# Edexcel International A Level (IAL) Physics

Your notes

## Practical Skills II: Analysis

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Your notes

# Calculations Using Experimental Data

- Collecting experimental data is only some of the work required when carrying out a practical
- When setting up a data table, space must always be left for some calculations
- The most common calculation is the **mean** for repeat readings

$$\text{Mean} = \frac{sum\ of\ the\ readings}{number\ of\ readings}$$

- The value of the mean is then used in for further calculations
  - Anomalous readings should be ignored in this calculation
- The mean should have the **same** number of **significant figures** as the readings used to calculate it
- The experiment may require to calculate a variable which you can't directly measure
  - E.g., the area of a wire
- In this case, other measurements are taken, which then by using an equation, the variable that is required can then be calculated
  - E.g., area of a wire = $\pi r^2$, so $r$ is measured for the wire using a micrometer and substituted into this equation to calculate the corresponding area for each value of $r$
- Another example of this is finding the 'log' of a value
  - One column in a data table should be for the measurement
  - A column next to it should be the for the 'log' of that measurement
- In the Hooke's law experiment, the 'extension' cannot be measured direction, but can be calculated from the final and initial length, which can be measured

**Hooke's Law Table of Results**

| Mass m / g | Load F / N | Initial length / mm | Final length / mm | Extension x ($\times 10^{-3}$) / m |
|---|---|---|---|---|
| 200 | 2.0 | 500 | 500.1 | 0.1 |
| 300 | 2.9 | 500.1 | 500.4 | 0.3 |
| 400 | 3.9 | 500.4 | 501.0 | 0.6 |
| 500 | 4.9 | 501.0 | 501.9 | 0.9 |
| 600 | 5.9 | 501.9 | 503.2 | 1.3 |
| 700 | 6.9 | 503.2 | 504.9 | 1.7 |
| 800 | 7.8 | 504.9 | 507.0 | 2.1 |



Your notes

### Worked Example

A student wants to find the resistivity of a constantan wire. They set up the experiment by attaching one end of the wire to a circuit with a 6.0 V battery and the other with a flying lead and measuring the length with a ruler. Attaching the flying lead onto the wire at different lengths, they obtain the following table of results.

| Length of wire L / m | Current $I_1$ / A | Current $I_2$ / A | Current $I_3$ / A | Average Current I / A | Resistance R / Ω |
|---|---|---|---|---|---|
| 0.25 | 1.34 | 1.34 | 1.35 | | |
| 0.50 | 0.85 | 0.85 | 0.83 | | |
| 0.75 | 0.51 | 0.51 | 0.50 | | |
| 1.00 | 0.35 | 0.36 | 0.35 | | |
| 1.25 | 0.30 | 0.31 | 0.31 | | |
| 1.50 | 0.27 | 0.27 | 0.27 | | |
| 1.75 | 0.23 | 0.21 | 0.21 | | |
| 2.00 | 0.18 | 0.17 | 0.18 | | |

Calculate the the missing values from the table.

**Answer:**

- The average current is calculated by

$$\frac{I_1 + I_2 + I_3}{3}$$

- The resistance is calculated using the equation

$$R = \frac{V}{I}$$

- All readings are to 3 significant figures, so all values calculated should also be to 3 s.f.

| Length of wire L / m | Current $I_1$ / A | Current $I_2$ / A | Current $I_3$ / A | Average Current I / A | Resistance R / Ω |
|---|---|---|---|---|---|
| 0.25 | 1.34 | 1.34 | 1.35 | 1.34 | 4.48 |
| 0.50 | 0.85 | 0.85 | 0.83 | 0.84 | 7.14 |
| 0.75 | 0.51 | 0.51 | 0.50 | 0.51 | 11.76 |
| 1.00 | 0.35 | 0.36 | 0.35 | 0.35 | 17.14 |
| 1.25 | 0.30 | 0.31 | 0.31 | 0.31 | 19.35 |
| 1.50 | 0.27 | 0.27 | 0.27 | 0.27 | 22.22 |
| 1.75 | 0.23 | 0.21 | 0.21 | 0.22 | 27.27 |
| 2.00 | 0.18 | 0.17 | 0.18 | 0.18 | 33.33 |



## Examiner Tips and Tricks

These calculations show why it's important not to draw your data tables too big, without leaving space for more columns and rows. Think carefully about what data you need to measure, but also what you may need to calculate in order to draw graphs in the future. Thinking ahead this way will reduce the change of drawing messy tables that you'll have to keep redoing in the exam!

Your notes

# Plotting Graphs

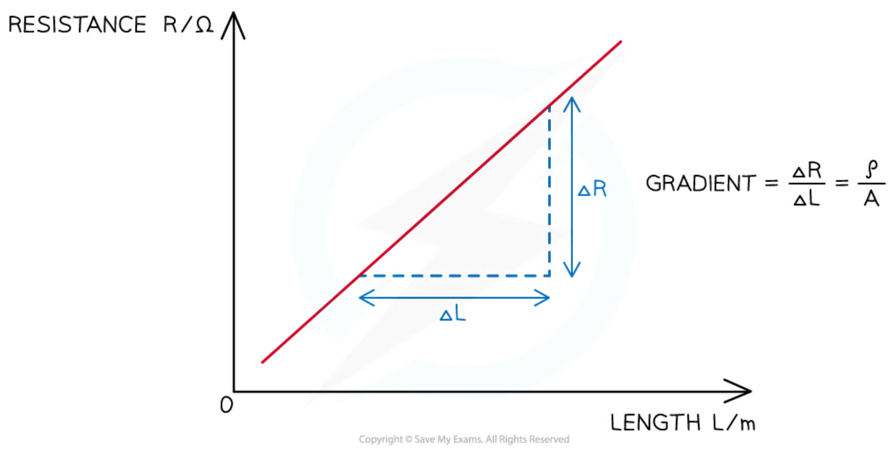
- When plotting graphs, it is important to consider the importance of the following factors:
  - Selecting appropriate scales
  - Labelling axes with quantities and units
  - Carefully plotting the points

## Choice of Scale

- When choosing a scale, it must be big enough to accommodate all the collected values using as much of the graph paper as possible
- At least half of the graph grid should be occupied in both the x and y directions
- Scales should be clearly indicated and have suitable, sensible ranges that are easy to work with
  - For example, scales with multiples of 3 should be avoided
- The scales should increase outwards and upwards from the origin
- Each axis should be labelled with the quantity that is being plotted, along with the correct unit

## Labelling the Axes

- Label each axis with the name of the quantity and its unit
  - For example, *F* / N means force measured in Newtons
- The convention is that a forward slash ( / ) is used to separate the quantity and the unit
- In general:
  - The **independent variable** goes on the x-axis
  - The **dependent variable** goes on the y-axis




*Example of labelled axes with the name of the variable, its symbol and its unit*

## Plotting the Points

- Points should be plotted so that they all fit on the graph grid and not outside it
- All values should be plotted, and the points must be precise to within **half a small square**
- Points must be clear, and not obscured by the line of best fit, and they need to be plotted with a sharp pencil so that they are thin
- There should be at least six points plotted on the graph, with any major outliers identified

## Line or Curve of Best Fit

- There should be equal numbers of points above and below the line of best fit
  - Using a clear plastic ruler will help with this
- Not all lines will pass through the origin and nor should they be forced to
- The line (or curve) of best fit should not be too thick or joined dot-to-dot like a frequency polygon
- Anomalous values that have not been identified during the implementation stage should be ignored if they are obviously incorrect
  - This is because they will have a large effect on the gradient of the line of best fit

## Determining the y-intercept

- The y-intercept is the y value obtained where the line crosses the y-axis at x = 0
- Values should be read accurately from the graph, with the scale on the y-axis being interpreted correctly

### Worked Example

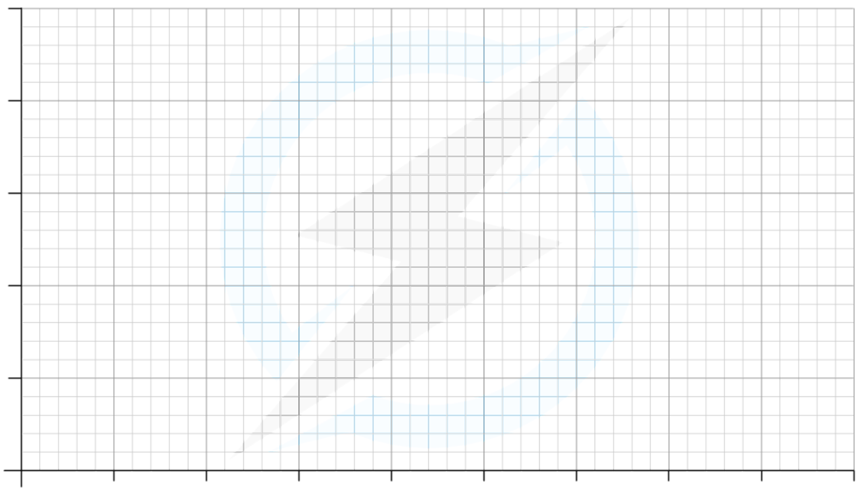
Your notes

A student investigates the effect of placing an electric fan in front of a wind turbine. The wind turbine is connected to a voltmeter. When the wind turbine turns, it generates voltage. The student obtains the following results:

| Blade angle / degree | Voltage / V |
|---|---|
| 0 | 0.0 |
| 10 | 2.0 |
| 20 | 2.2 |
| 30 | 2.0 |
| 40 | 1.7 |
| 50 | 1.4 |
| 60 | 1.0 |
| 70 | 0.6 |
| 80 | 0.2 |
| 90 | 0.0 |



Plot the student's results on the grid and draw a curve of best fit on the graph.





**Answer:**

**Step 1: Identify the independent and dependent variables**

- Independent variable = blade angle / °
- Dependent variable = voltage / V

**Step 2: Choose an appropriate scale**

- The range of the blade angle is 0 – 90°

Your notes

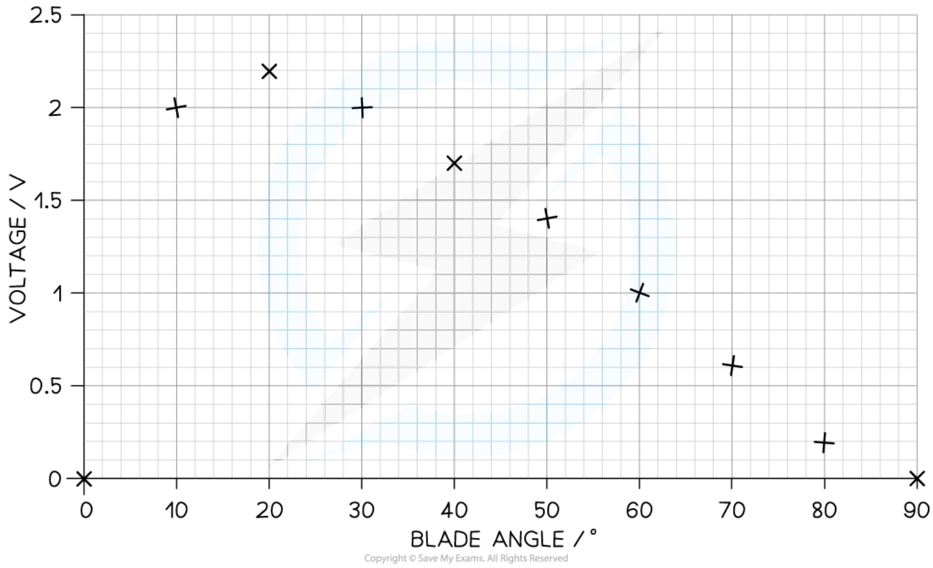
- Ideally, every small square represents 10°
- The range of the voltage is 0 – 2.2 V
- Ideally, each small square represents 0.5 V
- Both axes should occupy at least 50% of the grid

**Step 3: Label the axes**

- The dependent variable (voltage / V) goes on the y-axis
- The independent variable (blade angle / °) goes on the x-axis
- Both axes should be labelled with a quantity and a unit

**Step 4: Plot the points**

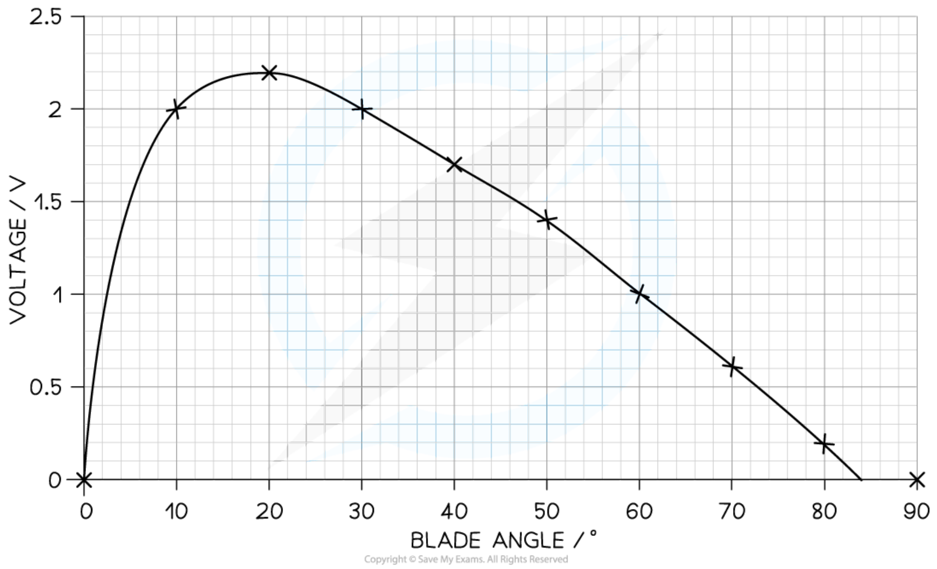
- Each point should be accurate within half a small square




**Step 5: Draw a curve of best fit**

- The curve should be smooth with a roughly equal distribution of points on either side of the curve
- It must start at (0,0) and peak at (20, 2.2)

Your notes

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### Examiner Tips and Tricks

Remember that 'sketching' and 'plotting' a graph are two different command words

- 'Sketch' means – Produce a freehand drawing. For a graph, this would require a line and labelled axis with important features indicated, the axes are not scaled.
- 'Plot' means – Produce a graph by marking points accurately on a grid from data that is provided and then drawing a line of best fit through these points. A suitable scale and appropriately labelled axes must be included if these are not provided in the question

The difference between these two command words is the use of scales. A plotted graph has scaled axes, whilst a sketch doesn't have to be but both times the axes should be clearly labelled

# Logarithmic Scales

- Graphs can be logarithmic in nature
- A logarithmic (log) scale is a non-linear scale often used for analysing a large range of quantities
  - The log of a number is always greater than 1, so all log values are only positive
  - Hence, when drawing a log-log graph, the graph will only have a positive quadrant
- Often, in practicals, if the log of a value is required, then a separate column is needed in the data table to calculate this, for example:

**Table of Results Using ln**

Your notes

| Time t/s | Potential Difference / V | ln(V) / V |
|---|---|---|
| 0.00 | 10.0 | 2.30 |
| 10.00 | 8.95 | 2.19 |
| 20.00 | 7.58 | 2.03 |
| 30.00 | 6.13 | 1.81 |
| 40.00 | 4.90 | 1.59 |
| 50.00 | 4.12 | 1.42 |
| 60.00 | 3.00 | 1.10 |
| 70.00 | 2.03 | 0.71 |



***A separate column is often needed to calculate*** ln(*V*)

- In the above case, the potential difference *V* is determined from a voltmeter, but the ln(*V*) values are calculated using a calculator
- The most common example of this in A level physics is in:
  - Radioactive decay
  - capacitor charge and discharge equations

## Using Natural logs (ln)

- Taking natural logs (ln) of an equation with an exponential function means the equation can become **linear** i.e. in the form ***y* = *mx* + *c***
- Straight-line graphs tend to be more useful than curves for interpreting data
  - Gradients and intercepts are useful values that can be seen from a straight-line graph
- Nuclei decay exponentially, therefore, to achieve a straight-line plot, logarithms can be used
- Take the exponential decay equation for the number of nuclei

$$N = N_0 e^{-\lambda t}$$

- Taking the natural logs of both sides

$$\ln N = \ln (N_0 e^{-\lambda t}) = \ln (N_0) + \ln(e^{-\lambda t})$$

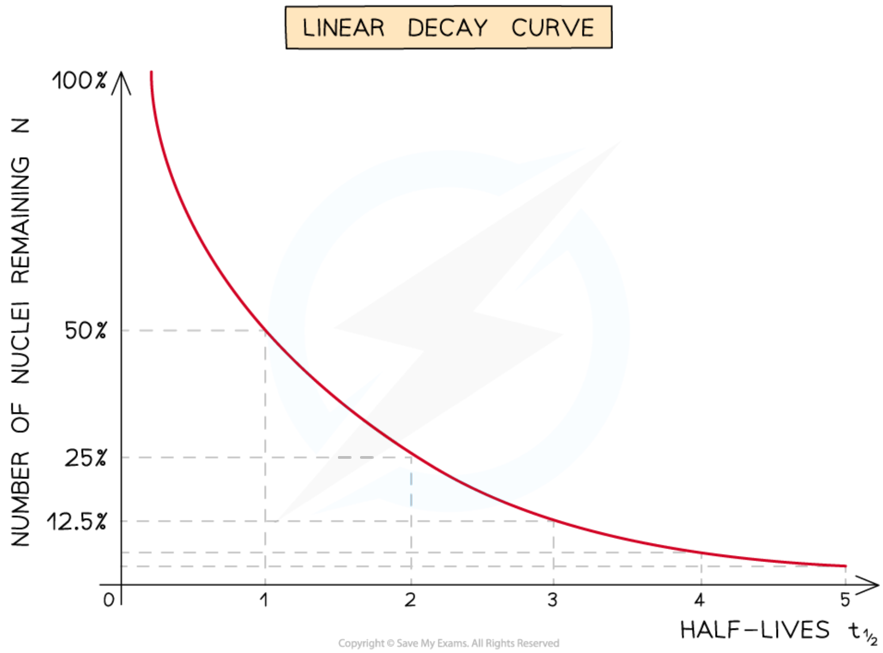
$$\ln N = \ln (N_0) - \lambda t$$

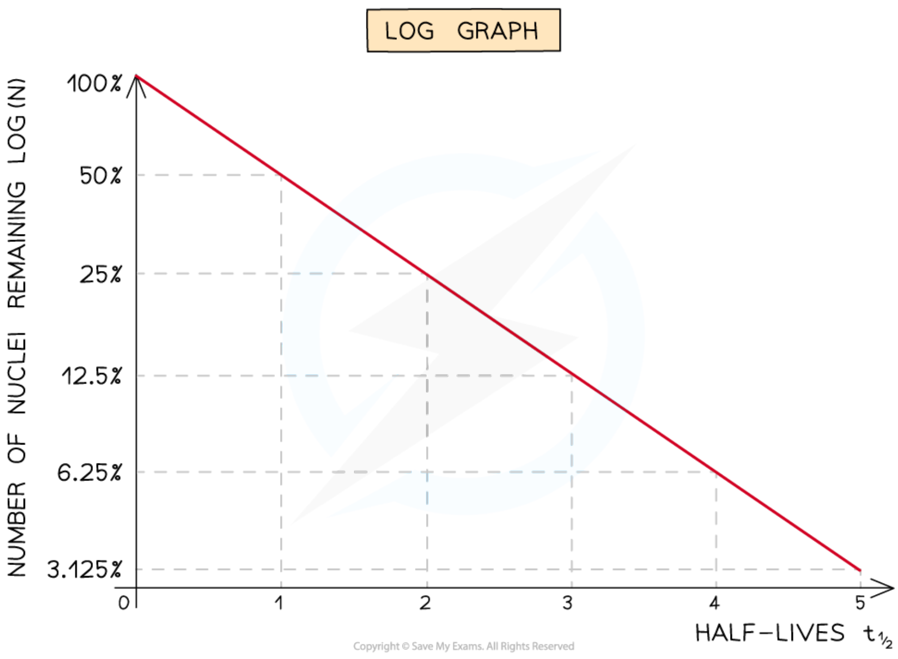
- In this form, this equation can be compared to the equation of a straight line

$$y = mx + c$$

$$\ln N = -\lambda t + \ln (N_0)$$

- Where:
  - $y = \ln (N)$ is plotted on the y-axis
  - $x = t$ is plotted on the x-axis
  - gradient, $m = -\lambda$
  - y-intercept = $\ln (N_0)$ is a constant
- The exponential decay version of the equation could produce a curve, whilst the $\ln(N)$ equation produces a straight line






*Linear decay curve vs. a log graph*

### Examiner Tips and Tricks

Remember that **log** and **ln** are subtly different! There are two different functions on your calculator.

- By default, log is to the base 10, $\log_{10}$ E.g., $\log 100 = \log_{10} 100 = 2$
  - This is very rarely used, if at all, in A level physics
- 'ln' is just log to the base e (the exponential function). Therefore, $\ln = \log_e$ E.g., $\ln(e^x) = \log_e(e^x) = x$
  - Therefore, if you ever have an exponential function, e in the equation - use 'ln' and not 'log'

'ln' follows all the same laws of logarithms of addition, subtraction and power. You can find more in the 'Logarithmic Function' A level Maths notes here on Save My Exams

Your notes

# Using Units Correctly

## SI Base Units

- Every time you measure or calculate a quantity, you need to give its **units**
- All units in Physics can be reduced to six base units from which every other unit can be derived
  - These other quantities are called derived units
- These seven units are referred to as the SI Base Units; this is the only system of measurement that is officially used in almost every country around the world

**SI Base Quantities Table**

| QUANTITY | SI BASE UNIT | SYMBOL |
|---|---|---|
| MASS | KILOGRAM | kg |
| LENGTH | METRE | m |
| TIME | SECOND | s |
| CURRENT | AMPERE | A |
| TEMPERATURE | KELVIN | K |
| AMOUNT OF SUBSTANCE | MOLE | mol |



## Derived Units

- Derived units are derived from the seven SI Base units mathematically
- The base units of physical quantities such as:
  - Newtons, **N**
  - Joules, **J**
  - Pascals, **Pa,** can be deduced
- To deduce the base units, it is necessary to use the definition of the quantity
- The Newton (N), the unit of force, is defined by the equation:
  - Force = mass × acceleration
  - $N = kg \times m\,s^{-2} = kg\,m\,s^{-2}$

- Therefore, the Newton (N) in SI base units is **kg m s$^{-2}$**

- The Joule (J), the unit of energy, is defined by the equation:
  - Energy = ½ × mass × velocity$^2$
  - J = kg × (m s$^{-1}$)$^2$ = kg m$^2$ s$^{-2}$
  - Therefore, the Joule (J) in SI base units is **kg m$^2$ s$^{-2}$**
- The Pascal (Pa), the unit of pressure, is defined by the equation:
  - Pressure = force ÷ area
  - Pa = N ÷ m$^2$ = (kg m s$^{-2}$) ÷ m$^2$ = kg m$^{-1}$ s$^{-2}$
  - Therefore, the Pascal (Pa) in SI base units is **kg m$^{-1}$ s$^{-2}$**
- It is essential that the correct scientific measurements are used when discussing experiments in physics
- Ensure that the **correct symbols** are used in conjunction with the unit of measurement
  - E.g. m$^3$ for cubic metres

**Units of Measurement Table**

| Measurement | Base unit | Symbol | Units used |
|---|---|---|---|
| Length | Metre | m | 1000 m = 1 km<br>0.01 m = 1 cm<br>0.001 m = 1 mm<br>0.000001 m = 1μm |
| Volume | Cubic metre | m$^3$ | $10^9$ m$^3$ = 1 km$^3$<br>0.000001 m$^3$ = 1 cm$^3$<br>$10^{-9}$ m$^3$ = 1 mm$^3$<br>$10^{-18}$ m$^3$ = 1μ m$^3$ |
| Volume | Cubic decimetre | dm$^3$ | 0.001 dm$^3$ = 1 cm$^3$<br>0.000001 dm$^3$ = 1 mm$^3$ |
| Area | Square metre | m$^2$ | 10000 m$^2$ = 1 ha<br>0.0001 m$^2$ = 1 cm$^2$ |

Your notes

| | | | |
|---|---|---|---|
| **Mass** | Kilogram | kg | 1000 kg = 1 tonne<br>0.001 kg = 1 g<br>0.000001 kg = 1 mg<br>$10^{-9}$ kg = 1 μg |
| **Time** | Second | s | 60 s = 1 min<br>60 min = 1 hour |
| **Pressure** | pascal | Pa | 1000 Pa = 1 kPa |
| **Energy** | joule | J | 1000 J = 1 kJ<br>1000000 J = 1 MJ |
| **Temperature** | degrees Celsius | °C | |
| **Amount of substance** | mole | mol | 0.001 mol = 1 millimole |



- Note:
  - $cm^3$ is the same as millilitre (ml)
  - $dm^3$ is the same as litre (l)

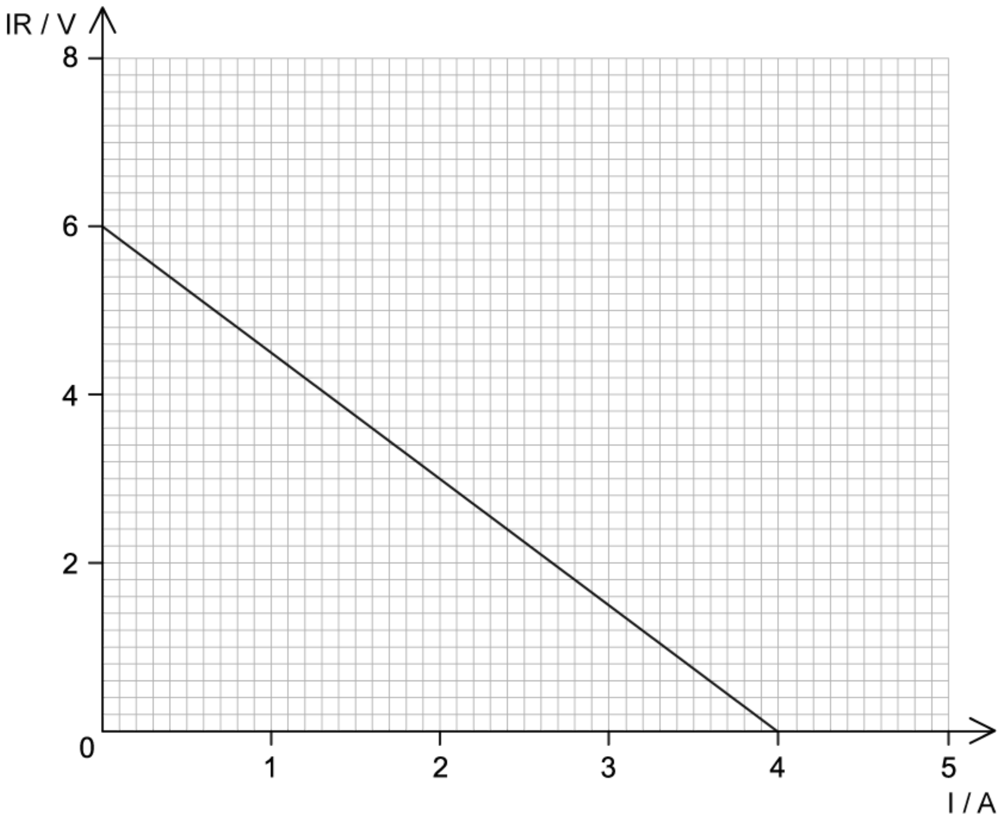
### Examiner Tips and Tricks

Units are **extremely** important in physics, and should always be stated when calculating any values if they are not already given on the paper. Units should always be included on the axes for graphs (either sketches or plotted) and table headings. Some variables may not have units, such as straight, refractive index and number of particles.

Your notes

# Trend & Patterns in Experimental Data

- Graphs are used to visualise the relationship between two sets of data from two different variables
- Trends and patterns can be identified from experimental data
- Common trends are:
  - Linear
  - Directly proportional
  - Inversely proportional
  - Rate of change
- A **linear** graph set of data is any data that creates a **straight line**




***An example of a linear graph***

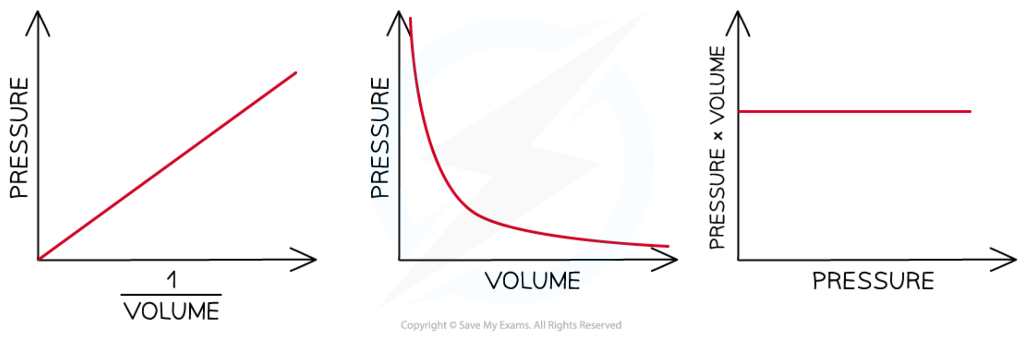
- The rate of change of a graph is how quickly a variable is increasing or decreasing with something else

- This can be seen from the change in **gradient** of the graph, an increasing gradient has an increasing rate of change and a decreasing gradient has a decreasing rate of change
- A direct proportionality relationship is where as one amount increases, another amount increases at the same rate
  - This is represented by a **straight-line** graph with a positive gradient
- For two variables, *y* and *x* this looks like:

$$y \propto x$$

- An inverse proportionality relationship is where as one amount increases, another amount **decreases** at the same rate
  - This is represented by a **curved** graph with a decreasing gradient
- For two variables, *y* and *x* this looks like:

$$y \propto \frac{1}{x}$$




***Sketched graphs show relationships between variables***

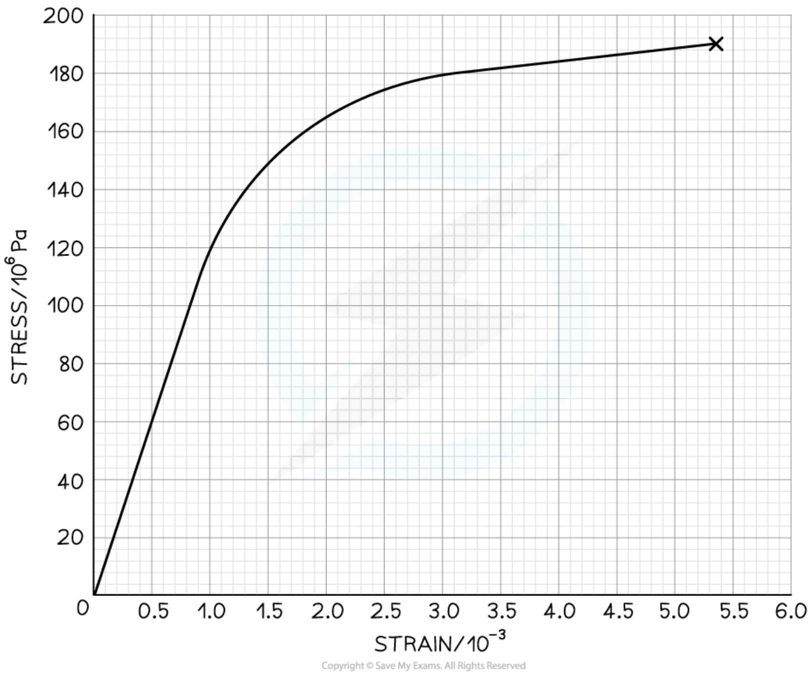
- In the first sketch graph, above you can see that the relationship is a straight line going through the origin
  - This means as you double one variable the other variable also doubles so we say the independent variable is **directly proportional** to the dependent variable
- The second sketched graph shows a shallow curve
  - This is the characteristic shape when two variables have an **inversely proportional** relationship
- The third sketched graph shows a straight horizontal line,
  - This means as the independent variable (x-axis) increases the dependent variable does not change or is constant

Your notes

Your notes

### Worked Example

Comment on the trend of the graph.




**Answer:**

- Stress and strain are proportional to each other, but not directly
- The graph is linear with a positive gradient up to a strain of $1.0 \times 10^{-3}$
- After this, the rate of change of the strain with stress decreases, as the gradient of the graph decreases up to the breaking stress at 190 MPa

# Relationships between Variables

- Identifying the relationship between two variables shows **how** one variable **changes** with another
  - This is best figured out from an equation that links both variables together
- Two variables can be:
  - Directly proportional
  - Inversely proportional
- For two variables, *y* and *x* that are directly proportional, their relationship looks like:

$$y \propto x$$

- This means that as *y* increases, *x* also increases at the same rate (and vice versa)
- An example of this is

$$F = ma$$

- Since *m* is a constant, *F* and *a* are directly proportional
  - If *a* is doubled, then so is *F*
- For two variables, *y* and *x* that are inversely proportional, this looks like:

$$y \propto \frac{1}{x}$$

- This means that as *y* increases, *x* decreases at the same rate (or vice versa)
- An example of this is

$$R = \frac{V}{I}$$

- If *V* is constant, then *R* and *I* are inversely proportional
  - *If* I is doubled, the *R* is halved
- It is important to note that in both of these examples, the remaining variable is **constant**, this is important to consider and check before stating the relationship between two variables
  - In *F* = *ma*, if *m* changed as well with *a* then *F* would not increase by the same amount as *a* (i.e. it would no longer be directly proportional)
- Therefore, the directly proportional relationship can be turned into an equation by replacing '$\propto$' with an '=' sign, and adding a constant *k*

$$y = kx$$

- This now means that as *y* increases, *x* increases with the amount determined by the constant *k*
  - If *k* is 3 then $y = 3x$ so the both increase by a factor of 3
- The same happens for an inversely proportional relationship

$$y = \frac{k}{x}$$

- This now means that as *y* increases, *x* increases with the amount determined by the constant *k*
  - If *k* is 3 then $y = \frac{3}{x}$ so *y* decreases by a factor of 3
- Another common relationship is the **inverse square law**
- For two variables, *y* and *x* that are related by the inverse square law, this looks like:

$$y \propto \frac{1}{x^2}$$

- This means that if *x* **increases** by a factor of 2, then *y* **decreases** by a factor of $2^2 = 4$!
- An example of this is

$$F = \frac{L}{4\pi d^2}$$

- If *L* is constant, then *d* and *F* are inversely proportional
  - If the distance *d* is 3 times larger, then the flux intensity, *F* is $3^2 = 9$ times smaller

## Worked Example

A student collects the following data of the count rate on a geiger counter increasing in distance from a gamma ray source.

| Distance d / cm | Count rate C / counts min$^{-1}$ |
|---|---|
| 10 | 512 |
| 20 | 128 |
| 30 | 57 |
| 40 | 32 |

Show that the relationship between distance and count rate is an inverse square law relationship.

Your notes

Your notes

**Answer:**

**Step 1: State the inverse square law relationship**

- The count rate is inversely proportional to the distance **squared**

$$C \propto \frac{1}{d^2}$$

**Step 2: Change relationship into an equation**

$$C = \frac{k}{d^2}$$

**Step 3: Rearrange for constant, *k***

$$k = Cd^2$$

**Step 4: Show all pairs of C and *d* have the same constant, *k***

Row 1: $k = 512 \times (10)^2 = 51200$

Row 2: $k = 128 \times (20)^2 = 51200$

Row 3: $k = 57 \times (30)^2 = 51300$

Row 4: $k = 32 \times (40)^2 = 51200$

**Step 5: Comment on constant and refer back to relationship**

- Since all values have the same constant $k$ to 2 significant figures (51000), $C$ and $d$ have an inverse square law relationship

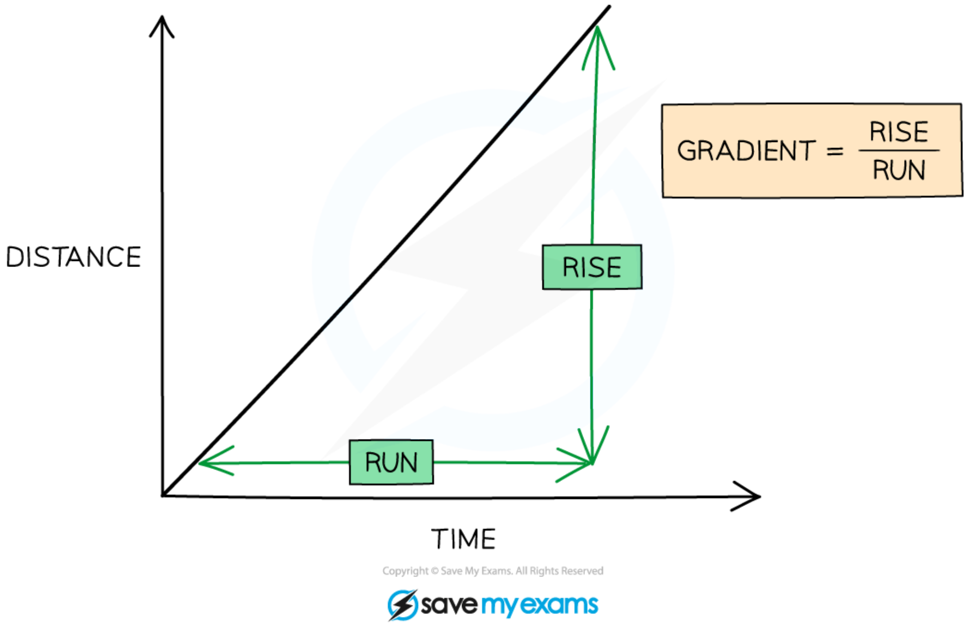
### Examiner Tips and Tricks

When you're comparing two variables you **must** check whether the other variables are constant before declaring that they're inversely or directly proportional. Otherwise, one will not increase at the same rate as the other, which goes against the definition!

# Determining Constants from Graphs

- Straight line graphs (linear relationships) are common in A-level physics
  - These graphs are useful because we can calculate a **constant** value from them
  - This is the **gradient**
- The gradient can be calculated by dividing the **rise** (change in y) by the **run** (change in x)

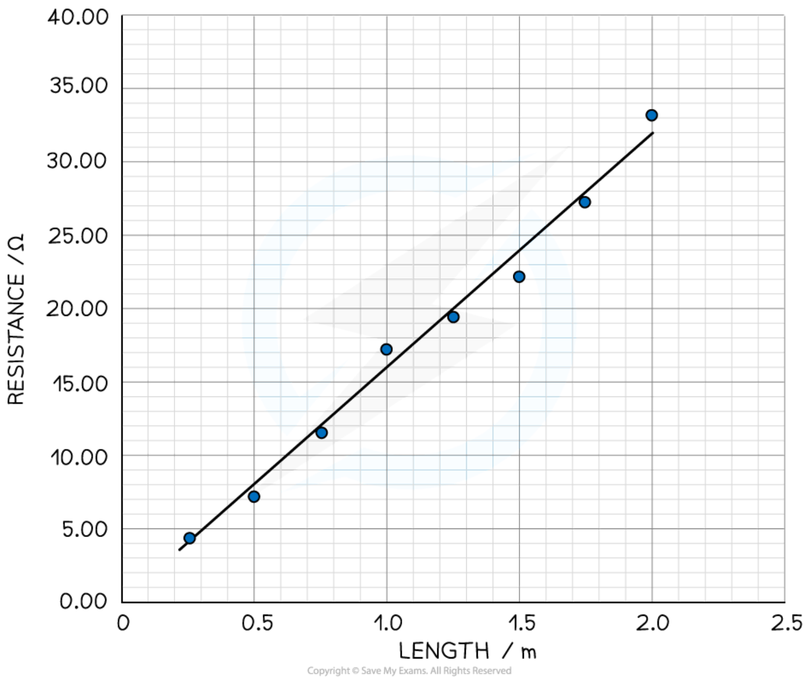
Your notes




- The full calculation of the gradient needs to be shown in the working out, including the correct substitution of identified plotted points from the axes into the equation
- The triangle used to calculate the gradient should be drawn on the graph and it needs to be **as large as possible**
  - Small triangles are **not** acceptable for working out a gradient
- When using the results from a table of values, the triangle that is used to obtain the gradient can utilise points that lie on the line of best fit but **not** values that lie away from the line
  - Try to avoid using data points to calculate this where possible
- The units of the gradient will be the ratio of the units of the *y* variable and units of the *x* variable
  - E.g., For a graph for extension *x* (in m) against force *F* (in N) the units of the gradient would be N $m^{-1}$

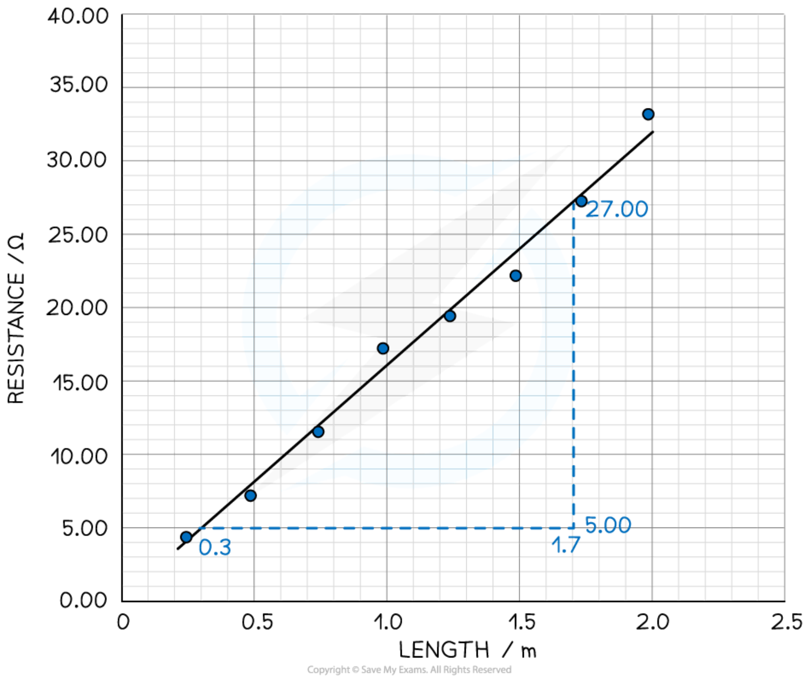
## Worked Example

Calculate the gradient of the following graph.




**Answer:**

**Step 1: Draw a large gradient triangle**




**Step 2: Use the gradient equation**

$$\text{Gradient} = = \frac{27.00 - 5.00}{1.7 - 0.3} = 15.7\ \Omega\ \text{m}^{-1}$$

Your notes

## Examiner Tips and Tricks

The general rule is to draw a gradient triangle that takes up **more than half** of the graph. Drawing triangles too small, even if you get the correct answer, will not achieve full marks in the practical paper!

There is normally a range of answers accepted in the mark scheme for gradients, as everyone's line of best fit may be slightly different, but don't count on this! This range will often be very small so always use a sharp pencil and ruler to draw lines where possible. Show your working out on the paper always to help this.

Remember to always check the **units** and **scale** when reading values from a graph! Don't just assume that all lengths are in m or that forces will be in N. They could be in mm or kN. Also watch out for the powers of ten e.g., Force $F \times 10^3$ / N which means a value of '5' on the graph will actually be $5 \times 10^3$ N (or 5 kN).

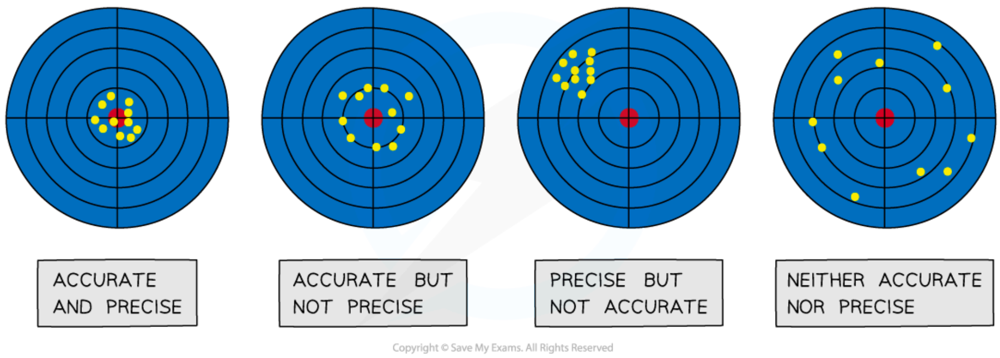
# Precision & Accuracy

## Precision

- Precision is how close the measured values are to each other
- If a measurement is repeated several times, then they can be described as precise when the values are very similar to, or the same as, each other
- The precision of a measurement is reflected in the values recorded
  - Measurements to a greater number of decimal places are said to be more **precise** than those to a whole number

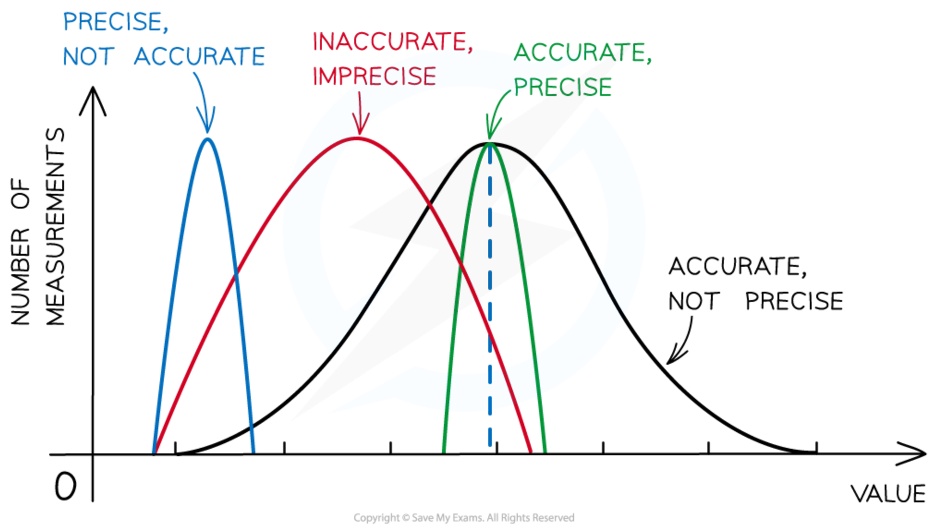
## Accuracy

- Accuracy is how close a measured value is to the true value
- Accuracy can be increased by repeating measurements and finding a mean average




***The difference between precise and accurate results***

- Measurements of quantities are made with the aim of finding the true value of that quantity
- In reality, it is impossible to obtain the true value of any quantity, there will always be a degree of uncertainty
- The uncertainty is an estimate of the difference between a measurement reading and the true value
- Random and systematic errors are two types of measurement errors which lead to uncertainty




***Representing precision and accuracy on a graph***

## Sensitivity

- A measuring instrument can have a sensitivity
  - This is the ratio of the changes in the output of an instrument to the change in value of the quantity being measured
- In other words, this is the smallest change the instrument can detect
- This is slightly different to resolution
- Resolution is the smallest change the instrument can **observe** but sensitivity is the smallest change that the instrument can **detect**
- If what you are measuring (the dependent variable) changes significantly when the independent variable is changed, then the instrument is deemed to be sensitive
  - If the value does not change significantly, with big changes to the independent variable, then the instrument is not sensitive
- An instrument with better sensitivity detects changes in a variable much better
  - For example, a thermometer could have a sensitivity of 1 °C (it only detects change of 1 °C)
  - A digital thermometer could have a sensitivity of 0.1 °C (it can detect changes as small as 0.1 °C)
- If you are taking measurements in very small intervals of temperature increase, the digital thermometer will be able to give much more accurate results

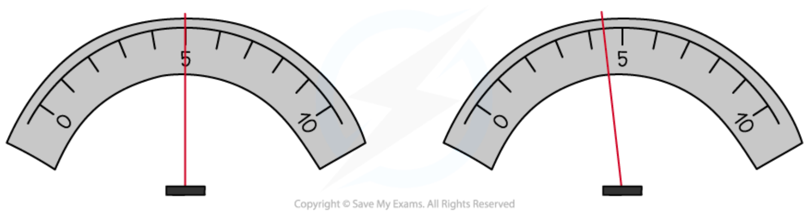
Your notes

## Examiner Tips and Tricks

Try not to confuse precision with accuracy - measurements can be precise but not accurate if each measurement reading has the same error. Precision refers to the ability to take multiple readings with an instrument that are close to each other, whereas accuracy is the closeness of those measurements to the true value.

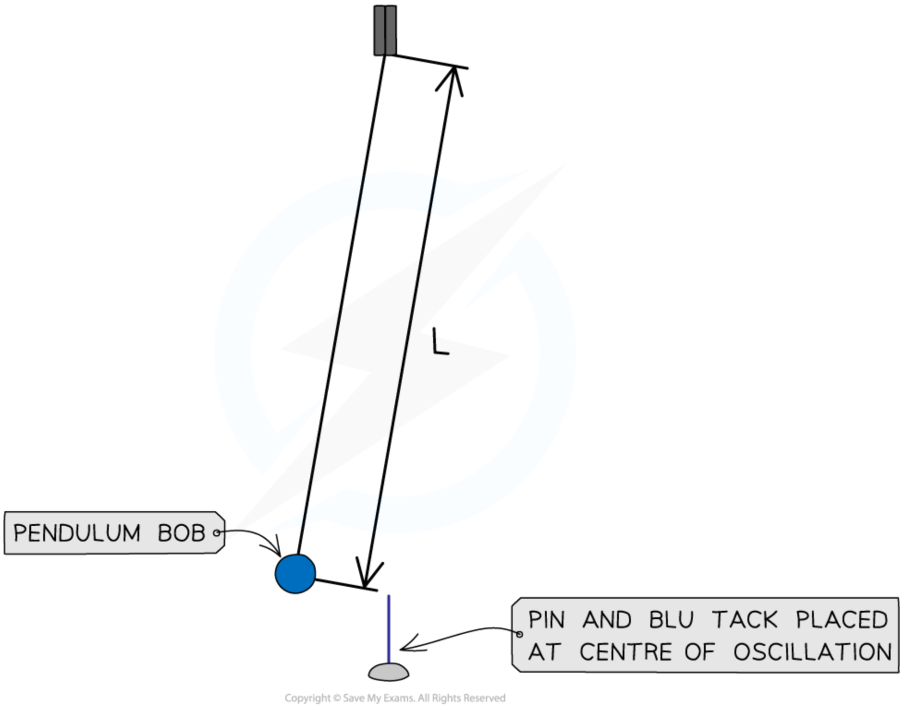
# Reducing Errors

- Reducing errors in an experiment is vital for obtaining more accurate results
- Even if the experimental result is close to the true value, there are always potential limitations of experimental methods such as the presence of random errors
- Random errors cannot be completely removed but their effect can be reduced by taking as many **repeats** as possible and using the **average** of the repeats
- There are always opportunities to identify limitations of the procedure, some common examples include:
  - **Parallax error** when reading scales
  - Not using a **fiducial marker** (eg. when measuring the time period of a pendulum using a stopwatch)
  - Not repeating measurements to reduce random errors
  - Not checking for zero errors to reduce systematic errors
  - The equipment not working properly or not checking beforehand with small tests
  - Equipment with poor precision and resolution (eg. using a ruler over a micrometer)
  - Difficult to control variables (eg. the temperature of the classroom)
  - Unwanted **heating effects** eg. in circuits
- Parallax error is minimised by reading the value on a scale only when the line of sight is perpendicular to the scale readings (i.e.. at eye level)
- Examples of where parallax error is common are:
  - Determining the volume of liquid
  - Making sure two objects are aligned
  - Reading the temperature from a thermometer
- If it makes it easier, use a marker to help where possible




***Reading the value of the needle head-on (left image) looks different to reading it from the right (right image). This is parallax error***

- A **fiducial marker** is a useful tool to act as a clear reference point, such as when measuring the time period of a pendulum using a stopwatch
- This improves the accuracy of a measurement of periodic time by:
  - Making timings by sighting the pendulum as it passes the fiducial marker
  - Sighting the pendulum as it passes the fiducial marker at its highest speed. The pendulum swings fastest at its lowest point and slowest at the top of each swing




***A fiducial marker is used to mark the centre of the oscillation of the pendulum***

- Zero errors must be checked for in both digital and analogue instruments
  - E.g., If there is no current through the circuit, an ammeter must read 0 A
- The common way to reduce unwanted heating effects in circuits is to **turn off** the power supply in between readings
  - As the temperature of a component increases, so does its resistance (e.g., in wires). This will affect the experiment and produce an error in your final result

## Worked Example

A student wants to determine the radius of a wire for an experiment to calculate its Young Modulus. They measure the radius using a ruler from one part of the wire.

Discuss ways in which the student can reduce the error in this reading.

**Answer:**

Your notes

Your notes

**Step 1: Comment on the instrument used**

- Since the radius of a wire is on the order of < 1 mm, and has a circular cross section, a micrometer screw gauge should have been used instead

**Step 2: Comment on the method**

- The student did not take any repeat readings
  - They should take between 3–5 repeat readings for each value of the radius from the micrometer

**Step 3: Suggest improvements to the method**

- The experiment assumes the wire is uniform the whole way through (i.e. has the same radius)
- This can be checked by measuring the radius at **different points** on the wire

# Suggesting Improvements

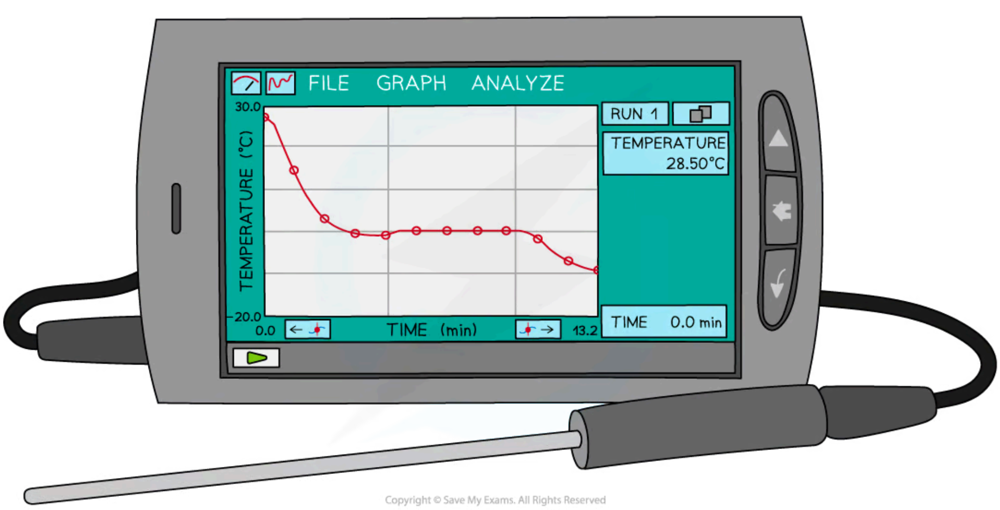
- Improvements to an experiment help make it more reliable and reproducible to gain more trust in the results
- A common method is to use **digital** methods of data collection where possible
  - These subsequently reduce uncertainties that are a result of human error (e.g., reaction time)

## Software & Tools

- Graph plotting and data analysis software, such as Microsoft Excel, can be an invaluable tool
  - Spreadsheets provide a very effective way of processing data, particularly when the amount of data is large
- **Cameras** can be used to take photos in experiments that happen too quickly to read a scale
  - A camera can be used to take a photo burst as the experiment happens
  - The scale can then be read from the photos afterwards
  - If the time each photo is taken is known, or if the frame rate is known, then properties such as velocity can be calculated

## Data Loggers

- Data loggers are a tool that allows for the **quick and efficient gathering of data**
  - They are more accurate, quick and reliable than manual logging
- The information contained within a data logger can be inputted into a computer and formatted into a **table**
- After this is done the computer is able to calculate the **average** and **plot graphs** using the data and calculate gradients which quicker and more accurately than humans
- They are electronic devices that automatically monitor and record environmental parameters over time such as temperature, pressure, voltage or current
  - It contains multiple sensors to receive the information and a computer chip to store it

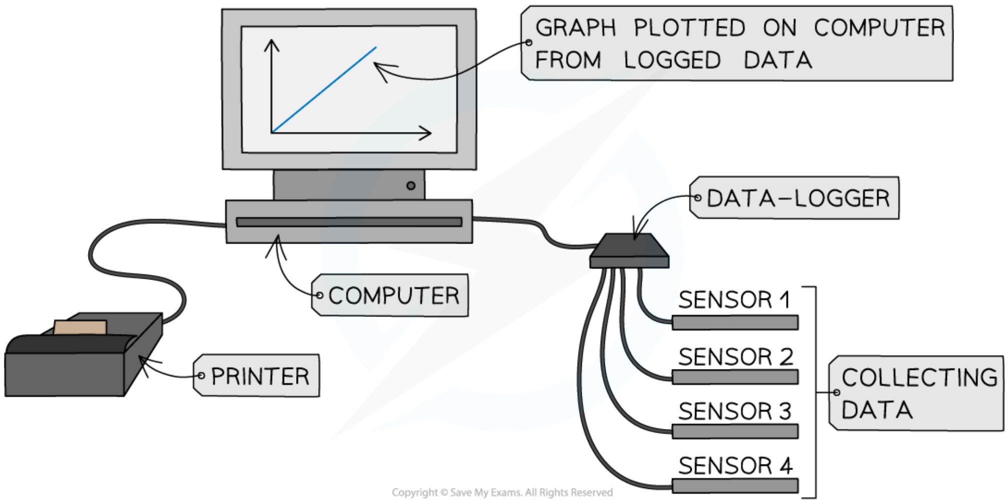



***A data logger measuring and displaying temperature using a probe***

- The benefits of using data loggers and ICT (information and communication technology) include:
  - Readings are taken with **higher** degrees of **accuracy**
  - Reduction of **human error** (e.g. human reaction times, subjectiveness)
  - Readings can be taken over a **long period of time** e.g. hourly readings of temperature over many days
  - Readings can be taken in a **very short period of time**, which would be too quick for humans to see a difference
  - Reduction in safety risks with **extreme conditions** such as measuring the temperature of boiling water

## Computer Modelling

- Computer modelling is commonly done in conjunction with devices such as a data logger
  - Modelling is about processing the data collected from a physics experiment into software or a spreadsheet
- Graphs and charts can be generated from a table of values
  - These can then be exported to a scientific report
- One of the benefits of these computer programs is that **time** can be **sped up to predict the future outcome** of an experiment




***Computer modelling uses a computer and sensors to analyse and display data***

## Making Methods Reproducible

- To improve upon an experimental method, it could be made more **reproducible**
  - This is the ability to be properly reproduced for other scientists to also see if they get the same results
- For example, when measuring the resistivity of a wire, a constantan wire may be used
  - If the same method is used to measure an accurate value of the resistivity of copper or aluminium, then this means the method is properly reproducible
- A further discussion of similarities and / or differences between the three wire materials can then be analysed
- Another example could be when measuring the count rate of a gamma ray source
  - By using a more or less active source, more differentiation in their readings can be achieved

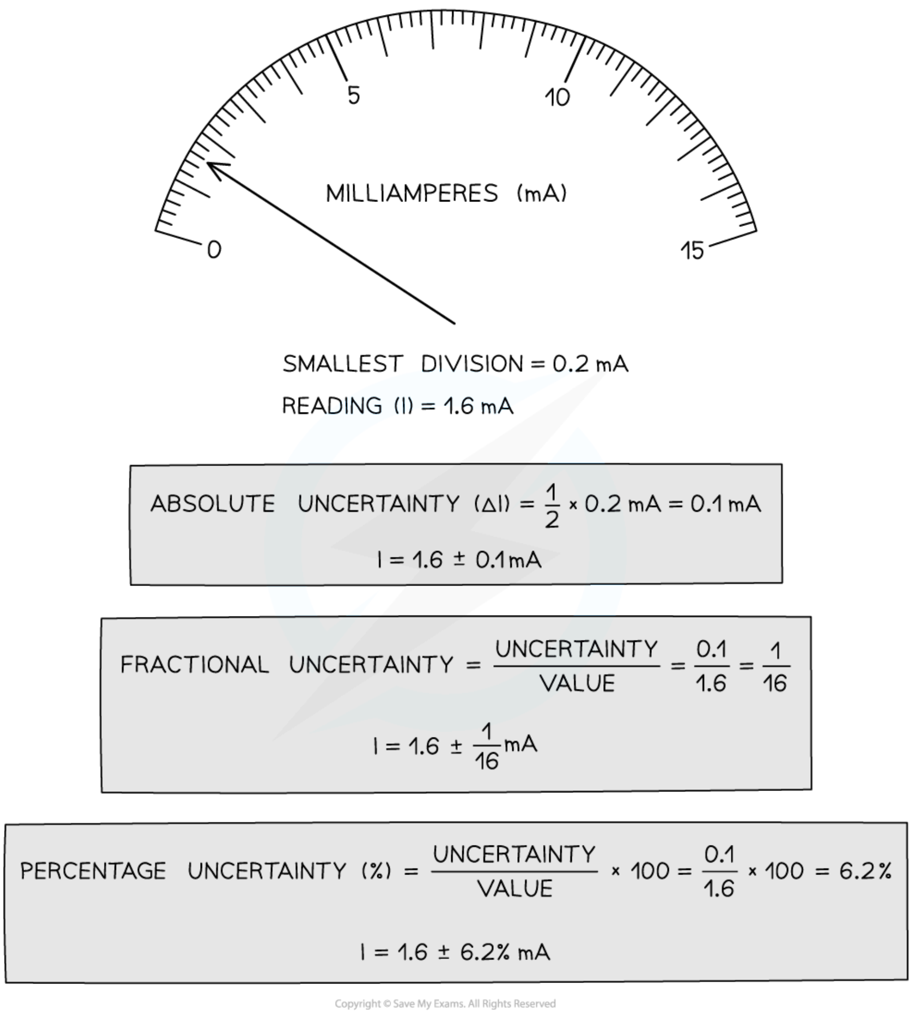
Your notes

# Uncertainties

- Uncertainties can be represented in a number of ways:
  - **Absolute Uncertainty:** where uncertainty is given as a fixed quantity
  - **Fractional Uncertainty:** where uncertainty is given as a fraction of the measurement
  - **Percentage Uncertainty:** where uncertainty is given as a percentage of the measurement
- Percentage uncertainty is defined by the equation:

$$\text{Percentage uncertainty} = \frac{uncertainty}{measured\ value} \times 100\ \%$$

- To find uncertainties in different situations:
- **The uncertainty in a reading:** ± half the smallest division
- **The uncertainty in a measurement:** at least ±1 smallest division
- **The uncertainty in repeated data:** half the range i.e. ± ½ (largest - smallest value)
- **The uncertainty in digital readings:** ± the last significant digit unless otherwise quoted




*How to calculate absolute, fractional and percentage uncertainty*

- Always make sure your absolute or percentage uncertainty is, at a maximum, to the same number of **significant figures** as the reading
- Absolute uncertainties are compounded when **adding** or **subtracting** data

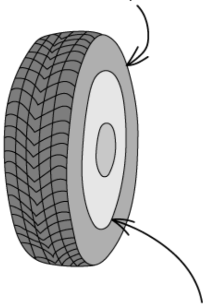
## Adding / Subtracting Data

- **Add** together the absolute uncertainties

Your notes

ADDING / SUBTRACTING DATA

DIAMETER OF TYRE ($d_1$) = 55.0 ± 0.5 cm



DIAMETER OF INNER TYRE ($d_2$) = 21.0 ± 0.7 cm

DIFFERENCE IN DIAMETERS ($d_1 - d_2$) = 55.0 − 21.0 = 34.0 cm

UNCERTAINTY IN DIFFERENCE = ±(0.5 + 0.7) = ± 1.2 cm

$d_1 - d_2$ = 34.0 ± 1.2 cm

## Examiner Tips and Tricks

Remember:

- Absolute uncertainties have the same units as the quantity
- The uncertainty in numbers and constants, such as π, is taken to be zero

In Edexcel International A level, the uncertainty should be stated to at least one few significant figures than the data but no more than the significant figures of the data.

For example, the uncertainty of a value of 12.0 which is calculated to be 1.204 can be stated as 12.0 ± 1.2 or 12.0 ± 1.20.

Your notes

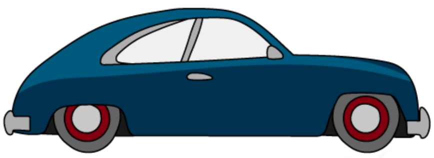
# Percentage Uncertainties

- Percentage uncertainties are compounded when **multiplying** or **dividing** data

## Multiplying / Dividing Data

- **Add** the percentage or fractional uncertainties

MULTIPLYING / DIVIDING DATA



DISTANCE = 50.0 ± 0.1 m

TIME = 5.00 ± 0.05 s

$$\text{SPEED (v)} = \frac{\text{DISTANCE (s)}}{\text{TIME (t)}}$$

$$V = \frac{50.0}{5.0} = 10.0\ \text{ms}^{-1}$$

$$\frac{\Delta v}{v} = \frac{\Delta s}{s} + \frac{\Delta t}{t} = \frac{0.1}{50.0} + \frac{0.05}{5.00} = 0.002 + 0.01 = 0.012$$

ABSOLUTE UNCERTAINTY $(\Delta v) = 10.0 \times 0.012 = \pm 0.12\ \text{ms}^{-1}$

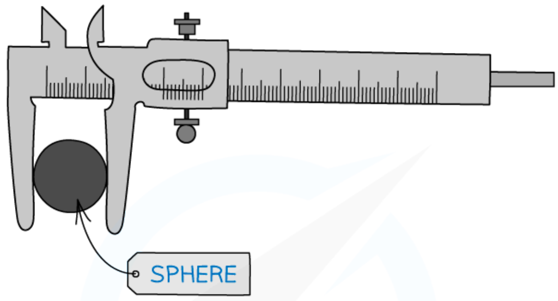
$v = 10.0 \pm 0.12\ \text{ms}^{-1}$



## Raising to a Power

- **Multiply** the percentage uncertainty by the power

RAISING TO A POWER




$$V = \frac{4}{3}\pi r^3$$

$$r = 2.50 \pm 0.02 \text{ cm}$$

$$V = \frac{4}{3}\pi (2.50)^3 = 65.5 \text{ cm}^3$$

$$\frac{\Delta V}{V} = 3 \times \frac{\Delta r}{r} = 3 \times \frac{0.02}{2.50} = 0.024$$

ABSOLUTELY UNCERTAINTY $(\Delta V) = 65.5 \times 0.024 = 1.57 \text{cm}^3$

PERCENTAGE UNCERTAINTY $(\% \Delta V) = 100 \times 0.024 = 2.4\%$



### Examiner Tips and Tricks

Remember:

- Percentage uncertainties have **no** units
- The uncertainty in numbers and constants, such as π, is taken to be zero

In Edexcel International A level, the uncertainty should be stated to at least one few significant figures than the data but no more than the significant figures of the data.

For example, the uncertainty of a value of 12.0 which is calculated to be 1.204 can be stated as 12.0 ± 1.2 or 12.0 ± 1.20.

# Single & Multiple Readings

## Single Reading

- Percentage uncertainty for a single reading (measured value) is defined by the equation:

$$\textbf{Percentage uncertainty} = \frac{uncertainty}{measured\ value} \times 100\ \%$$

- The (absolute) uncertainty in a single reading is **half** the resolution of the instrument

## Multiple Readings

- The percentage uncertainty in measurements from **multiple** readings (e.g. repeat readings) use **half** the **range** of the readings
  - The range of the readings is the **difference** between the highest and lowest reading

### Worked Example

A student achieves the following results in their experiment for the angular frequency, $\omega$.

0.154, 0.153, 0.159, 0.147, 0.152

Calculate the percentage uncertainty in the mean value of $\omega$.

**Answer:**

**Step 1: Calculate the mean value**

$$\text{mean } \omega = \frac{0.154 + 0.153 + 0.159 + 0.147 + 0.152}{5} = 0.153 \text{ rad s}^{-1}$$

**Step 2: Calculate half the range (this is the uncertainty for multiple readings)**

$$\frac{1}{2} \times (0.159 - 0.147) = 0.006 \text{ rad s}^{-1a}$$

**Step 3: Calculate percentage uncertainty**

$$\frac{uncertainty}{measured\ value} \times 100\,\% = \frac{\pm half\ the\ range}{mean} \times 100\,\%$$

$$\frac{0.006}{0.153} \times 100\,\% = 3.92\,\%$$

### Examiner Tips and Tricks

Remember that percentage uncertainties have **no** units, only the % sign! Always make sure your percentage uncertainty is at least one **significant figures** smaller than the measurement.

Your notes