1.1 Fundamental (base) quantities and their units

Fundamental Quantity	SI Unit
Mass	Kilogram, kg
Length	metre, m
Time	second, s
Quantity of matter	mole, mol
Temperature	Kelvin, K
Electric current	Ampere, A

NB there is a 7th one for light intensity (the Candela) but its not on the AQA spec.

1.2 Prefixes

PREFIX	SYMBOL	MEANING	ORDER OF MAGNITUDE
Tera	T	1 000 000 000 000	10^{12}
Giga	G	1 000 000 000	10^{9}
Mega	M	1 000 000	10^{6}
kilo	k	1 000	10^{3}
centi	c	1 /100	10^{-2}
milli	m	1 /1 000	10^{-3}
micro	μ	1 /1 000 000	10^{-6}
nano	n	1 /1 000 000 000	10^{-9}
pico	p	1 /1 000 000 000 000	10^{-12}
femto	f	1 /1 000 000 000 000 000	10^{-15}

1.3 Errors

- **measurement error**

  The difference between a measured value and the true value.

- **anomaly**

  This is a freak result – judged to not fit the main trend. It should be rejected and the reading repeated.

- **random error**

  These cause readings to be either above or below the true value.

  Random errors are present when any measurement is made, and cannot be corrected.

The effect of random errors can be reduced by making more measurements and calculating a new mean.

- **systematic error**

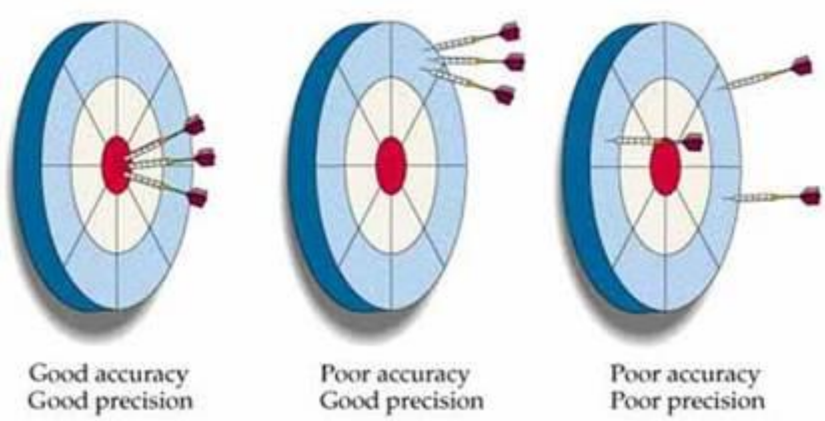
These cause readings to differ from the true value by a consistent amount each time a measurement is made.

Sources of systematic error can include the environment, methods of observation or instruments used (typically a **zero error**)

Systematic errors <u>cannot</u> be dealt with by simple repeats. If a systematic error is suspected, the data collection should be repeated using a different technique or a different set of equipment, and the results compared.

- **accuracy**

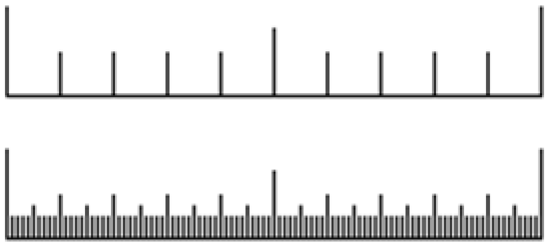
The closer you are to the true value the more accurate the measurement:



- **precision**

<u>Precise measurements</u> are ones in which there is very little spread about the mean value ie. not much random error – it gives no indication of how close results are to the true value.

A <u>precise scale</u> will have a high resolution:



The <u>resolution</u> of the instrument is the smallest change in the quantity that can be measured. For example the resolution of a stop clock is 0.01s, and the resolution of a digital voltmeter is 0.01V.

A <u>sensitive</u> instrument is one that responds to a small change of input with a large change in output.

- **Repeatability** a measurement is repeatable if the same person repeats using the same method and apparatus

- **Reproducibility** a measurement is reproducible if another person does the experiment and gets the same results

  (or the same person uses a different method/apparatus).

1.4 <u>Uncertainty</u>

If measurements are repeated, the uncertainty is calculated by finding <u>**half the range**</u> of the measured values.

For example these measurements taken from a vernier caliper:

Repeat	1	2	3	4
Distance/mm	10.23	10.32	10.27	10.22

Range = max.reading – min.reading = 10.32 – 10.22 = 0.10 , so uncertainty = 0.10 / 2 = 0.05

So we would quote: Mean distance: (10.26 ± 0.05) mm

If instead the measurements had all been the same:

Repeat	1	2	3	4
Distance/mm	10.26	10.26	10.26	10.26

Then to get the uncertainty we examine the resolution of the instrument, for Skinners' vernier calipers this would be 0.02mm.

So we would quote: Mean distance: (10.26 ± 0.02) mm

NB. Comparing the two methods it is quite typical for the resolution of the instrument to produce a small percentage error.

1.5 <u>Combining Errors</u>

You must know the rules:

For sum and difference simply add the absolute errors

Eg. $X = 20 \pm 1$, $Y = 10 \pm 2$

sum $X + Y = 30 \pm 3$, difference $X - Y = 10 \pm 3$

For product or quotient you must add the percentage errors:

Eg. % error in X = 1/20 = 5%, % error in Y = 2/10 = 20%

So % error in Product X.Y = 30%, % error in X / Y = 30% also,

So, X.Y = 200 ± 30% = 200 ± 60, X/Y = 2 ± 30% = 2 ± 0.6

For powers, multiply the percentage uncertainty by the power:

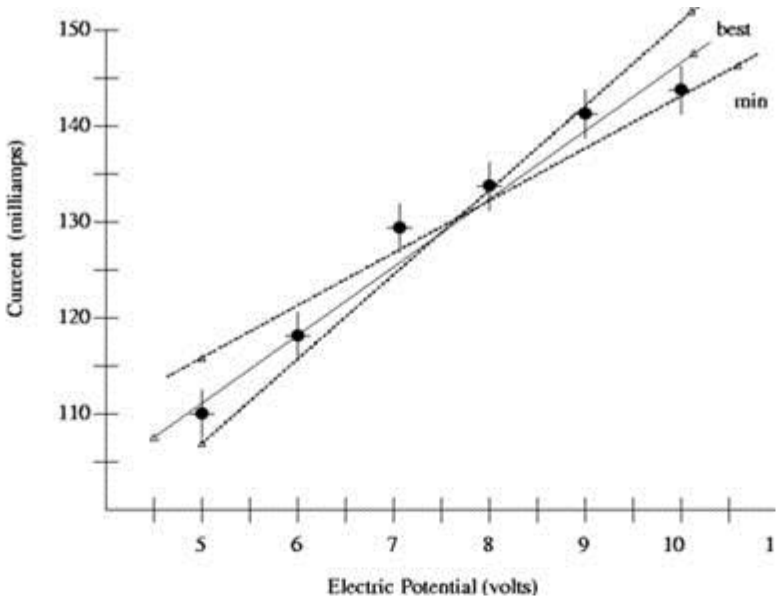
Eg. $X^3 = 8000$, so % error in X^3 = 3 x % error in X = 15%

So, $X^3 = 8000 \pm 1200$

1.6 <u>Error bars on graphs</u>

Having correctly drawn your graph including a best fit line, you will need to insert error bars. Error bars are the uncertainty in the measurement you have taken.

They are calculated from either the ± uncertainty of the device you are using to measure or the calculated percentage value from the device uncertainty.



1.7 Estimating

You will be expected to make reasonable estimations / approximations of some quantities.

Egs.

- Mass of an apple ~ 100g (from a weight of 1N)
- Mass of a car 1 000 kg (from 1 tonne)
- Mass of a person say, 75 kg
- Volume of air in a room. To do this one, estimate dimensions of room in m, then multiply them together.
- The above case could be extended to mass of air in room if you estimate the density of air to be 1 kgm^{-3}
- Density of water is about 1 000 kg/m^3
- One pace is about a metre
- Electricity: air breakdown is about 1 million volts/m. So about 1 million volts would make a spark jump across a distance of 1m
- If an apple falls a distance of 1m, then 1 J of work is done
- Speed of light is about a million X more than the speed of sound.
- Speed of air molecules is about same as the speed of sound (330 m/s)
- Atmospheric pressure is about 100,000 Pa

1.8 Recent changes

Table 1: Instruments which require one and two judgements

Reading (one judgement only)	Measurement (two judgements required)
thermometer	ruler
top pan balance	vernier calliper
measuring cylinder	micrometer
digital voltmeter	protractor
Geiger counter	stop watch
pressure gauge	analogue meter

When quoting the uncertainty of an instrument, you quote ± smallest division (for both readings and measurements covered in table 1), but when calculating percentage errors you do the following:

$$\%\ Error\ for\ a\ \boldsymbol{reading} = \frac{\pm\ half\ smallest\ division}{mean\ or\ median\ value\ taken} \times 100\%$$

$$\%\ Error\ for\ a\ \boldsymbol{measurement} = \frac{\pm\ smallest\ division}{mean\ or\ median\ value\ taken} \times 100\%$$