

AQA Physics A Level

Uncertainties and Methods

Notes



3.1 Measurements and their errors

3.1.1 - Uses of SI units and their prefixes

SI units are the **fundamental** units, they are made up of:

- Mass (m): **kg** (kilograms)
- Length (l): **m** (metres)
- Time (t): **s** (seconds)
- Amount of substance (n): **mol** (moles)
- Temperature (t): **K** (kelvin)
- Electric current (I): **A** (amperes)

The SI units of quantities can be derived by their equation, e.g. $F=ma$

For example, to find the SI units of force (F) multiply the units of mass and acceleration **kg x $m.s^{-2}$** gives **$kgm.s^{-2}$** (Also known as N)

The SI units of voltage can be found by a series of steps:

- $V = \frac{E}{Q}$ where E is energy and Q is charge, $E = \frac{1}{2} m v^2$ so the SI units for energy is **kg $m^2 s^{-2}$** (the units for speed (v) are ms^{-1} so squaring these gives $m^2 s^{-2}$)
- $Q=It$ (where I is current) so the units for Q are **As** (ampere seconds)
- So $V = \frac{kgm^2s^{-2}}{As}$ **$V = kgm^2s^{-3}A^{-1}$**

Below are the **prefixes** which could be added before any of the above SI units:

Name	Symbol	Multiplier
Tera	T	10^{12}
Giga	G	10^9
Mega	M	10^6
Kilo	k	10^3
Centi	c	10^{-2}
Milli	m	10^{-3}
Micro	μ	10^{-6}
Nano	n	10^{-9}
Pico	p	10^{-12}
Femto	f	10^{-15}

Some examples:

6pF (picofarads) is **$6 \times 10^{-12} F$**

9G Ω (gigaohms) is **$9 \times 10^9 \Omega$**

10 μ m (micrometres) is **$10 \times 10^{-6} m$**



Converting mega electron volts to joules:

$$1\text{eV} = 1.6 \times 10^{-19} \text{ J}$$

e.g. convert 76 MeV to joules:

First, convert from MeV to eV by multiplying by 10^6

$$76 \times 10^6 \text{ eV}$$

Then convert to joules by multiplying by 1.6×10^{-19}

$$1.216 \times 10^{-11} \text{ J}$$

Converting kWh (kilowatt hours) to Joules:

$$1 \text{ kW} = 1000 \text{ J/s} \quad 1 \text{ hour} = 3600 \text{ s}$$

$$1 \text{ kWh} = 1000 \times 3600$$

$$= 3.6 \times 10^6 \text{ J}$$

$$= 3.6 \text{ MJ}$$



3.1.2 - Limitation of Physical Measurements

Random errors affect **precision**, meaning they cause differences in measurements which causes a spread about the mean. You cannot get rid of all random errors.

An example of random error is **electronic noise** in the circuit of an electrical instrument

To reduce random errors:

- Take **at least 3 repeats** and calculate a **mean**, this method also allows **anomalies to be identified**
- Use **computers/data loggers/cameras** to reduce human error and enable **smaller intervals**
- Use **appropriate equipment**, e.g a micrometer has higher resolution (0.1 mm) than a ruler (1 mm)

Systematic errors affect **accuracy** and occur due to the apparatus or faults in the experimental method. Systematic errors cause all results to be **too high or too low by the same amount** each time.

An example is a balance that isn't zeroed correctly (zero error) or reading a scale at a different angle (this is a **parallax error**).

To reduce systematic error:

- **Calibrate** apparatus by measuring a known value (e.g. weigh 1 kg on a mass balance), if the reading is inaccurate then the systematic error is easily identified
- in radiation experiments correct for **background radiation** by measuring it beforehand and excluding it from final results
- read the **meniscus** (the central curve on the surface of a liquid) **at eye level** (to reduce parallax error) and use **controls** in experiments

Precision	Precise measurements are consistent, they fluctuate slightly about a mean value - this doesn't indicate the value is accurate
Repeatability	If the original experimenter can redo the experiment with the same equipment and method then get the same results it is repeatable
Reproducibility	If the experiment is redone by a different person or with different techniques and equipment and the same results are found, it is reproducible
Resolution	The smallest change in the quantity being measured that gives a recognisable change in reading
Accuracy	A measurement close to the true value is accurate

The **uncertainty** of a measurement is the bounds in which the accurate value can be expected to lie e.g. $20^{\circ}\text{C} \pm 2^{\circ}\text{C}$, the true value could be within $18\text{-}22^{\circ}\text{C}$

Absolute Uncertainty: uncertainty given as a fixed quantity e.g. $7 \pm 0.6 \text{ V}$

Fractional Uncertainty: uncertainty as a fraction of the measurement e.g. $7 \pm \frac{3}{35} \text{ V}$

Percentage Uncertainty: uncertainty as a percentage of the measurement e.g. $7 \pm 8.6\% \text{ V}$



To reduce percentage and fractional uncertainty measure larger quantities e.g. a longer rope.

Resolution and Uncertainty

Readings are when **one value** is found e.g. reading a thermometer, measurements are when the **difference between 2 readings** is found, e.g. a ruler (as both the starting point and end point are judged).

The **uncertainty in a reading** is **\pm half the smallest division**,
 e.g. for a thermometer the smallest division is 1°C so the uncertainty is $\pm 0.5^\circ\text{C}$

The **uncertainty in a measurement** is **at least ± 1 smallest division**,
 e.g. a ruler, must include both the uncertainty for the start and end value, as each end has $\pm 0.5\text{mm}$, they are added so the uncertainty in the measurement is $\pm 1\text{mm}$

Digital readings and given values will either have the uncertainty quoted or assumed to be **\pm the last significant digit** e.g. $3.2 \pm 0.1\text{ V}$, the **resolution** of an instrument affects its uncertainty

For repeated data the uncertainty is **half the range** (largest - smallest value), show as **mean $\pm \frac{\text{range}}{2}$**

You can reduce uncertainty by **fixing one end** of a ruler as only the uncertainty in **one reading** is included. You can also reduce uncertainty by measuring **multiple instances**,
 E.g. to find the time for 1 swing of a pendulum, measure the time for 10 e.g. 10 swings in $6.2 \pm 0.1\text{ s}$, the time for 1 swing is $0.62 \pm 0.01\text{ s}$ (**the uncertainty is also divided by 10**)

Uncertainties should be given to the **same number of significant figures** as the data.

Combining uncertainties

- Adding / subtracting data- **ADD ABSOLUTE UNCERTAINTIES**

E.g. A thermometer with an uncertainty of $\pm 0.5\text{ K}$ shows the temperature of water falling from

$298 \pm 0.5\text{ K}$ to $273 \pm 0.5\text{ K}$, what is the difference in temperature?

$$298 - 273 = 25\text{K} \quad 0.5 + 0.5 = 1\text{K (add absolute uncertainties)} \quad \text{difference} = 25 \pm 1\text{ K}$$

- Multiplying/dividing data- **ADD PERCENTAGE UNCERTAINTIES**

E.g. a force of $91 \pm 3\text{ N}$ is applied to a mass of $7 \pm 0.2\text{ kg}$, what is the acceleration of the mass?

$$a = F/m = 91/7 = 13\text{m.s}^{-2}$$

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{value}} \times 100$$



Work out % uncertainties $\frac{3}{91} \times 100 + \frac{0.2}{7} \times 100 = 3.3\% + 2.9\%$

add % uncertainties

$$= 6.2\%$$

So $a = 13 \pm 6.2\% \text{ m s}^{-2}$ 6.2% of 13 is 0.8

$$a = 13 \pm 0.8 \text{ m s}^{-2}$$

- Raising to a power- **MULTIPLY PERCENTAGE UNCERTAINTY BY POWER**

The radius of a circle is $5 \pm 0.3 \text{ cm}$, what is the percentage uncertainty in the area of the circle?

$$\text{Area} = \pi \times 25 = 78.5 \text{ cm}^2$$

$$\text{area} = \pi r^2$$

% uncertainty in radius = $\frac{0.3}{5} \times 100 = 6\%$ % uncertainty in area = 6×2 (2 is the power from r^2)

$$= 12\%$$

$$78.5 \pm 12\% \text{ cm}^2$$

Uncertainties and graphs

Uncertainties are shown as **error bars** on graphs,

e.g. if the uncertainty is 5mm then have 5 squares of error bar on either side of the point

A line of best fit on a graph should **go through all error bars** (excluding anomalous points)

The **uncertainty in a gradient** can be found by lines of best and worst fit, this is especially useful when the gradient represents a value such as the acceleration due to gravity:

- Draw a **steepest and shallowest** line of worst fit, it must go through all the error bars
- Calculate the gradient of the best and worst line, the uncertainty is the **difference between the best and worst gradients**

percentage uncertainty = $\frac{|\text{best gradient} - \text{worst gradient}|}{\text{best gradient}} \times 100\%$ (modulus lines show it's always positive)

When the best and worst lines have different y intercepts, you can find the **uncertainty in the y-intercept**, which is $|\text{best y intercept} - \text{worst y intercept}|$

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



3.1.3 - Estimation of physical quantities

Orders of magnitude - Powers of ten which describe the size of an object, and which can also be used to compare the sizes of objects

E.g The diameter of nuclei have an order of magnitude of around 10^{-14} m.

100 m is two orders of magnitude greater than 1m

You may be asked to give a value to the nearest order of magnitude, here you must simply calculate the value the question is asking you for and give it only as a power of ten

E.g If the diameter of a hydrogen atom is 1.06×10^{-10} m, find the approximate area of the entire atom (assuming it is perfectly spherical), to the nearest order of magnitude.

Find the area using $A = \pi r^2$ $\pi \times (0.53 \times 10^{-10})^2 = 8.82 \times 10^{-21} \text{ m}^2 = 1 \times 10^{-20} \text{ m}^2$ (to 1 s.f)

Therefore the area to the nearest order of magnitude is 10^{-20} m^2 .

Estimation is a skill physicists must use in order to approximate the values of physical quantities, in order to make **comparisons**, or to check if a value they've calculated is **reasonable**.

Experiment design

Variables - quantities that have potential to change

Independent variable - the variable changed in an experiment

Dependent variable - variable that is measured in an experiment

Control variables - variables that are kept constant in an experiment

Apparatus and techniques

Think about what **units** the measurements will be in and the **range** over which you'll take them, a **pilot experiment** (a small scale experiment in preparation) can help plan this so the most appropriate **apparatus** can be chosen e.g. not using a mass that is too heavy

The experiment must test what it sets out to and have a clear method, controlled variables, appropriate apparatus and techniques, and a method that gives **precise** results and is **safe and ethical**.

Risks and hazards must be identified and safety measures taken e.g. radiation shielding, work ethically by not harming animals and the environment

Data

Discrete - only certain values can be taken, e.g. number of objects. Display on scatter graphs and bar charts

Continuous - can take any value on a scale e.g. current in a circuit. Display on line or scatter graph

Categoric - values that can be sorted into categories e.g. types of material. Display on a pie or bar chart

Ordered - data that can be put in ordered categories e.g. low, medium, high. Bar charts can display ordered data



When data is displayed in a table the first column should be for the **independent variable**, the next n columns for n repeats of the **dependent variable** and the columns after that for processing the data e.g. calculations. The data within a column should be to the same number of significant figures. Quantitative data uses numbers whereas qualitative data is observed but not measured with a numerical value e.g. colour.

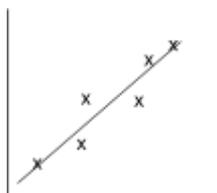
$$\text{mean} = \frac{\text{sum of repeated measurements}}{\text{no. repeats}}$$

Anomalous results (results which don't fit the trend) should be ignored in calculating averages.

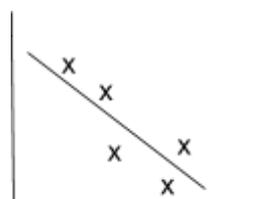
Graphs

Scatter graphs show correlation of data by putting a line of best fit through the points.

If two variables are **positively correlated**, it means that if one increases in value, so does the other.



Whereas **negative correlation** means the opposite - if one variable increases the other decreases.



No correlation means there's no relationship between the variables



For lines of best fit on curved graphs draw a **smooth curve** with about half the points on either side of it (excluding any anomalous results). 2 variables may not be correlated but both affected by a **third variable** (correlation doesn't indicate causation) e.g. ice cream sales are positively correlated to suncream sales but temperature is the variable affecting them both



For relationships where $y=k/x$ plot a graph of y against $1/x$ to get a straight line rather than a **reciprocal** graph so the gradient and y intercept can be worked out.

Data can be analysed by looking at any **patterns or trends** the results show. See whether the experiment answered the question asked and whether it is **valid** and produced **precise** results. If you have a true value see how close the measured value is to it (accuracy of the result). The instruments should have had a high enough **resolution**. Look at **anomalies** in the results and their causes as well as whether **uncertainty** is large.

To evaluate experiment design make sure everything was done to reduce uncertainties such as **controlling** all variables and preventing **anomalous** results. Valid data (**evidence**) must always support the conclusion.

Plotting logarithmic and exponential functions as straight line graphs

To plot an equation as a straight line graph it must be in the form $y=mx+c$,

E.g. $R = kA^n$ is an exponential relationship between nuclear radius and nucleon number

$\ln R = \ln kA^n$ take natural logs of both sides

$\ln R = \ln k + \ln A^n$ use rule $\log ab = \log a + \log b$

$\ln R = \ln k + n \ln A$ use rule $\log a^n = n \log a$

$Y = C + MX$

So a straight line graph of $\ln R$ against $\ln A$ can be plotted and the **gradient** and **y intercept** used to calculate the values of k and n .

