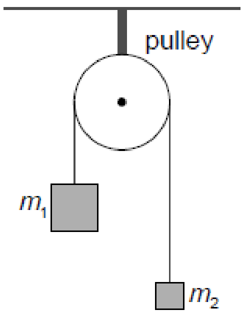
Measurement-practice-ShortA

[179 marks]

In an experiment to measure the acceleration of free fall a student ties two different blocks of masses m_1 and m_2 to the ends of a string that passes over a frictionless pulley.



The student calculates the acceleration a of the blocks by measuring the time taken by the heavier mass to fall through a given distance. Their theory predicts that $a = g\frac{m_1 - m_2}{m_1 + m_2}$ and this can be re-arranged to give $g = a\frac{m_1 + m_2}{m_1 - m_2}$.

In a particular experiment the student calculates that a = (0.204 ±0.002) ms^{-2} using m_1 = (0.125 ±0.001) kg and m_2 = (0.120 ±0.001) kg.

1a. Calculate the percentage error in the measured value of g. *[3 marks]*

1b. Deduce the value of g and its absolute uncertainty for this experiment. *[2 marks]*

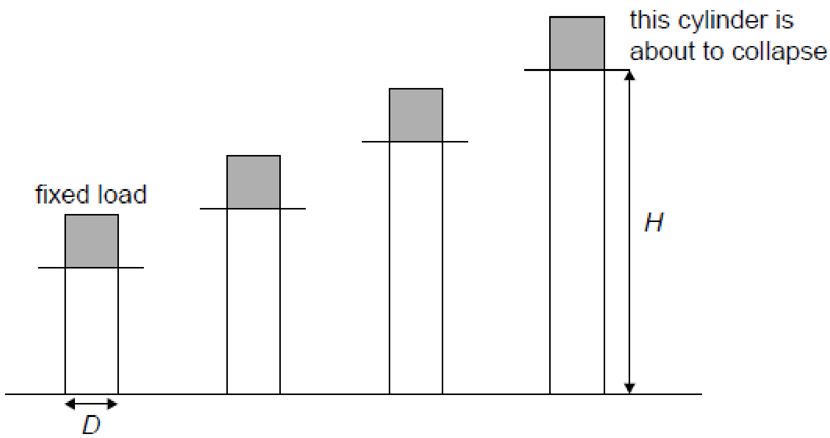
1c. There is an advantage and a disadvantage in using two masses that are almost equal. *[2 marks]*

State and explain the advantage with reference to the magnitude of the acceleration that is obtained.

1d. There is an advantage and a disadvantage in using two masses that are almost equal. *[2 marks]*

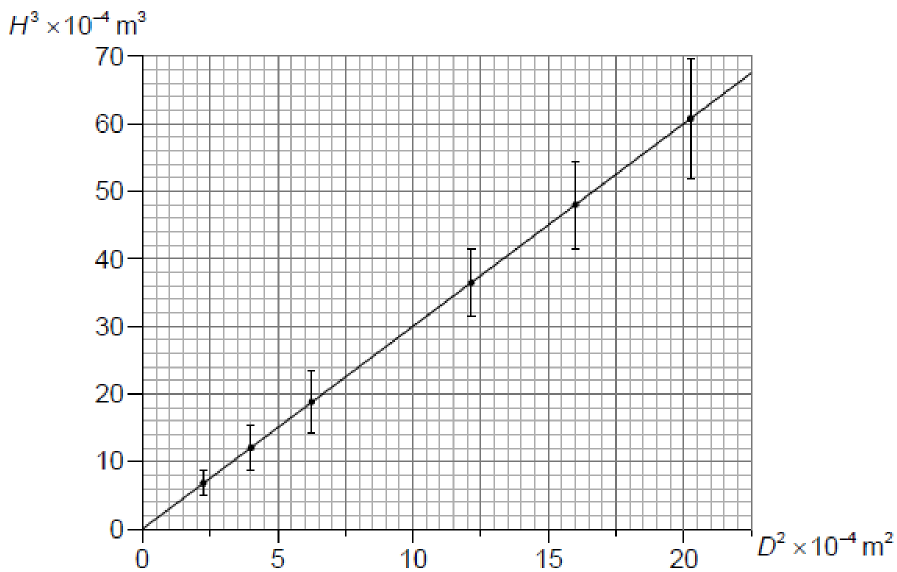
State and explain the disadvantage with reference to your answer to (a)(ii).

In an investigation a student folds paper into cylinders of the same diameter D but different heights. Beginning with the shortest cylinder they applied the same fixed load to each of the cylinders one by one. They recorded the height H of the first cylinder to collapse.



They then repeat this process with cylinders of different diameters.

The graph shows the data plotted by the student and the line of best fit.



Theory predicts that $H = cD^{\frac{2}{3}}$ where c is a constant.

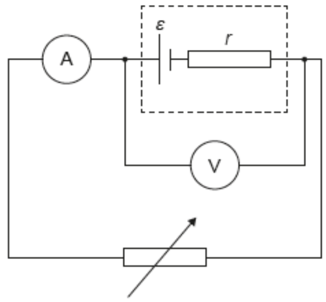
2a. Suggest why the student's data supports the theoretical prediction. *[2 marks]*

2b. Determine c. State an appropriate unit for c. *[3 marks]*

2c. Determine c. State an appropriate unit for c. *[3 marks]*

2d. Identify **one** factor that determines the value of c. *[1 mark]*

A student investigates the electromotive force (emf) ε and internal resistance r of a cell.



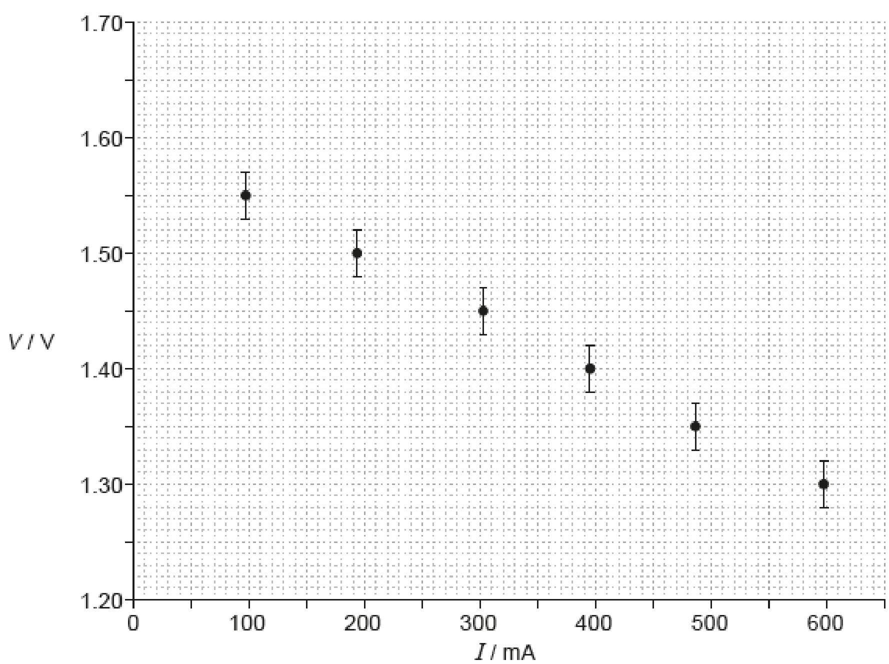
The current I and the terminal potential difference V are measured.

For this circuit $V = \varepsilon - Ir$.

The table shows the data collected by the student. The uncertainties for each measurement
are shown.

I / mA ± 1 mA	V / V ± 0.02 V
97	1.55
193	1.50
304	1.45
395	1.40
487	1.35
598	1.30

The graph shows the data plotted.



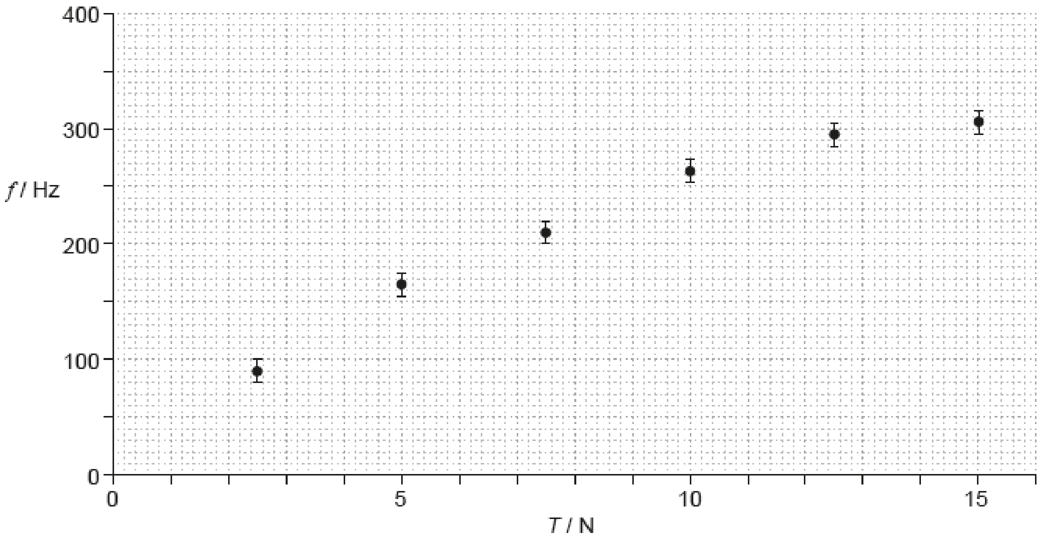
3a. The student has plotted error bars for the potential difference. Outline why no error bars are shown for the current. *[1 mark]*

3b. Determine, using the graph, the emf of the cell including the uncertainty for this value. Give your answer to the correct number of significant figures. *[3 marks]*

3c. Outline, **without** calculation, how the internal resistance can be determined from this graph. *[2 marks]*

An experiment is conducted to determine how the fundamental frequency *f* of a vibrating wire varies with the tension *T* in the wire.

The data are shown in the graph, the uncertainty in the tension is not shown.



4a. Draw the line of best fit for the data. *[1 mark]*

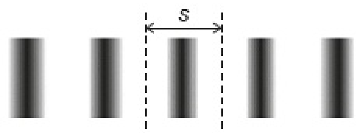
It is proposed that the frequency of oscillation is given by $f^2 = kT$ where *k* is a constant.

4b. Determine the fundamental SI unit for *k*. *[1 mark]*

4c. Write down a pair of quantities that, when plotted, enable the relationship $f^2 = kT$ to be verified. *[1 mark]*

4d. Describe the key features of the graph in (b)(ii) if it is to support this relationship. *[2 marks]*

A student uses a Young's double-slit apparatus to determine the wavelength of light emitted by a monochromatic source. A portion of the interference pattern is observed on a screen.



The distance *D* from the double slits to the screen is measured using a ruler with a smallest scale division of 1 mm.

The fringe separation s is measured with uncertainty ± 0.1 mm.

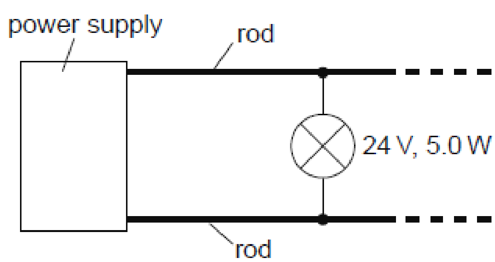
The slit separation d has negligible uncertainty.

The wavelength is calculated using the relationship $\lambda = \frac{sd}{D}$.

5a. When d = 0.200 mm, s = 0.9 mm and D = 280 mm, determine the percentage uncertainty in the wavelength. *[2 marks]*

5b. Explain how the student could use this apparatus to obtain a more reliable value for λ. *[2 marks]*

A lighting system consists of two long metal rods with a potential difference maintained between them. Identical lamps can be connected between the rods as required.



The following data are available for the lamps when at their working temperature.

Lamp specifications 24 V, 5.0 W

Power supply emf 24 V

Power supply maximum current 8.0 A

Length of each rod 12.5 m

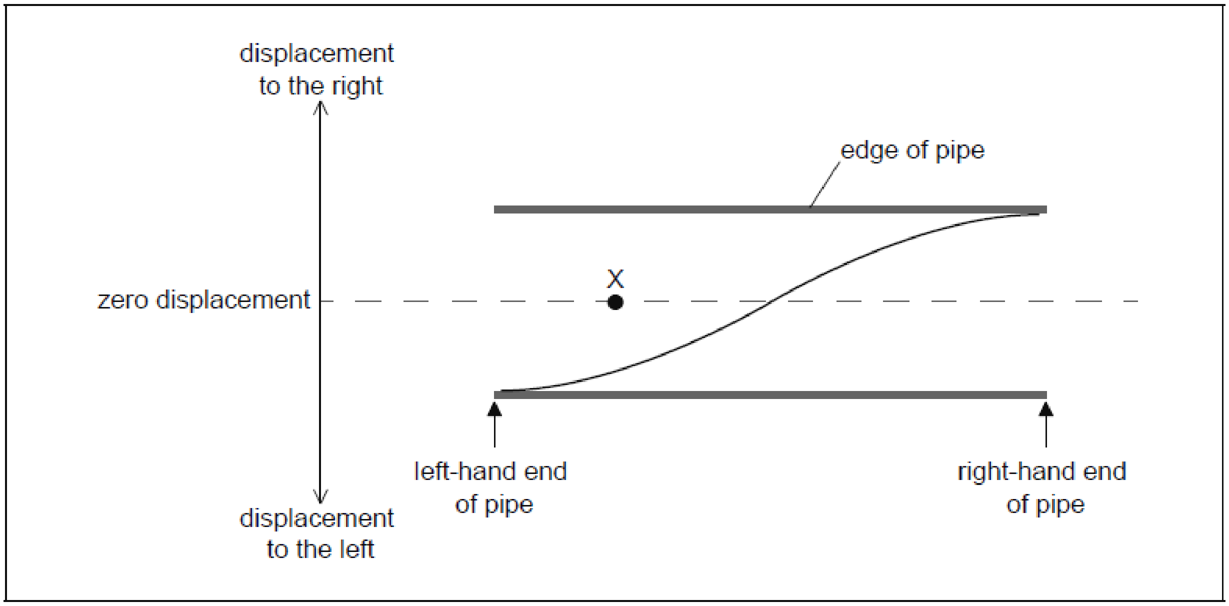
Resistivity of rod metal 7.2×10^{-7} Ω m

6a. Each rod is to have a resistance no greater than 0.10 Ω. Calculate, in m, the minimum radius of each rod. Give your answer to an appropriate number of significant figures. *[3 marks]*

6b. Calculate the maximum number of lamps that can be connected between the rods. Neglect the resistance of the rods. *[2 marks]*

6c. One advantage of this system is that if one lamp fails then the other lamps in the circuit remain lit. Outline **one** other electrical advantage of this system compared to one in which the lamps are connected in series. *[1 mark]*

A pipe is open at both ends. A first-harmonic standing wave is set up in the pipe. The diagram shows the variation of displacement of air molecules in the pipe with distance along the pipe at time $t = 0$. The frequency of the first harmonic is f.



7a. An air molecule is situated at point X in the pipe at $t = 0$. Describe the motion of this air molecule during one complete cycle of the standing wave beginning from $t = 0$. *[2 marks]*

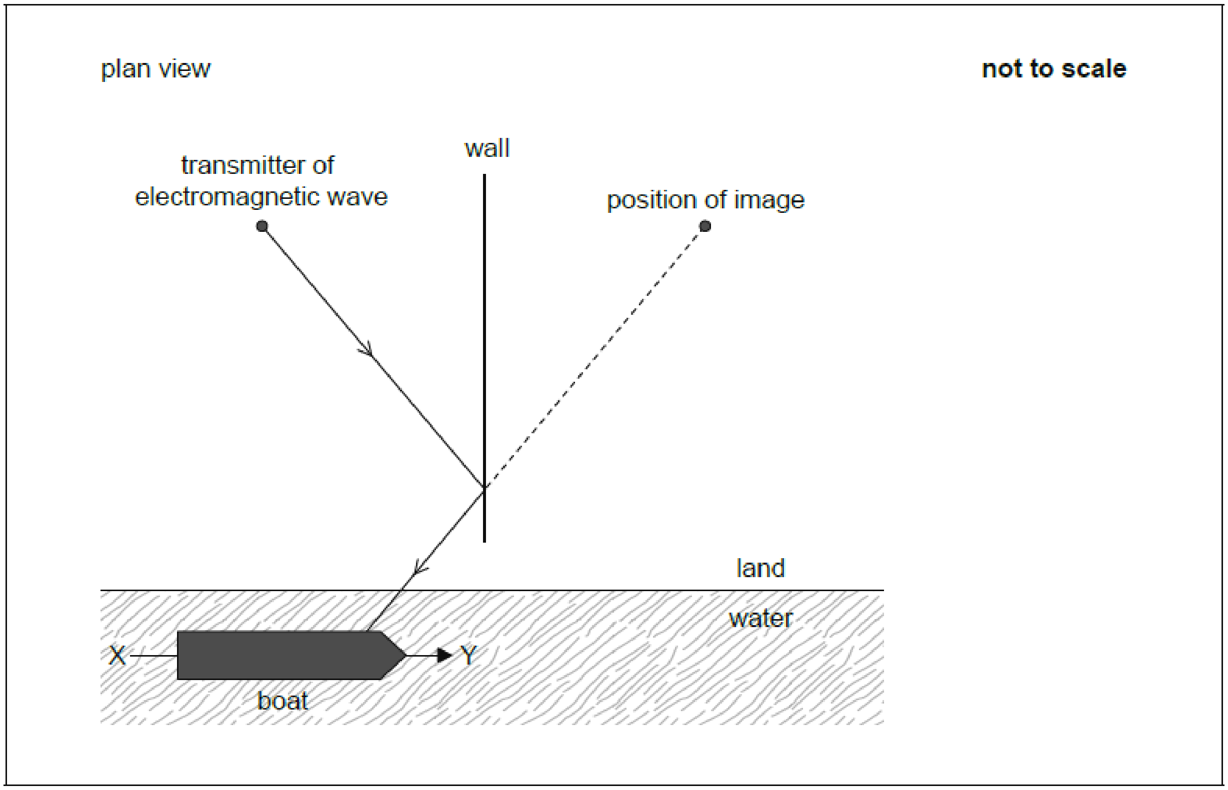
7b. The speed of sound c for longitudinal waves in air is given by *[3 marks]*

$$c = \sqrt{\frac{K}{\rho}}$$

where ρ is the density of the air and K is a constant.

A student measures f to be 120 Hz when the length of the pipe is 1.4 m. The density of the air in the pipe is 1.3 kg m^{-3}. Determine, in kg m^{-1} s^{-2}, the value of K for air.

A transmitter of electromagnetic waves is next to a long straight vertical wall that acts as a plane mirror to the waves. An observer on a boat detects the waves both directly and as an image from the other side of the wall. The diagram shows one ray from the transmitter reflected at the wall and the position of the image.



7c. Demonstrate, using a second ray, that the image appears to come from the position indicated. *[1 mark]*

7d. Outline why the observer detects a series of increases and decreases in the intensity of the received signal as the boat moves along the line XY. *[2 marks]*

8a. Each rod is to have a resistance no greater than 0.10 Ω. Calculate, in m, the minimum radius of each rod. Give your answer to an appropriate number of significant figures. *[3 marks]*

8b. Calculate the maximum number of lamps that can be connected between the rods. Neglect the resistance of the rods. *[2 marks]*

8c. One advantage of this system is that if one lamp fails then the other lamps in the circuit remain lit. Outline **one** other electrical advantage of this system compared to one in which the lamps are connected in series. *[1 mark]*

A step-down transformer is used to transfer energy to the two rods. The primary coil of this transformer is connected to an alternating mains supply that has an emf of root mean square (rms) magnitude 240 V. The transformer is 95 % efficient.

8d. Outline how eddy currents reduce transformer efficiency. *[2 marks]*

8e. Determine the peak current in the primary coil when operating with the maximum number of lamps. *[4 marks]*

9a. Sketch, on the diagram, the variation of displacement of the air molecules with distance along the pipe when $t = \frac{3}{4f}$. *[1 mark]*

9b. An air molecule is situated at point X in the pipe at $t = 0$. Describe the motion of this air molecule during one complete cycle of the standing wave beginning from $t = 0$. *[2 marks]*

9c. The speed of sound c for longitudinal waves in air is given by *[4 marks]*

$$c = \sqrt{\frac{K}{\rho}}$$

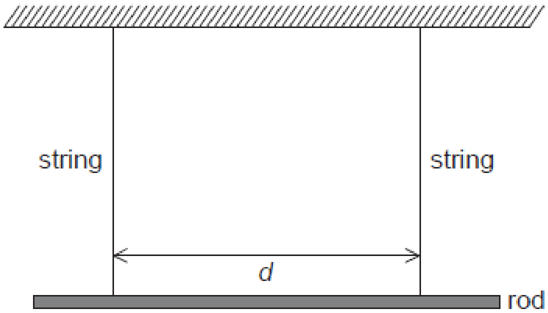
where ρ is the density of the air and K is a constant.

A student measures f to be 120 Hz when the length of the pipe is 1.4 m. The density of the air in the pipe is 1.3 kg m^{-3}. Determine the value of K for air. State your answer with the appropriate fundamental (SI) unit.

9d. Demonstrate, using a second ray, that the image appears to come from the position indicated. *[1 mark]*

9e. Outline why the observer detects a series of increases and decreases in the intensity of the received signal as the boat moves along the line XY. *[2 marks]*

In an investigation to measure the acceleration of free fall a rod is suspended horizontally by two vertical strings of equal length. The strings are a distance *d* apart.



When the rod is displaced by a small angle and then released, simple harmonic oscillations take place in a horizontal plane.

The theoretical prediction for the period of oscillation *T* is given by the following equation

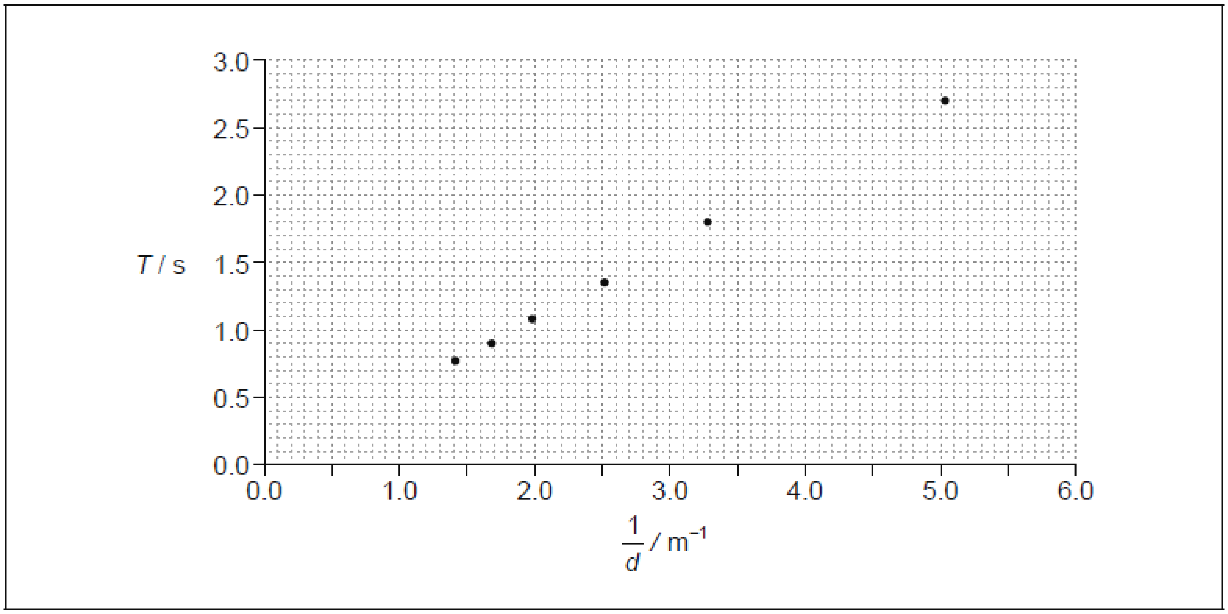
$$T = \frac{c}{d\sqrt{g}}$$

where *c* is a known numerical constant.

10a. State the unit of *c*. *[1 mark]*

10b. A student records the time for 20 oscillations of the rod. Explain how this procedure leads to a more precise measurement of the time for **one** oscillation *T*. *[2 marks]*

In one experiment d was varied. The graph shows the plotted values of T against $\frac{1}{d}$. Error bars are negligibly small.



10c. Draw the line of best fit for these data. *[1 mark]*

10d. Suggest whether the data are consistent with the theoretical prediction. *[2 marks]*

10e. The numerical value of the constant c in SI units is 1.67. Determine g, using the graph. *[4 marks]*

In an experiment to measure the specific latent heat of vaporization of water L_v, a student uses an electric heater to boil water. A mass m of water vaporizes during time t. L_v may be calculated using the relation

$$L_v = \frac{VIt}{m}$$

where V is the voltage applied to the heater and I the current through it.

11a. Outline why, during the experiment, V and I should be kept constant. *[1 mark]*

11b. Outline whether the value of L_v calculated in this experiment is expected to be larger or smaller than the actual value. *[2 marks]*

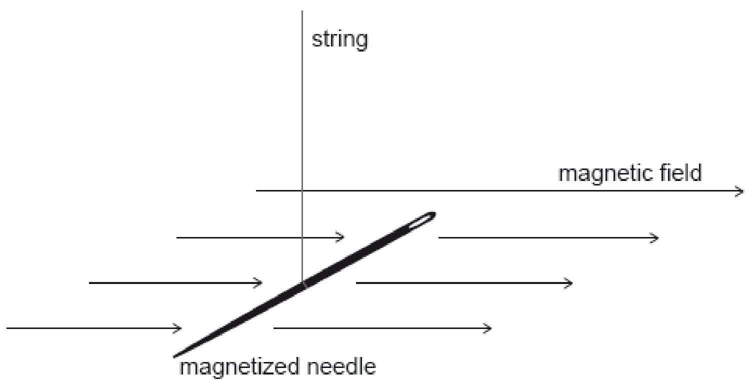
11c. A student suggests that to get a more accurate value of L_v the experiment should be performed twice using different heating rates. *[2 marks]*

With voltage and current V_1, I_1 the mass of water that vaporized in time t is m_1.
With voltage and current V_2, I_2 the mass of water that vaporized in time t is m_2.
The student now uses the expression

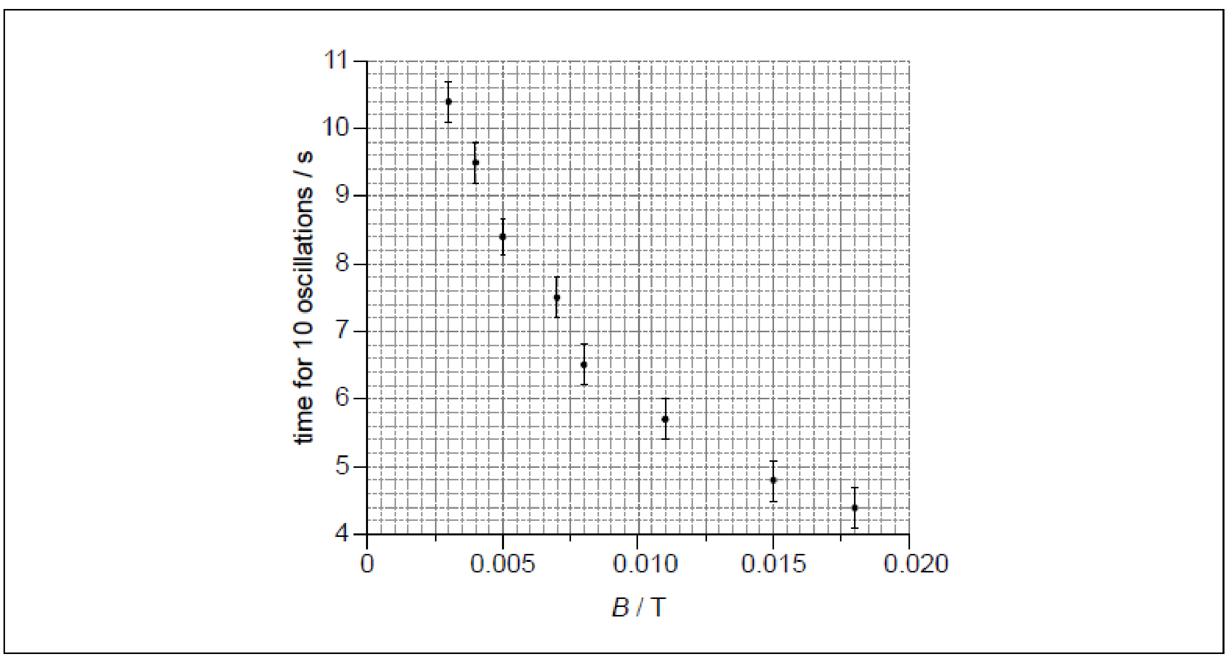
$$L_v = \frac{(V_1 I_1 - V_2 I_2)\,t}{m_1 - m_2}$$

to calculate L_v. Suggest, by reference to heat losses, why this is an improvement.

A magnetized needle is oscillating on a string about a vertical axis in a horizontal magneticfield B. The time for 10 oscillations is recorded for different values of B.



The graph shows the variation with B of the time for 10 oscillations together with the uncertainties in the time measurements. The uncertainty in B is negligible.



12a. Draw on the graph the line of best fit for the data. *[1 mark]*

12b. Write down the time taken for one oscillation when B = 0.005 T with its absolute uncertainty. *[1 mark]*

12c. A student forms a hypothesis that the period of one oscillation P is given by: *[3 marks]*

$$P = \frac{K}{\sqrt{B}}$$

where K is a constant.

Determine the value of K using the point for which B = 0.005 T.

State the uncertainty in K to an appropriate number of significant figures.

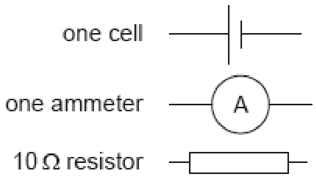
12d. State the unit of K. *[1 mark]*

12e. The student plots a graph to show how P^2 varies with $\frac{1}{B}$ for the data. *[2 marks]*

Sketch the shape of the expected line of best fit on the axes below assuming that the relationship $P = \frac{K}{\sqrt{B}}$ is verified. You do **not** have to put numbers on the axes.

12f. State how the value of K can be obtained from the graph. *[1 mark]*

An experiment to find the internal resistance of a cell of known emf is to be set. The following equipment is available:

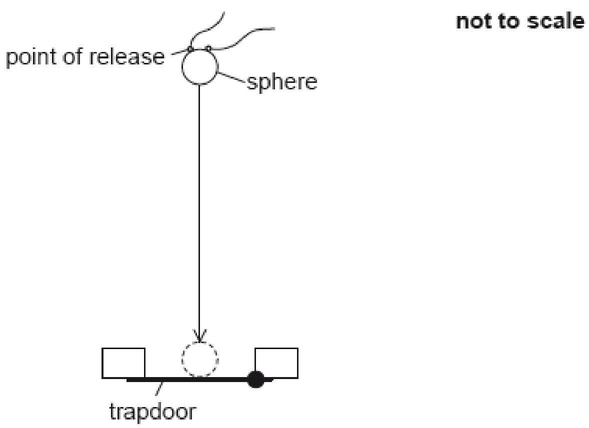


13a. Draw a suitable circuit diagram that would enable the internal resistance to be determined. *[1 mark]*

13b. It is noticed that the resistor gets warmer. Explain how this would affect the calculated value of the internal resistance. *[3 marks]*

13c. Outline how using a variable resistance could improve the accuracy of the value found for the internal resistance. *[2 marks]*

To determine the acceleration due to gravity, a small metal sphere is dropped from rest and the time it takes to fall through a known distance and open a trapdoor is measured.



The following data are available.

Diameter of metal sphere	$= 12.0 \pm 0.1$ mm
Distance between the point of release and the trapdoor	$= 654 \pm 2$ mm
Measured time for fall	$= 0.363 \pm 0.002$ s

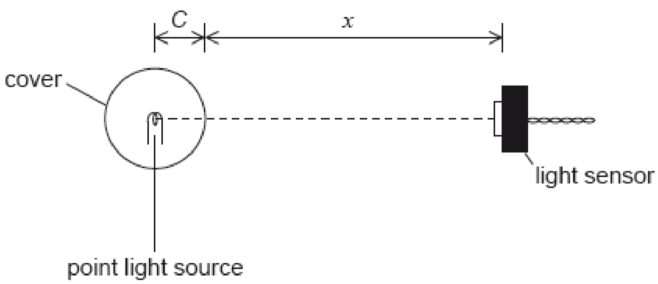
14a. Determine the distance fallen, in m, by the centre of mass of the sphere including an estimate of the absolute uncertainty in your answer. *[2 marks]*

14b. Using the following equation *[4 marks]*

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

calculate, for these data, the acceleration due to gravity including an estimate of the absolute uncertainty in your answer.

A student carries out an experiment to determine the variation of intensity of the light with distance from a point light source. The light source is at the centre of a transparent spherical cover of radius *C*. The student measures the distance *x* from the surface of the cover to a sensor that measures the intensity *I* of the light.



The light source emits radiation with a constant power *P* and all of this radiation is transmitted through the cover. The relationship between *I* and *x* is given by

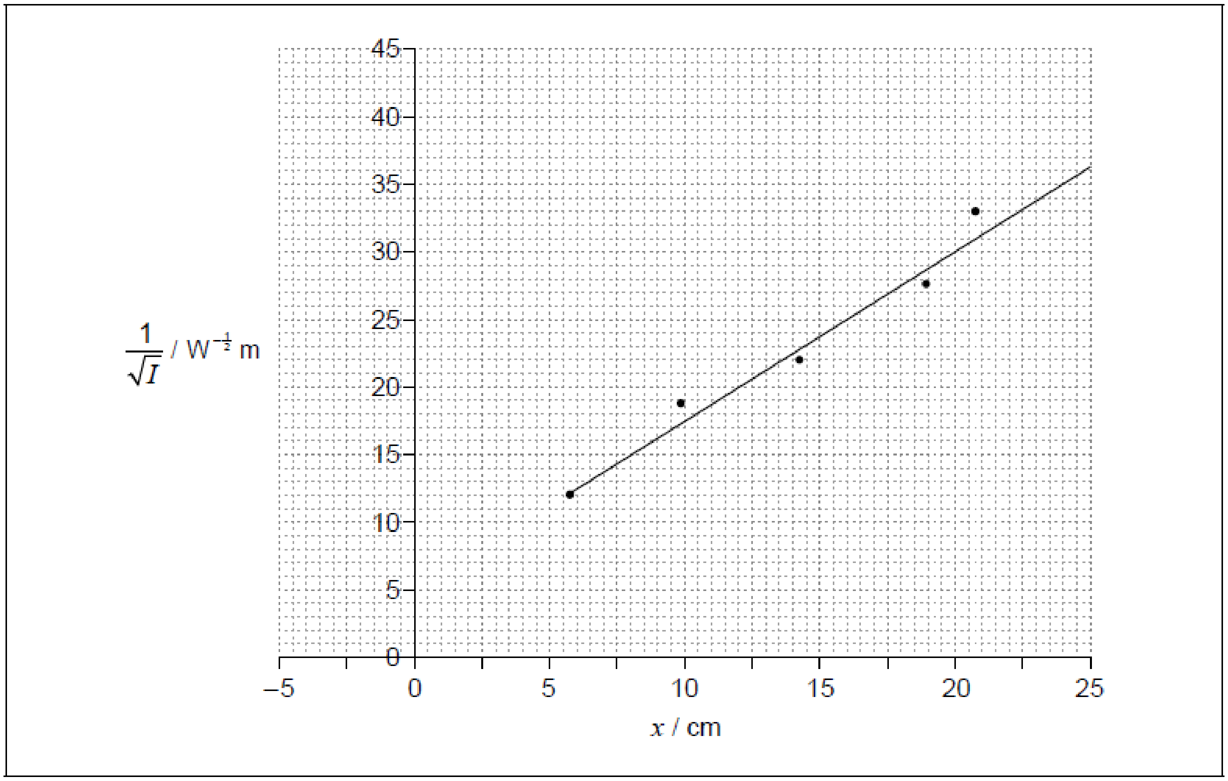
$$I = \frac{P}{4\pi(C+x)^2}$$

15a. This relationship can also be written as follows. *[1 mark]*

$$\frac{1}{\sqrt{I}} = Kx + KC$$

Show that $K = 2\sqrt{\frac{\pi}{P}}$.

The student obtains a set of data and uses this to plot a graph of the variation of $\frac{1}{\sqrt{I}}$ with *x*.

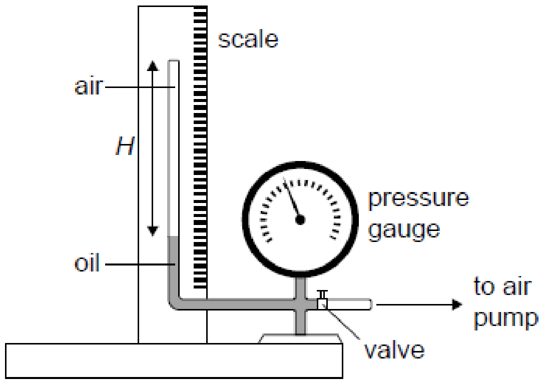


15b. Estimate *C*. *[2 marks]*

15c. Determine *P*, to the correct number of significant figures including its unit. *[4 marks]*

15d. Explain the disadvantage that a graph of *I* versus $\frac{1}{x^2}$ has for the analysis in (b)(i) and (b)(ii). *[2 marks]*

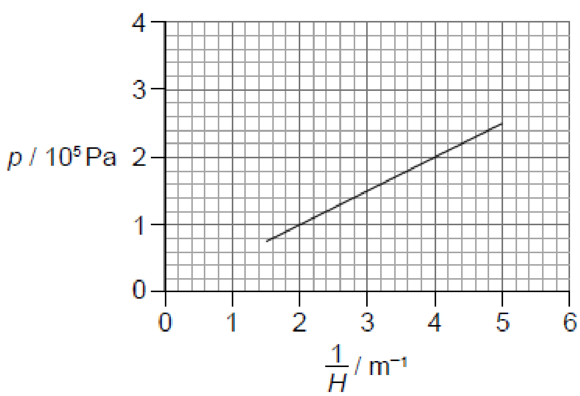
The equipment shown in the diagram was used by a student to investigate the variation with volume, of the pressure *p* of air, at constant temperature. The air was trapped in a tube of constant cross-sectional area above a column of oil.



The pump forces oil to move up the tube decreasing the volume of the trapped air.

16a. The student measured the height *H* of the air column and the corresponding air pressure *p*. After each reduction in the volume the student waited for some time before measuring the pressure. Outline why this was necessary. *[1 mark]*

16b. The following graph of *p* versus $\frac{1}{H}$ was obtained. Error bars were negligibly small. *[3 marks]*



The equation of the line of best fit is $p = a + \frac{b}{H}$.

Determine the value of *b* including an appropriate unit.

16c. Outline how the results of this experiment are consistent with the ideal gas law at constant temperature. *[2 marks]*

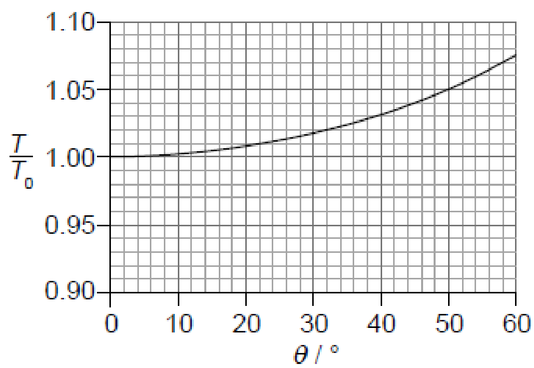
16d. The cross-sectional area of the tube is 1.3×10^{-3} m^2 and the temperature of air is 300 K. Estimate the number of moles of air in the tube. *[2 marks]*

16e. The equation in (b) may be used to predict the pressure of the air at extremely large values of $\frac{1}{H}$. Suggest why this will be an unreliable estimate of the pressure. *[2 marks]*

17a. In a simple pendulum experiment, a student measures the period T of the pendulum many times and obtains an average value T = (2.540 ± 0.005) s. The length L of the pendulum is measured to be L = (1.60 ± 0.01) m. *[3 marks]*

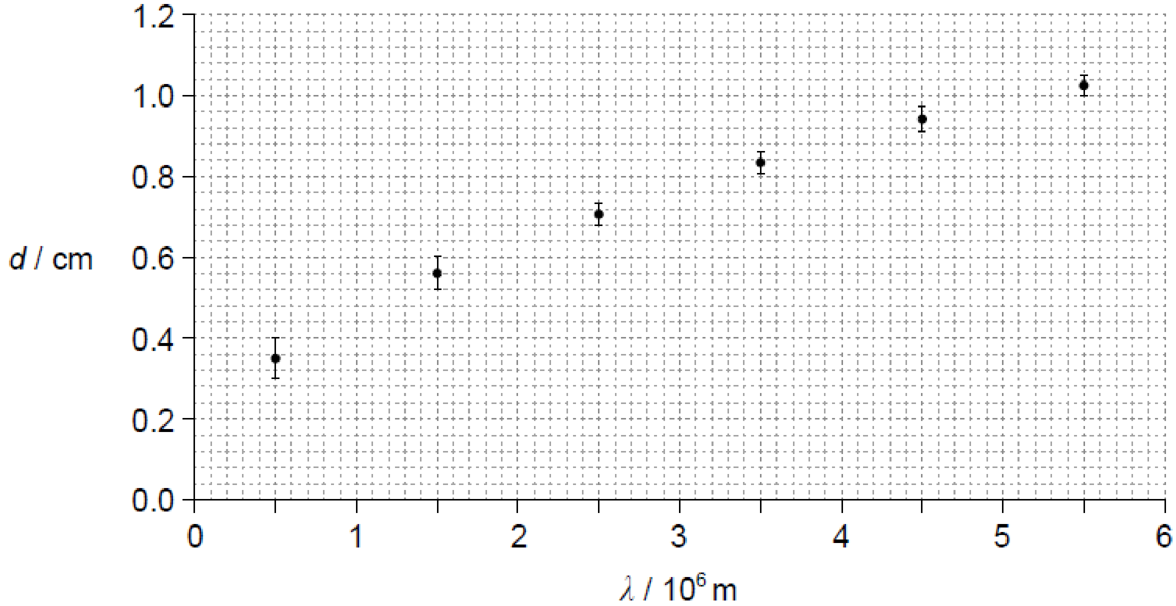
Calculate, using $g = \frac{4\pi^2 L}{T^2}$, the value of the acceleration of free fall, including its uncertainty. State the value of the uncertainty to one significant figure.

17b. In a different experiment a student investigates the dependence of the period T of a simple pendulum on the amplitude of oscillations θ. The graph shows the variation of $\frac{T}{T_0}$ with θ, where T_0 is the period for small amplitude oscillations. *[2 marks]*



The period may be considered to be independent of the amplitude θ as long as $\frac{T-T_0}{T_0} < 0.01$. Determine the maximum value of θ for which the period is independent of the amplitude.

A radio wave of wavelength λ is incident on a conductor. The graph shows the variation with wavelength λ of the maximum distance *d* travelled inside the conductor.



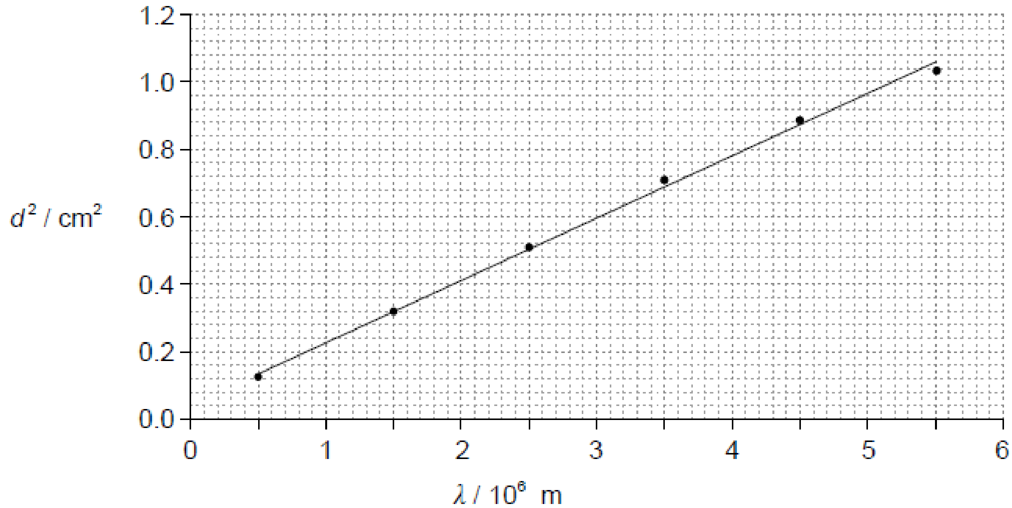
18a. Suggest why it is unlikely that the relation between *d* and λ is linear. *[1 mark]*

For λ = 5.0 x 10^5 m, calculate the

18b. fractional uncertainty in *d*. *[2 marks]*

18c. percentage uncertainty in d^2. *[1 mark]*

The graph shows the variation with wavelength λ of d^2. Error bars are not shown and the line of best-fit has been drawn.



A student states that the equation of the line of best-fit is $d^2 = a + b\lambda$. When d^2 and λ are expressed in terms of fundamental SI units, the student finds that $a = 0.040 \times 10^{-4}$ and $b = 1.8 \times 10^{-11}$.

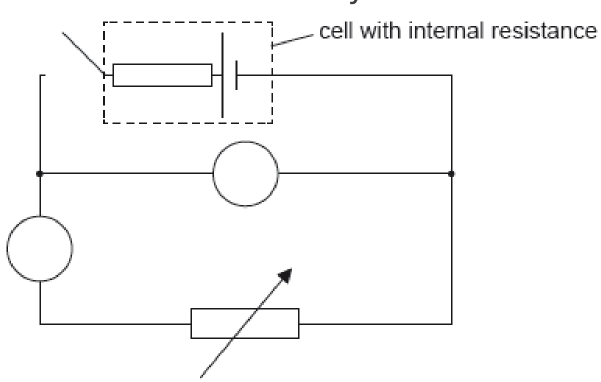
18d. State the fundamental SI unit of the constant *a* and of the constant *b*. *[2 marks]*

a: . . . .

b: . . . .

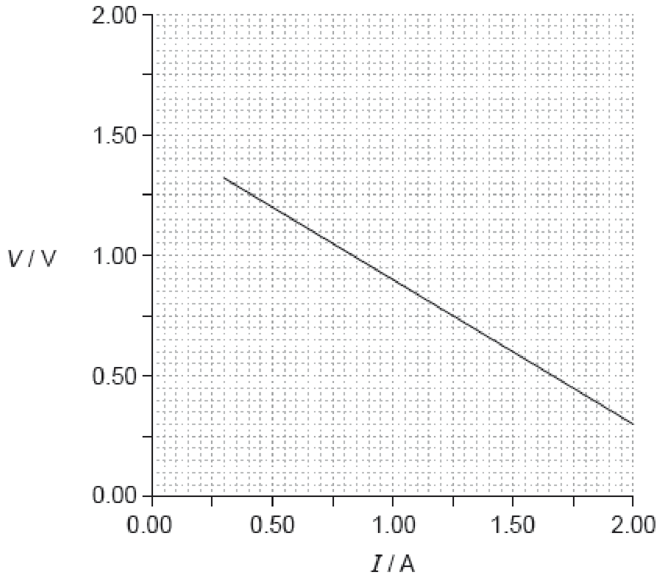
18e. Determine the distance travelled inside the conductor by very high frequency electromagnetic waves. *[2 marks]*

The circuit shown may be used to measure the internal resistance of a cell.



19a. An ammeter and a voltmeter are connected in the circuit. Label the ammeter with the letter A and the voltmeter with the letter V. *[1 mark]*

19b. In one experiment a student obtains the following graph showing the variation with current *I* of the potential difference *V* across the cell. *[3 marks]*



Using the graph, determine the best estimate of the internal resistance of the cell.

The ammeter used in the experiment in (b) is an analogue meter. The student takes measurements without checking for a “zero error” on the ammeter.

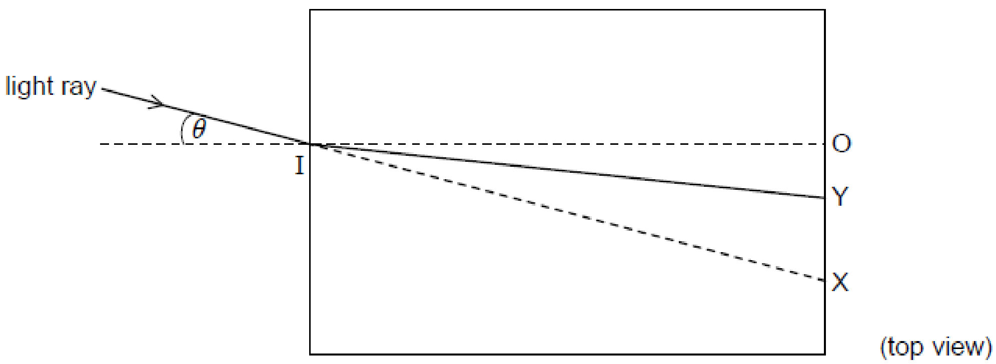
19c. State what is meant by a zero error. *[1 mark]*

19d. After taking measurements the student observes that the ammeter has a positive zero error. Explain what effect, if any, this zero error will have on the calculated value of the internal resistance in (b). *[2 marks]*

A student measures the refractive index of water by shining a light ray into a transparent container.

IO shows the direction of the normal at the point where the light is incident on the container. IX shows the direction of the light ray when the container is empty. IY shows the direction of the deviated light ray when the container is filled with water.

The angle of incidence θ is varied and the student determines the position of O, X and Y for each angle of incidence.



The table shows the data collected by the student. The uncertainty in each measurement of length is ±0.1 cm.

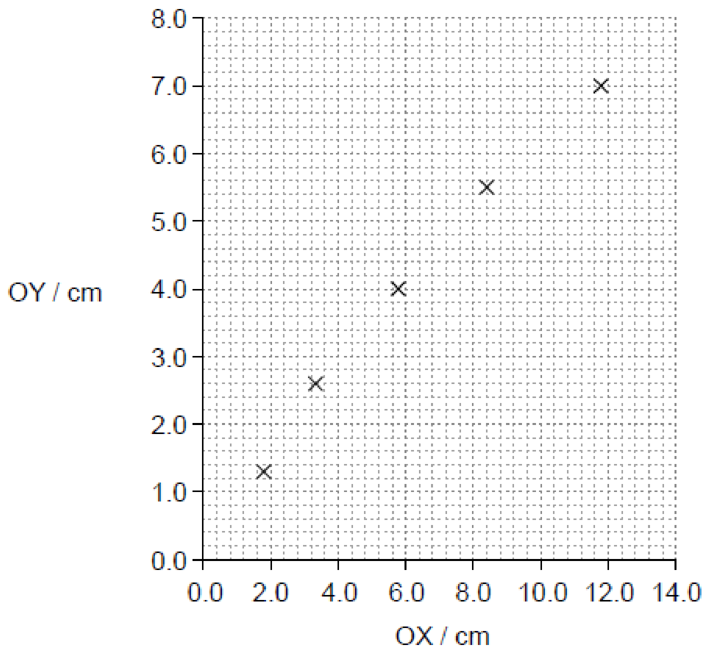
OX / cm	OY / cm
1.8	1.3
3.6	2.6
5.8	4.0
8.4	5.5
11.9	7.3
17.3	9.5
27.4	12.2

20a. (i) Outline why OY has a greater percentage uncertainty than OX for each pair of data points. *[3 marks]*

(ii) The refractive index of the water is given by $\frac{\mathrm{OX}}{\mathrm{OY}}$ when OX is small.

Calculate the fractional uncertainty in the value of the refractive index of water for OX = 1.8 cm.

20b. A graph of the variation of OY with OX is plotted. *[5 marks]*



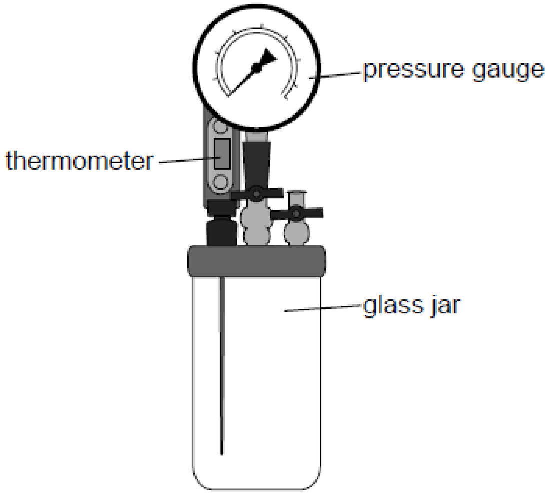
(i) Draw, on the graph, the error bars for OY when OX = 1.8 cm **and** when OY = 5.8 cm.

(ii) Determine, using the graph, the refractive index of the water in the container for values of OX less than 6.0 cm.

(iii) The refractive index for a material is also given by $\frac{\sin i}{\sin r}$ where *i* is the angle of incidence and *r* is the angle of refraction.

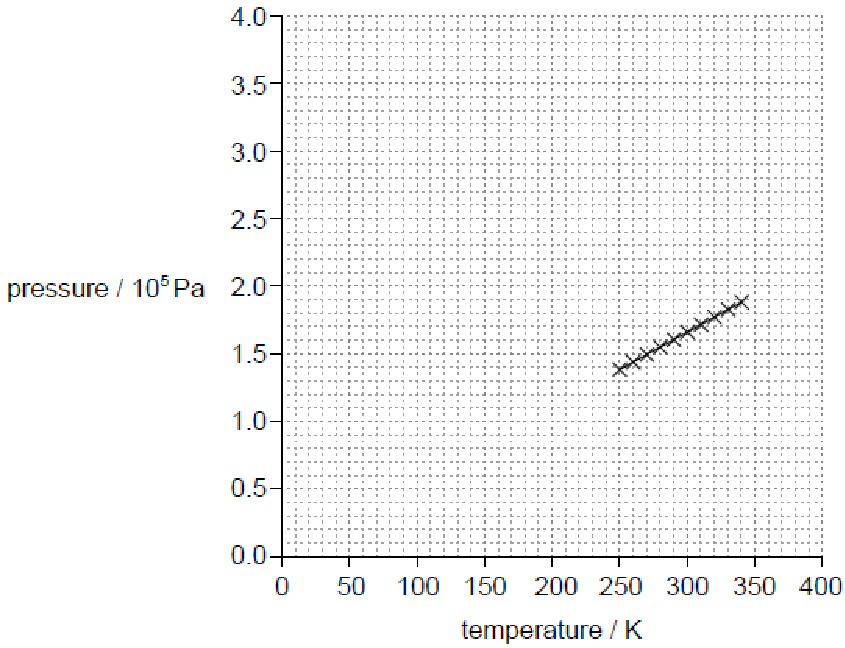
Outline why the graph deviates from a straight line for large values of OX.

An apparatus is used to verify a gas law. The glass jar contains a fixed volume of air. Measurements can be taken using the thermometer and the pressure gauge.



The apparatus is cooled in a freezer and then placed in a water bath so that the temperature of the gas increases slowly. The pressure and temperature of the gas are recorded.

21a. The graph shows the data recorded. *[1 mark]*



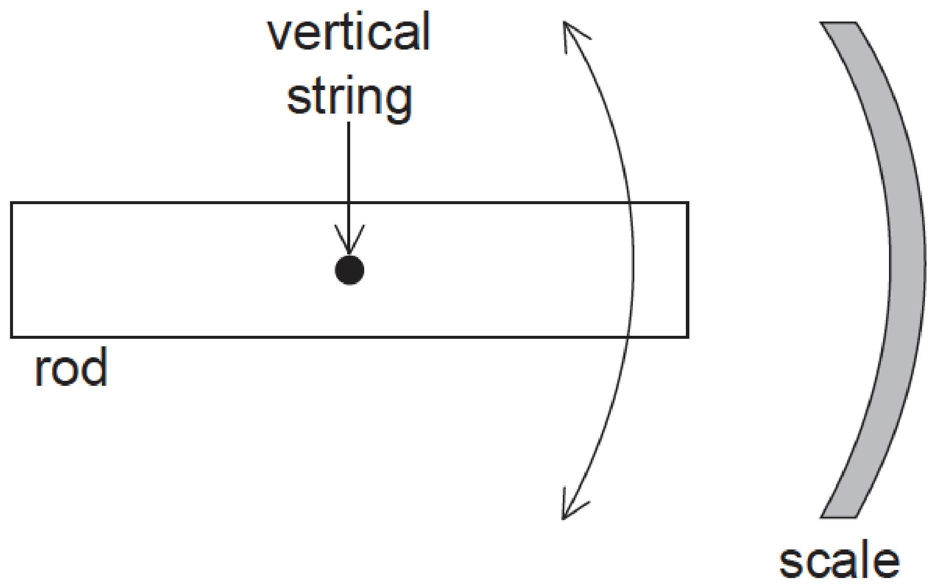
Identify the fundamental SI unit for the gradient of the pressure–temperature graph.

21b. The experiment is repeated using a different gas in the glass jar. The pressure for both experiments is low and both gases can be considered to be ideal. *[3 marks]*

(i) Using the axes provided in (a), draw the expected graph for this second experiment.

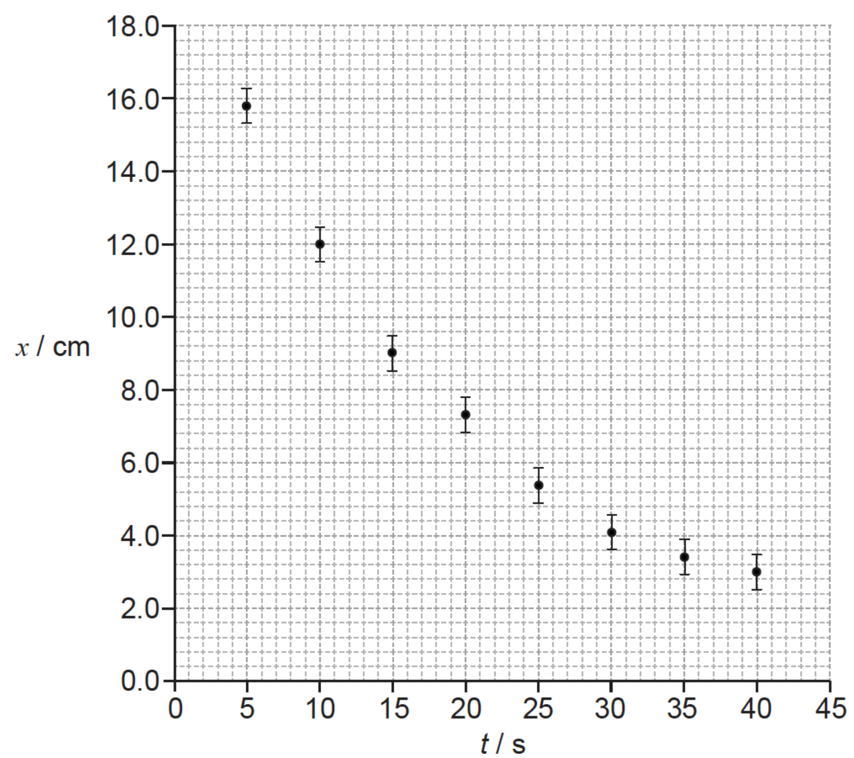
(ii) Explain the shape and intercept of the graph you drew in (b)(i).

A student investigates the oscillation of a horizontal rod hanging at the end of a vertical string. The diagram shows the view from above.



The student starts the rod oscillating and measures the largest displacement for each cycle of the oscillation on the scale and the time at which it occurs. The student begins to take measurements a few seconds after releasing the rod.

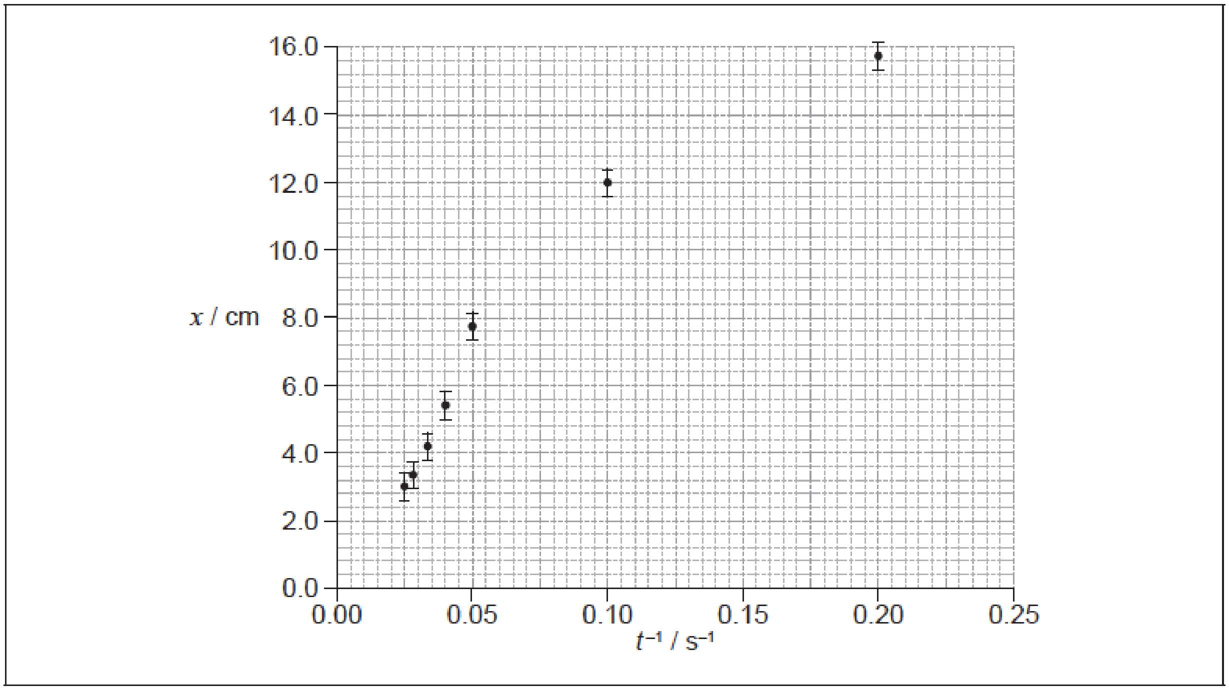
The graph shows the variation of displacement *x* with time *t* since the release of the rod. The uncertainty for *t* is negligible.



22a. On the graph above, draw the line of best fit for the data. *[1 mark]*

22b. Calculate the percentage uncertainty for the displacement when t=40s. *[2 marks]*

22c. The student hypothesizes that the relationship between x and t is $x = \frac{a}{t}$ *[3 marks]*
where a is a constant.
To test the hypothesis x is plotted against $\frac{1}{t}$ as shown in the graph.

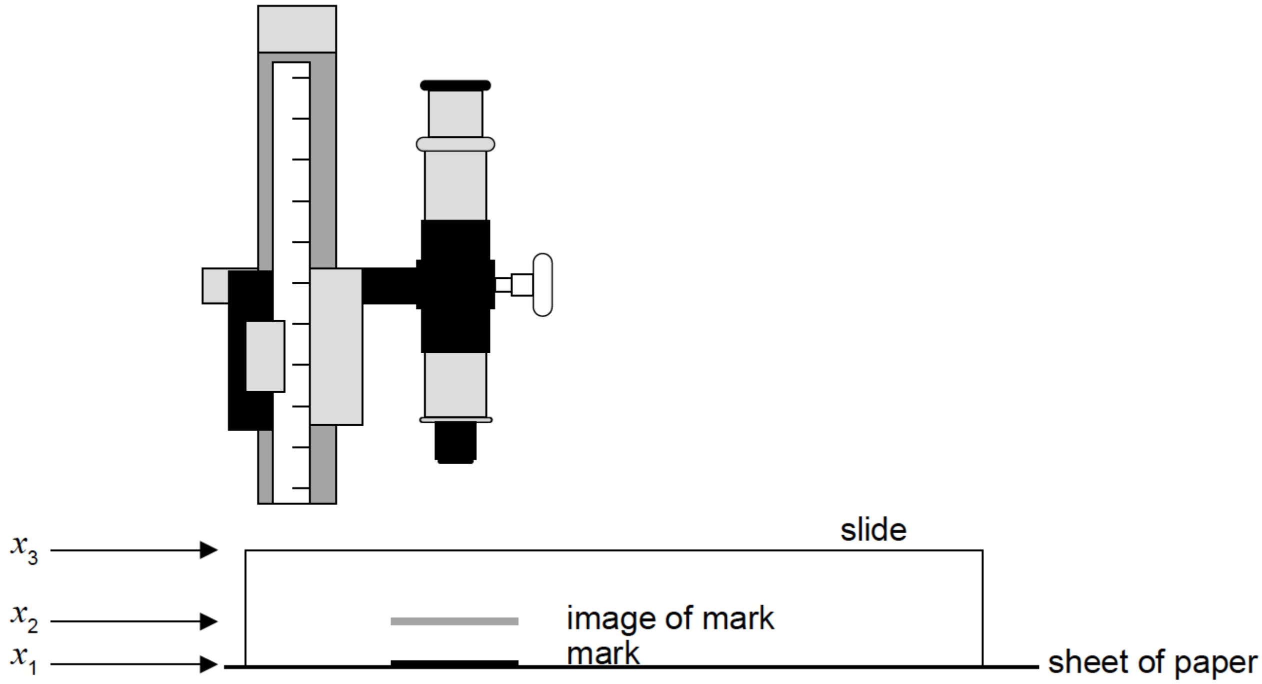


(i) The data point corresponding to t=15s has not been plotted. Plot this point on the graph above.

(ii) Suggest the range of values of t for which the hypothesis may be assumed to be correct.

A student measures the refractive index of the glass of a microscope slide.

He uses a travelling microscope to determine the position x_1 of a mark on a sheet of paper. He then places the slide over the mark and finds the position x_2 of the image of the mark when viewed through the slide. Finally, he uses the microscope to determine the position x_3 of the top of the slide.



The table shows the average results of a large number of repeated measurements.

	Average position of mark / mm
x_1	0.20 ±0.02
x_2	0.59 ±0.02
x_3	1.35 ±0.02

23a. The refractive index of the glass from which the slide is made is given by *[4 marks]*

$$\frac{x_3 - x_1}{x_3 - x_2}$$

.

Determine

(i) the refractive index of the glass to the correct number of significant figures, ignoring any uncertainty.

(ii) the uncertainty of the value calculated in (a)(i).

23b. After the experiment, the student finds that the travelling microscope is badly adjusted so that the measurement of each position is too large by 0.05mm. *[3 marks]*

(i) State the name of this type of error.

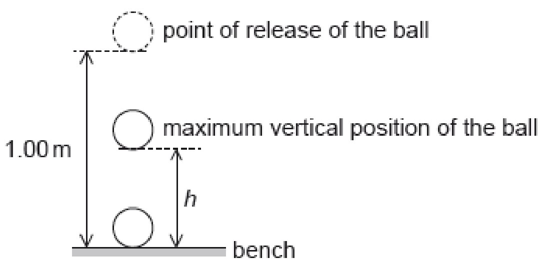
(ii) Outline the effect that the error in (b)(i) will have on the calculated value of the refractive index of the glass.

23c. After correcting the adjustment of the travelling microscope, the student repeats the experiment using a glass block 10 times thicker than the original microscope slide. Explain the change, if any, to the calculated result for the refractive index and its uncertainty. *[2 marks]*

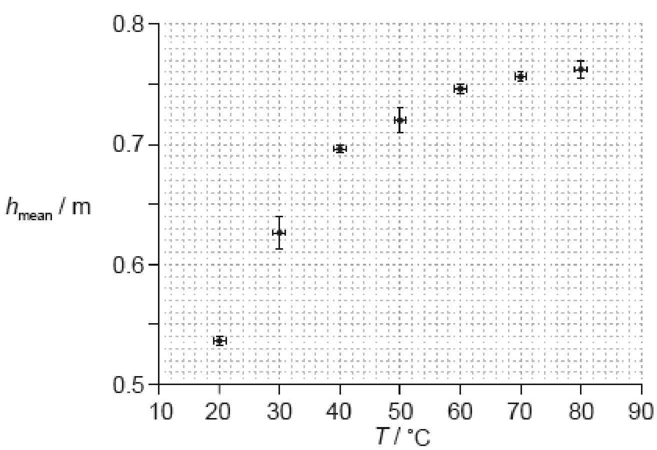
Data analysis question.

An experiment is undertaken to investigate the relationship between the temperature of a ball and the height of its first bounce.

A ball is placed in a beaker of water until the ball and the water are at the same temperature. The ball is released from a height of 1.00 m above a bench. The maximum vertical height h from the bottom of the ball above the bench is measured for the first bounce. This procedure is repeated twice and an average h_{mean} is calculated from the three measurements.



The procedure is repeated for a range of temperatures. The graph shows the variation of h_{mean} with temperature T.



24a. Draw the line of best-fit for the data. *[1 mark]*

24b. State why the line of best-fit suggests that h_{mean} is not proportional to T. *[1 mark]*

24c. State the uncertainty in each value of T. *[1 mark]*

24d. The temperature is measured using a liquid in glass thermometer. State what physical characteristic of the thermometer suggests that the change in the liquid's length is proportional to the change in temperature. *[1 mark]*

24e. Another hypothesis is that $h_{\text{mean}} = KT^3$ where K is a constant. Using the graph on page 2, calculate the absolute uncertainty in K corresponding to $T = 50^{\circ}\text{C}$. *[4 marks]*