Topic 1 Measurement and uncertainties

Fundamental units in the SI system.

Many different types of measurements are made in physics. To provide a consistent approach, a specific system of units is used across all sciences. This system is called the International System of Units (SI from the French "Système International d'unités").

The SI system is composed of seven fundamental units:

Quantity	Unit name	Unit symbol
mass	kilogram	kg
length	metre	M
time	second	S
temperature	kelvin	K
electric current	ampere	A
amount of substance	mole	mol
luminous intensity	candela	cd

Note that the last unit, candela, is not used in the IB diploma program.

Difference between fundamental and derived units

SI base units are often combined to form new ones. For example, speed is a derived quantity, involving distance and time. We would calculate speed from distance/time and write m/s (or, more correctly m s^{-1}) for the unit. m s^{-1} is a derived unit, whereas m and s are fundamental (base) units.

Certain combinations of SI units have been given a new unit and symbol, to make the data simpler to read.
Eg. The unit for work done would be written in SI units as kg m^2 s^{-2}. This is used often and so a new unit has been derived from it called the joule (symbol: J).

Examples of SI derived units:

SI derived unit	Symbol	SI base unit	Alternative unit
newton	N	$kg\ m\ s^{-2}$	-
joule	J	$kg\ m^{2}\ s^{-2}$	Nm
hertz	Hz	s^{-1}	-
watt	W	$kg\ m^{2}\ s^{-3}$	$J\ s^{-1}$
volt	V	$kg\ m^{2}\ s^{-3}\ A^{-1}$	$W\ A^{-1}$
ohm	Ω	$kg\ m^{2}\ s^{-3}\ A^{-2}$	$V\ A^{-1}$
pascal	Pa	$kg\ m^{-1}\ s^{-2}$	$N\ m^{-2}$

Converting between different units.

Often, we need to convert between different units. For example, batteries are rated in ampere-hours, which tells us how much charge is stored and is an alternative unit to the Coulomb. We can convert A-h to C, 1 A-h=1C/s x 60x60 = 3600C of charge. A typical charger stores 2000mAh when fully charged = 2A-h, meaning it stores 3600x2 = 7200C of charge.

Stating units in the accepted SI format.

There can be many ways to write derived units. For example, speed has units of meters per second, which can be written as m/s or $m\ s^{-1}$, but only $m\ s^{-1}$ is accepted as a valid format for this unit. You should always write meters per second (speed) as $m\ s^{1}$ and meters per second per second (acceleration) as $m\ s^{-2}$.

Prefixes

When expressing large or small quantities we often use prefixes in front of the unit. For example, instead of writing 10000 V we write 10 kV, where k stands for kilo, which is 1000. We do the same for small quantities such as 1 mV which is equal to 0,001 V, m standing for milli meaning one thousandth (1/1000).

In speech, we say ‘3 kilowatts’ and ‘5 milliwatts’, rather than saying the symbols for the units.

A table of prefixes is given in the physics data booklet.

Random and systematic errors.

Random errors
A random error, is an error which affects a reading at random.
Sources of random errors include:

- The observer being less than perfect
- The readability of the equipment
- External effects on the observed item

Systematic errors

A systematic error, is an error which occurs at each reading.
Sources of systematic errors include:

- The observer being less than perfect in the same way every time
- An instrument with a 'zero offset' error
- An instrument that is improperly calibrated

Precision and accuracy

Precision
A measurement is said to be accurate if it has very small systematic errors.

Accuracy
A measurement is said to be precise if it has very small random errors.

A measurement can be of great precision but be inaccurate (for example, if the instrument used had a 'zero offset' error).

Reducing the effects of random errors

The effect of random errors on a set of data can be reduced by repeating readings. On the other hand, because systematic errors occur at each reading, repeating readings does not reduce their effect on the readings.

Significant figures in results and calculations.

The number of significant figures in any answer should reflect the number of significant figures in the given data.

The number of significant figures stated in a result should reflect the precision of the input data. When dividing and multiplying, the number of significant figures should not exceed that of the least precise value.

Example:
Find the speed of a train that travels 14.31 meters in 3.43 seconds.

14.31 x 3.43 = 49.0833

The answer contains 6 significant figures. However, since the value for time (3.43 s) is only 3 s.f. we write the answer as 49.1 m s^{-1}.

Absolute, fractional and percentage uncertainties.

Absolute uncertainties
When marking the absolute uncertainty in a piece of data, we simply add ± 1 of the smallest significant figure.

Example:

14.61 m ± 0.01
0.004 g ± 0.001
1.6 s ± 0.1
24 V ± 1

Fractional uncertainties
To calculate the uncertainty as a fraction of a value we simply divide the uncertainty by the value.

Example:

2.5 s ± 0.1

Fractional uncertainty:

0.1 / 2.5 = 0.04

Percentage uncertainties
To calculate the percentage uncertainty of a value we simply multiply the fractional uncertainty by 100.

Example:

2.5 s ± 0.1

Percentage uncertainty:

0.1 / 2.5 x 100 = 4.0 %

Uncertainties in results

We need to include uncertainties it in any calculations we do with our data from experiments.

Addition and subtraction
When adding and subtracting, we simply add together the absolute uncertainties.

Example:

Add the values 1.4 ± 0.1, 14.02 ± 0.01, 6.71 ± 0.01

1.4 + 14.02 + 6.71 = 22.13
0.1 + 0.01 + 0.01 = 0.12
22.13 ± 0.12

Multiplication, division and powers
When multiplying, dividing, or dealing with powers, we add together the percentage uncertainties.

Example:

Calculate r^2, with uncertainty, given r = 2.3±0.1

r^2 = 5.3

% uncertainty in r = 0.1/2.3 x100 = 4.3%

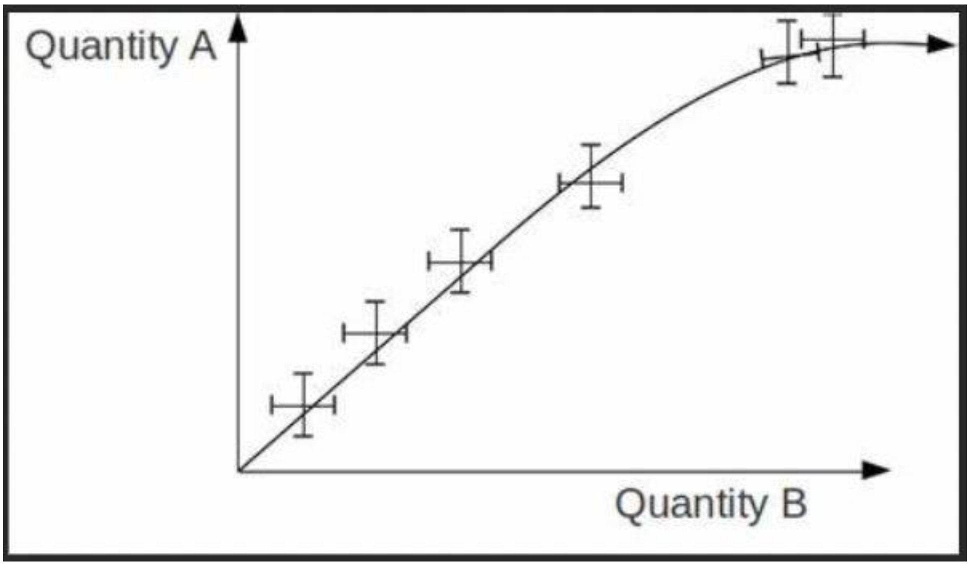
% uncertainty in r^2 =4.3% + 4.3% = 8.6%

Absolute uncertainty in r r^2= 0.086x5.3 = 0.455 = ±0.5

5.3±0.5

Error bars in graphs.

In graphs, uncertainty in the data points is represented by adding error bars. The uncertainty range is indicated by the length of the error bar in each direction. An example of error bars on a graph can be seen below:



Note that in IB physics, error bars only need to be used when the uncertainty in one or both of the plotted quantities are significant.

To add error bars to a point on a graph, we simply take the uncertainty range, expressed as a ± value in the data, and draw lines of this length (using the scale on the axes) above and below or on each side of the point depending on which axis the value corresponds to.

Where error bars are too small to draw on one or both axes, we can assume they are insignificant.