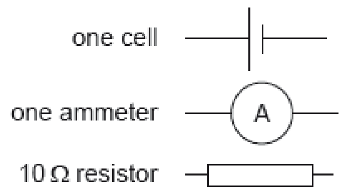
SL Paper 3

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



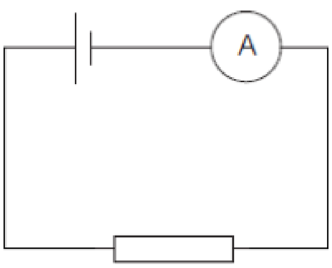
a. Draw a suitable circuit diagram that would enable the internal resistance to be determined. [1]

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

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

Markscheme

a.



ammeter and resistor in series

[1 mark]

b. resistance of resistor would increase / be greater than 10 Ω

$R + r$ «from $\varepsilon = \boldsymbol{I}(R + r)$» would be overestimated / lower current

therefore calculated r would be larger than real

Award MP3 only if at least one previous mark has been awarded.

[3 marks]

c. variable resistor would allow for multiple readings to be made

gradient of V-I graph could be found «to give r»

*Award **[1 max]** for taking average of multiple.*

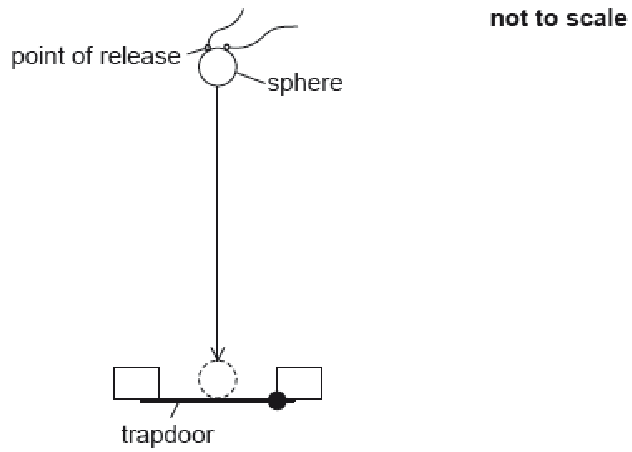
[2 marks]

Examiners report

[N/A]

a.
b. [N/A]
c. [N/A]

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

a. 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]

b. Using the following equation [4]

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

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

Markscheme

a. distance fallen = 654 – 12 = 642 «mm»

absolute uncertainty = 2 + 0.1 «mm» ≈ 2×10^{-3} «m» **or** = 2.1×10^{-3} «m» **or** 2.0×10^{-3} «m»

Accept answers in mm or m

[2 marks]

b. «$a = \frac{2s}{t^2} = \frac{2 \times 0.642}{0.363^2}$» = 9.744 «$ms^{-2}$»

fractional uncertainty in distance = $\frac{2}{642}$ ***AND*** fractional uncertainty in time = $\frac{0.002}{0.363}$

total fractional uncertainty = $\frac{\Delta s}{s} + 2\frac{\Delta t}{t}$ «= 0.00311 + 2 × 0.00551»

total absolute uncertainty = 0.1 ***or*** 0.14 ***AND*** same number of decimal places in value and uncertainty, *ie*: 9.7 ± 0.1 ***or*** 9.74 ± 0.14

Accept working in % for MP2 and MP3

Final uncertainty must be the absolute uncertainty

[4 marks]

Examiners report

a. [N/A]
b. [N/A]

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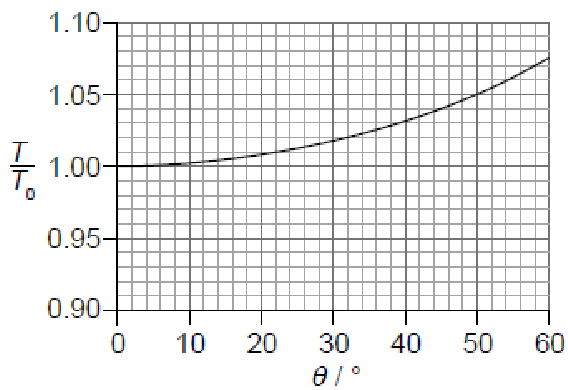
a. In a simple pendulum experiment, a student measures the period T of the pendulum many times and obtains an average value T = (2.540 ± 0.005) s. The length L of the pendulum is measured to be L = (1.60 ± 0.01) m. [3]

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.

b. 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]



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.

Markscheme

a. $g = \frac{4\pi^2 \times 1.60}{2.540^2} = 9.7907$

$\Delta g = g\left(\frac{\Delta L}{L} + 2 \times \frac{\Delta T}{T}\right) =$ «$9.7907\left(\frac{0.01}{1.60} + 2 \times \frac{0.005}{2.540}\right) =$» 0.0997

OR

1.0%

hence g = (9.8 ± 0.1) «m s^{-2}» ***OR*** Δg = 0.1 «m s^{-2}»

For the first marking point answer must be given to at least 2 dp.
Accept calculations based on

$g_{\max} = 9.8908$

$g_{\min} = 9.6913$

$\frac{g_{\max} - g_{\min}}{2} = 0.099 \approx 0.1$

[3 marks]

b. $\frac{T}{T_0} = 1.01$

θ_{max} = 22 «°»

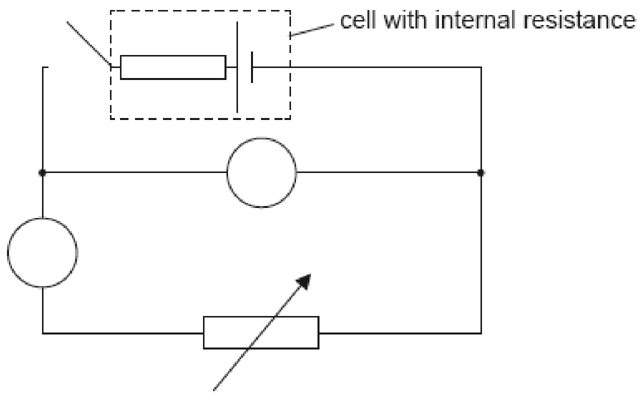
Accept answer from interval 20 to 24.

[2 marks]

Examiners report

a. [N/A]
b. [N/A]

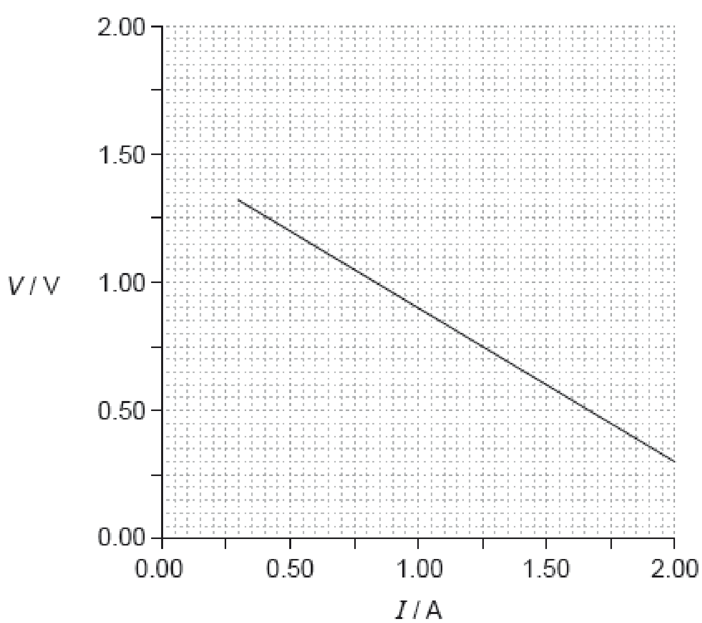
The circuit shown may be used to measure the internal resistance of a cell.



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.

a. 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]

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



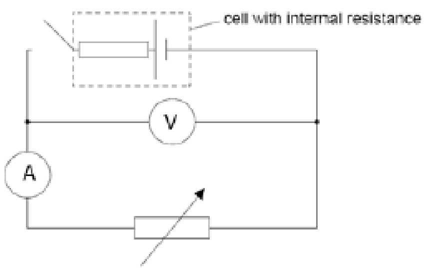
Using the graph, determine the best estimate of the internal resistance of the cell.

c.i. State what is meant by a zero error. [1]

c.ii. 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]

Markscheme

a. correct labelling of both instruments



[1 mark]

b. *V* = *E* – *Ir*

large triangle to find gradient and correct read-offs from the line
OR
use of intercept *E* = 1.5 V and another correct data point

internal resistance = 0.60 Ω

For MP1 – do not award if only $R = \frac{V}{I}$ *is used.*

For MP2 points at least 1A apart must be used.

For MP3 accept final answers in the range of 0.55 Ω to 0.65 Ω.

[3 marks]

c.i. a non-zero reading when a zero reading is expected/no current is flowing

OR

a calibration error

OWTTE
Do not accept just "systematic error".

[1 mark]

c.ii. the error causes «all» measurements to be high/different/incorrect

effect on calculations/gradient will cancel out
OR
effect is that value for *r* is unchanged

*Award **[1 max]** for statement of "no effect" without valid argument.*

OWTTE

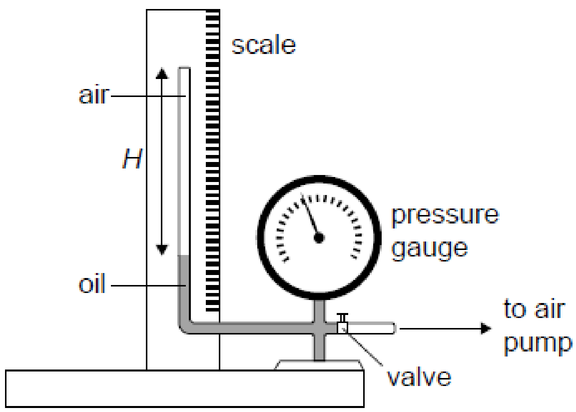
[2 marks]

Examiners report

a. [N/A]
b. [N/A]
c.i. [N/A]
c.ii. [N/A]

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.

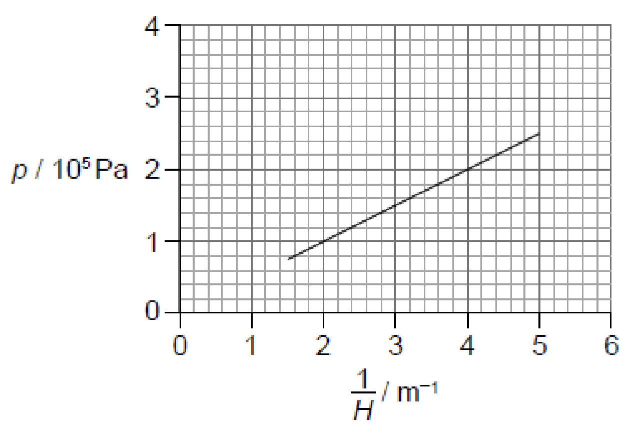
The air was trapped in a tube of constant cross-sectional area above a column of oil.



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

a. 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]

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



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

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

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

d. The cross-sectional area of the tube is $1.3 \times 10^{-3}\,m^2$ and the temperature of air is 300 K. Estimate the number of moles of air in the tube. [2]

e. 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]

Markscheme

a. in order to keep the temperature constant

in order to allow the system to reach thermal equilibrium with the surroundings/OWTTE

Accept answers in terms of pressure or volume changes only if clearly related to reaching thermal equilibrium with the surroundings.

[1 mark]

b. recognizes *b* as gradient

calculates *b* in range 4.7×10^4 to 5.3×10^4

Pa m

*Award **[2 max]** if POT error in b.*
Allow any correct SI unit, eg kg s^{-2}.

[3 marks]

c. $V \propto H$ thus ideal gas law gives $p \propto \frac{1}{H}$

so graph **should be** «a straight line through origin,» as **observed**

[2 marks]

d. $n = \frac{bA}{RT}$ ***OR*** correct substitution of one point from the graph

$n = \frac{5 \times 10^4 \times 1.3 \times 10^{-3}}{8.31 \times 300} = 0.026 \approx 0.03$

Answer must be to 1 or 2 SF.

Allow ECF from (b).

[2 marks]

e. very large $\frac{1}{H}$ means very small volumes / very high pressures

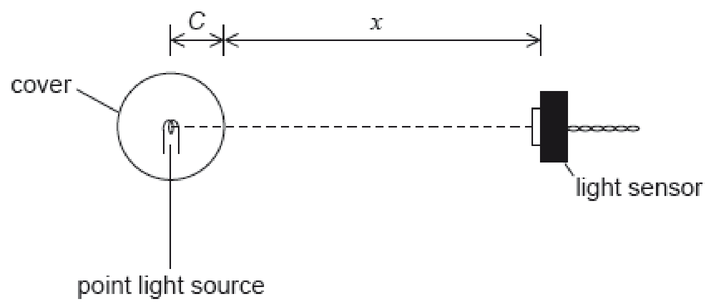
at very small volumes the ideal gas does not apply
OR
at very small volumes some of the assumptions of the kinetic theory of gases do not hold

[2 marks]

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]

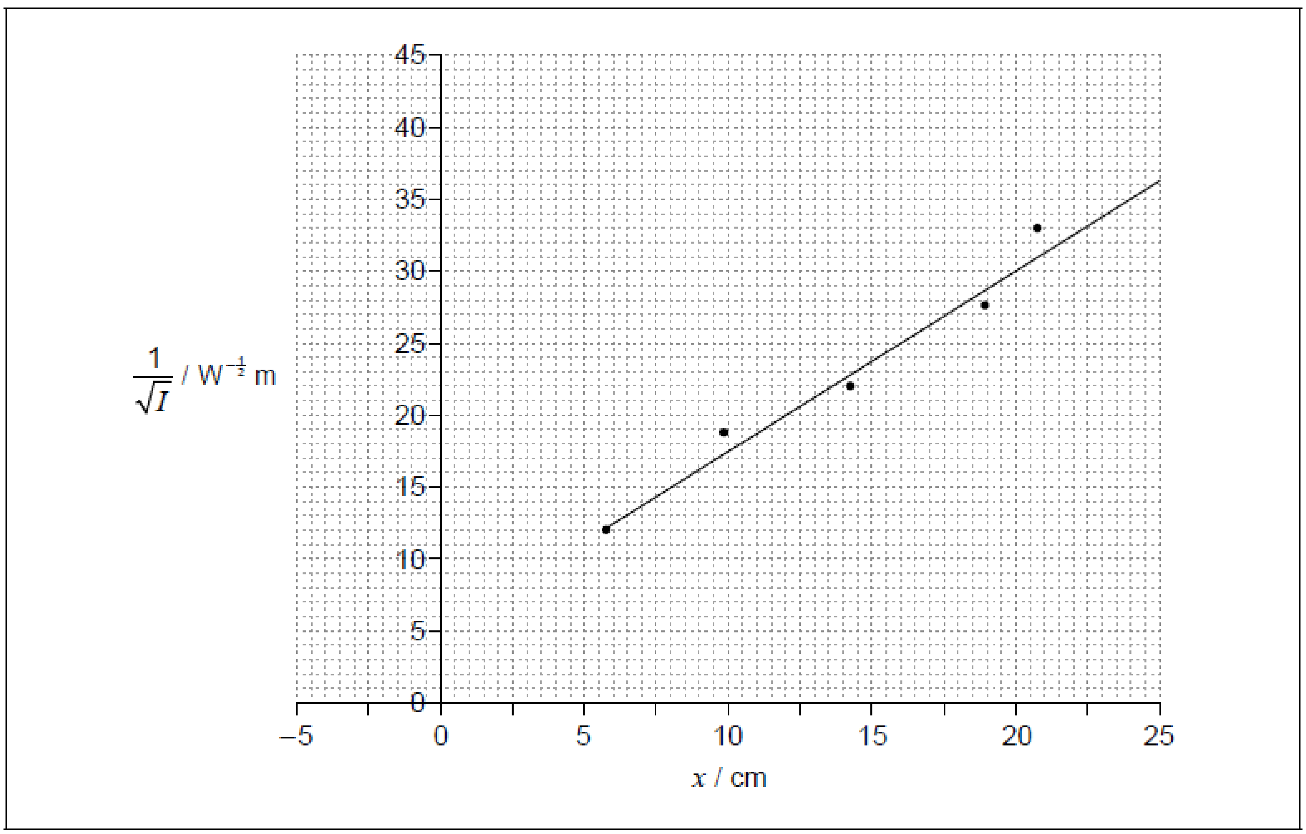
A student carries out an experiment to determine the variation of intensity of the light with distance from a point light source. The light source is at the centre of a transparent spherical cover of radius *C*. The student measures the distance *x* from the surface of the cover to a sensor that measures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

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

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



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

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

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

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

b.ii. Determine P, to the correct number of significant figures including its unit. [4]

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

Markscheme

a. combines the two equations to obtain result

«for example $\frac{1}{I} = K^2(C + x)^2 = \frac{4\pi}{P}(C + x)^2$»

OR

reverse engineered solution – substitute $K = 2\sqrt{\frac{\pi}{P}}$ into $\frac{1}{I} = K^2(C + x)^2$ to get $I = \frac{P}{4\pi(C+x)^2}$

There are many ways to answer the question, look for a combination of two equations to obtain the third one

[1 mark]

b.i. extrapolating line to cross x-axis / use of x-intercept

OR

Use $C = \frac{y\text{ - intercept}}{\text{gradient}}$

OR

use of gradient and one point, correctly substituted in one of the formulae

accept answers between 3.0 and 4.5 «cm»

*Award **[1 max]** for negative answers*

[2 marks]

b.ii. ***ALTERNATIVE 1***

Evidence of finding gradient using two points on the line at least 10 cm apart

Gradient found in range: 115–135 ***or*** 1.15–1.35

Using $P = \frac{4\pi}{K^2}$ to get value between 6.9×10^{-4} and 9.5×10^{-4} «W» and POT correct

Correct unit, W **and** answer to 1, 2 or 3 significant figures

ALTERNATIVE 2

Finds $I\left(\frac{1}{y^2}\right)$ from use of one point (x and y) on the line with $x > 6$ cm and C from(b)(i)to use in $I = \frac{P}{4\pi(C+x)^2}$ or $\frac{1}{\sqrt{I}} = Kx + KC$

Correct re-arrangementto get P between 6.9×10^{-4} and 9.5×10^{-4} «W» and POT correct

Correct unit, W **and** answer to 1, 2 or 3 significant figures

*Award **[3 max]** for an answer between 6.9 W and 9.5 W (POT penalized in 3rd marking point)*

*Alternative 2 is worth **[3 max]***

[4 marks]

c. this graph will be a curve / not be a straight line

more difficult to determine value of *K*

OR

more difficult to determine value of *C*

OR

suitable mathematical argument

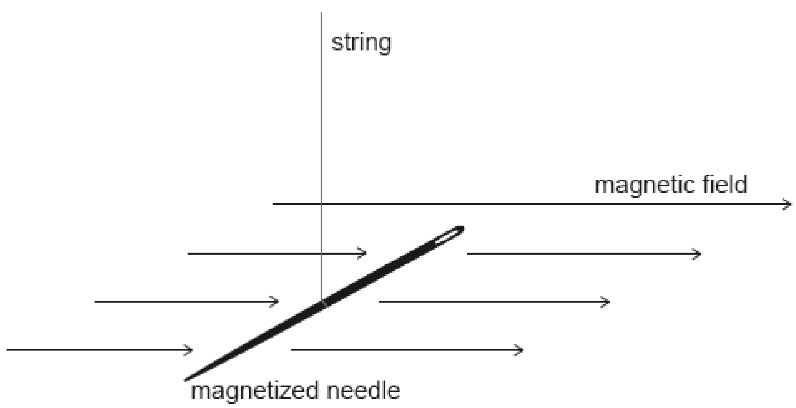
OWTTE

[2 marks]

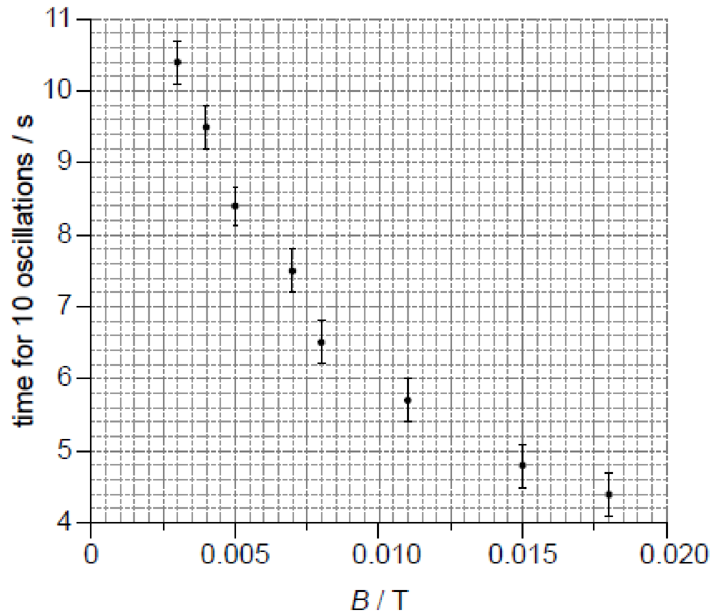
Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]

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.



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

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

b.ii A student forms a hypothesis that the period of one oscillation P is given by: [3]

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

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.

b.iii State the unit of K. [1]

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

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.

d. State how the value of K can be obtained from the graph. [1]

Markscheme

a. smooth line, not kinked, passing through all the error bars.

[1 mark]

b.i. 0.84 ± 0.03 «s»

Accept any value from the range: 0.81 to 0.87.

*Accept uncertainty 0.03 **OR** 0.025.*

[1 mark]

b.ii. $K = \sqrt{0.005} \times 0.84 = 0.059$

«$\frac{\Delta K}{K} = \frac{\Delta P}{P}$»

$\Delta K = \frac{0.03}{0.84} \times 0.0594 = 0.002$

«*K* =(0.059 ± 0.002)»

uncertainty given to 1sf

*Allow ECF **[3 max]** if 10T is used.*

*Award **[3]** for BCA.*

[3 marks]

b.iii. $\mathrm{sT}^{\frac{1}{2}}$

Accept $s\sqrt{T}$ or in words.

[1 mark]

c. straight ***AND*** ascending line

through origin

[2 marks]

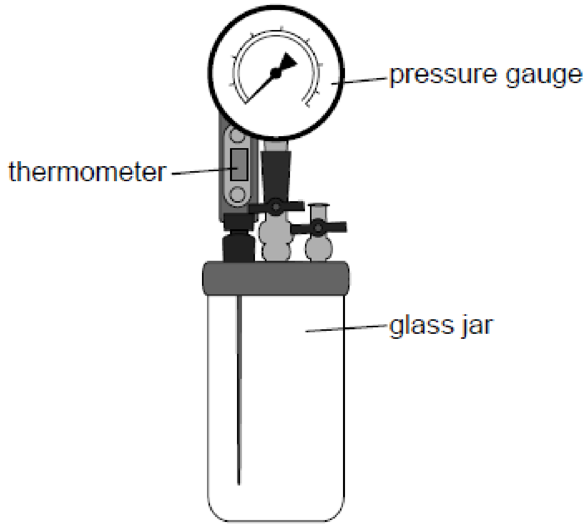
d. $K = \sqrt{\text{slope}}$

[1 mark]

Examiners report

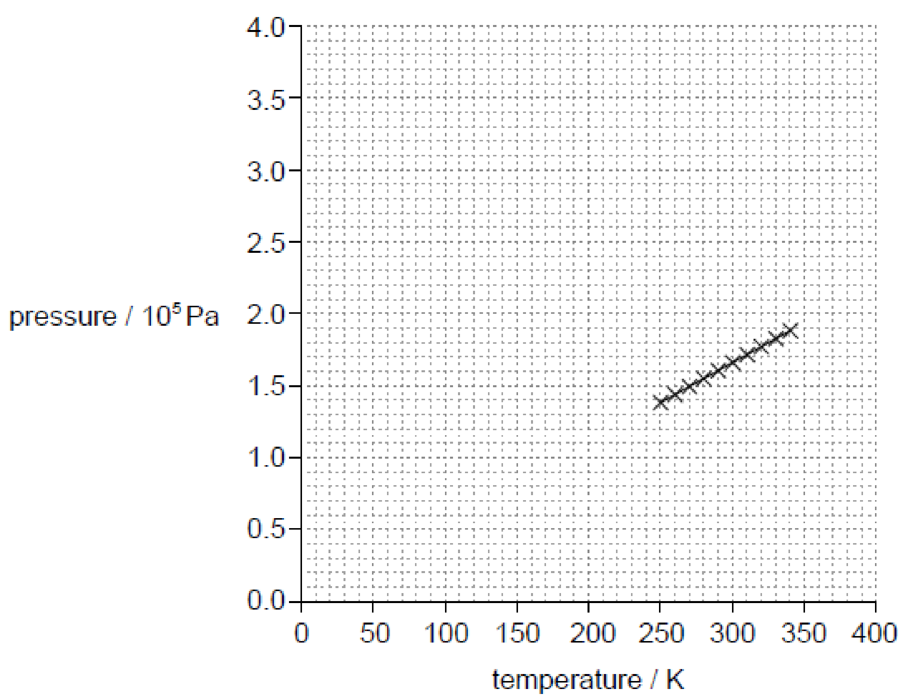
a. [N/A]
b.i. [N/A]
b.ii. [N/A]
b.iii. [N/A]
c. [N/A]
d. [N/A]

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.

a. The graph shows the data recorded. [1]



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

b. 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]

(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).

Markscheme

a. kg m^{-1} s^{-2} K^{-1}

b. i

any straight line that either goes or would go, if extended, through the origin

ii

for ideal gas *p* is proportional to *T* / P= nRT/V

gradient is constant /graph is a straight line

line passes through origin / 0,0

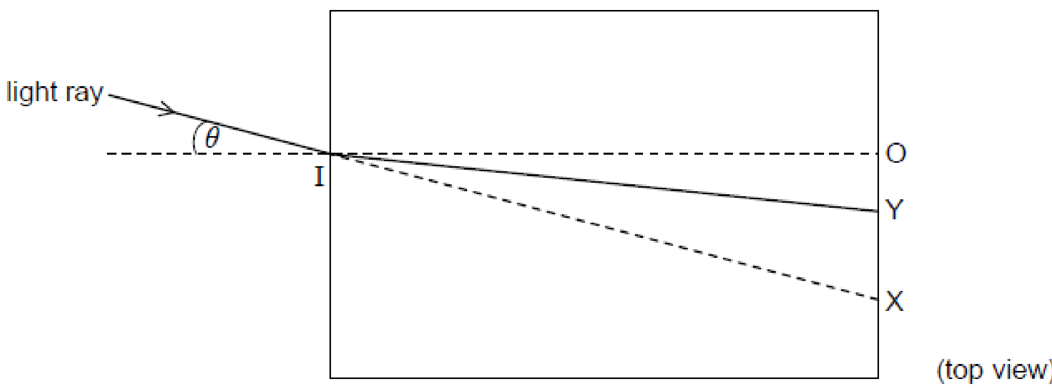
Examiners report

a. [N/A]
b. [N/A]

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.

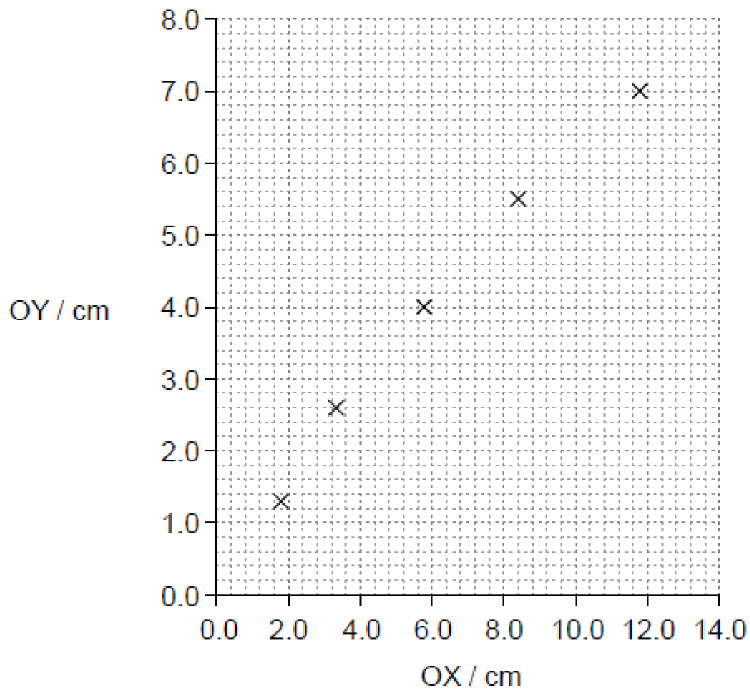
OX / cm	OY / cm
1.8	1.3
3.6	2.6
5.8	4.0
8.4	5.5
11.9	7.3
17.3	9.5
27.4	12.2

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

(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.

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



(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.

Markscheme

a. i

OY always smaller than OX ***AND*** uncertainties are the same/0.1

« so fraction $\frac{0.1}{\text{OY}} > \frac{0.1}{\text{OX}}$ »

ii

$\frac{0.1}{1.3}$ ***AND*** $\frac{0.1}{1.8}$

= 0.13 ***OR*** 13%

Watch for correct answer even if calculation continues to the absolute uncertainty.

b. i

total length of bar = 0.2 cm

Accept correct error bar in one of the points: OX= 1.8 cm ***OR*** *OY= 5.8 cm (which is not a measured point but is a point on the interpolated line)* ***OR*** *OX= 5.8 cm.*
Ignore error bar of OX.
Allow range from 0.2 to 0.3 cm, by eye.

ii

suitable line drawn extending at least up to 6 cm
OR
gradient calculated using two out of the first three data points

inverse of slope used

value between 1.30 and 1.60

*If using one value of OX and OY from the graph for any of the first three data points award **[2 max]**.*
*Award [**3**] for correct value for each of the three data points and average.*
*If gradient used, award [**1 max**].*

iii

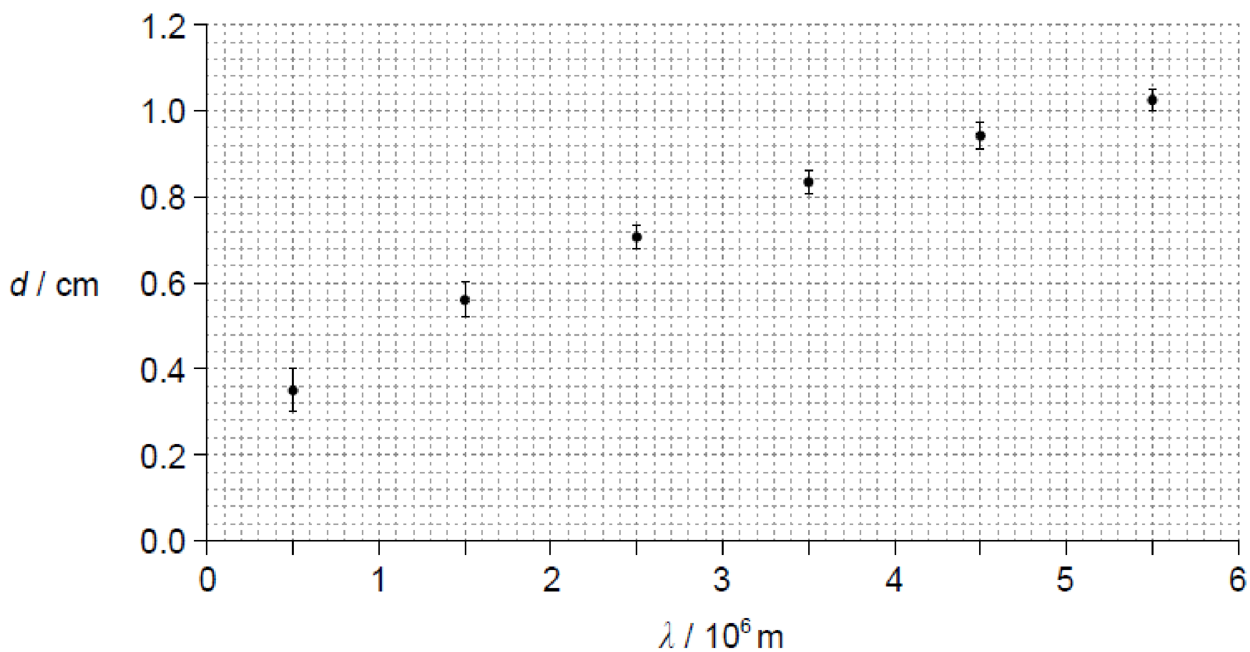
«the equation $n=\frac{\text{OX}}{\text{OY}}$» involves a tan approximation/is true only for small θ «when sinθ = tanθ»
OR
«the equation $n=\frac{\text{OX}}{\text{OY}}$» uses OI instead of the hypotenuse of the ΔIOX or IOY

OWTTE

Examiners report

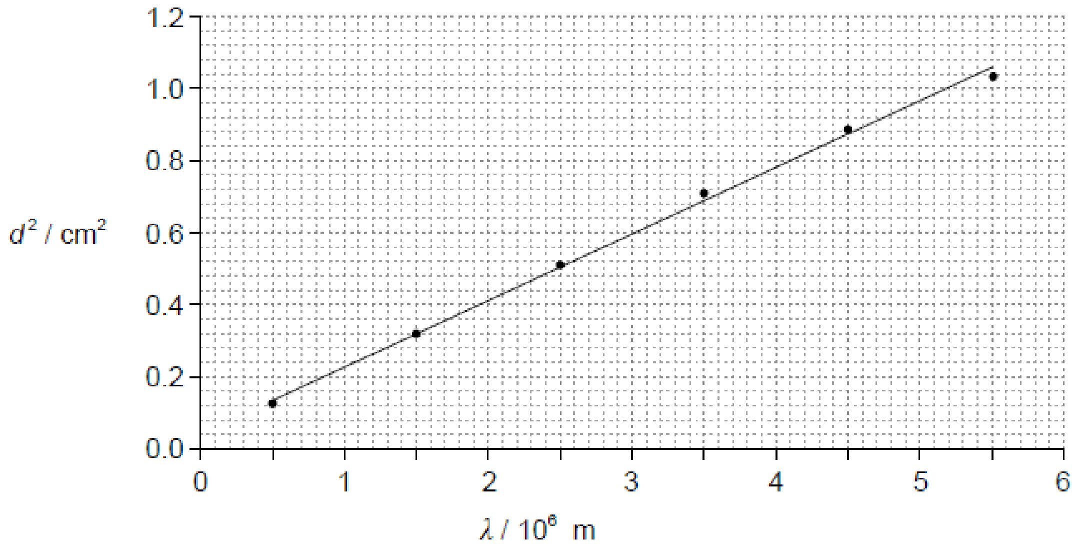
a. [N/A]
b. [N/A]

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.



For λ = 5.0 x 10^5 m, calculate the

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

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

b.i. fractional uncertainty in d. [2]

b.ii. percentage uncertainty in d^2. [1]

c.i. State the fundamental SI unit of the constant a and of the constant b. [2]

a: . . . .

b: . . . .

c.ii. Determine the distance travelled inside the conductor by very high frequency electromagnetic waves. [2]

Markscheme

a. it is not possible to draw a straight line through all the error bars

OR

the line of best-fit is curved/not a straight line

Treat as neutral any reference to the origin.

Allow "linear" for "straight line".

[1 mark]

b.i. $d = 0.35 \pm 0.01$ ***AND*** $\Delta d = 0.05 \pm 0.01$ «cm»

«$\frac{\Delta d}{d} = \frac{0.5}{0.35}$» = 0.14

OR

$\frac{1}{7}$ ***or*** 14% ***or*** 0.1

Allow final answers in the range of 0.11 to 0.18.

*Allow **[1 max]** for 0.03 to 0.04 if $\lambda = 5 \times 10^6$ m is used.*

[2 marks]

b.ii 28 to 30%

Allow ECF from (b)(i), but only accept answer as a %

[1 mark]

c.i. *a:* m^2

b: m

Allow answers in words

[2 marks]

c.ii ***ALTERNATIVE 1*** – if graph on page 4 is used

$d^2 = 0.040 \times 10^{-4}$ «m^2»

$d = 0.20 \times 10^{-2}$ «m»

ALTERNATIVE 2 – if graph on page 2 is used

any evidence that *d* intercept has been determined

$d = 0.20 \pm 0.05$ «cm»

For MP1 accept answers in range of 0.020 to 0.060 «cm^2» if they fail to use given value of "a".

For MP2 accept answers in range 0.14 to 0.25 «cm» .

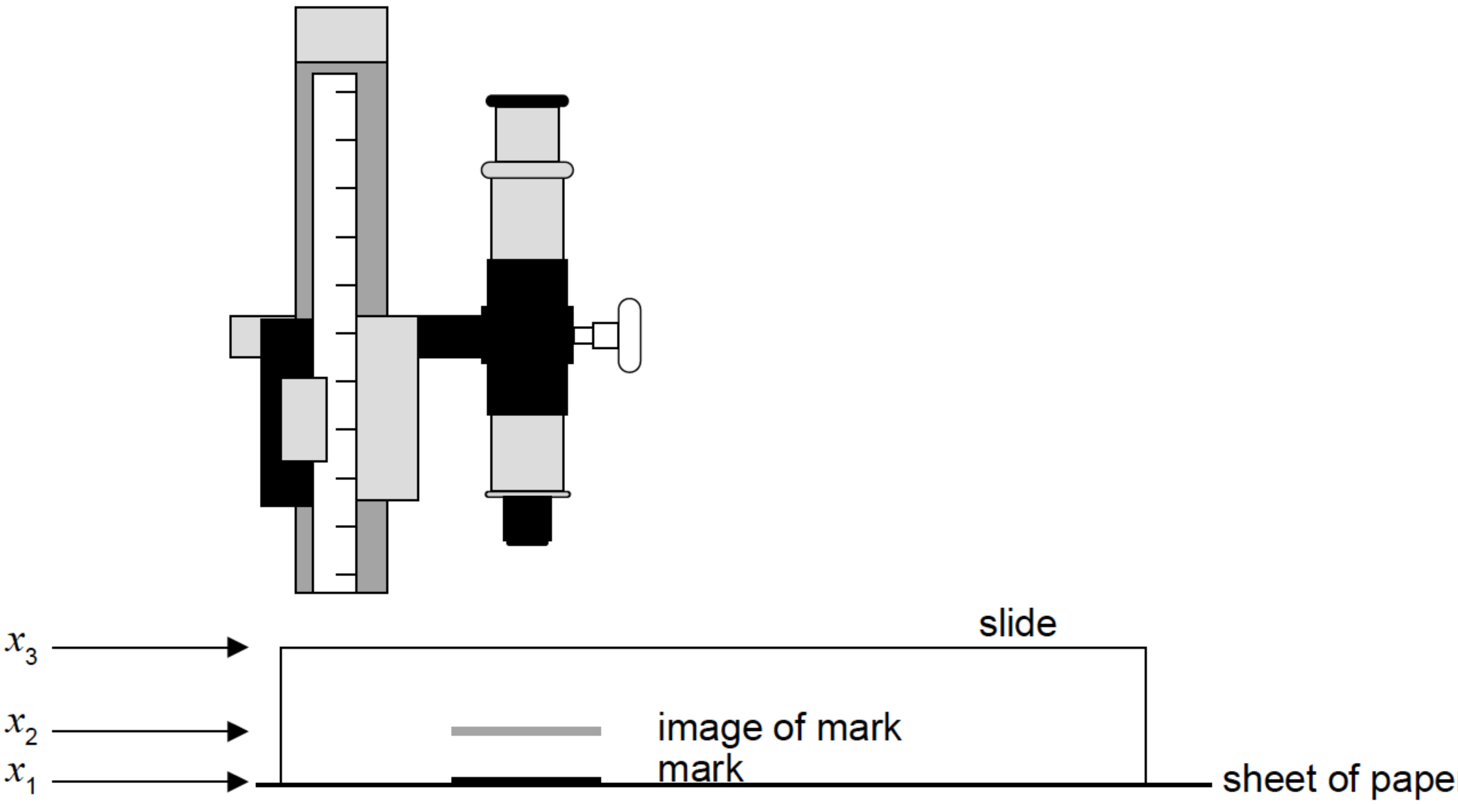
[2 marks]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c.i. [N/A]
c.ii. [N/A]

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

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

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

.

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).

b. 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]

(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.

c. 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]

Markscheme

a. (i) refractive index = 1.5

*Both correct value and 2SF required for **[1]**.*

(ii) fractional uncertainty $x_3 - x_1 = \frac{0.04}{1.15} = 0.035$ ***AND*** $x_3 - x_2 = \frac{0.04}{0.76} = 0.053$

sum of fractional uncertainty = 0.088

«uncertainty = their RI × 0.088» = 0.1

Accept correct calculation using maximum and minimum values giving the same answer.

b. (i) systematic error

Accept "zero error/offset".

(ii) calculated refractive index is unchanged
because both numerator and denominator are unchanged
Accept calculation of refractive index with 0.05 subtracted to each x value.

c. numerator and denominator will be 10 times larger so refractive index is unchanged

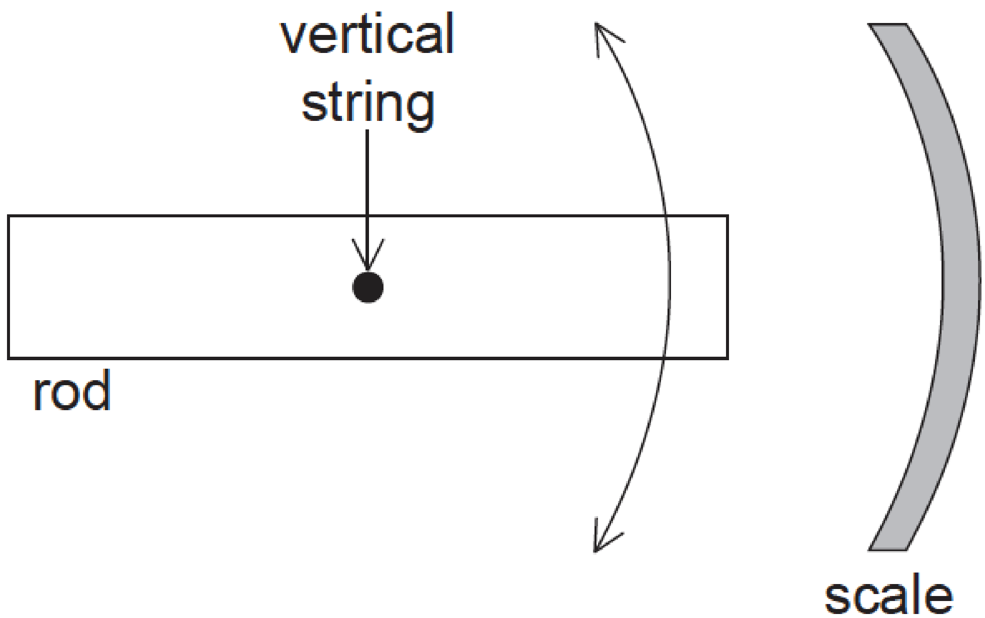
relative/absolute uncertainty will be smaller

"Constant material" is not enough for MP1.

Examiners report

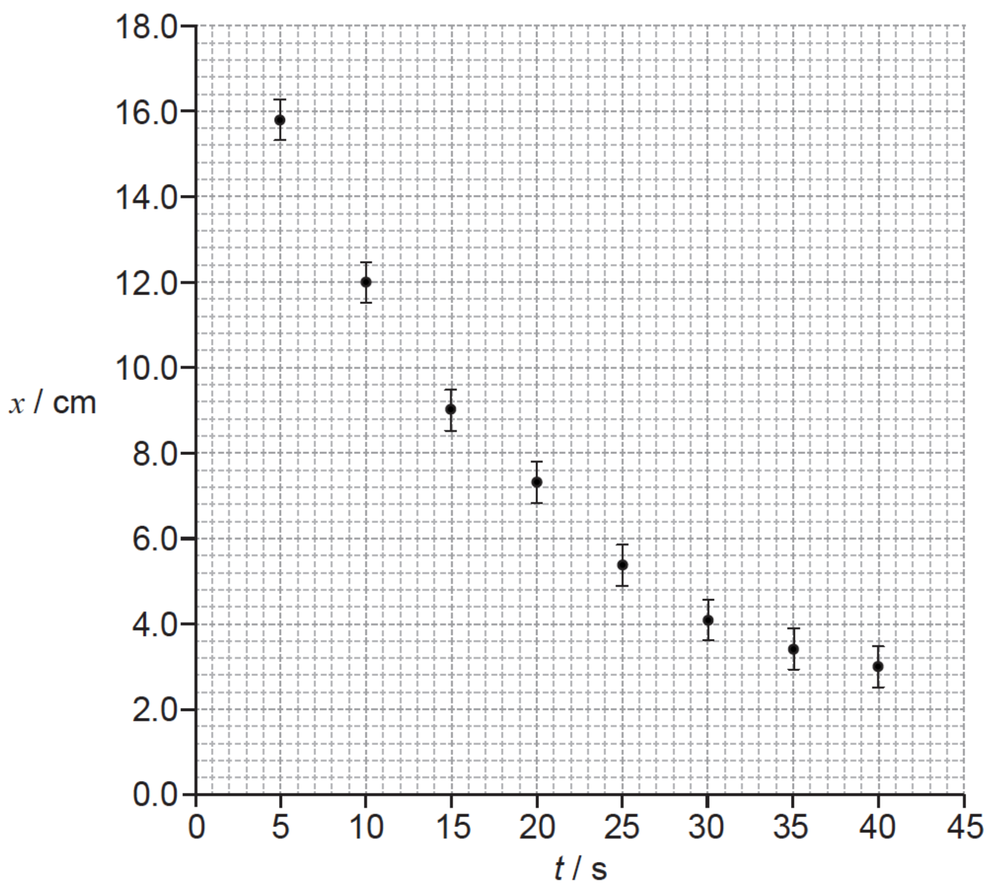
a. [N/A]
b. [N/A]
c. [N/A]

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.

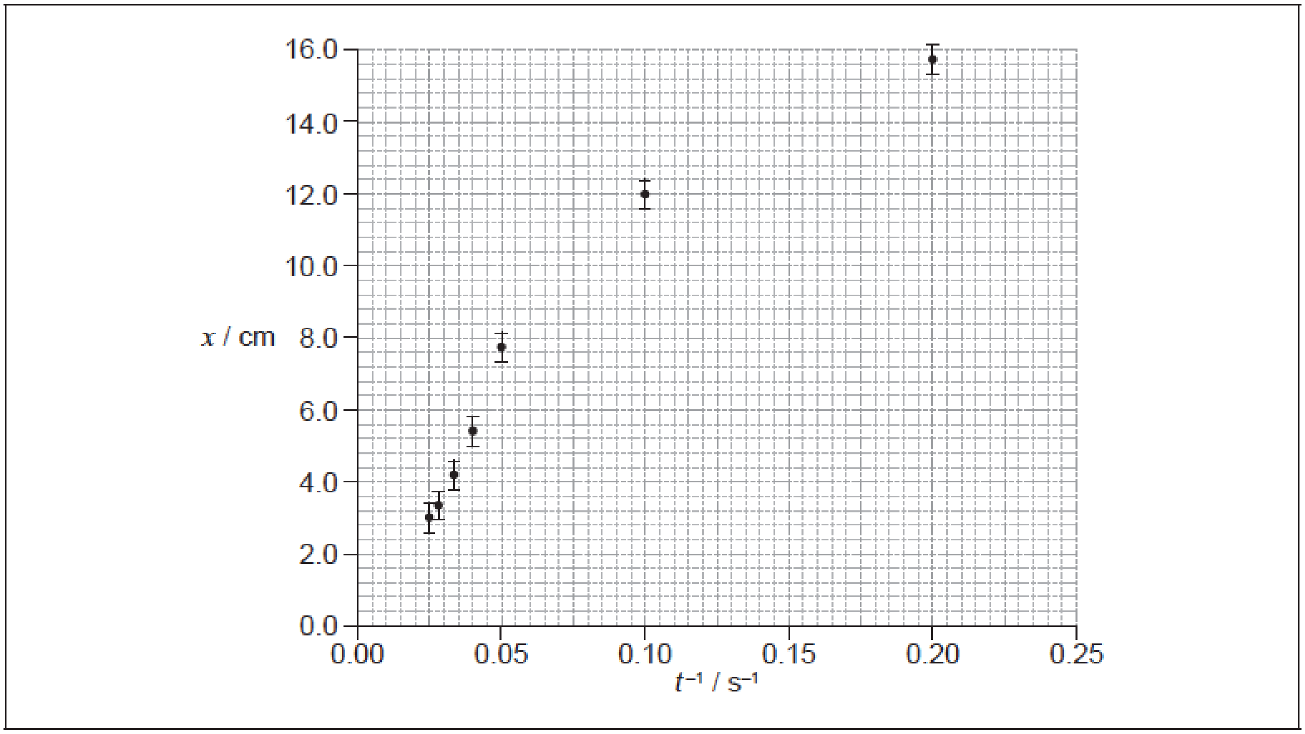


a. On the graph above, draw the line of best fit for the data. [1]

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

c. The student hypothesizes that the relationship between x and t is $x = \frac{a}{t}$ where a is a constant. [3]

To test the hypothesis x is plotted against $\frac{1}{t}$ as shown in the graph.

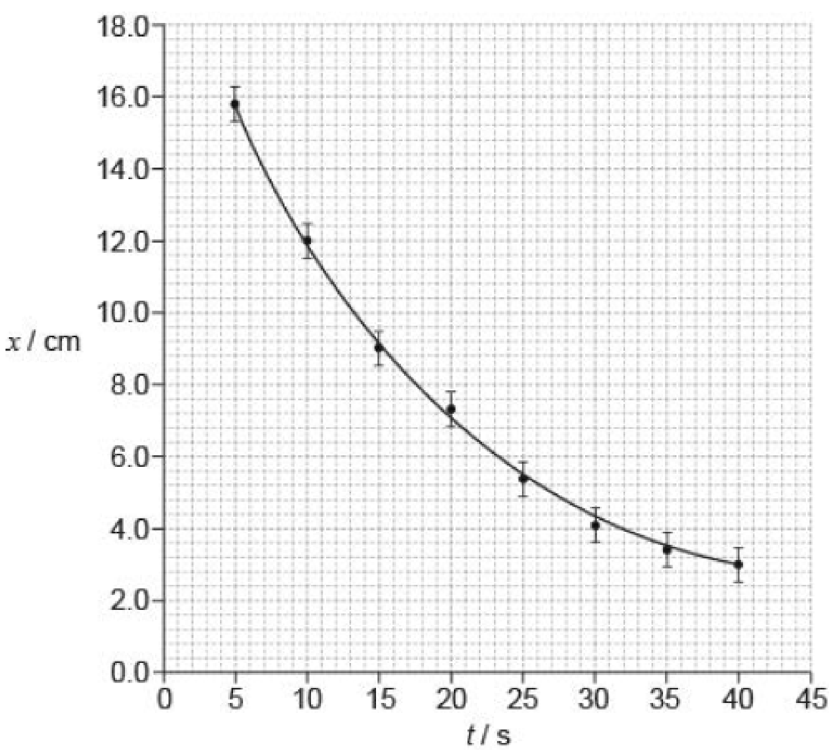


(i) The data point corresponding to t=15s has not been plotted. Plot this point on the graph above.

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

Markscheme

a. smooth curve passing through all error bars

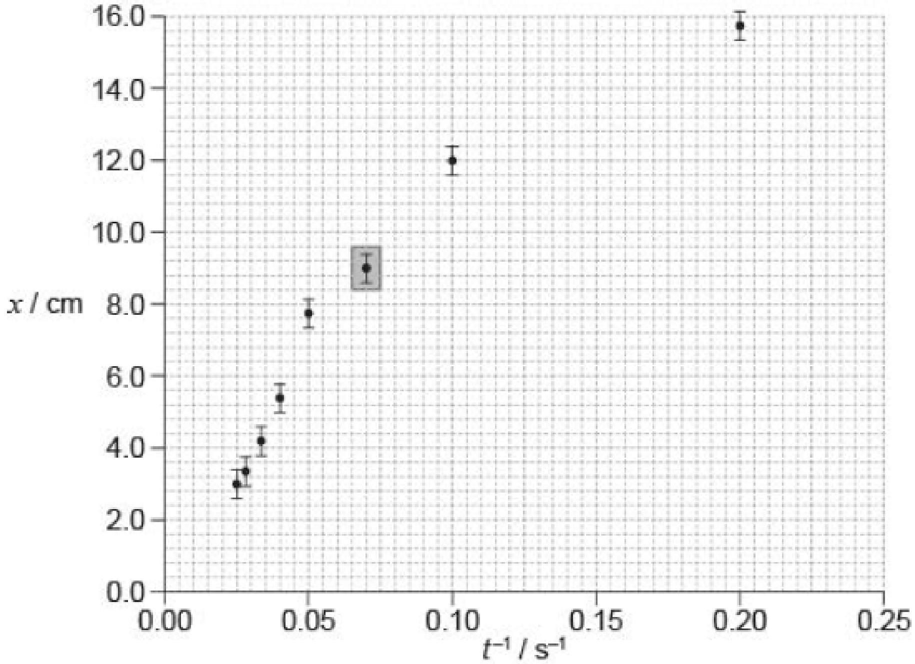


b. x=2.5 cm±0.2cm ***AND*** $\Delta 0x$=0.5cm±0.1cm

«$\frac{0.5}{2.5}$=»20%

Accept correctly calculated value from interval 15% to 25%.

c. (i) plotted point (0.07, 9.0) as shown



Allow any point within the grey square. The error bar is not required.

(ii) ***ALTERNATIVE 1***
t^{-1} from 0.025 s^{-1} to 0.04 s^{-1}
giving t from 25 to 40

ALTERNATIVE 2
the data do not support the hypothesis

any relevant support for the suggestion, *eg* straight line cannot be fitted through the error bars and the origin

Do not allow ECF from MP1 to MP2.

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]