Measurements

1. Key points to know

You must know:
- what is meant by random errors and systematic errors
- what is meant by absolute, fractional and percentage uncertainties
- that error bars are used on graphs to indicate uncertainties in data
- that gradients and intercepts on graphs have uncertainties.
- explain how random and systematic errors can be identified and reduced
-collect data that include absolute and/or fractional uncertainties and go on to state these as an uncertainty range
-determine the overall uncertainty when data with uncertainties are combined in calculations involving addition, subtraction, multiplication, division and raising to a power
-determine the uncertainty in gradients and intercepts of graphs.

1.2 Uncertainties

Uncertainty in measurement is expressed in three ways.
-Absolute uncertainty: the numerical uncertainty associated with a quantity. For example, when a length of quoted value 5.00 m has an actual value somewhere between 4.95 m and 5.05 m, the absolute uncertainty is ± 0.05 m. The length will be expressed as $[5.00 \pm 0.05]$m.
-Fractional uncertainty $= \frac{\text{absolute uncertainty in quantity}}{\text{numerical value of quantity}}$. A fractional uncertainty has no unit.
-Percentage uncertainty = fractional uncertainty $\times 100$ expressed as a percentage. There is no unit.

1.2 Errors

-Random errors are unpredictable changes in data collected in an experiment. Examples include fluctuations in a measuring instrument or changes in the environmental conditions where the experiment is being carried out.
-Systematic errors are often produced within measuring instruments. Suppose that an ammeter gives a reading of +0.1 A when there is no current between the meter terminals. This means that every reading made using the meter will read 0.1 A too high. The effect of a systematic error can produce a non-zero intercept on a graph where a line through the origin is expected.

1.3 Combining uncertainties

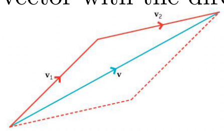
- The absolute uncertainties are added when quantities are added and subtracted.
When $y = a \pm b$ then $\Delta y = \Delta a + \Delta b$
- The fractional uncertainties are added when quantities are multiplied or divided.
When $y = \frac{ab}{c}$ then $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$
- When a quantity is raised to a power n, the fractional uncertainty is multiplied by n.
When $y = a^2$, this is the same as $a \times a$ so using the algebraic rule above:
$\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta a}{a} = \frac{2\Delta a}{a}$. In the general case, when $y = a^n$, $\frac{\Delta y}{y} = \left|n\frac{\Delta a}{a}\right|$, where || means the absolute value or magnitude of the expression.

1.4 Scalars and Vectors

-Scalars are quantities that have magnitude (size) but no direction. They generally have a unit associated with them.
-Vectors are quantities that have both magnitude and a physical direction. A unit is associated with the number part of the vector.

1.5 Vector operations

Figure below shows the addition of two vectors. The vectors must be drawn to the same scale and the direction angles drawn accurately too. A further construction produces the parallelogram with the red solid and dashed lines. Then the magnitude of the new vector $\mathbf{v}_1 + \mathbf{v}_2$ is given by the length of the blue vector with the direction as shown.



-Vector Resolution: