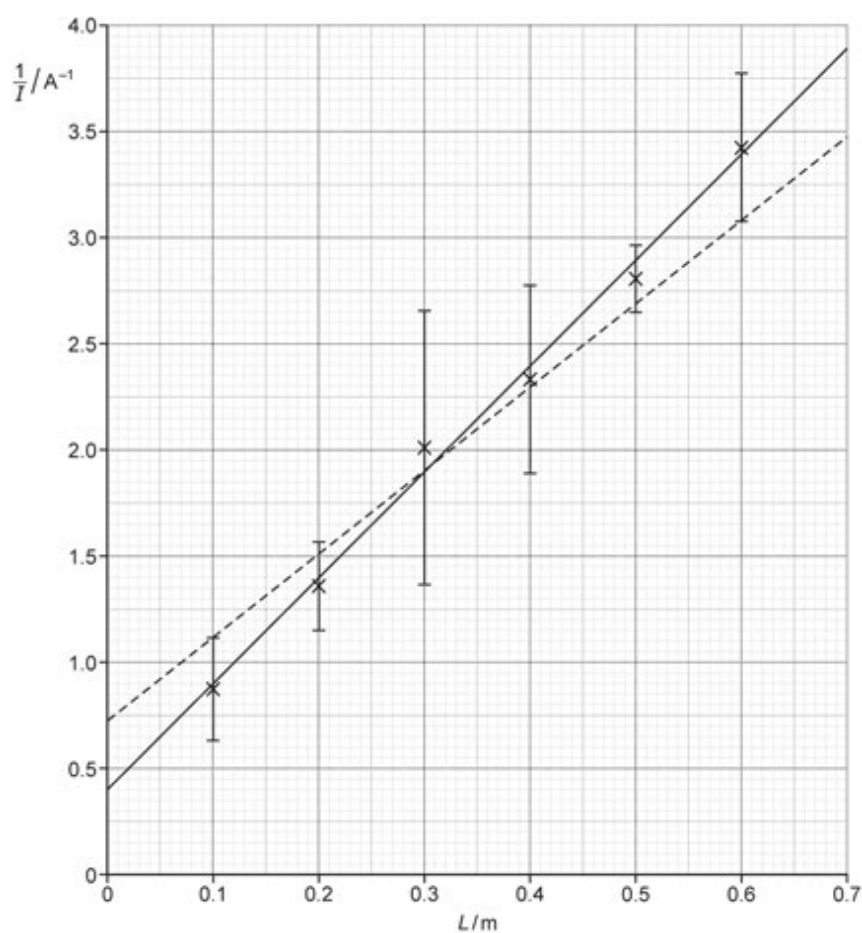
The student varies the length L of the wire in the circuit and records the current I using the ammeter.

i. Show that

$$\frac{1}{I} = \left(\frac{4\rho}{\pi \epsilon Q^2} \right) L + \frac{r}{\epsilon}$$

[3]

- ii. The student plots a graph of $\frac{1}{I}$ against L . The data points, error bars, line of best fit and a line of worst fit are shown in the graph below.



The cell has e.m.f. $\mathcal{E} = 1.45 \pm 0.05 \text{ V}$

The wire has diameter $d = 0.455 \pm 0.005 \text{ mm}$

Calculate the gradient of the best fit line and use this to determine a value for the resistivity ρ of the wire.

- 1 You are **not** required to determine an uncertainty.

$$\rho = \dots\dots\dots \Omega \text{ m} \text{ [2]}$$

Determine a value for the internal resistance r of the cell **and** its absolute uncertainty.

2

$$r = \dots\dots\dots \pm \dots\dots\dots \Omega \text{ [4]}$$

9. A student carries out an experiment to determine the speed v of sound in air. The student forms stationary sound waves in a resonance tube with water at the bottom as shown in **Fig. 7.1**.

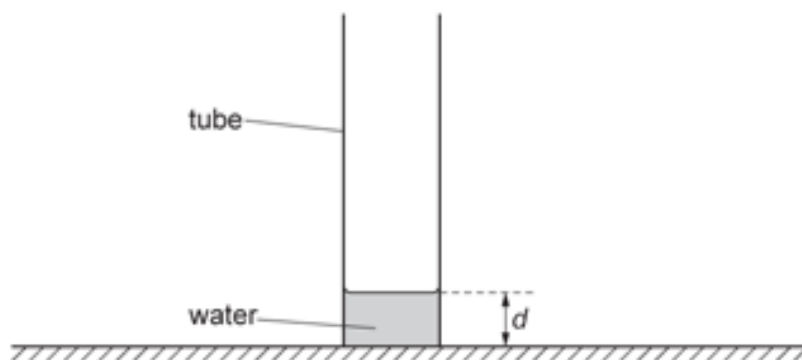


Fig. 7.1

The depth of the water is d .

Sound is produced by a signal generator connected to a loudspeaker. The sound is detected by a microphone connected to an oscilloscope.

The signal generator is adjusted. The frequency f of the fundamental mode of vibration of the sound in air is determined.

The experiment is repeated for different values of d .

The table shows the results. Values of $\frac{1}{f}$ have been included.

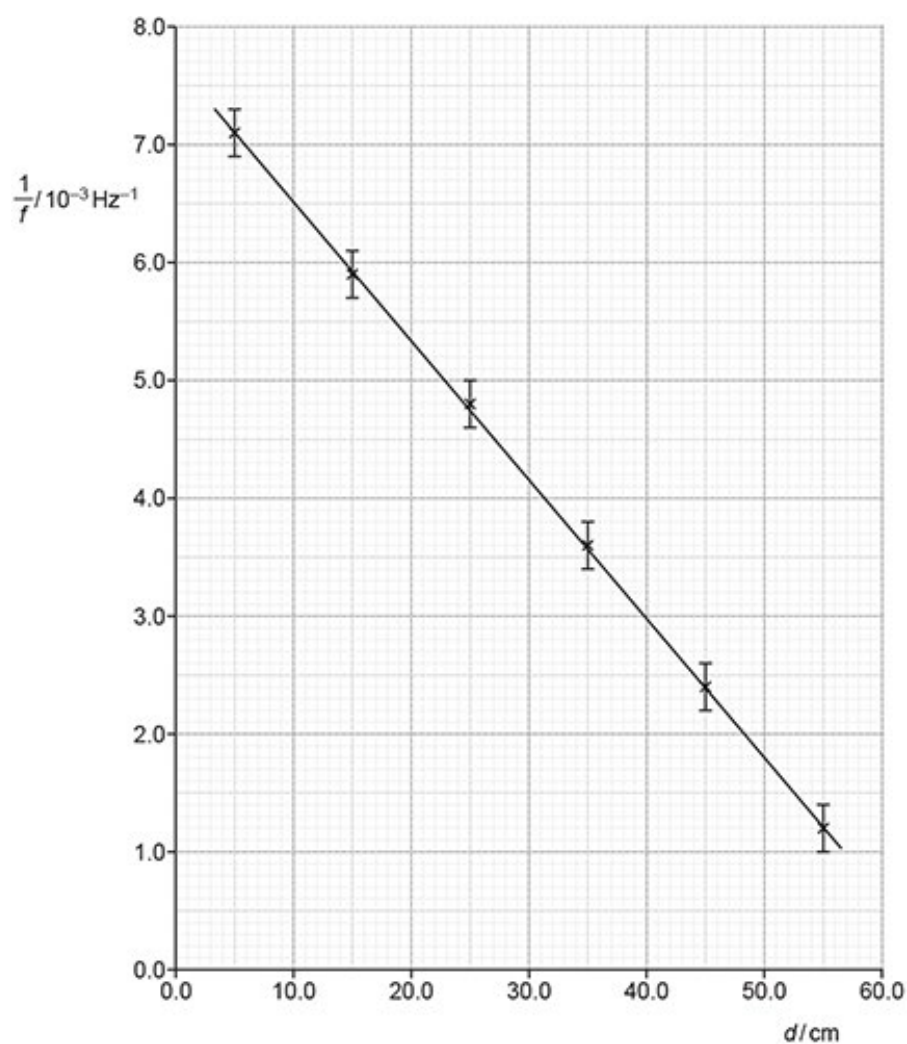
d / cm	f / Hz	$\frac{1}{f} / 10^{-3} \text{Hz}^{-1}$
5.0	140	7.1 ± 0.2
15.0	170	5.9 ± 0.2
25.0	210	4.8 ± 0.2
35.0	280	3.6 ± 0.2
45.0	420	2.4 ± 0.2
55.0	840	1.2 ± 0.2

It is suggested that the relationship between f and d is

$$\frac{1}{f} = -\frac{4d}{v} + c$$

where v is the speed of sound in air and c is a constant.

A graph of $\frac{1}{f} / 10^{-3} \text{Hz}^{-1}$ on the y-axis against d / cm on the x-axis is plotted as shown below.



This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

10. Two identical springs each have a force constant of 36 N m^{-1} . In an experiment, the two springs are suspended from a fixed support as shown in **Fig. 4.1**.

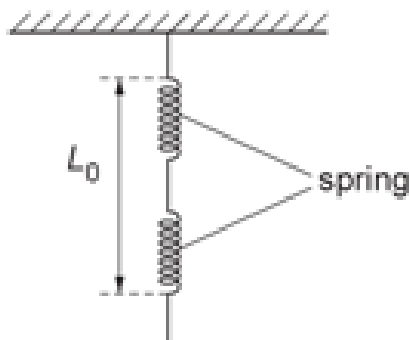


Fig. 4.1

The initial length of the spring arrangement is L_0 .

An object of mass M is added to the spring arrangement as shown in **Fig. 4.2**.

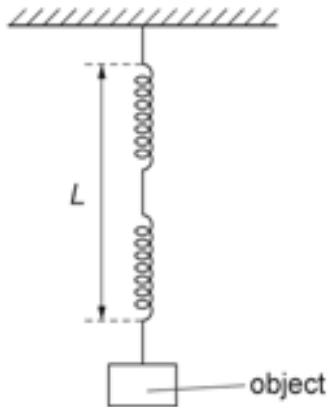


Fig. 4.2

The new length of the spring arrangement is L .

A student measures L_0 and L and records the results in a table.

Quantity	Measurement / mm
L_0	(22.2 ± 0.1)
L	(54.9 ± 0.1)

- i. State the name of the instrument the student used to measure L_0 and L .
-[1]
- ii. Determine the extension x of the spring arrangement. Include the absolute uncertainty in your answer.
- $x = \text{.....} \pm \text{..... mm}$ [1]
- iii. Calculate the mass M of the object. Write your answer to **2** significant figures.
- $M = \text{.....kg}$ [2]

- iv. Calculate the total energy W stored by the springs when the object is suspended.

$$W = \dots\dots\dots \text{J} \quad [2]$$

11. The Hipparcos space telescope used stellar parallax with a precision of 9.7×10^{-4} arcseconds to determine the distance to stars.

One of the stars studied was Polaris A. Data about this star is in the table below.

Parallax angle	7.5×10^{-3} arcseconds
Radius	2.1×10^{10} m
Mass	1.1×10^{31} kg
Surface temperature	6000 K
Temperature of the atmosphere of the star	4.0×10^6 K

- i. Estimate the maximum stellar distance in parsecs that could be measured using Hipparcos.

$$\text{maximum stellar distance} = \dots\dots\dots \text{pc} \quad [1]$$

- ii. Calculate the percentage uncertainty in the calculated value of the distance to Polaris A.

$$\text{percentage uncertainty} = \dots\dots\dots \% \quad [2]$$

12. The accepted value of g is 9.81 ms^{-2} . In an experiment to verify the value of g , students obtained a value of 10.20 ms^{-2} .

What is the percentage difference between the students' value and the accepted value of g ?

- A** 1%
B 2%
C 4%
D 8%

Your answer

[1]

13. A student investigates the oscillations of a uniform rod of length L which is pivoted at the top, as shown in **Fig. 2. 1**.

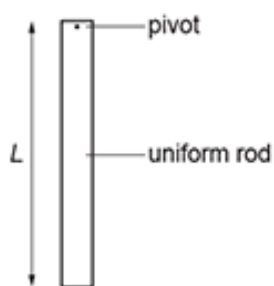


Fig. 2.1

The relationship between the frequency f of the oscillations of the rod and its length L is

$$f = \frac{1}{2\pi} \sqrt{\frac{3g}{2L}},$$

where g is the acceleration of free fall.

The student varies the length L of the rod and determines the period T for each length.

The student plots a graph of T^2 against L , shown in **Fig. 2.2**. A line of best fit has already been drawn.

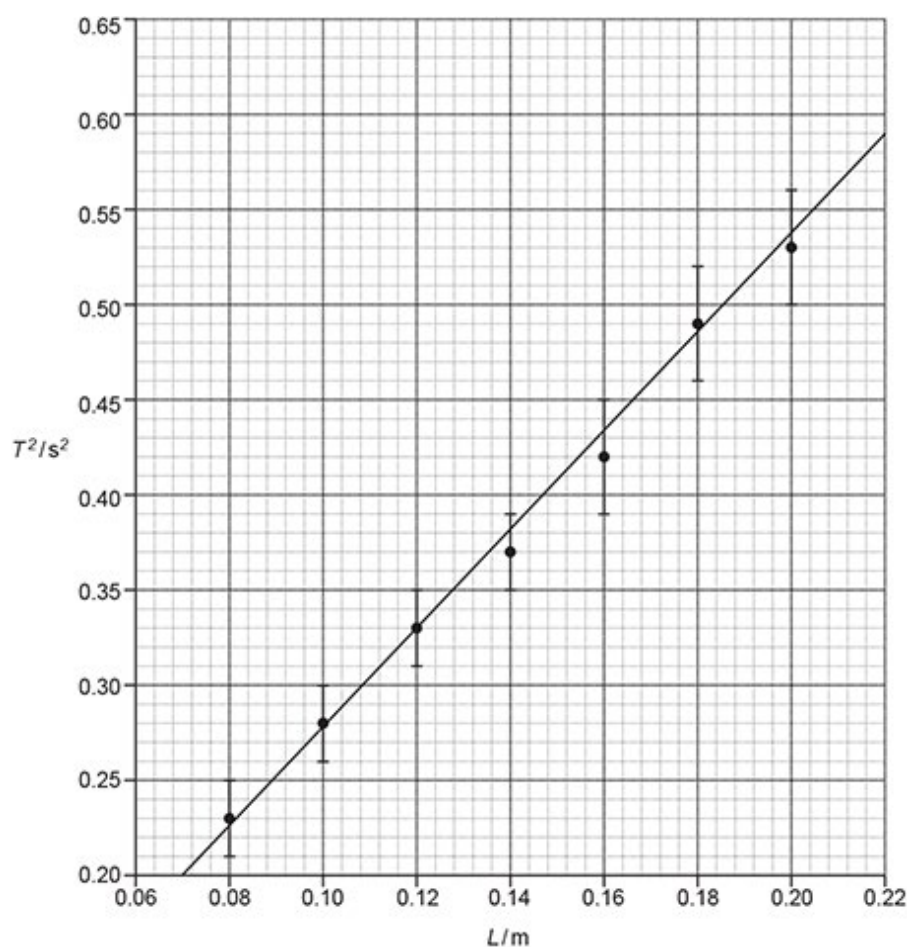


Fig. 2.2

- i. Show that the gradient of the graph is given by the equation

$$\text{gradient} = \frac{8\pi^2}{3g}$$

[2]

- ii. The gradient of the line of best fit on **Fig. 2.2** is $2.64 \text{ s}^2 \text{ m}^{-1}$.

Use this value to determine g .

$$g = \dots\dots\dots \text{ms}^{-2} \quad [2]$$

- iii. Draw a line of worst fit on **Fig. 2.2**.

[1]

- iv. Use your line of worst fit to calculate the percentage uncertainty in g .

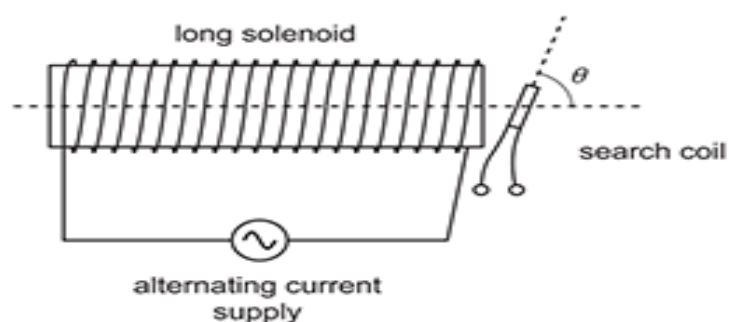
$$\text{percentage uncertainty} = \dots\dots\dots\% \quad [3]$$

- v. Use the true value of g (9.81 ms^{-2}) to evaluate the accuracy of the student's value of g from this experiment. Include a calculation in your answer.

[2]

14.

A student is carrying out an experiment using a search coil.



A long solenoid is connected to an alternating current supply.

The search coil is placed at one end of the solenoid. The plane of the search coil is tilted such that it makes an angle θ with the central axis of the solenoid. The maximum alternating induced electromotive force (e.m.f.) across the ends of the search coil is E_0 .

- i. Name an instrument that can be used to determine E_0

----- [1]

- ii. The equation for E_0 is:

$$E_0 = K I_0 ANf \sin \theta$$

where I_0 = maximum current in the solenoid, A = cross-sectional area of the search coil, N = number of turns of the search coil, f = frequency of the alternating current in the solenoid and $K = 4.0 \times 10^{-3} \text{ VA}^{-1} \text{ m}^{-2} \text{ s}$.

The magnitude of the induced e.m.f. in the search coil can be determined using Faraday's law of electromagnetic induction:

e.m.f. = rate of change of magnetic flux linkage

In the experiment, angle θ is changed and E_0 measured.

Suggest the quantity, or quantities, in the equation $E_0 = K I_0 ANf \sin \theta$ linked to

- 1 the 'rate' part of the law

----- [1]

- 2 the 'change of magnetic flux linkage' part of the law.

----- [1]

- iii. The student plots a straight-line graph of E_0 against $\sin \theta$.

Determine f , including the absolute uncertainty. Write your value of f to **2** significant figures.

$$I_0 = (8.0 \pm 0.2) \text{ A}$$

$$A = (7.8 \pm 0.1) \times 10^{-5} \text{ m}^2$$

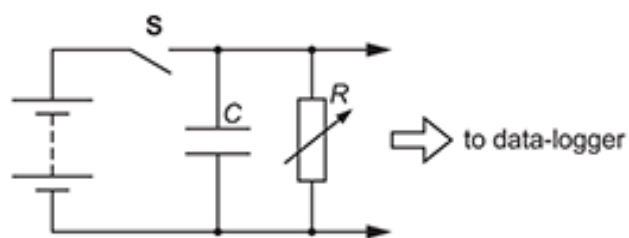
$$N = 5000$$

$$\text{gradient of line} = K I_0 ANf = (0.62 \pm 0.03) \text{ V}$$

$$f = \text{.....} \pm \text{..... Hz [4]}$$

15.

A student discharges a capacitor of capacitance C through a variable resistor of resistance R using the arrangement below.



The capacitor is made from two parallel metal plates separated by a sheet of paper of thickness 8.0×10^{-5} m. The area of overlap between the plates is 3.1×10^{-2} m².

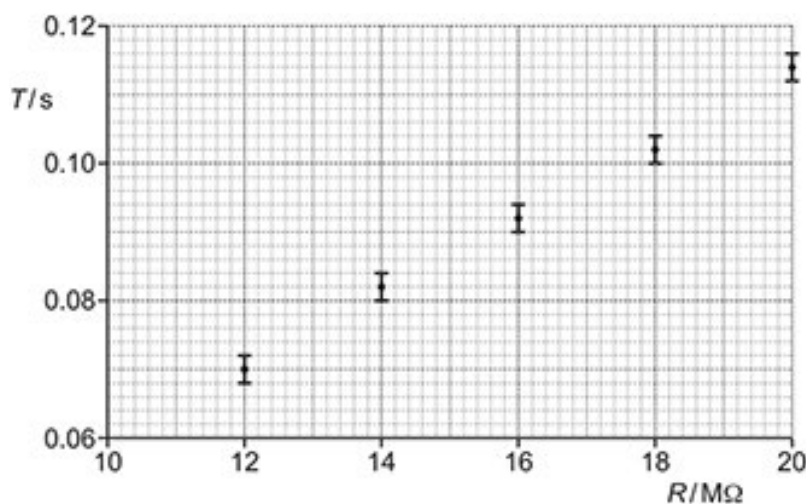
The capacitor is charged fully by closing switch **S**. At time $t = 0$, **S** is opened and the capacitor discharges through the resistor. After $t = T$, the potential difference across the capacitor is halved. The student repeats this for several values of R .

- i. The student decides to plot T against R to obtain a straight-line graph.

Show that the line has gradient $= C \ln 2$.

[2]

- ii. The data points plotted by the student are shown below.



Draw a best-fit straight line through the data points and use the gradient of this line to determine C .

1

$C = \dots\dots\dots$ F [3]

Use your answer in (ii)1 to calculate the permittivity ϵ of the paper.

2

$$\epsilon = \dots\dots\dots \text{F m}^{-1} \quad [2]$$

16. The diameter of a wire is measured in five different places along its length. The results are shown below.

1.92mm 1.88mm 1.90mm 1.86mm 1.89mm

What is the absolute uncertainty in the diameter of this wire?

- A 0.01 mm
- B 0.03 mm
- C 0.05 mm
- D 0.06 mm

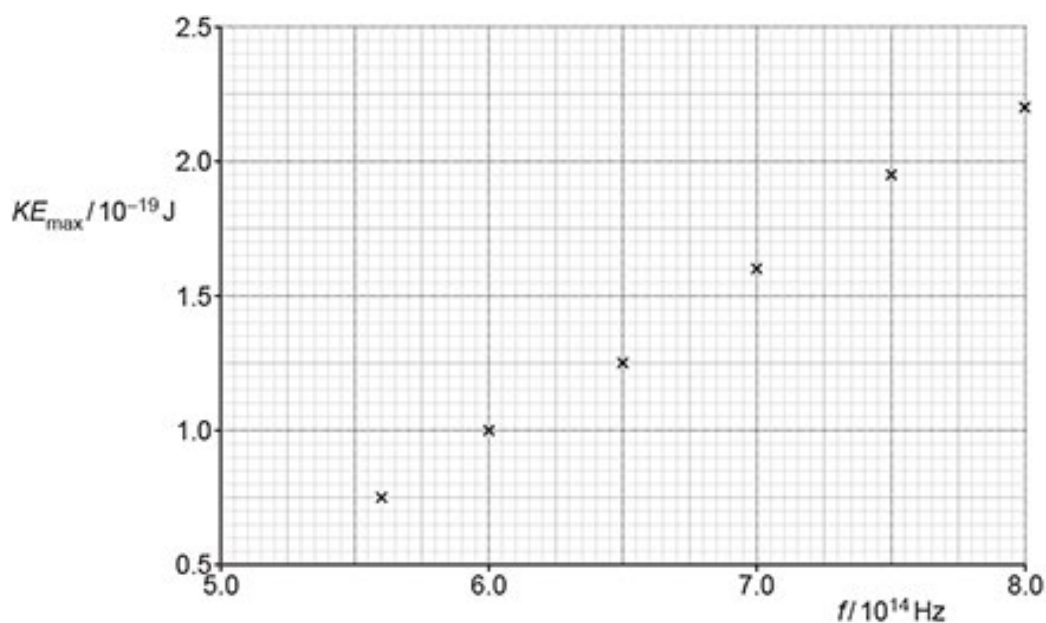
Your answer

[1]

17.

A researcher is carrying out an experiment to determine the work function ϕ of a new material. The material is illuminated by electromagnetic radiation of frequency f and the maximum kinetic energy KE_{max} of the photoelectrons is determined.

The researcher plots the data points shown below.



- i. Draw a straight line of best fit through the data points.

[1]

- ii. Use the gradient of this line, and Einstein's photoelectric equation, to determine the work function ϕ of the material.

$$\phi = \dots\dots\dots \text{ J [3]}$$

18.

A wire is fixed between two supports, as shown in **Fig. 24**.



Fig. 24.

The wire is plucked in the middle. A stationary wave of fundamental frequency f is formed on the stretched wire.

The tension T in the stretched wire is given by the expression $T = 4f^2 mL$, where f is the frequency of the oscillating wire, m is the mass of the wire and L is the length of the wire.

A student is performing an experiment to determine the tension T in the wire. The measurements are shown in the table below.

Quantity	Measurement	Percentage uncertainty
f	58 Hz	2.5
m	$9.7 \times 10^{-4} \text{ kg}$	1.0
L	0.62m	0.5

- i. Suggest how the student may have determined the fundamental frequency of the oscillating wire in the laboratory.

[2]

- ii. Use the data in the table to determine

1

the wavelength of the progressive waves on the stretched wire

wavelength = m [1]

2

the speed of the progressive waves on the stretched wire

speed = m s⁻¹ [2]

3

the **absolute** uncertainty in the tension T . Write your answer to 2 significant figures.

absolute uncertainty in T = N [2]

19(a). An electric cooker has two independent heating rings **A** and **B** as shown in **Fig. 7.1**.



Fig. 7.1

The cooker rings **A** and **B** are connected in parallel to a 230 V power supply. At maximum power, ring **A** has a power of 1100 W and ring **B** has a power of 1700 W.

The filament in ring **A** is a metallic wire of length 11.8 m.

At maximum power the wire has resistance $31\ \Omega$ and the metal has resistivity $4.8 \times 10^{-7}\ \Omega\text{ m}$.

Calculate the diameter d of the wire.

$$d = \dots\dots\dots\text{ m [3]}$$

(b). **Fig. 7.2** shows the circuit symbol for ring **A**.



Fig. 7.2

A student uses a battery of four cells, an ammeter and a voltmeter to determine the resistance of the wire in ring **A** experimentally.

- i. Complete **Fig. 7.2** to show how the student should connect the circuit to determine the resistance.

[2]

- ii. The current in the wire is $0.34 \pm 0.02\text{ A}$ and the potential difference across the wire is $6.2 \pm 0.2\text{ V}$.

Calculate the resistance R of the wire.

$$R = \dots\dots\dots\ \Omega \text{ [1]}$$

- iii. Calculate the percentage uncertainty in R .

percentage uncertainty = % **[2]**

- iv. Suggest why R from **(c)(ii)** is less than $31\ \Omega$.

[2]

- v. Suggest **two** improvements to the student's experiment to determine R experimentally.

1

2

[2]

END OF QUESTION PAPER