Module 2 Foundations in Physics

Module 2: Foundations of physics

The aim of this module is to introduce important conventions and ideas that permeate the fabric of physics. Understanding of physical quantities, S.I. units, scalars and vectors helps physicists to effectively communicate their ideas within the scientific community (HSW8, 11).

You are here! →

Module 2 – Foundations of physics

- 2.1 Physical quantities and units
- 2.2 Making measurements and analysing data
- 2.3 Nature of quantities

Module 3 – Forces and motion

- 3.1 Motion
- 3.2 Forces in action
- 3.3 Work, energy and power
- 3.4 Materials
- 3.5 Newton's laws of motion and momentum

Module 4 – Electrons, waves and photons

- 4.1 Charge and current
- 4.2 Energy, power and resistance
- 4.3 Electrical circuits
- 4.4 Waves
- 4.5 Quantum physics

2.2 Making Measurements & Analysing Data

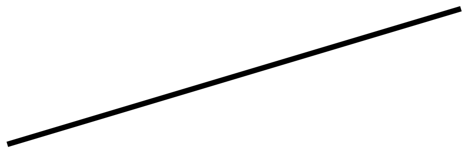
2.2.1 Measurements and uncertainties

	Learning outcomes
	Learners should be able to demonstrate and apply their knowledge and understanding of:
(a)	systematic errors (including zero errors) and random errors in measurements
(b)	precision and accuracy
(c)	absolute and percentage uncertainties when data are combined by addition, subtraction, multiplication, division and raising to powers
(d)	graphical treatment of errors and uncertainties; line of best fit; worst line; absolute and percentage uncertainties; percentage difference.

Is an error the same as a mistake?

No!

- Using a ruler measure the length of this line:



  - Do it independently, without telling anyone else what you measure its length to be.
  - **What measurements did you all get?**
  - **Are they all the same? You're Yr12, surely you can measure the length of a single line!**

Mistakes v Errors

- Mistakes:
  - When you make a measurement incorrectly.
  - When you complete an experiment incorrectly.
  - We can rectify mistakes by repeating our procedures in the right way.
- Errors:
  - All measurements have errors.
  - Errors are the difference between a measured value and the true value for the quantity being measured.

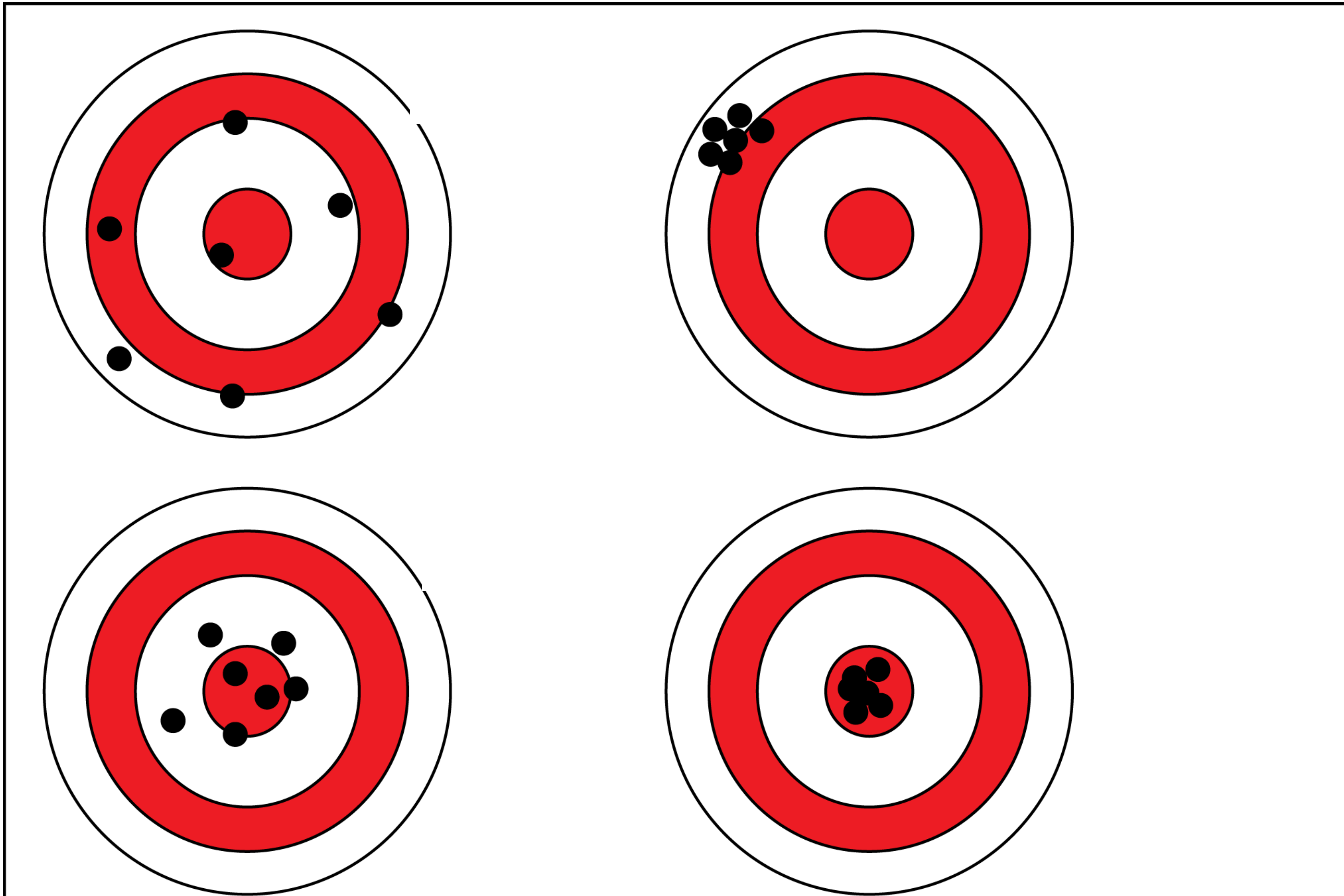
Types of Errors

- Random errors:
  - The measurement errors are unpredictable.
    - They show a normal distribution around the mean value.
  - Random errors cannot be corrected.
    - The best we can do is take repeated measurements and report the mean value.
  - Causes of random errors:
    - Factors not controlled in an experiment.
    - Difficulty reading the measured value on the measuring tool.
- Systematic errors:
  - Measurements differ from the true value by a consistent amount each time.
    - The measurement may always be “a bit high”.
  - Causes of systematic errors:
    - The time/place a measurement is taken.
    - Faulty measurement tools.
    - Incorrect tool calibration.
    - Failing to ensure the measurement tool reads zero before making the measurement.
      - These are called zero errors.

Precision and Accuracy

- Many students use these words interchangeably – and they are wrong!
  - Precision:
    - How close repeated measurements are to each other.
  - Accuracy:
    - How close to the true value a measurement is.

Which is accurate, which is precise?



How certain are we that measurements are uncertain?

Uncertainty

- As stated before, all measurements contain an element of error.
  - This may just be due to the precision of the measurement tool.
    - Imagine trying to measure the volume of a teaspoon of water using a car’s fuel gauge.
- The combination of random & systematic errors is called measurement uncertainty.

Consider your measurements of the diagonal line from earlier:

- The individual measurements will not all be the same.
  - There will be a range of measurements.
  - We can calculate the mean value to make our measurement more accurate.
- The measurement uncertainty is the interval in which the true value is expected to be:
  - Absolute uncertainty can be approximated as half the range.

Absolute Uncertainty

- Absolute uncertainty can be shown as the mean value +/- half the range.
- What is the uncertainty of these repeated measurements of aluminium foil thicknesses?

0.22 +/- 0.04 mm

Foil thickness is measured several times in different places over the area of the foil.

Some data taken are:
0.25mm
0.22mm
0.18mm
0.26mm
0.21mm

Percentage Uncertainty

- Often it is useful to express the uncertainty as a percentage of the value being measured.

$$\%\ \text{Uncertainty} = \frac{\text{Absolute Uncertainty}}{\text{Measured (mean) Value}} \times 100\%$$

- In the above example (**0.22 +/- 0.04 mm**), what is the percentage uncertainty?

  0.22 mm +/- 18%

Single measurements

- Not all measurements are repeated.
  - If I ask you for your height you'll just measure it once and tell me what it is.

- What's the uncertainty with this measurement?
  - Here the uncertainty can be approximated as the smallest division in the measurement tool.
  - My height, measured with a metre rule is

    1.772 +/- 0.001m

Repeat measurements with no variation

- A similar method applies when repeat measurements give consistent readings:
  - The absolute uncertainty here is approximated as the smallest division in the measurement tool.

Why do we even bother recording uncertainties?

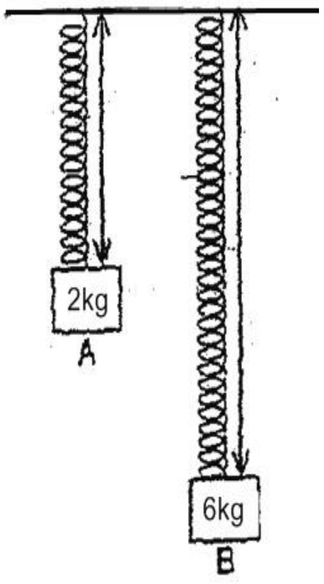
Analysing Uncertainties

- Why?
  - Uncertainties of measurements can help us identify the areas of greatest error in an experiment.
  - We can then work to improve the measurement by:
    - Using a better (more precise) measurement tool.
    - Changing to a more reliable measurement method.

Combining Quantities

- Often, the quantity we want to report is a combination of two or more separate quantities:
  - Extension of a spring:
    - Extension = final length – initial length.
  - Density of a material:
    - Density = mass / volume
  - Kinetic energy of a projectile:
    - Energy = mass x velocity^2 / 2
- What should we do about the uncertainties of these separate quantities?

Adding/Subtracting Quantities



- When adding or subtracting quantities we should add the absolute uncertainties together.

- Extension = Final length – Initial length
- So, x = 0.076 +/- 0.001m – 0.054 +/- 0.001m

- Therefore, x = 0.022 +/- 0.002m

Subtract the quantity values

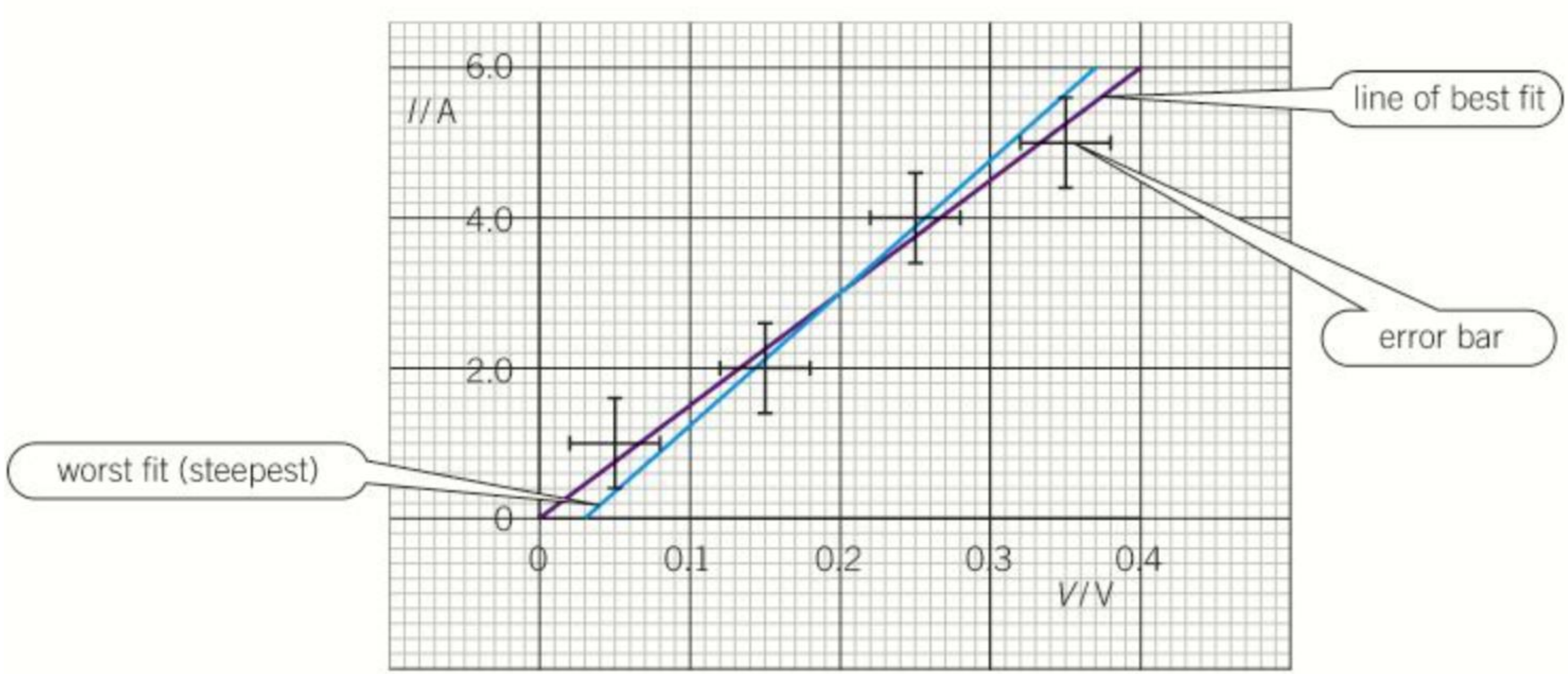
Add the uncertainties

Multiplying/Dividing Quantities

- When multiplying or dividing quantities we need to calculate the uncertainties as percentages, then add the percentage uncertainties together.
- Then we should convert the final percentage uncertainty back into an absolute uncertainty.

Uncertainties in Lines of Best Fit

- Draw the LOBF and LOWF:



The absolute uncertainty in the gradient is the positive difference between the gradient of the line of best fit and the gradient of the line of worst fit.

The percentage uncertainty in the gradient can be calculated as

$$\% \text{ uncertainty in gradient} = \frac{\text{absolute uncertainty}}{\text{gradient best fit line}} \times 100\%$$

Percentage Error (Difference)

- Used to evaluate how close a measured value is to the accepted (true) value of a quantity.
  - Eg. The value for g is generally accepted to be $9.81ms^{-2}$ (2sf).
    - Imagine an experiment to measure g produces a result of $9.74 \pm 0.10ms^{-2}$.
  - The percentage error would be calculated as:

$$\% \text{ Error} = \frac{\text{Difference between measured value and accepted value}}{\text{Accepted value}} \times 100\%$$

So how accurate is this result?

- A result’s accuracy can be assessed by comparing its percentage uncertainty with its percentage error.
  - A result is accurate if its percentage uncertainty is greater than its percentage error.
  - Ie the range of possible values includes the true (accepted) value.

So,

- How accurate is 9.74±0.10ms^{-2} as a measurement of g?

$$\% \text{ Uncertainty} = \frac{\text{Abs Uncertainty}}{\text{Measured value}} \times 100\% = \frac{0.10}{9.74} \times 100\% = 1\%$$

$$\% \text{ Error} = \frac{|\text{accepted} - \text{experimental}|}{\text{accepted value}} \times 100\% = \frac{0.05}{9.81} \times 100\% = 0.7\%$$

$$\%\textbf{Uncertainty} > \%\textbf{Error}$$

2.2 Making Measurements & Analysing Data (review)

2.2.1 Measurements and uncertainties

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