

Measurement techniques: errors and uncertainties

Typed version of the handwritten class notes (21 September 2020) for O and AS Level Physics. The original handwritten page, with its margin notes, is on the same page of megalecture.com.

Errors

Errors are uncertainties in readings which arise from sources such as:

- limitations of the observer's measurement skills;
- limitations of the actual instruments;
- limitations of the method or procedure;
- randomly varying factors of the physical environment, e.g. temperature, pressure, wind speed etc.

These errors or uncertainties cause the reading to deviate from the true value. Errors can be classified as **systematic errors** or **random errors**.

Systematic errors

Systematic errors are a constant deviation of the reading in **one direction** from the true value, such as:

- **Zero error:** e.g. a positive or negative zero error in vernier callipers and micrometers, the background count rate in a GM tube, losses of heat into the surroundings in experiments to measure specific heat capacity.
- **Incorrectly calibrated instruments:** e.g. a slow-running stopwatch or a fast-running stopwatch.
- The observer persistently carrying out a mis-timed action (e.g. in starting or stopping the stopwatch), or for example using g as 10 m/s^2 instead of 9.81 m/s^2 , which is the exact value.

Systematic errors will either cause all values to be overstated or all values to be understated.

How systematic errors affect the shape of the graph. Question: construct the new shape of a distance–time graph if all values of time are overstated.

Conclusion: the graph remains parallel to the original but shifts, so it now has a y-intercept.

- Systematic errors such as a zero error can be removed either by changing the instrument, or by noting down the zero error and either adding or subtracting it from the observed value.
- Systematic errors, however, cannot be eliminated by averaging repeated trials.

Random errors

Random errors refer to the scatter of readings about a mean value. These include flawed observations or actions, e.g. in locating the image of the pins through a glass block in the light experiment, or human reaction time in starting or stopping a stopwatch.



Random errors are of varying signs and magnitude and generally cannot be eliminated; however, they can be reduced by taking the average of repeated readings. Systematic errors cannot be reduced or eliminated by obtaining averages.

- Random errors will cause some values to be overstated and some values to be understated: e.g. trying to measure the speed of sound in air while the direction of the wind changes continuously, or human reaction time.
- A scatter of readings about a mean value indicates random error.
- They can be reduced by averaging repeated trials or, in the case of a graph, by constructing a line of best fit.

Precision and accuracy

Precision is the degree of agreement among a series of measurements of the same quantity. It is a measure of the reproducibility of the results rather than their correctness.

Accuracy is the degree of agreement between the experimental result and the true value.

Quoting a physical quantity

Whenever a physical quantity is expressed, its value is generally quoted in the form $x \pm \Delta x$, where x is the absolute value and Δx is the absolute uncertainty. For example:

- $L = 18.5 \pm 0.5 \text{ mm}$
- $I = 1.0 \pm 0.2 \text{ A}$
- $M = 25.0 \pm 0.1 \text{ g}$
- $T = 2.50 \pm 0.05 \text{ s}$

The **fractional error** is defined as $\Delta x / x$, and the **percentage error** (percentage uncertainty) is defined as $(\Delta x / x) \times 100$.

For derived quantities, uncertainties can be estimated as follows.

- **For the sum or difference of two quantities**, the absolute uncertainty is the sum of the individual uncertainties. E.g. two lengths are given as $x = 18.5 \pm 0.5 \text{ mm}$ and $y = 12.5 \pm 0.5 \text{ mm}$: $x + y = 31 \pm 1 \text{ mm}$, and $x - y = 6 \pm 1 \text{ mm}$.
- **For the product or quotient of two quantities**, the fractional uncertainty is the sum of the fractional uncertainties of those two quantities. E.g. $x = 18.5 \pm 0.5 \text{ mm}$, $y = 12.5 \pm 0.5 \text{ mm}$. (The handwritten page ends here, part-way through this example.)

Checked by Mega Lecture

This typed version follows the handwritten page, with the red margin notes placed beside the points they explain. Only spelling was corrected. Spotted a mistake? Tell us on WhatsApp: +92 336 780 1123.