



MODULE 2

FOUNDATIONS OF PHYSICS

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FOUNDATIONS OF PHYSICS:

Physical Quantities:

- Physical quantities have a numerical value and a unit. These are physical quantities that can be quantified: Examples are
 - Mass
 - Length
 - Temperature
 - Time
- Estimates of physical units can be made.

S.I. Units: Systeme Internationale

- **S.I. Units:** These are a set of base units and also a scientific method of expressing the magnitudes of quantities of important natural phenomena.
- S.I. Units are used to reduce confusion between different units that are used to measure the same natural phenomena. By using the SI units, time is saved converting between units, and it also makes scientific data trading with other countries efficient.
- The SI base quantities and units that you **need** to learn are:
 - Mass – Kilogram (kg)
 - Length – Metre (m)
 - Time – Second (s)
 - Current – Ampere (A)
 - Temperature – Kelvin (K)
 - Amount of Substance – Moles (mol)
- **Derived units:** Derived units are units which may be expressed in terms of base units by means of mathematical symbols of multiplication and division.
E.g. Momentum = kgms^{-1} and Density = kg/m^3
- **Homogeneity of physical equations:** It is said that an equation is homogenous if both sides of the equations can be simplified to the same base unit or set of base units. This means that the equation could be correct, as long as there are no numerical errors made.
- If an equation is not homogenous then it is incorrect.

- **Unit Prefixes:** Prefixes are used to form decimal multiples and submultiples of SI units. Use the following table to learn the prefixes that are to be learnt.

Metric prefixes in everyday use			
Text	Symbol	Factor	Factor
tera	T	1000000000000	10^{12}
giga	G	1000000000	10^9
mega	M	1000000	10^6
kilo	k	1000	10^3
(none)	(none)	1	1
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	μ	0.000001	10^{-6}
nano	n	0.000000001	10^{-9}
pico	p	0.000000000001	10^{-12}

Measurements and Uncertainties:

- **Accuracy:** An experiment is accurate if the quantity being measured has a value that's very close to the commonly accepted or true value. For example an experimental value for the acceleration of free fall of 9.78 m s^{-2} is much more accurate than an experimental value of 9.05 m s^{-2} .
- **Precision:** The results of an experiment are precise if they are close together and have a small range. The smaller the range of the repeated values, the higher the precision. The term precision is linked to the spread of the data or the percentage uncertainty in a measurement. A precise experiment has a smaller spread in the data or the smaller the uncertainty. Hence, an experiment with an acceleration of free fall of $(9.05 \pm 0.05) \text{ ms}^{-2}$ is much more precise than an experiment with $(9.78 \pm 1.20) \text{ ms}^{-2}$; but the latter is much more accurate.

- **Systematic Error:** A systematic error is an error that does not happen by chance but instead is introduced by an inaccuracy in the apparatus or its use by the person conducting the investigation.
 - **Zero Error:** an error that occurs when the apparatus shows a non-zero value when it should be registering a value of exactly zero.
 - **Parallax Error:** an error produced whenever a scale, gauge, or pointer is observed wrongly during scientific experimentation due to position of viewing and perception.
- **Random Error:** A random error is an experimental error caused by unknown or unpredictable changes to the apparatus or conditions.
- Random errors can be reduced, by improving techniques, making multiple measurements or using instruments with a higher degree of precision. This increases precision.
- Systematic errors can be reduced or totally eliminated by the use of better techniques and instruments. This increases the accuracy of the experiment.
- **Resolution (precision):** The smallest change in a quantity that an instrument can measure. The higher the resolution, the higher the precision in repeat readings.
- If a measurement or test is reliable, it gives consistent results each time the activity is repeated. A reliable experiment has consistent results for the same measurement. Experiments are unreliable if repeated measurements give different results or if the scatter of measurements on a line graph is large (or so great that establishing a line of best fit is difficult).

Uncertainties

- **Absolute Uncertainties:** The absolute uncertainty (usually called absolute error - but "error" connotes "mistake", and these are NOT mistakes) is the size of the range of values in which the "true value" of the measurement probably lies
- If **single readings** have been taken then the **uncertainty** should be the **smallest interval** or division on the measuring instrument. Consider the example below.
 - Example: A metre rule is used to measure the length of a book. uncertainty in the measuring instrument (the ruler) = $\pm 1\text{mm}$ length = $(295 \pm 1)\text{ mm}$
- The expression **Percentage Uncertainty** = $\left(\frac{\text{Uncertainty}}{\text{Average value}}\right) \times 100$
 - Referring back to the previous example about the ruler, The percentage uncertainty in the length is % uncertainty = $\pm (1/295) \times 100 = \pm 0.34\%$
- If **multiple readings** have been taken then half of the range of the readings will be the uncertainty in the measured or calculated quantity.

- Determining the uncertainty in time measurements using a stopwatch raises a few issues. Almost all stopwatches will give times to one hundredth of a second, but humans clearly cannot operate the watch to this accuracy. Human reaction time will give errors of (typically) 0.1s to 0.6s, which are reasonable estimates of the uncertainty.
- Similar ideas apply to measurement of length, where parallax errors may make it difficult for people to measure a length to the accuracy of the rule used.

The rules for determining percentage uncertainties

A key assessment objective of the evaluative tasks is going to be determining the final uncertainty in a quantity. Here are some useful rules:

- If $y = ab$
 - Rule: % uncertainty in 'y' = % uncertainty in 'a' + % uncertainty in 'b'
- If $y = a/b$ (For example when determining the gradient of a line)
 - Rule: % uncertainty in 'y' = % uncertainty in 'a' + % uncertainty in 'b'
- If $y = a^n$
 - Rule: % uncertainty in 'y' = 'n' × % uncertainty in 'a'

Determining the uncertainty in the gradient using maximum and minimum gradients

We can determine the uncertainty in the gradient by drawing lines of maximum and minimum gradients through their scattered data points. What happens when there is little scatter of the data points? This is when we draw error bars. Error bars show the range a point is likely to lie in.

The uncertainty in the gradient can be determined as follows:

- Error bars may be added to each plotted point if the data points are not too scattered.
- Draw a best fit line through the scattered points (or through the error bars). The worst acceptable line is then drawn. This will either be the steepest or shallowest line.
- Determine the gradient of the best fit line and the gradient of the worst acceptable line.
- Uncertainty = |gradient of best fit line – gradient of worst acceptable line|.
- The percentage uncertainty in the gradient can be determined as follows:
 - **Percentage Uncertainty** = $\left(\frac{\text{Uncertainty}}{\text{Gradient of best fit line}} \right) \times 100$

Determining the uncertainty in the y-intercept using maximum and minimum gradients

We can also determine the uncertainty in the y-intercept by using lines of maximum and/or minimum gradients through their scattered data points. What happens when there is little scatter of the data points? This is again when we can draw error bars.

- a. Error bars may be added to each plotted point if the data points are not too scattered.
- b. Draw a best fit line through the scattered points (or through the error bars). The worst acceptable line is then drawn. This will either be the steepest or shallowest line.
- c. Determine the y-intercept of the worst acceptable line and the y-intercept of the best fit line.
- d. Uncertainty = |y-intercept of best fit line – y-intercept of worst acceptable line|.
- e. The percentage uncertainty in the y-intercept can be determined as follows:
 - **Percentage Uncertainty** = $\left(\frac{\text{Uncertainty}}{\text{y-intercept}}\right) \times 100$

Percentage difference

You may be asked to determine the percentage difference between experimental values and accepted values. 'Experimental values' are those that are derived from measurement or calculation, whereas 'accepted' or 'theoretical' values are values that are accepted by the scientific community.

The percentage difference between an experimental and accepted value is determined as follows:

$$\text{Percentage Difference} = \left(\frac{\text{Experimental value} - \text{Accepted Value}}{\text{Accepted Value}}\right) \times 100$$

Scalars and Vectors

- A Scalar quantity is a quantity which only has **magnitude**. Some **examples** of Scalar quantities are:
 - Mass
 - Time
 - Temperature
 - Length
 - Speed
 - Energy
- A Vector quantity is a quantity that has both magnitude and direction. Some examples of Vector quantities are:
 - Displacement
 - Force
 - Velocity
 - Acceleration
 - Momentum
- Both Vectors and Scalars have magnitudes, and sometimes the same units, like in the case of Speed and Velocity. However, vectors have a direction and scalars do not.
- Vectors can be added together to find the resultant vector. For vectors acting along the same line of action, can simply be added or subtracted from each other depending on its direction.
- For two vectors that are at right angles to each other, they should be drawn from head to tail, and then using Pythagoras' Theorem, the resultant vector can be calculated. The resultant vector is one vector that produces the same overall effect that several vectors could produce.
- For vectors that form non-right angle triangles, then the cosine rule and the sine rule can be used to work out any unknown lengths.
- A scaled drawing can also be used to work out the resultant vector by drawing a system to scale and using it to work out distances.
- Vectors can also have horizontal and vertical components. When we find the components of a vector, it is called resolution.
- Use these formulas to resolve a vector into two perpendicular components; $F_x = F \cos \theta$; $F_y = F \sin \theta$.

