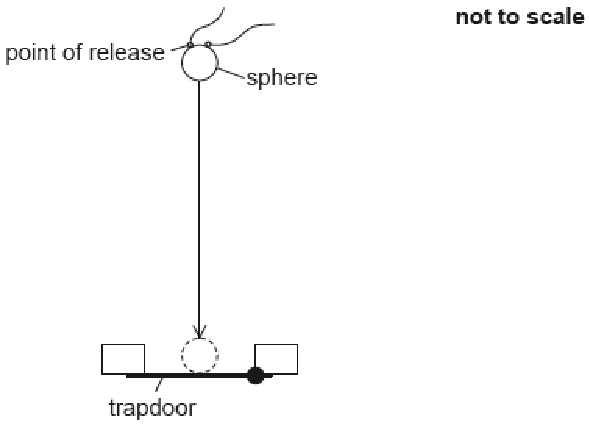
Motion-practice-2-ShortA *[213 marks]*

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.

$$\begin{array}{ll} \text{Diameter of metal sphere} & = 12.0 \pm 0.1 \text{ mm} \\ \text{Distance between the point of release and the trapdoor} & = 654 \pm 2 \text{ mm} \\ \text{Measured time for fall} & = 0.363 \pm 0.002 \text{ s} \end{array}$$

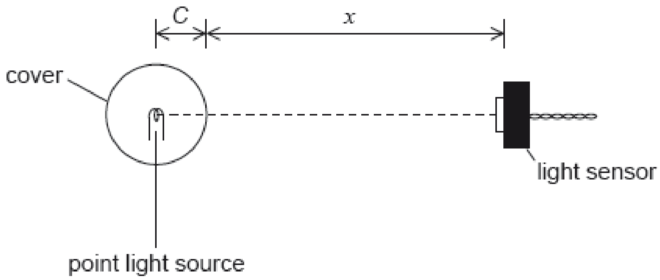
1a. Determine the distance fallen, in m, by the centre of mass of the sphere including an estimate of the absolute uncertainty in your answer. *[2 marks]*

1b. 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

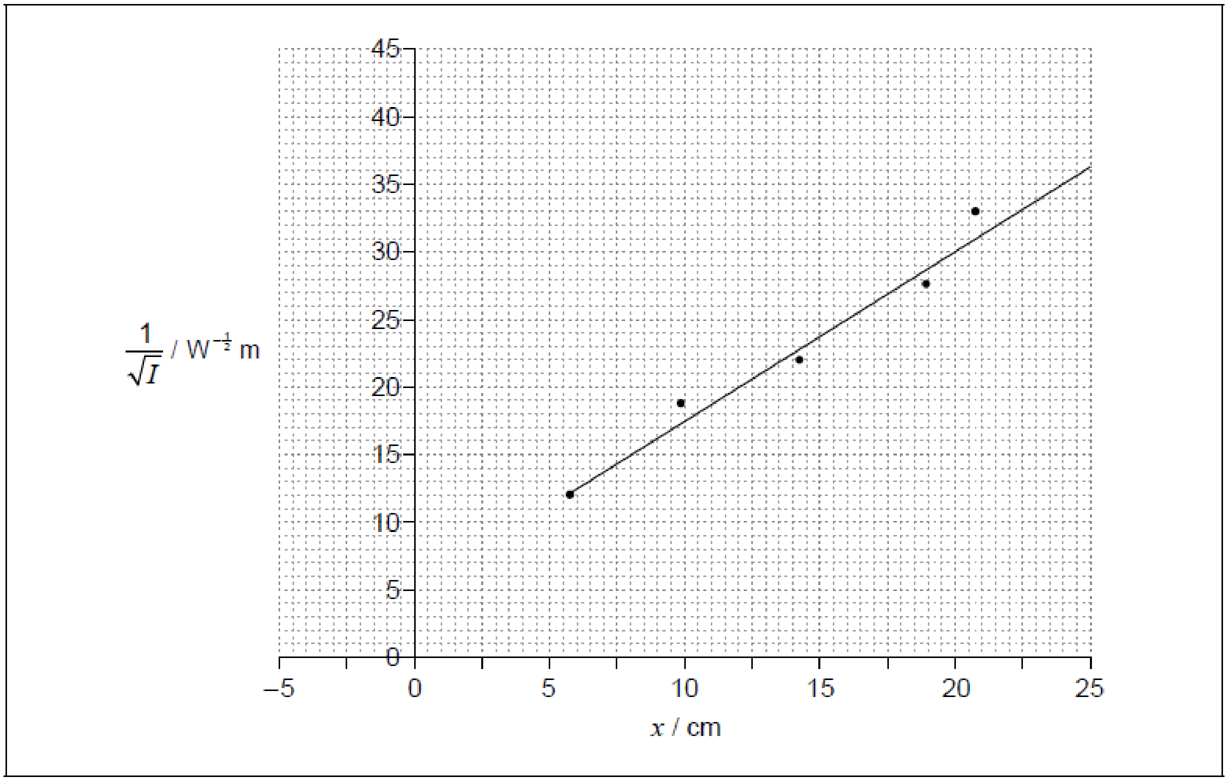
$$I = \frac{P}{4\pi(C+x)^2}$$

2a. 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*.

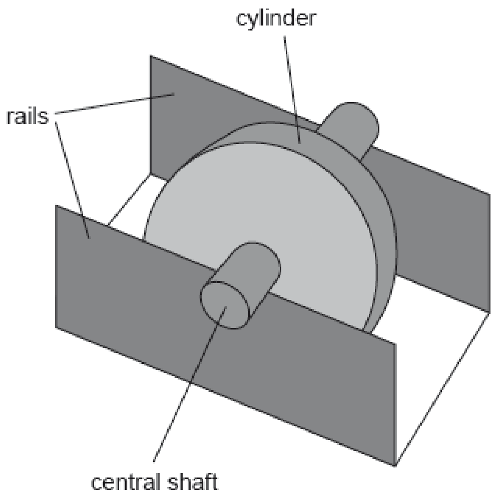


2b. Estimate *C*. *[2 marks]*

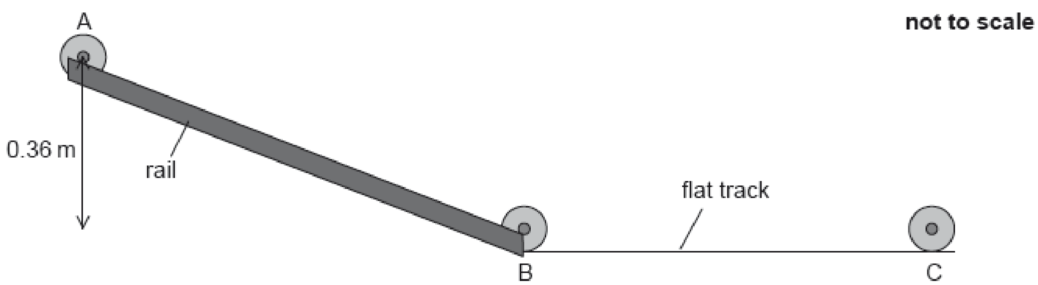
2c. Determine *P*, to the correct number of significant figures including its unit. *[4 marks]*

2d. 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]*

A wheel of mass 0.25 kg consists of a cylinder mounted on a central shaft. The shaft has a radius of 1.2 cm and the cylinder has a radius of 4.0 cm. The shaft rests on two rails with the cylinder able to spin freely between the rails.



The stationary wheel is released from rest and rolls down a slope with the shaft rolling on the rails without slipping from point A to point B.

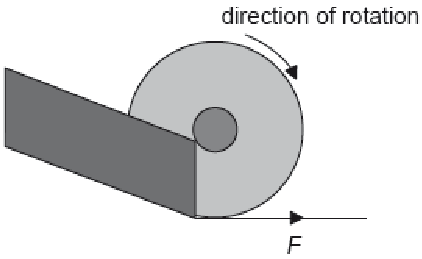


3a. The moment of inertia of the wheel is 1.3×10^{-4} kg m^2. Outline what is meant by the moment of inertia. *[1 mark]*

3b. In moving from point A to point B, the centre of mass of the wheel falls through a vertical distance of 0.36 m. Show that the translational speed of the wheel is about 1 m s^{-1} after its displacement. *[3 marks]*

3c. Determine the angular velocity of the wheel at B. *[1 mark]*

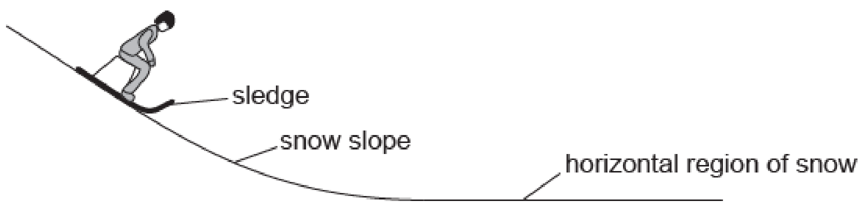
The wheel leaves the rails at point B and travels along the flat track to point C. For a short time the wheel slips and a frictional force *F* exists on the edge of the wheel as shown.



3d. Describe the effect of *F* on the linear speed of the wheel. *[2 marks]*

3e. Describe the effect of *F* on the angular speed of the wheel. *[2 marks]*

A girl on a sledge is moving down a snow slope at a uniform speed.



4a. Draw the free-body diagram for the sledge at the position shown on the snow slope. *[2 marks]*

4b. After leaving the snow slope, the girl on the sledge moves over a horizontal region of snow. Explain, with reference to the physical origin of the forces, why the vertical forces on the girl must be in equilibrium as she moves over the horizontal region. *[3 marks]*

4c. When the sledge is moving on the horizontal region of the snow, the girl jumps off the sledge. The girl has no horizontal velocity after the jump. The velocity of the sledge immediately after the girl jumps off is 4.2 m s^{-1}. The mass of the girl is 55 kg and the mass of the sledge is 5.5 kg. Calculate the speed of the sledge immediately before the girl jumps from it. *[2 marks]*

4d. The girl chooses to jump so that she lands on loosely-packed snow rather than frozen ice. Outline why she chooses to land on the snow. *[3 marks]*

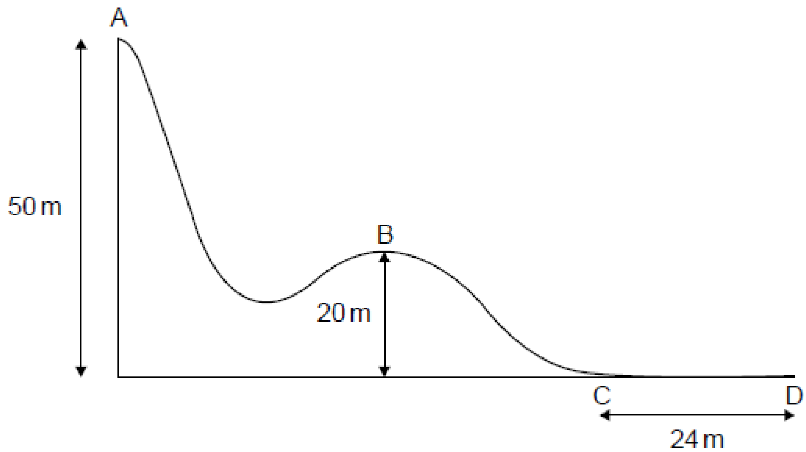
The sledge, without the girl on it, now travels up a snow slope that makes an angle of 6.5° to the horizontal. At the start of the slope, the speed of the sledge is 4.2 m s^{-1}. The coefficient of dynamic friction of the sledge on the snow is 0.11.

4e. Show that the acceleration of the sledge is about –2 m s^{-2}. *[3 marks]*

4f. Calculate the distance along the slope at which the sledge stops moving. Assume that the coefficient of dynamic friction is constant. *[2 marks]*

4g. The coefficient of static friction between the sledge and the snow is 0.14. Outline, with a calculation, the subsequent motion of the sledge. *[2 marks]*

The diagram below shows part of a downhill ski course which starts at point A, 50 m above level ground. Point B is 20 m above level ground.

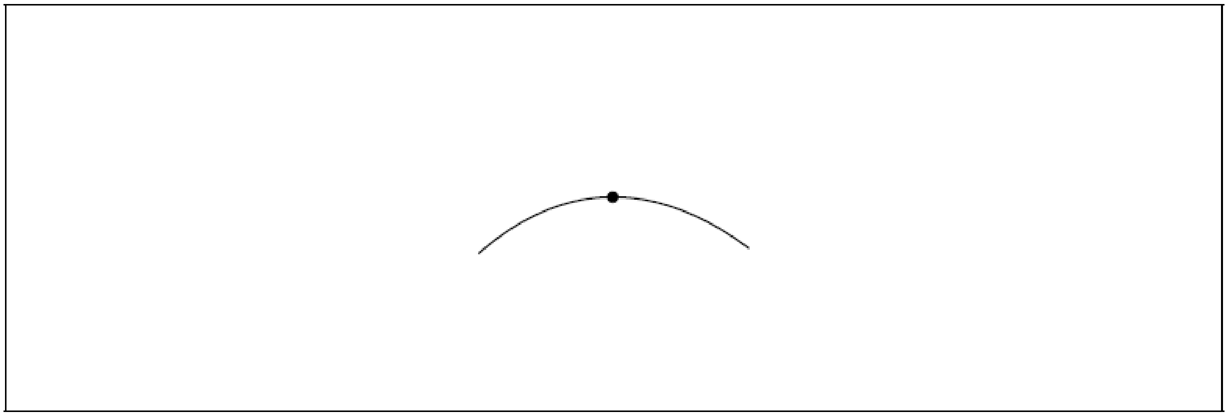


A skier of mass 65 kg starts from rest at point A and during the ski course some of the gravitational potential energy transferred to kinetic energy.

5a. From A to B, 24 % of the gravitational potential energy transferred to kinetic energy. Show that the velocity at B is 12 m s^{-1}. *[2 marks]*

5b. Some of the gravitational potential energy transferred into internal energy of the skis, slightly increasing their temperature. Distinguish between internal energy and temperature. *[2 marks]*

5c. The dot on the following diagram represents the skier as she passes point B. *[2 marks]*
Draw and label the vertical forces acting on the skier.



5d. The hill at point B has a circular shape with a radius of 20 m. Determine whether the skier will lose contact with the ground at point B. *[3 marks]*

5e. The skier reaches point C with a speed of 8.2 m s^{-1}. She stops after a distance of 24 m at point D. *[3 marks]*

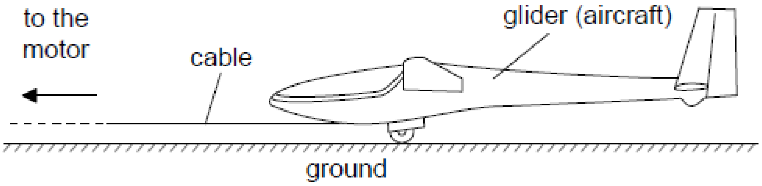
Determine the coefficient of dynamic friction between the base of the skis and the snow. Assume that the frictional force is constant and that air resistance can be neglected.

At the side of the course flexible safety nets are used. Another skier of mass 76 kg falls normally into the safety net with speed 9.6 m s^{-1}.

5f. Calculate the impulse required from the net to stop the skier and state an appropriate unit for your answer. *[2 marks]*

5g. Explain, with reference to change in momentum, why a flexible safety net is less likely to harm the skier than a rigid barrier. *[2 marks]*

A glider is an aircraft with no engine. To be launched, a glider is uniformly accelerated from rest by a cable pulled by a motor that exerts a horizontal force on the glider throughout the launch.



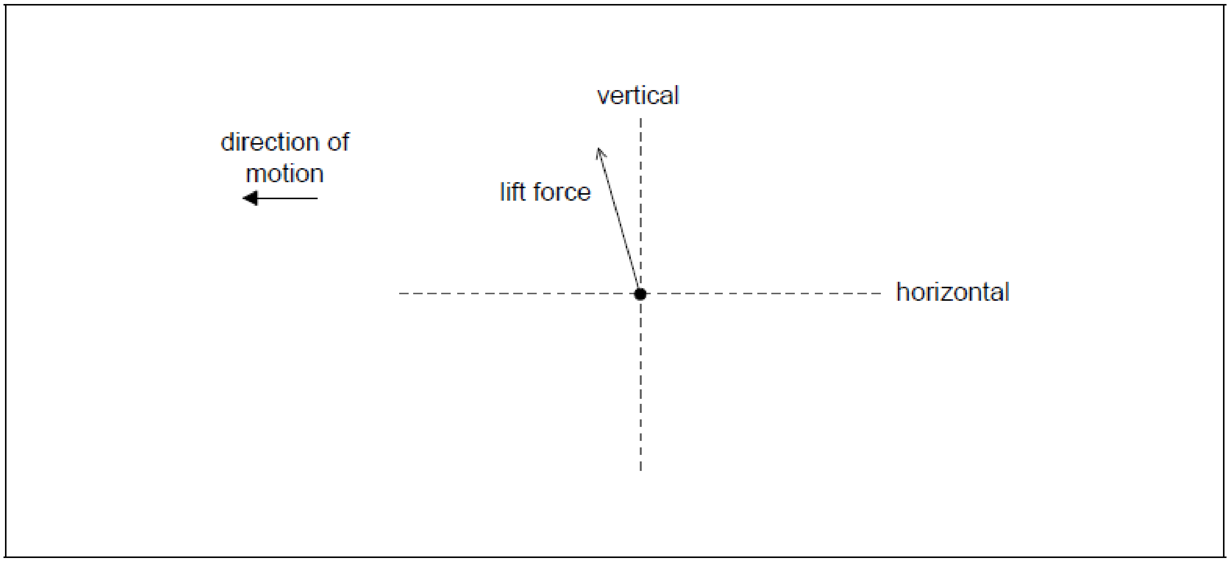
6a. The glider reaches its launch speed of 27.0 m s^{-1} after accelerating for 11.0 s. Assume that the glider moves horizontally until it leaves the ground. Calculate the total distance travelled by the glider before it leaves the ground. *[2 marks]*

6b. The glider and pilot have a total mass of 492 kg. During the acceleration the glider is subject to an average resistive force of 160 N. Determine the average tension in the cable as the glider accelerates. *[3 marks]*

6c. The cable is pulled by an electric motor. The motor has an overall efficiency of 23 %. Determine the average power input to the motor. *[3 marks]*

6d. The cable is wound onto a cylinder of diameter 1.2 m. Calculate the angular velocity of the cylinder at the instant when the glider has a speed of 27 m s^{-1}. Include an appropriate unit for your answer. *[2 marks]*

6e. After takeoff the cable is released and the unpowered glider moves horizontally at constant speed. The wings of the glider provide a lift force. The diagram shows the lift force acting on the glider and the direction of motion of the glider. *[2 marks]*

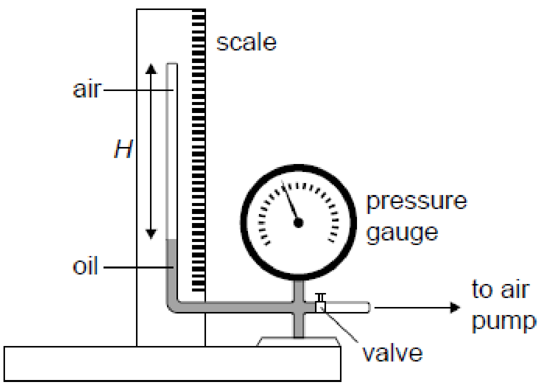


Draw the forces acting on the glider to complete the free-body diagram. The dotted lines show the horizontal and vertical directions.

6f. Explain, using appropriate laws of motion, how the forces acting on the glider maintain it in level flight. *[2 marks]*

6g. At a particular instant in the flight the glider is losing 1.00 m of vertical height for every 6.00 m that it goes forward horizontally. At this instant, the horizontal speed of the glider is 12.5 m s^{-1}. Calculate the **velocity** of the glider. Give your answer to an appropriate number of significant figures. *[3 marks]*

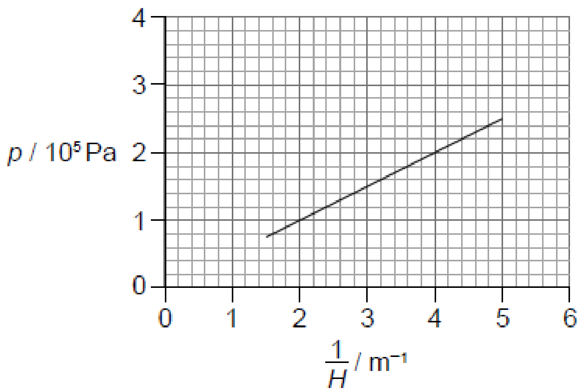
The equipment shown in the diagram was used by a student to investigate the variation with volume, of the pressure *p* of air, at constant temperature. The air was trapped in a tube of constant cross-sectional area above a column of oil.



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

7a. 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]*

7b. 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.

7c. Outline how the results of this experiment are consistent with the ideal gas law at constant temperature. *[2 marks]*

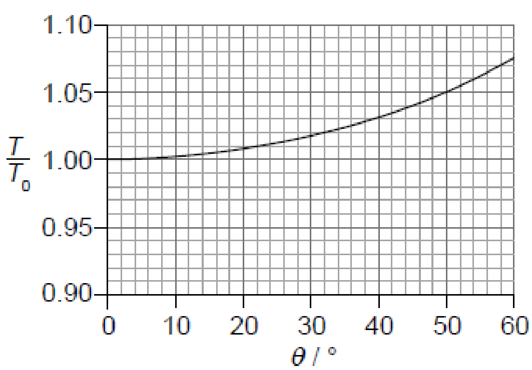
7d. The cross-sectional area of the tube is 1.3×10^{-3} m^2 and the temperature of air is 300 K. Estimate the number of moles of air in the tube. *[2 marks]*

7e. 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]*

8a. 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]*

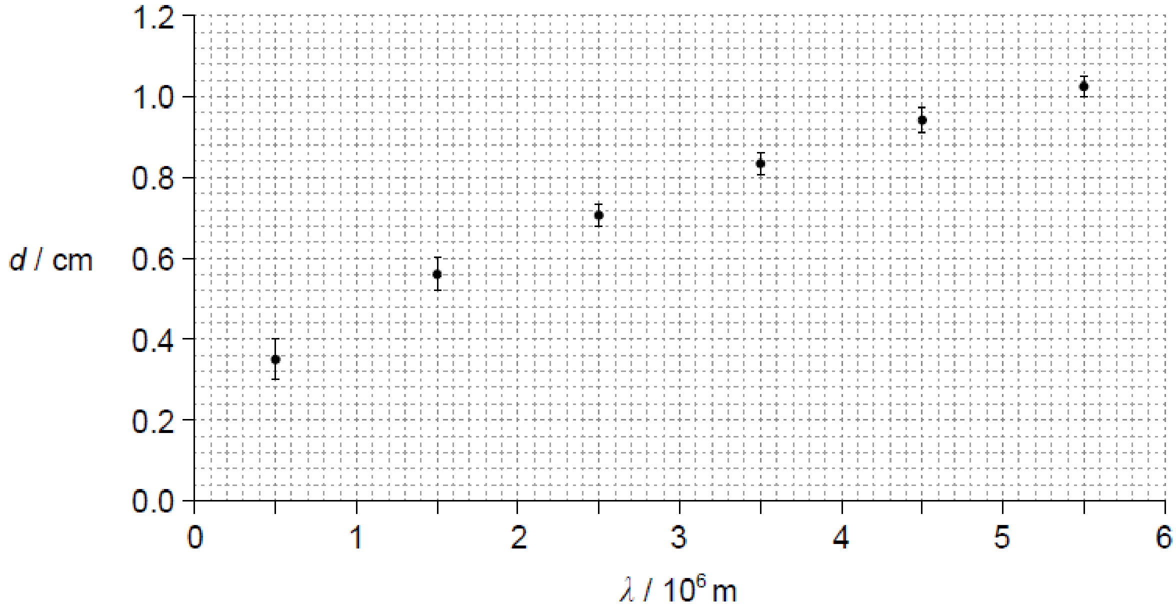
Calculate, using $g = \frac{4\pi^2 L}{T^2}$, the value of the acceleration of free fall, including its uncertainty. State the value of the uncertainty to one significant figure.

8b. 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.



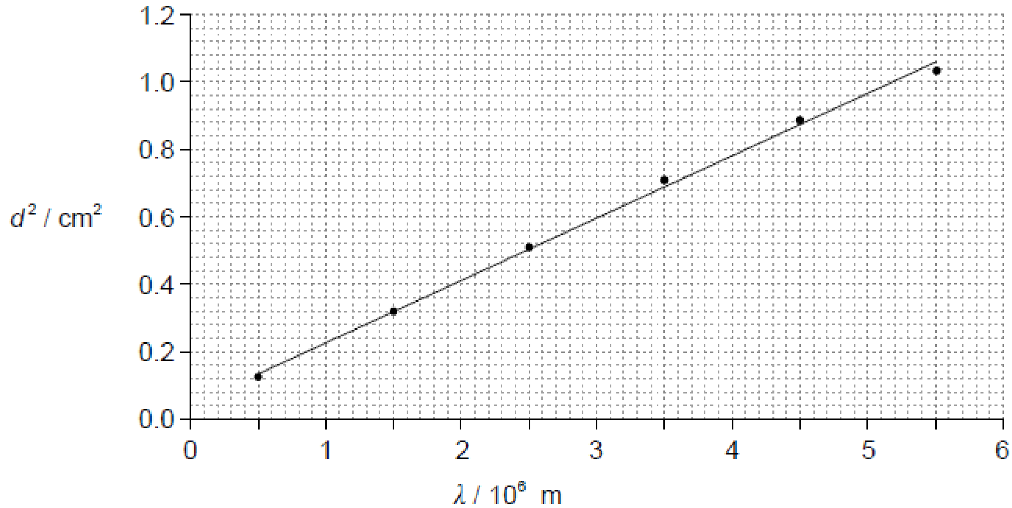
9a. Suggest why it is unlikely that the relation between *d* and λ is linear. *[1 mark]*

For λ = 5.0 x 10^5 m, calculate the

9b. fractional uncertainty in *d*. *[2 marks]*

9c. 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 $b = 1.8 \times 10^{-11}$.

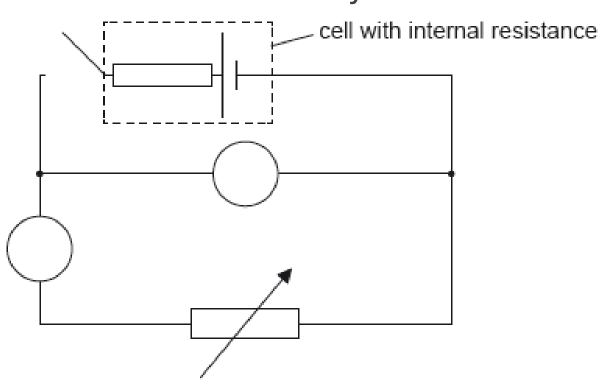
9d. State the fundamental SI unit of the constant *a* and of the constant *b*. *[2 marks]*

a: ....

b: ....

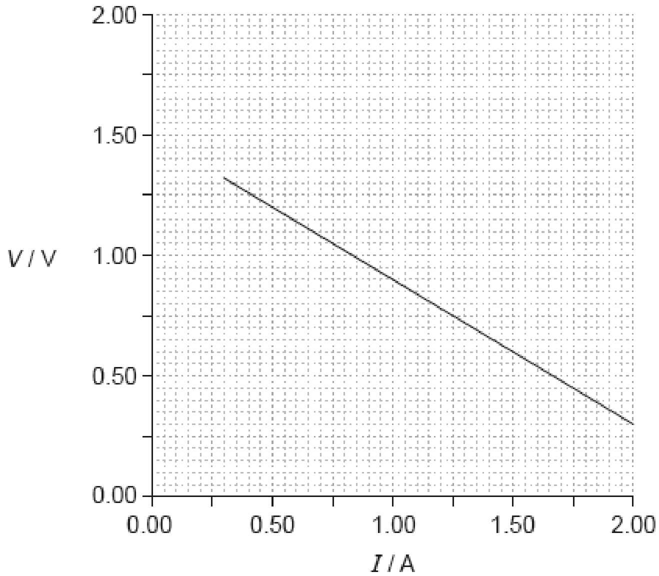
9e. Determine the distance travelled inside the conductor by very high frequency electromagnetic waves. *[2 marks]*

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



10a. 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]*

10b. 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.

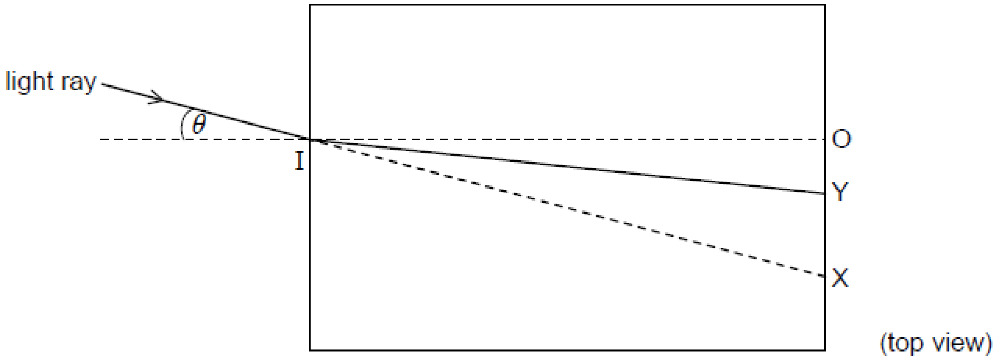
10c. State what is meant by a zero error. *[1 mark]*

10d. 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.

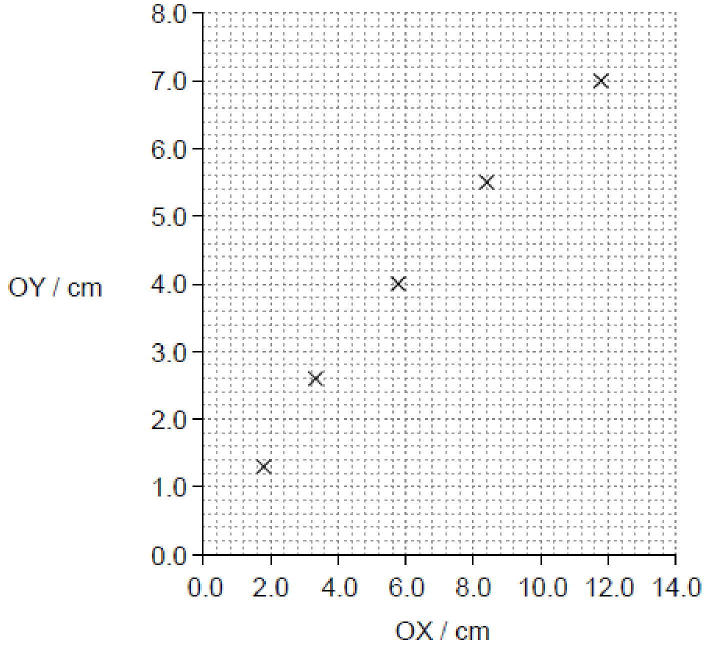
OX / cm	OY / cm
1.8	1.3
3.6	2.6
5.8	4.0
8.4	5.5
11.9	7.3
17.3	9.5
27.4	12.2

11a. (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 $\frac{OX}{OY}$ when OX is small.

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

11b. A graph of the variation of OY with OX is plotted. *[5 marks]*



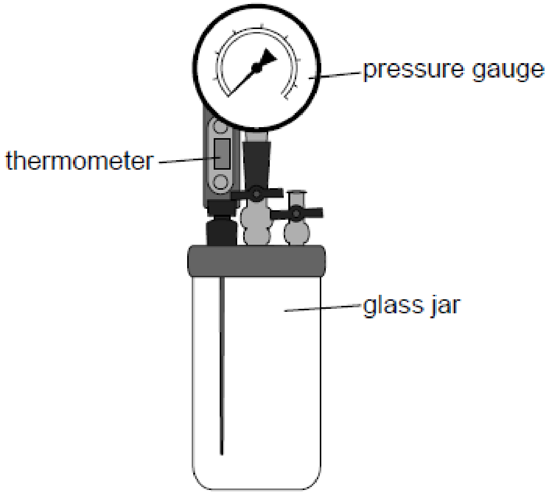
(i) Draw, on the graph, the error bars for OY when OX = 1.8 cm **and** when OY = 5.8 cm.

(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.

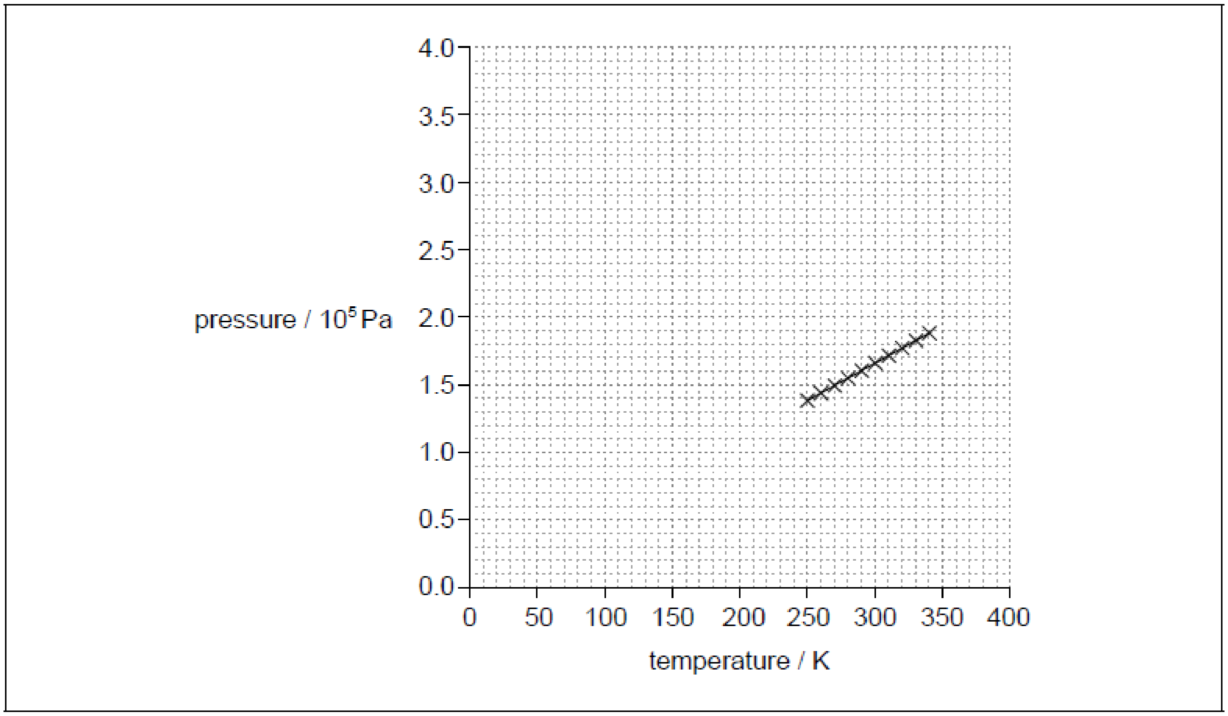
Outline why the graph deviates from a straight line for large values of OX.

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.

12a. The graph shows the data recorded. *[1 mark]*



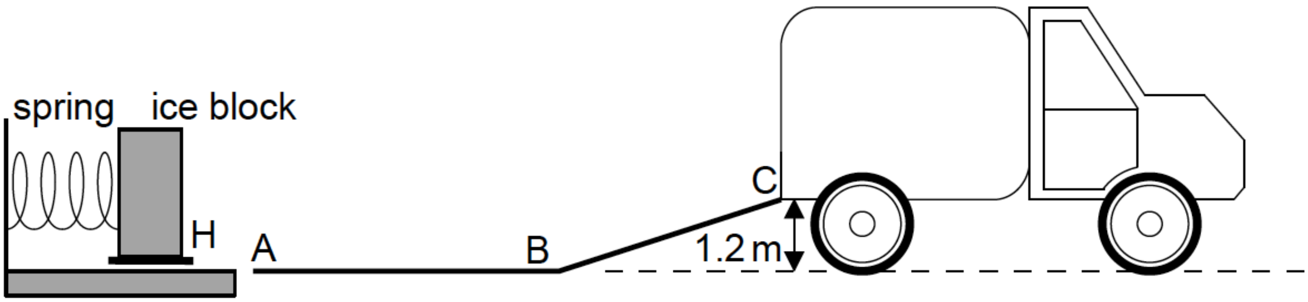
Identify the fundamental SI unit for the gradient of the pressure–temperature graph.

12b. 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 company designs a spring system for loading ice blocks onto a truck. The ice block is placed in a holder H in front of the spring and an electric motor compresses the spring by pushing H to the left. When the spring is released the ice block is accelerated towards a
ramp ABC. When the spring is fully decompressed, the ice block loses contact with the spring at A. The mass of the ice block is 55 kg.



Assume that the surface of the ramp is frictionless and that the masses of the spring and the holder are negligible compared to the mass of the ice block.

13a. (i) The block arrives at C with a speed of $0.90 ms^{-1}$. Show that the elastic energy stored in the spring is 670J. *[4 marks]*

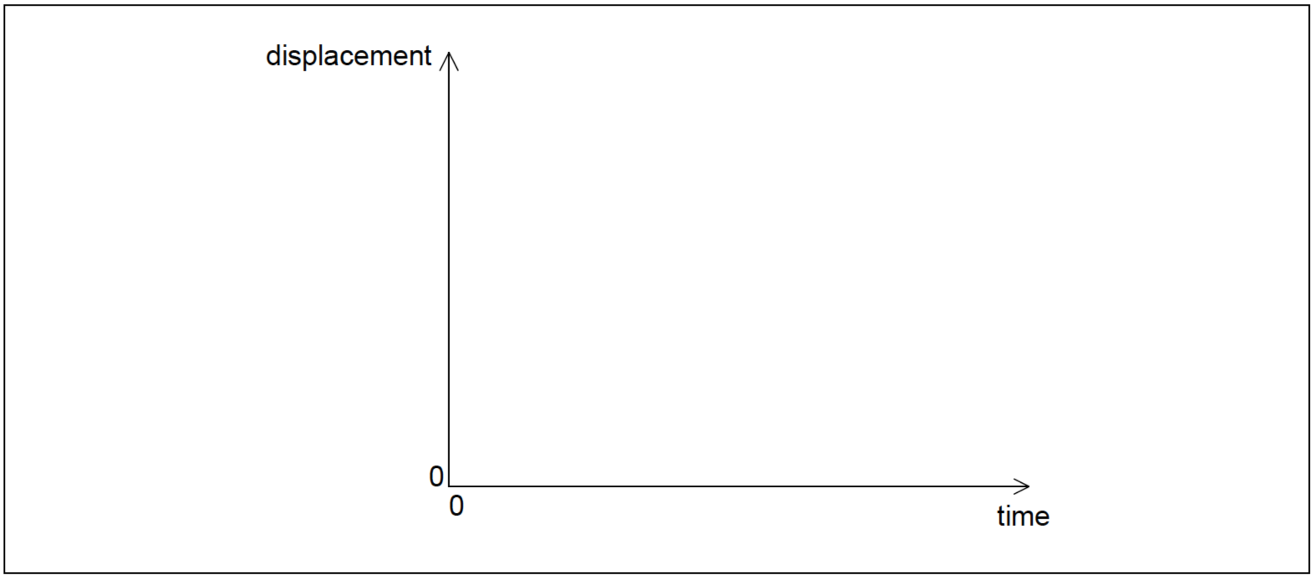
(ii) Calculate the speed of the block at A.

13b. Describe the motion of the block *[3 marks]*

(i) from A to B with reference to Newton's first law.

(ii) from B to C with reference to Newton's second law.

13c. On the axes, sketch a graph to show how the displacement of the block varies with time from A to C. (You do not have to put numbers on the axes.) *[2 marks]*

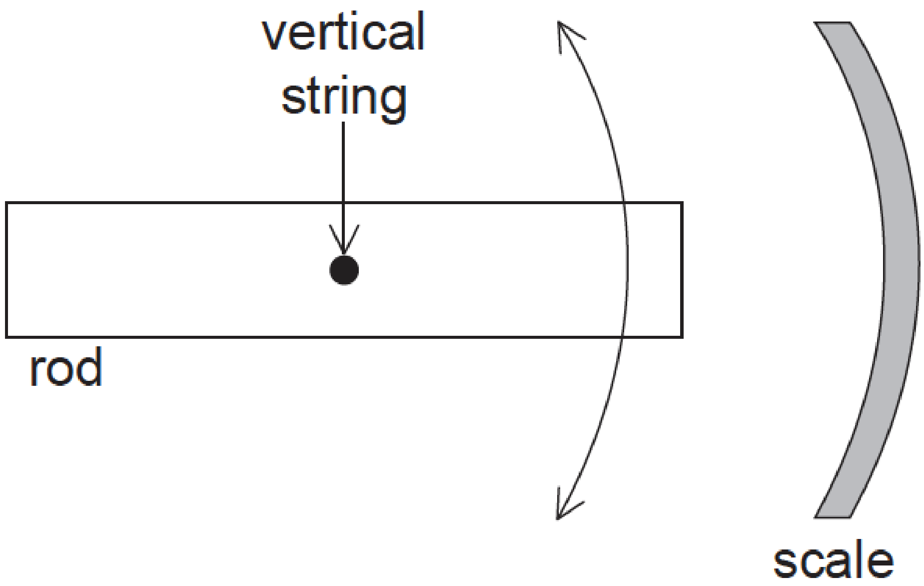


13d. The spring decompression takes 0.42s. Determine the average force that the spring exerts on the block. *[2 marks]*

13e. The electric motor is connected to a source of potential difference 120V and draws a current of 6.8A. The motor takes 1.5s to compress the spring. *[2 marks]*

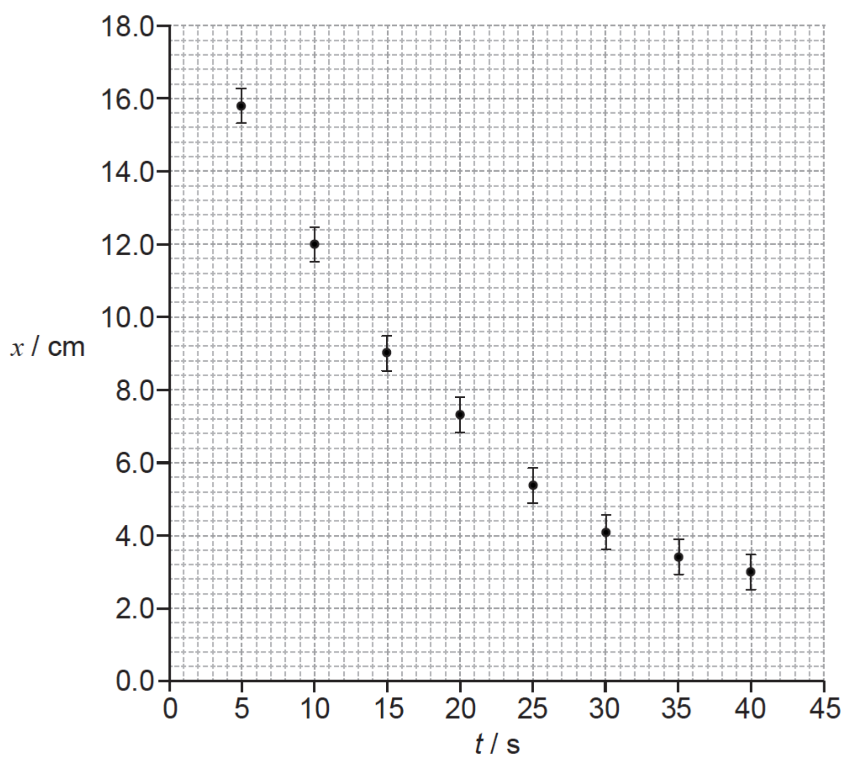
Estimate the efficiency of the motor.

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.



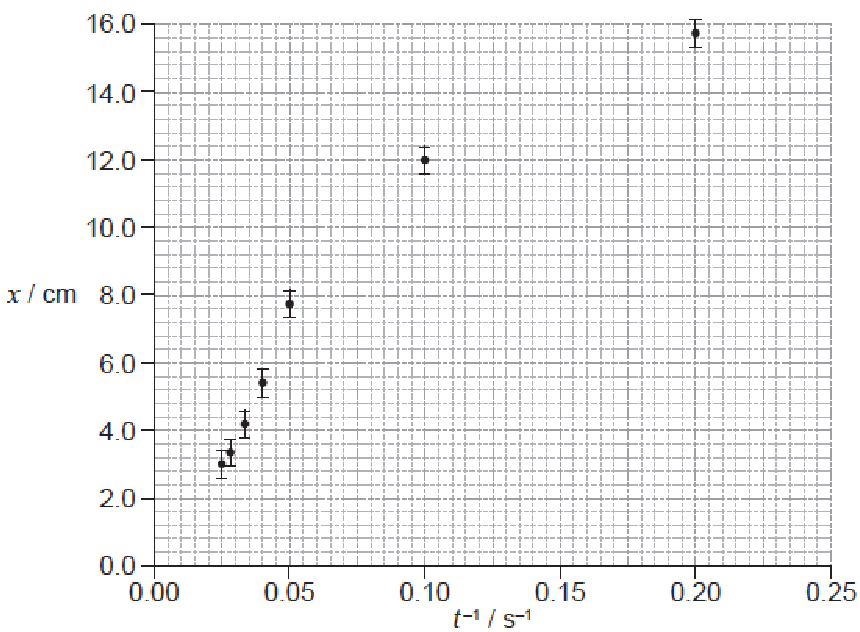
14a. On the graph above, draw the line of best fit for the data. *[1 mark]*

14b. Calculate the percentage uncertainty for the displacement when *t*=40s. *[2 marks]*

14c. 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.

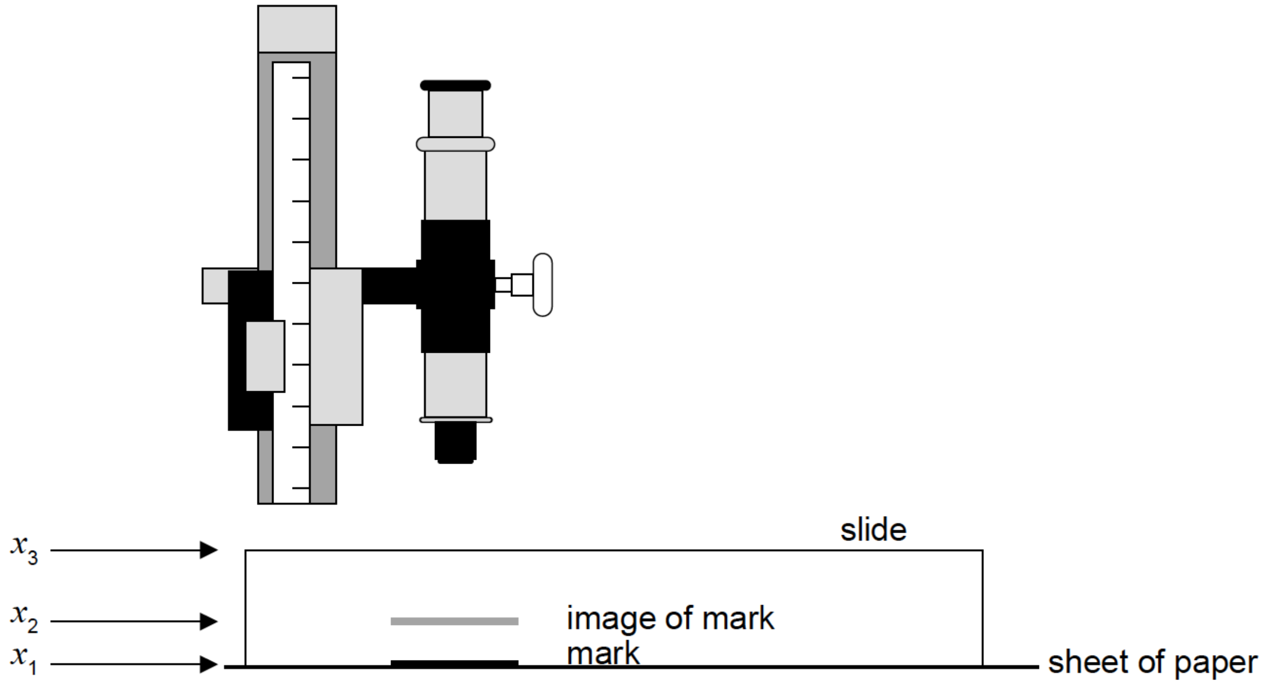


(i) The data point corresponding to *t*=15s has not been plotted. Plot this point on the graph above.

(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

15a. 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).

15b. 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.

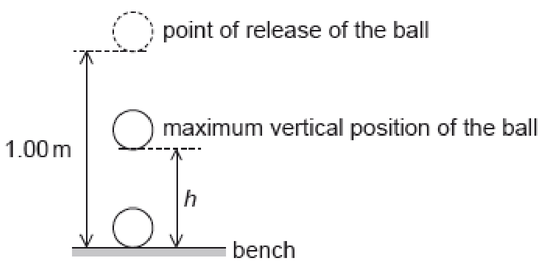
(ii) Outline the effect that the error in (b)(i) will have on the calculated value of the refractive index of the glass.

15c. 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]*

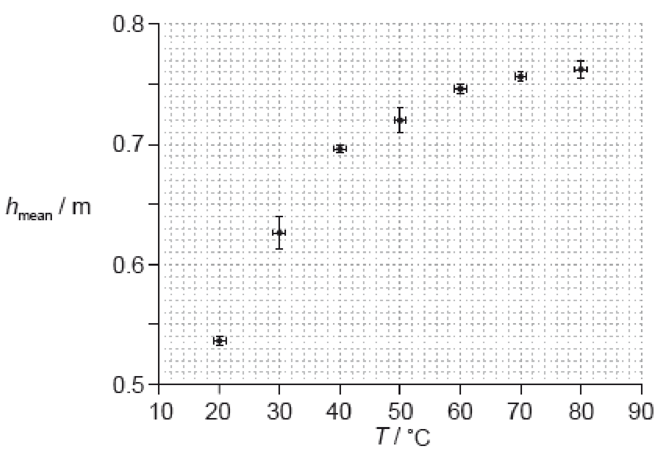
Data analysis question.

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.



16a. Draw the line of best-fit for the data. *[1 mark]*

16b. State why the line of best-fit suggests that h_{mean} is not proportional to T. *[1 mark]*

16c. State the uncertainty in each value of T. *[1 mark]*

16d. 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]*

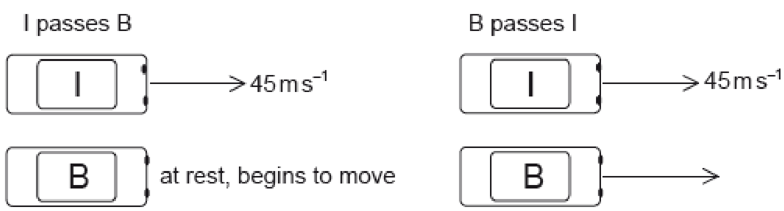
16e. Another hypothesis is that $h_{\text{mean}} = KT^3$ where K is a constant. Using the graph on page 2, calculate the absolute uncertainty in K corresponding to $T = 50^\circ\text{C}$. *[4 marks]*

This question is in **two** parts. **Part 1** is about kinematics and Newton's laws of motion.

Part 2 is about electrical circuits.

Part 1 Kinematics and Newton's laws of motion

Cars I and B are on a straight race track. I is moving at a constant speed of $45\ \text{m}\,\text{s}^{-1}$ and B is initially at rest. As I passes B, B starts to move with an acceleration of $3.2\ \text{m}\,\text{s}^{-2}$.



At a later time B passes I. You may assume that both cars are point particles.

17a. Show that the time taken for B to pass I is approximately 28 s. *[4 marks]*

17b. Calculate the distance travelled by B in this time. *[2 marks]*

17c. B slows down while I remains at a constant speed. The driver in each car wears a seat belt. Using Newton's laws of motion, explain the difference in the tension in the seat belts of the two cars. *[3 marks]*

A third car O with mass 930 kg joins the race. O collides with I from behind, moving along the same straight line as I. Before the collision the speed of I is $45\ \text{m}\,\text{s}^{-1}$ and its mass is 850 kg. After the collision, I and O stick together and move in a straight line with an initial combined speed of $52\ \text{m}\,\text{s}^{-1}$.

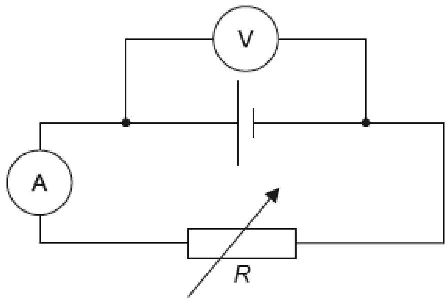
17d. Calculate the speed of O immediately before the collision. *[2 marks]*

17e. The duration of the collision is 0.45 s. Determine the average force acting on O. *[2 marks]*

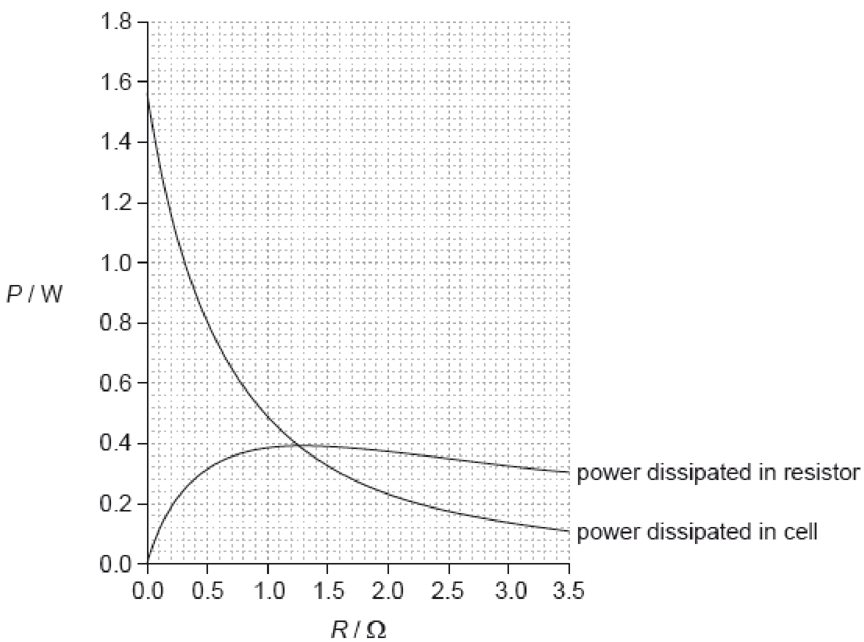
This question is in **two** parts. **Part 1** is about kinematics and Newton's laws of motion.

Part 2 Electrical circuits

The circuit shown is used to investigate how the power developed by a cell varies when the load resistance R changes.



The variable resistor is adjusted and a series of current and voltage readings are taken. The graph shows the variation with R of the power dissipated in the cell and the power dissipated in the variable resistor.



17f. An ammeter and a voltmeter are used to investigate the characteristics of a variable resistor of resistance R. State how the resistance of the ammeter and of the voltmeter compare to R so that the readings of the instruments are reliable. *[2 marks]*

17g. Show that the current in the circuit is approximately 0.70 A when $R = 0.80\ \Omega$. *[3 marks]*

The cell has an internal resistance.

17h. Outline what is meant by the internal resistance of a cell. *[2 marks]*

17i. Determine the internal resistance of the cell. *[3 marks]*

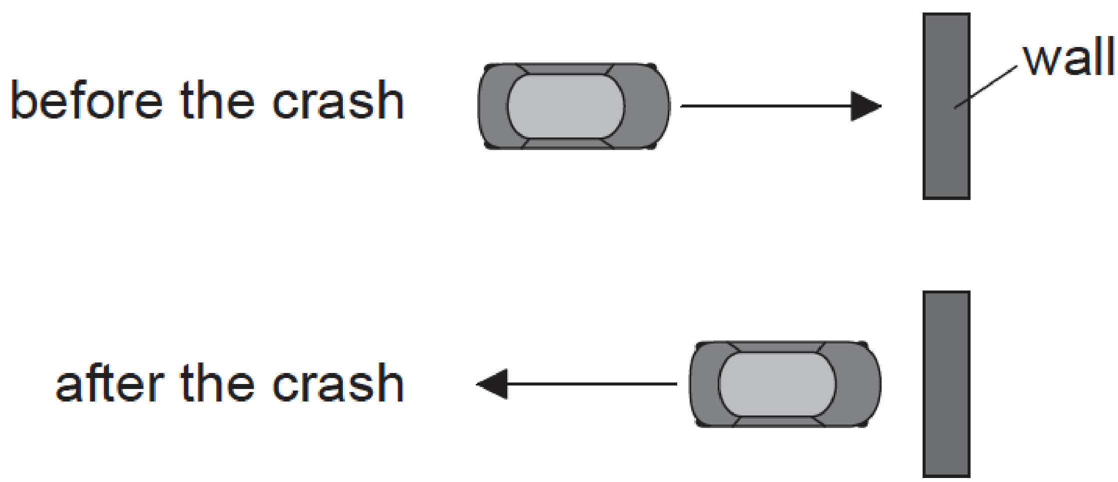
17j. Calculate the electromotive force (emf) of the cell. *[2 marks]*

This question is in two parts. **Part 1** is about momentum. **Part 2** is about electric point charges.

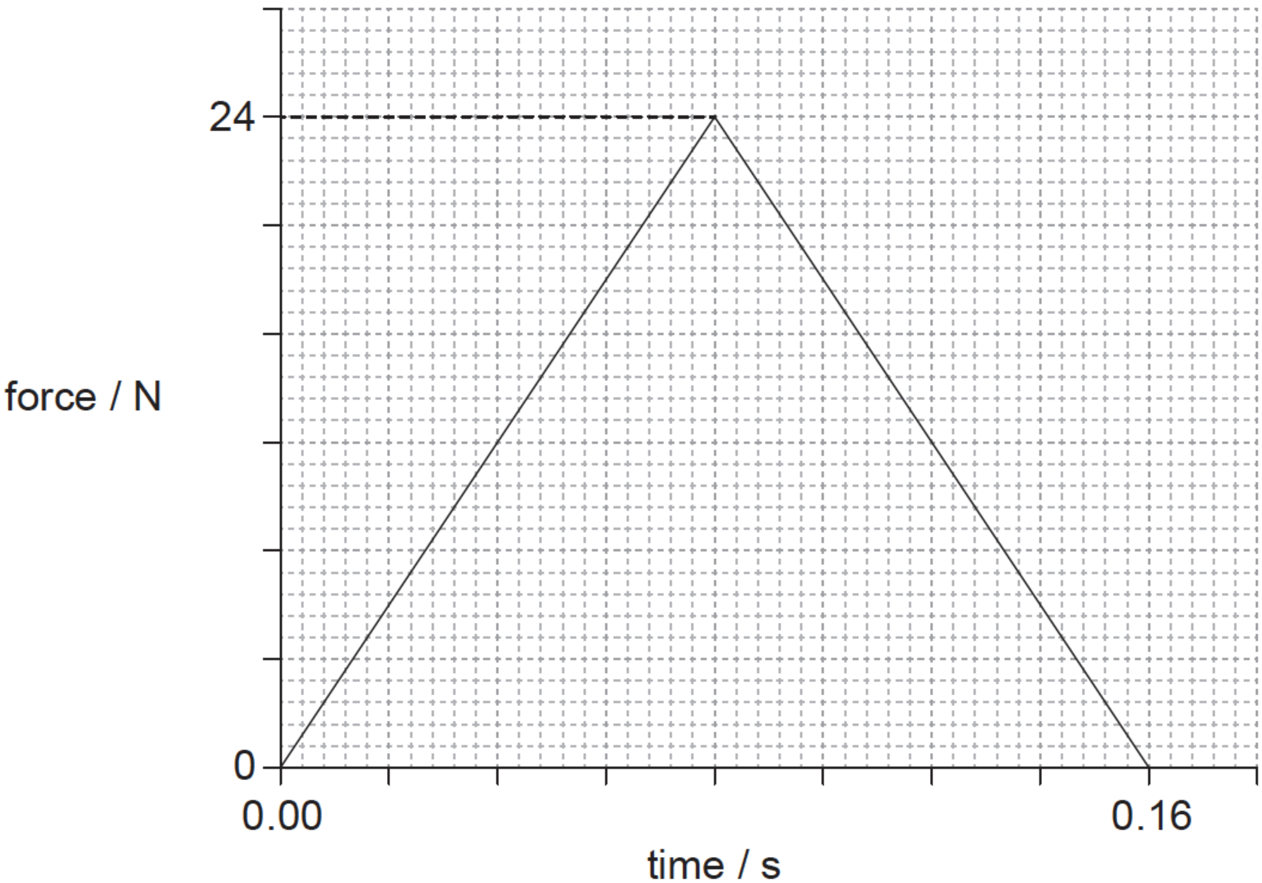
Part 1 Momentum

18a. State the law of conservation of linear momentum. *[2 marks]*

18b. A toy car crashes into a wall and rebounds at right angles to the wall, as shown in the plan view. *[9 marks]*



The graph shows the variation with time of the force acting on the car due to the wall during the collision.

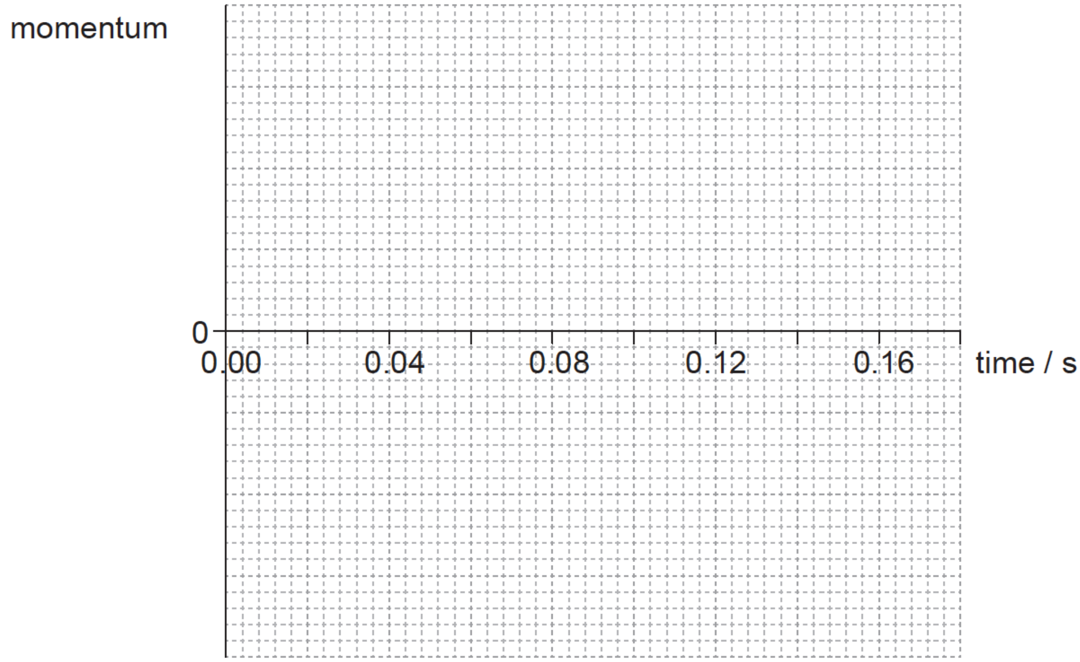


The kinetic energy of the car is unchanged after the collision. The mass of the car is 0.80 kg.

(i) Determine the initial momentum of the car.

(ii) Estimate the average acceleration of the car before it rebounds.

(iii) On the axes, draw a graph to show how the momentum of the car varies during the impact. You are not required to give values on the y-axis.

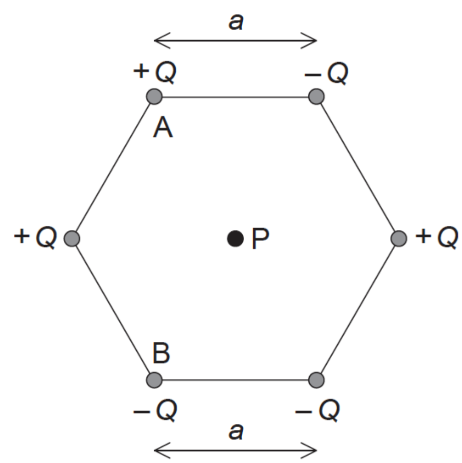


18c. Two identical toy cars, A and B are dropped from the same height onto a solid floor without rebounding. Car A is unprotected whilst car B is in a box with protective packaging around the toy. Explain why car B is less likely to be damaged when dropped. *[4 marks]*

Part 2 Electric point charges

18d. Define *electric field strength* at a point in an electric field. *[2 marks]*

18e. Six point charges of equal magnitude Q are held at the corners of a hexagon with the signs of the charges as shown. Each side of the hexagon has a length a. *[8 marks]*



P is at the centre of the hexagon.

(i) Show, using Coulomb's law, that the magnitude of the electric field strength at point P due to **one** of the point charges is

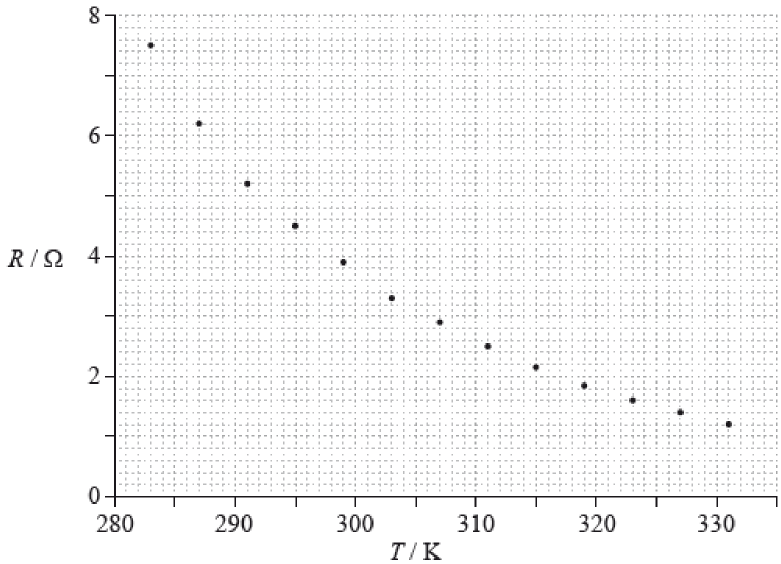
$$\frac{kQ}{a^2}$$

(ii) On the diagram, draw arrows to represent the direction of the field at P due to point charge A (label this direction A) and point charge B (label this direction B).

(iii) The magnitude of Q is 3.2 μC and length a is 0.15 m. Determine the magnitude and the direction of the electric field strength at point P due to all six charges.

Data analysis question.

A student sets up a circuit to study the variation of resistance R of a negative temperature coefficient (NTC) thermistor with temperature T. The data are shown plotted on the graph.



19a. Draw the best-fit line for the data points. *[1 mark]*

19b. Calculate the gradient of the graph when $T = 291\ \mathrm{K}$. *[3 marks]*

19c. State the unit for your answer to (b)(i). *[1 mark]*

19d. The uncertainty in the resistance value is 5%. The uncertainty in the temperature is negligible. On the graph, draw error bars for the data point at $T = 283\ \mathrm{K}$ and for the data point at $T = 319\ \mathrm{K}$. *[2 marks]*

The electric current through the thermistor for $T = 283\ \mathrm{K}$ is 0.78 mA. The uncertainty in the electric current is 0.01 mA.

19e. Calculate the power dissipated by the thermistor at $T = 283\ \mathrm{K}$. *[1 mark]*

19f. Determine the uncertainty in the power dissipated by the thermistor at $T = 283\ \mathrm{K}$. *[3 marks]*