

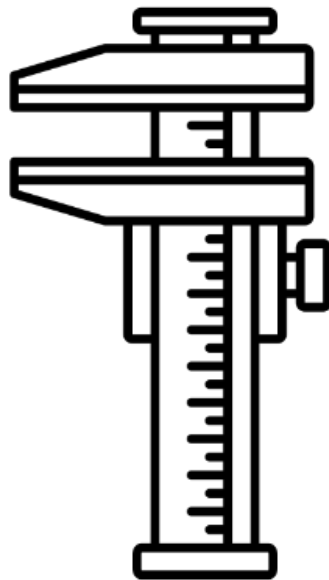
A-Level Physics

Summer Task

Measurements & Errors

To help you prepare and bridge the gap from GCSE to A-level Physics please read the notes and complete as many questions as you can.

Please hand in during your first Year 12 Physics Lesson.



Name _____

Use of SI units and their prefixes

The phrase SI units refers to the “Système International” units that scientists all over the world have agreed to use so that they can easily compare their work.

There are 7 SI units:

Quantity	Unit	Unit Symbol
Length	Metre	m
Time	Second	s
Mass	Kilogram	kg
Electric Current	Ampere	A
Temperature	Kelvin	K
Amount of Substance	Mole	mol
Luminosity (not needed at A Level)	Candela	cd

Most units are actually combinations of these SI units.

Simple examples include:

$$\text{velocity (ms}^{-1}\text{)} = \frac{\text{displacement (m)}}{\text{time (s)}}$$

$$\text{Momentum (kgms}^{-1}\text{)} = \text{mass (kg)} \times \text{velocity (ms}^{-1}\text{)}$$

Some combinations have their own unit name:

$$\text{Force (N)} = \text{mass (kg)} \times \text{acceleration (ms}^{-2}\text{)}$$

This shows that 1 Newton is equivalent to 1 kgms⁻² in SI units.

1. Use the equation $Work\ Done = Force \times Displacement$ to choose which of the following combinations is equivalent to 1 Joule in SI units

- a. kgm^2s^{-2}
- b. kgm^3s^{-2}
- c. $kgms^{-3}$
- d. $kgms^{-2}$

2. Use the equation $Charge = Current \times Time$ to write 1 Coulomb in SI units

3. Use the equation $Energy = Charge \times Potential\ Difference$ to write 1 volt in SI units

4. Use the equation $Wavespeed = Wavelength \times Frequency$ to write 1 Hertz in SI units

5. Use the equation linking energy and power to write 1 Watt in SI units

6. Which of the following is correct?

- a. $Js = kgm^2s^{-3}$
- b. $Js = kgm^2s^{-1}$
- c. $Js = kgms^{-2}$
- d. $Js = kgm^2s$

7. Which of the following is correct?

- a. $J/N = s$
- b. $J/N = kg$
- c. $J/N = m$
- d. $J/N = ms^{-1}$

8. Use the formula $Force = Magnetic\ Flux\ Density \times Current \times Length$ to find a unit for magnetic field density

Converting Units

Many quantities are commonly represented by units other than their base units, for a variety of reasons. Some examples are displayed below:

Quantity	Symbol	Alternative unit	Unit symbol	Value in SI units
Energy	E	electron volt	eV	1.6×10^{-19} J
Charge	Q	charge on electron	e	1.6×10^{-19} C
Mass	m	atomic mass unit	u	1.67×10^{-27} J
Mass	m	tonne	t	10^3 kg
Time	t	hour	hr	3,600 s
Time	t	year	yr	3.16×10^7 s
Distance	d	miles	miles	1,609 m
Distance	d	astronomical unit	AU	3.09×10^{11} m
Distance	d	light year	ly	9.46×10^{15} m
Distance	d	parsec	pc	3.09×10^{16} m

Convert the following quantities:

1. What is 13.6 eV expressed in joules?
2. What is a charge of 6e expressed in coulombs?
3. An atom of Lead-208 has a mass of 207.9766521 u, convert this mass into kg.
4. What is 2.39×10^8 kg in tonnes?
5. It has been 49 years since England won the World Cup, how long is this in seconds?
6. A TV program lasts 2,560s, how many hours is this?
7. The semi-major axis of Pluto's orbit around the Sun is 5.91×10^{12} m, what is this distance in AU?
8. Convert 0.023 kms^{-1} into ms^{-1} .
9. Express 3456 m hr^{-1} into km hr^{-1}
10. What is 30 miles hr^{-1} in ms^{-1} ?
11. What is 50 ms^{-1} in miles hr^{-1} ?
12. Convert 33 km hr^{-1} into ms^{-1} .
13. Express $234 \text{ miles hr}^{-1}$ in km hr^{-1} .

Mathematical Prefixes

Prefix	Symbol	Multiplier
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
kilo	k	10^3
mega	M	10^6
giga	G	10^9
tera	T	10^{12}
peta	P	10^{15}

When you are given a variable with a prefix you must convert it into its numerical equivalent in standard form before you use it in an equation.

Convert the following:

$1.4 \text{ kW} =$

$10 \mu\text{C} =$

$24 \text{ cm} =$

$340 \text{ MW} =$

$46 \text{ pF} =$

$0.03 \text{ mA} =$

$52 \text{ Gbytes} =$

$43 \text{ k}\Omega =$

$0.03 \text{ MN} =$

$83 \text{ Pm} =$

Now convert between different prefixes

$5.46\text{m to cm} =$

$65\text{mm to m} =$

$3\text{cm to m} =$

$0.98\text{m to mm} =$

$34\text{kW to GW} =$

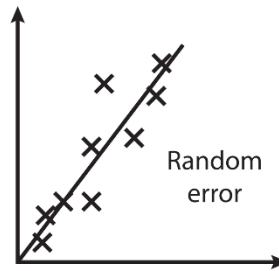
$76\text{nN to kN} =$

Challenge Task

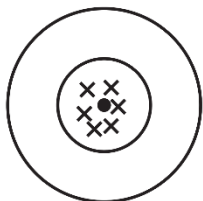
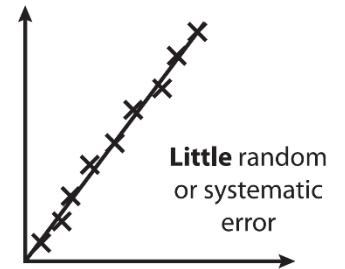
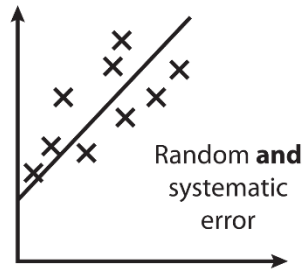
1. What is 5.2 mm^3 in m^3 ?
2. What is 24 cm^2 in m^2 ?
3. What is 34 m^3 in μm^3 ?
4. What is $0.96 \times 10^6 \text{ m}^2$ in km^2 ?
5. Convert 34 Mm^3 into pm^3 .

Limitation of physical measurements

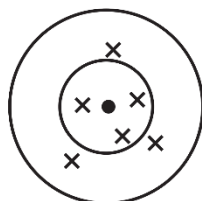
Random error: Measurements vary due to unpredictable circumstances. They cannot be corrected and can only be mitigated by making more measurements and calculating a new mean.



Systematic error: Measurements differ from the true value by a consistent amount each time. They can be corrected by using a different technique to take measurements.

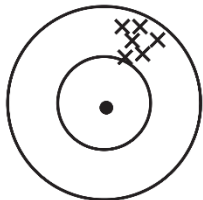


Precise and accurate

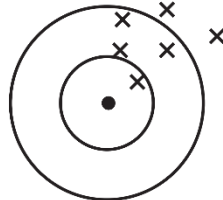


Not precise but accurate

Precision: How close measurements are to each other and the mean.



Precise but not accurate



Not precise and not accurate

Accuracy: How close a measurement is to the true value.

Repeatable: When the original experimenter repeats the investigation using the same method and equipment and obtains the same results.

Reproducible: When somebody else repeats the investigation or the investigation is performed using different equipment or techniques and the same results are obtained.

Resolution: The smallest change in a quantity being measured that gives a perceptible change in the reading.

Measurement	Instrument	Resolution	Uncertainty or precision
Length	Metre rule	1 mm	± 1 mm
	Vernier caliper	0.1 mm	± 0.1 mm
	Micrometer	0.01 mm	± 0.01 mm
Time	Manual stopwatch	0.01 s	± 0.2 s (reaction time)
	Electronic timer	0.01 s	± 0.005 s
Mass	Top-pan balance	0.01 g	± 0.005 g or ± 0.01 g
	Spring balance	1.0 g	± 0.5 g
Temperature	Mercury thermometer	0.1°C	± 0.05 °C (or ± 0.1 °C)

The **uncertainty** of a result is the interval within which the true value can be expected to lie.

The **absolute uncertainty** of a reading is no smaller than plus or minus half of the smallest division. The absolute uncertainty of a measurement, where two judgements are required (e.g. measuring a length using a ruler), is twice this. For multiple readings, the absolute uncertainty is half the range. Absolute uncertainties have the same units as the quantity.

$$\text{absolute uncertainty} = \frac{\text{range (largest value} - \text{smallest value)}}{2}$$

All measurements should be written as mean value \pm measurement error ($a \pm \Delta a$). E.g. A voltmeter gives a reading of 1.70 ± 0.01 V.

Quoting results along with errors:

- When giving results in terms of scientific notation or in standard form, always quote the value and the error with the same exponent.
 - Quote the result to the same number of significant figures as the quoted error implies.
 - Always quote the error to 1 or at most 2 significant figures.
1. A stopwatch that is accurate to 100^{th} of a second is used to record timings of an object in motion. What is the resolution of the stopwatch and what would be a typical value for its precision?
 2. A metre rule is being used to determine the vertical height of an object. Give two precautions that should be taken to ensure an accurate result.
 3. What device can be used to measure widths typically less than a centimetre and what is the precision of such a device?
 4. A measured value of 132 is quoted with an uncertainty of 18. Write the value to 2 s.f. along with the uncertainty.
 5. A measured value of 11.448 is quoted with an uncertainty of 0.25. Write the value to an appropriate degree of accuracy along with the uncertainty.
 6. The potential difference measured on a digital voltmeter is 3.36 V. Give this value together with the instrument uncertainty.

7. A current is measured with an analogue ammeter using a scale from 0 to 5 A. The reading obtained is 4.25 A and the interval size is 0.2 A. Give the value on the ammeter together with the uncertainty.
8. A metre rule is used to measure the width of a bench. The ruler's smallest interval is 1 mm and the length of the bench is measured to be 64.5 cm. Express this length together with the uncertainty in metres.
9. A set of measurements for the diameter of a piece of wire is made and the results are shown in the table.

Diameter (mm)	5.01	4.94	4.98	4.92	4.95
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- a) What is the name of the device used to measure such small distances? Give both the value of the resolution and the precision of this device.
 - b) What precautions should be taken before using this device?
 - c) The true value is 4.81 mm. Explain whether the results are accurate and/or precise.
10. A thermometer is used to record the temperature of water as it is heated from frozen. The results are shown in the table.

Temperature (°C)	1.0	2.4	3.9	5.0	6.3	7.1	7.9	9.6	10.1
Time (min)	0	1	2	3	4	5	6	7	8

- a) What is the resolution and uncertainty in the measuring device?
 - b) Draw a graph and plot the results of temperature (y-axis) against time (x-axis).
 - c) Draw the best line of fit through the points.
 - d) Given what you found in part a), determine the nature of the results in terms of random and/or systematic errors and justify your conclusion.
11. A steel rule is being used to measure the length of a metal bar that has a "true" length of 795 mm. The rule can be read to the nearest millimetre. Repeated measurements give the following results.

Reading	1	2	3	4	5
Value (mm)	792	791	791	792	792

- a) What is the mean value for the length?
- b) Are the readings accurate to 1 mm? Give a reason for your answer.
- c) Are the readings precise to 1 mm? Give reasons for your answer.

The **fractional uncertainty** is the absolute uncertainty divided by the measured value (if multiple readings, divided by the mean).

$$\text{fractional uncertainty} = \frac{\text{absolute uncertainty}}{\text{mean value}} = \frac{\Delta a}{a}$$

This can be converted into a **percentage uncertainty** by multiplying by 100.

$$\frac{\Delta a}{a} \times 100 = \epsilon a$$

There are different rules for combining uncertainties. Remember:

Δa = absolute uncertainty

ϵa = percentage uncertainty

When adding or subtracting data with uncertainties, add the absolute uncertainties.

When multiplying or dividing data with uncertainties, add the percentage uncertainties.

When raising data with an uncertainty to a power, multiply the percentage uncertainty by that power.

Combination	Uncertainties
$a = b \pm c$	$\Delta a = \Delta b + \Delta c$
$a = bc$ or $a = b/c$	$\epsilon a = \epsilon b + \epsilon c$
$a = b^c$	$\epsilon a = c \times \epsilon b$

When multiplying data with an uncertainty by a constant, multiply the absolute uncertainty by that constant but not the percentage uncertainty.

1. A thermometer is graduated in intervals of 1°C . What is the measurement uncertainty associated with this thermometer?
2. What is meant by the resolution of an instrument?
3. If the resolution of a set of weighing scales is said to be 0.1 g, what is the uncertainty in the values obtained?
4. An analogue ammeter is graduated in intervals of 0.2 A. What is the uncertainty of the device for recording current?
5. If the value of a measurement is a , what does Δa mean?
6. How is the percentage uncertainty determined from a single measurement whose value is a ?
7. How is the absolute uncertainty determined from a range of measurements?
8. A particular resistor was measured on five occasions to give the following results: 1.20 k Ω , 1.16 k Ω , 1.24 k Ω , 1.22 k Ω and 1.28 k Ω . What is the mean value of the resistor?
9. In the above set of results, what is the uncertainty associated with the measuring device used?
10. In question 8, what is the absolute uncertainty in the measurement?
11. In question 10, what is the percentage uncertainty in the measurement?
12. The resistance of a component is being measured. The potential difference across it is $8.2 \pm 0.2 \text{ V}$ and the current through it is $0.8 \pm 0.1 \text{ A}$. The resistance, R , of any component is given by the equation $V = IR$, where V is the potential difference and I is the current.
 - a) What is the value of the resistance of the component?
 - b) Determine the percentage uncertainties in both the potential difference and current readings?
 - c) From part b) calculate i) the total percentage uncertainty in R and ii) the absolute uncertainty in R .
 - d) Give the final value of the resistance together with its uncertainty.

13. The density of a piece of metal in the shape of a cube is being determined. The mass of the cube is measured to give the following results: 34.5 g, 34.2 g, 34.7 g, 34.9 g and 34.1 g.

- a) Calculate the mean mass of the metal cube. Give your answer to an appropriate number of significant figures.
- b) What is the uncertainty in the weighing scales used to determine the mass?
- c) Determine the absolute and percentage uncertainty in the above set of measurements and give your answer in the form: mass \pm uncertainty in the mass.

The dimension of the cube is 2.3 ± 0.01 cm for each side.

- d) Determine the volume of the cube and calculate the percentage and absolute uncertainty in the volume of the cube.
- e) Density is given by $\rho = m/V$. Calculate the absolute uncertainty in the density of the metal and give your final answer in units of kg/m^3 .

14. Hooke's law states that the extension of a spring is directly proportional to the load, i.e. $F = kx$ where F is the load in N, x is the extension in m and k is a constant, known as the spring constant.

- a) If the spring extends by 4.6 mm when a load of 15 N is applied, determine the value of the spring constant in N/m.

The uncertainty in the extension is ± 0.5 mm and the uncertainty in the force is ± 0.5 N.

- b) Calculate the percentage uncertainties in i) the extension and ii) the load.
- c) Determine the absolute uncertainty in the spring constant and write your answer as spring constant \pm uncertainty.

Other measurements taken using the same spring give a set of spring constants of values 3300, 3240, 3190 and 3140 N/m.

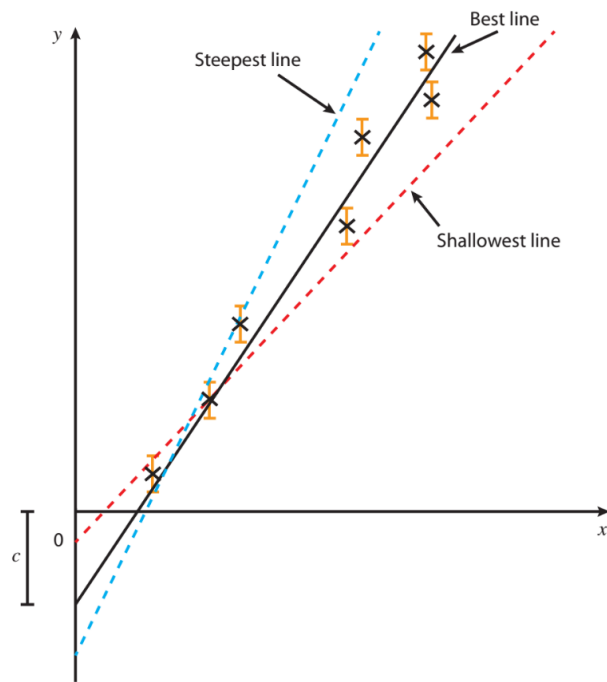
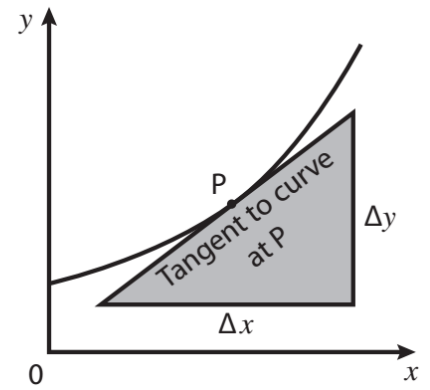
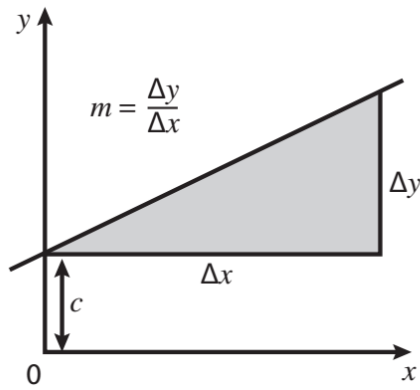
- d) Using the result in part c) together with the four other results above, determine the mean spring constant and the measured uncertainty in this set of results.

Usually (but not always!) **independent variable** goes on the x-axis and **dependent variable** goes on the y axis.

Equation of a straight line graph: $y = mx + c$

$$m = \Delta y \div \Delta x$$

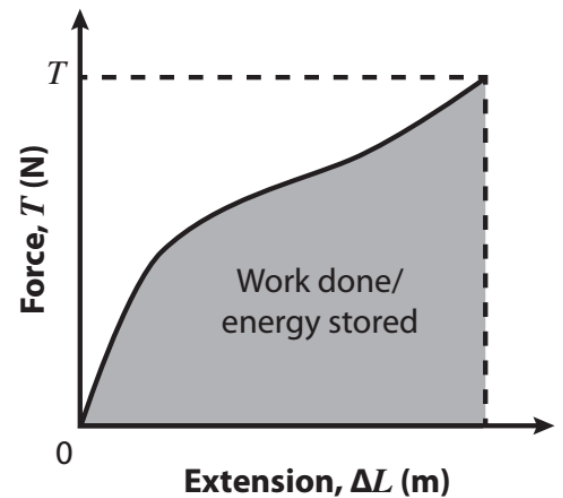
For gradient on a curve, you need to draw a tangent.



Errors can be show by **error bars** on a graph. Absolute uncertainties of a gradient can be calculated from **worst case** lines of best fit.

Can work out some other quantities from **area under the graph**.

E.g. area under a force vs extension graph gives **work done**.



The uncertainty in a data point on a graph, can be represented by using error bars. Two lines of best fit should be drawn on the graph. The 'best fit line', which passes as close to the plotted points as is possible, and the 'worst line of best fit', either the steepest, or the shallowest possible line which is constrained by the error bars. The percentage uncertainty in the gradient, and y intercept, can them be found as:

$$\% \text{ uncertainty} = \frac{(\text{best gradient} - \text{worst gradient})}{\text{best gradient}} \times 100$$

$$\% \text{ uncertainty} = \frac{(\text{best y intercept} - \text{worst y intercept})}{\text{best y intercept}} \times 100$$

What Graph?

An essential aspect of carrying out a practical is plotting the data to determine how your variables are related. It also allows us to determine values for constants to help decide whether the data collected is accurate.

For the practicals outlined below, state the graph(s) that should be plotted. From this, explain what further analysis you can do with the graph.

1. Energy of a photon

In an experiment there were a variety of LEDs, each with a different wavelength. The experiment allowed us to determine the energy of the photons emitted by each LED. The following equation relates energy and the wavelength:

$$E = \frac{hc}{\lambda}$$

- What graph should be plotted to show a straight line relationship between E and λ ?
- What would the gradient of this line be? How could this be used to verify the accuracy of the experiment?

2. Acceleration of a falling ball

In an experiment a metal ball bearing was dropped from a range of heights. The time taken for the ball to fall the distance was measured. The following equation relates acceleration and time taken:

$$a = \frac{2s}{t^2}$$

where s is the vertical displacement fallen by the ball bearing.

- Use the equation to decide on a graph to plot that shows the relationship between s and t as a straight line.
- What would the gradient of this line be? How could this be used to verify the accuracy of the experiment?

3. Resistivity of a wire

In an experiment, the resistance of a wire is obtained at a variety of different lengths. The resistivity, a property of the material of the wire, is determined using the following equation:

$$\rho = \frac{RA}{L}$$

where R is the resistance, A is the cross-sectional area of the wire and L is the length of the wire.

- Considering the quantities measured in the experiment, explained above, decide on a graph to plot in order to get a straight line relationship between those quantities.
- What would the gradient of this line be? How could this be used to verify the accuracy of the experiment?

4. An experiment is carried out to determine the value of an unknown resistor. The table shows the results of the experiment.

Current, I (A)	0.3	0.5	0.7	0.9	1.1	1.3
Potential difference, V (V)	1.2	1.9	3.1	3.6	4.7	5.2

The uncertainty in the current reading was ± 0.1 A and in the potential difference was ± 0.2 V.

- Plot a graph of V against I . For each point, draw an error bar to represent the uncertainties. Draw the line of best fit.
 - Determine the gradient of the line of best fit and give its units.
 - Draw the shallowest and steepest line that goes through these points and determine the gradients of these lines.
 - Express the gradient with the associated uncertainty based on these results.
5. A parachutist jumped from an aeroplane and the first 7 seconds of free fall was recorded as shown in the table.

Time, t (s)	0	1	2	3	4	5	6	7
Velocity, v (m/s)	0	4.6	6.9	7.6	7.8	8.0	8.0	8.0

- Plot a graph of v against t between 0 and 7 seconds.
 - From the graph determine the gradient at i) $t = 0.5$ s ii) $t = 2$ s iii) $t = 6$ s.
 - What does the gradient represent? Give its units.
 - Determine the area under the curve for time between i) 0 and 1 s ii) 0 and 7 s.
 - What does the area under the curve represent?
6. The kinetic energy of a car of mass 1 tonne is determined as a function of its speed on a straight track. The table shows the data that was obtained.

Speed, v (m/s)	5	10	15	20	40	60	100
Kinetic energy, E (J)	12,000	47,000	115,000	195,000	710,000	1,855,000	4,875,000

- Plot a graph of kinetic energy (J) as a function of the speed, v , in m/s.
- Re-plot the graph to obtain a straight-line relationship and determine the gradient of the line.
- What does the gradient of the line represent?

Q1.

Data analysis question

Capillary action can cause a liquid to rise up a hollow tube. **Figure 1** shows water that has risen to a height h in a narrow glass tube because of capillary action.

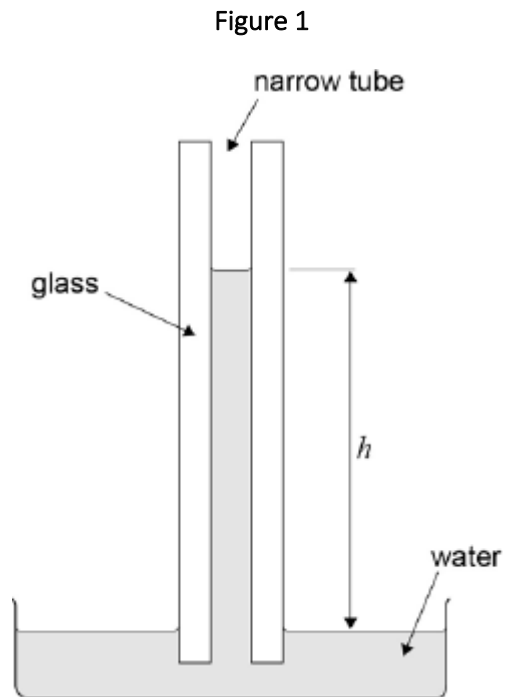
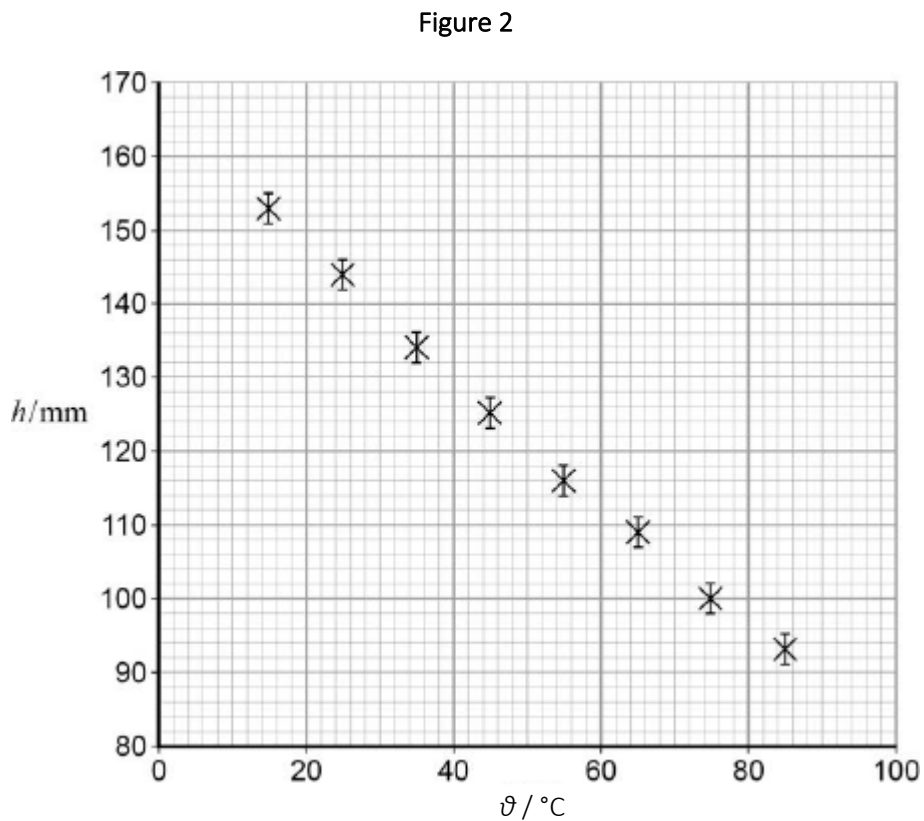


Figure 2 shows the variation of h with temperature ϑ for this particular tube.



The uncertainty in the measurement of h is shown by the error bars. Uncertainties in the measurements of temperature are negligible.

(a) Draw a best-fit straight line for these data (**Figure 2**).

(1)

(b) It is suggested that the relationship between h and θ is

$$h = h_0 - (h_0 k)\theta$$

where h_0 and k are constants.

Determine h_0 .

$$h_0 = \text{_____ mm}$$

(1)

(c) Show that the value of $h_0 k$ is about 0.9 mm K^{-1} .

(3)

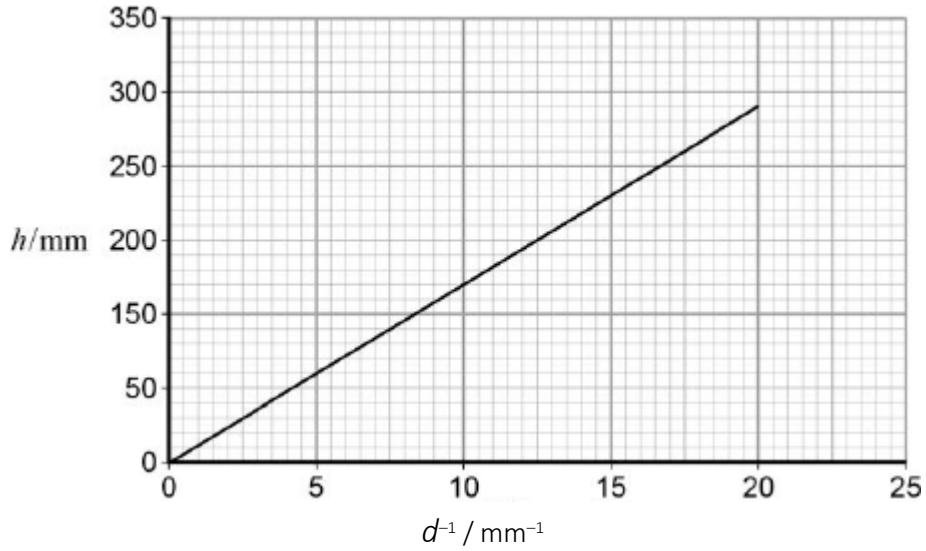
(d) Determine k . State a unit for your answer.

$$k = \text{_____ unit} = \text{_____}$$

(2)

- (e) A similar experiment is carried out at constant temperature with tubes of varying internal diameter d . Figure 3 shows the variation of h with d^{-1} at a constant temperature.

Figure 3



It is suggested that capillary action moves water from the roots of a tree to its leaves.

The gradient of Figure 3 is 14.5 mm^2 .

The distance from the roots to the top leaves of the tree is 8.0 m .

Calculate the internal diameter of the tubes required to move water from the roots to the top leaves by capillary action.

(2)

- (f) Comment on the accuracy of your answer for the internal tube diameter in part (v).

(1)

(Total 10 marks)

Q1.

A student performs an experiment to find the acceleration due to gravity. The student measures the time t for a spherical object to fall freely through measured vertical distances s . The time is measured electronically. The results are shown in the table below.

s/m	t_1/s	t_2/s	t_3/s	mean time t_m/s	t_m^2/s^2
0.300	0.245	0.246	0.244	0.245	0.0600
0.400	0.285	0.286	0.286	0.286	0.0818
0.500	0.319	0.321	0.318	0.319	0.102
0.600	0.349	0.351	0.348	0.349	0.122
0.700	0.378	0.380	0.378	0.379	0.144
0.800	0.403	0.406	0.404		
0.900	0.428	0.428	0.430		

(a) Complete the table by entering the missing values for t_m and t_m^2

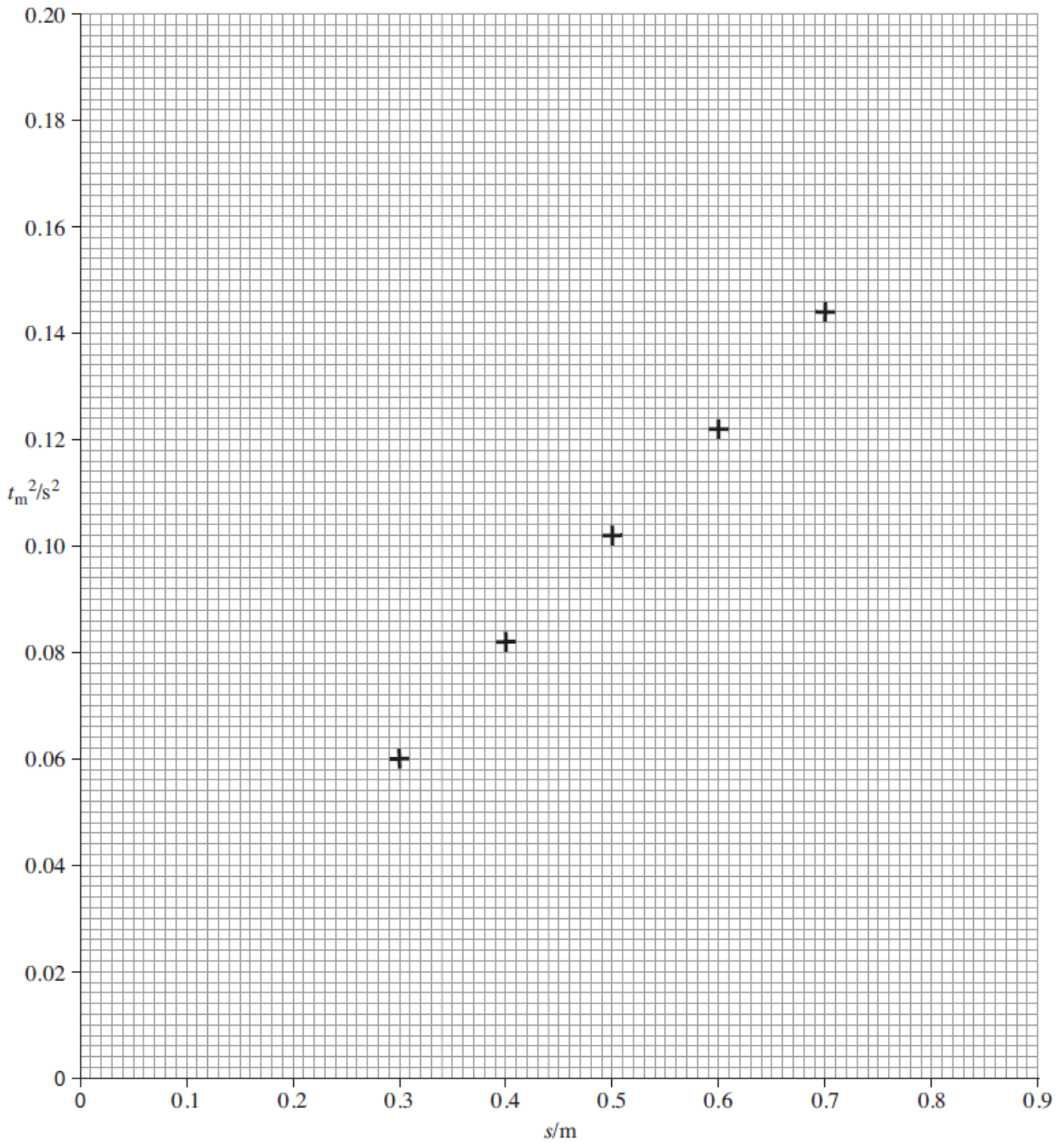
(1)

(b) Complete the graph below by plotting the remaining two points and draw a line of best fit.

(2)

(c) Determine the gradient of the graph.

(3)



- (d) Theory suggests that the equation for the line is $t^2 = \frac{2s}{g}$ where g is the acceleration due to gravity.

Calculate a value for g using the above equation and the gradient of your graph above.

- (e) Calculate the percentage difference between your value for g and the accepted value of 9.81 m s^{-2} .

(1)

- (f) Calculate the uncertainty in the smallest value of t_m .

(1)

- (g) Calculate the value of g which would be given from the smallest value of t_m and the corresponding value of s .

(3)

- (h) The uncertainty in each value of s is $\pm 0.001 \text{ m}$.

Calculate the uncertainty in the value of g you calculated in part (g).

You will need to use the uncertainty for t_m you calculated in part (f).

(3)

Estimation

1. Define the term Order of Magnitude

2. For the following, estimate to the nearest order of magnitude:

Example	Order of Magnitude Estimate
Height of a human in m	
Height of a human in cm	
Mass of a human in kg	
Weight of an apple in N	
Thickness of a piece of paper in m	
Height of a house in m	
Diameter of a dinner plate in m	
The length of a lesson in s	
Volume of a pencil in m^3	
Mass of a standard car in kg	
Wavelength of visible light in m	

3. Make order of magnitude estimates of the following quantities:

a. Surface area of a door in m^2

b. Volume of a raindrop in m^3

c. Density of wood in kgm^{-3}

d. Work done in lifting a physics textbook in J

e. Energy transferred by passing through a 2kW kettle to make a cup of tea, in J

f. Impact force on a football ($F = \text{change in momentum} / \text{impact time}$) in N

Acknowledgements:

The questions on SI units were originally from TES user LightbulbScience. The original resources can be downloaded here:

<https://www.tes.com/teaching-resource/si-units-and-dimensional-analysis-12200994>

Questions in multiple areas (including use of SI units, limitation of physical measurements and estimations) are originally from TES user dathomson. The original resources can be downloaded here:

<https://www.tes.com/teaching-resource/aqa-a-level-physics-unit-1-measurements-and-their-errors-11061217>

Some notes in the limitation of physical measurements section are from physics and maths tutor. The original notes can be downloaded here:

<https://pmt.physicsandmathstutor.com/download/Physics/A-level/Notes/AQA/01-Measurements-and-Errors/Key%20Points%20-%20Section%201%20Measurements%20and%20Their%20Errors%20-%20AQA%20Physics%20A-level.pdf>