

Practical Skills

1 Tabulating data

- Left column is the independent variable, the rest are the dependent variables
- No units in the body of the table, only in the header

1.1 Tabulating logarithmic values

Logs have no units, however the thing the log is of does, so it should have units

Example:

$\text{Log}(\text{Time/s})$

2 Significant figures

Data should be written in tables to the same number of significant figures, determined by resolution or uncertainty.

When crossing a multiple of 10, keep the same number of decimal places, accuracy is more important than number of significant figures.

Give answers to calculations to the least number of significant figures used in the calculation.

Uncertainty should be rounded to the same number of decimal places as the value.

For example a thermometer measuring to the nearest 0.5°C would have an uncertainty of ± 0.25 , but would be quoted at ± 0.3 as the values are to one decimal place

3 Uncertainty

Examples of issues to consider when assessing uncertainty

- The resolution of the instrument used
- The manufacturer's tolerance on instruments
- The judgements made by the experimenter
- The procedures adopted
- The size of the increments available

Resolution is the **minimum** possible uncertainty

3.1 Readings and measurements

It is useful when discussing uncertainties to separate measurements into two forms:

- Readings: Values found from a single judgement when using a piece of equipments
- Measurements: Values taken as the difference between the judgements of two values

| Reading | Measurement |
|--------------------|------------------|
| Thermometer | Ruler |
| Top pan balance | Vernier calliper |
| Measuring cylinder | Micrometer |
| Digital voltmeter | Protractor |
| Geiger counter | Stopwatch |
| Pressure gauge | Analogue meter |

The uncertainty in a reading when using a particular instrument is **no smaller** than plus or minus half of the smallest division or greater.

However when using a ruler, the readings of the start and end are made, meaning that instead of having $\pm 0.5\text{cm}$, it would instead have uncertainty of $\pm 1\text{cm}$.

3.2 Other factors

When using a stopwatch, the main uncertainty does not come from the resolution, but the person using the stopwatch. To show this, the number of significant figures should be reduced in the **final result only**.

3.3 Uncertainties in given values

In a given value, the uncertainty is assumed to be ± 1 of the last significant digit.

3.4 Multiple instances of measurements

For example, when measuring the time for 10 pendulum swings to $\pm 0.1\text{s}$, the time for 1 pendulum swing is accurate to $\pm 0.01\text{s}$

3.5 Repeated measurements

With repeated measurements, the uncertainty is half the range of measured values.

3.6 Percentage uncertainties

$$\text{Percentage uncertainty} = \frac{\text{Uncertainty}}{\text{Value}} \times 100\%$$

3.6.1 Error bars

- Plot the data point at the mean value
- Calculate the range of data, ignoring any anomalies
- Add error bars with the lengths equal to half the range on either side of the data point

3.6.2 Uncertainties from gradients

To find the uncertainty in a gradient, two lines should be drawn on the graph.

- The "best" line of best fit
- The steepest or shallowest possible line of best fit

Uncertainty in gradient is calculated by:

$$\text{Percentage uncertainty} = \frac{|\text{Best Gradient} - \text{Worst Gradient}|}{\text{Best Gradient}} \times 100\%$$

In the same way, the percentage uncertainty in the y intercept can be found by:

$$\text{Percentage uncertainty} = \frac{|\text{Best y intercept} - \text{Worst y intercept}|}{\text{Best y intercept}} \times 100\%$$

3.6.3 % error on gradient

Total % error = % error on X + % error on Y

% error on X = 1 Small Square / Number of squares on triangle

% error on Y = 1 Small Square / Number of squares on triangle

3.7 Combing uncertainties

| Combination | Operation |
|--|--|
| Adding or subtracting $a = b + c$ | Add the absolute uncertainties $\Delta a = \Delta b + \Delta c$ |
| Multiplying values $a = b \times c$ | Add the percentage uncertainties $\epsilon a = \epsilon b + \epsilon c$ |
| Dividing values $a = \frac{b}{c}$ | Add the percentage uncertainties $\epsilon a = \epsilon b + \epsilon c$ |
| Power rules $a = b^c$ | Multiply the percentage uncertainty by the power $\epsilon a = c \times \epsilon b$ |

Absolute uncertainty(Δ) - Same units as quantity

Percentage uncertainty(ϵ) - No units

4 Graphing

Axis labels should have units, no units on the intervals.

Data points should be marked with a cross

4.1 Scales and origins

Data should take up as much of the graph as possible Need to consider:

- The maximum and minimum values of each variable
- The size of the graph paper
- Whether the origin should be included as a data point
- If you need to calculate the equation of a line, needing the y intercept
- How to draw the axes without using difficult scale markings
- Plots should cover **at least half** the grid supplied with the graph

4.2 Lines of best fit

Things to consider when drawing a line of best fit

- Is the data supposed to be following an equation - helps to decide if the line should be straight or curved
- Are there any anomalous results
- Are there uncertainties in the measurements - line of best fit should lie within the error bars

A non zero intercept may imply a systematic error

4.3 Dealing with anomalous results

Anomalous results can be ignored if you know the reason for it being there, or if the results are expected to be the same (when calculating a mean etc).

Otherwise, it should be included to reduce the probability that a key point is being ignored.

Anomalous results should be recorded, and only removed at the data analysis stage.

It is good practice to repeat measurements where an anomalous result is found.

4.4 Measuring gradients

When finding the gradient of a line of best fit, a triangle should be drawn with the hypotenuse at least half as big as the line of best fit. It is best for the points on the triangle to lie on gridlines for more accurate measurements,

When finding the gradient of a curve, draw a tangent at the relevant value of the independent variable.

4.5 Testing relationships

If plotting a graph results in a straight line, there is a relationship.

One of the values may be raised to a power in order to get a straight line, this still shows a relationship.

4.5.1 More complex relationships

For more complex relationships given by a formula, they should be rearranged to give it in $y = mx + c$ form, c may be zero.

5 Definitions

Accuracy

A measurement is considered accurate if it is judged to be close to the true value

Calibration

Marking a scale on a measuring instrument

This involves establishing the relationship between indications of a measuring instrument against standard or reference values.

Data

Information, either qualitative or quantitative, that has been collected

Errors

Measurement error

The difference between a measured value and the true value

Anomalies

These are values in a set of results which are judged not to be part of the variation caused by random uncertainty

Random error

These cause readings to be spread about the true value, due to results varying in an unpredictable way from one measurement to the next

Systematic error

These cause readings to differ from the true value by a consistent amount each time a measurement is made

Zero error

Any indication that a measuring system gives a false reading when the true value of a measured quantity

Evidence

Data which has been shown to be valid

Fair test

A fair test is one in which only the independent variable has been allowed to affect the dependent variable

Hypothesis

A proposal intended to explain certain facts or observations

Interval

The quantity between readings

Precision

Measurements where there is very little spread about the mean value

Prediction

A statement suggesting what will happen in the future, based on observation, experience or a hypothesis

Range

The maximum and minimum values of the independent or dependent variables

Repeatable

If the original experimenter repeats the investigation using the same method and equipment and obtains the same results

Reproducible

If the investigation is repeated by another person, or by using different equipment or techniques, and the same results are obtained

Resolution

The smallest change in the quantity being measured of a measuring instrument that gives a perceptible change in the reading

Sketch graph

A line graph showing the general relationship between two variables

True value

The value that would be obtained in an ideal measurement

Uncertainty

The interval within which the true value can be expected to lie, with a given level of confidence or probability

Validity

The suitability of the investigative procedure to answer the question being asked

Valid conclusion

A conclusion supported by valid data, obtained from an appropriate experimental design and based on sound reasoning

Variables

Physical, chemical or biological quantities or characteristics

Categoric variables

Values that have labels

Continuous variables

Variables that have values

Control variables

A variable that may, in addition to the independent variable, affect the outcome of the investigation and so must be kept the same

Dependent variables

The variable of which the value is measured to each and every change of the independent variable

Independent variable

The variable for which values are changed or selected by the investigator