1.1 Practical Skills: Written Assessment

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1.1.1 EXPERIMENTAL DESIGN

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Experimental Design

- Planning is an essential part of experimental biology
- **Preliminary research** can be very helpful when trying to design an experiment to investigate a particular theory or hypothesis
    - Preliminary means "to come before"
- Researching other **similar studies** or experiments can help you with:
    - Choosing the appropriate apparatus
    - Using the correct techniques
    - Identifying variables
    - Controlling other variables
    - Recording and collecting data accurately
    - Processing and presenting data in a useful way
- The **choice** of apparatus and techniques should be **based on the science** surrounding the issue being investigated
- For example, when testing the effect of different pH levels on enzyme activity is crucial that you know:
    - How to quantify/measure enzyme activity accurately
    - What other conditions (variables) will affect the function of an enzyme
    - For example, if the temperature becomes too high all the enzymes will denature and the enzyme activity will be 0 (no matter what the pH level is)
- Once the preliminary research has been completed then **preliminary studies** can be conducted to further aid the experimental design
- These studies are very important for:
    - Identifying additional variables that affect the experiment
    - Finding the best way to control these variables
    - Deciding on the quantities and volumes of substances that are needed so that you do not run out of reactants/reagents
- Any experiment conducted without preliminary research or studies is likely to be invalid as the other variables that affect the results in the experiment will not have been identified and controlled

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1.1.2 IDENTIFICATION OF VARIABLES

Identification of Variables

Types of variables

- In an experiment, a variable is any factor that could change or be changed
- There are different types of variables within an experiment
  - The **independent variable**: the only variable that should be changed throughout an experiment
  - The **controlled/confounding variables**: any other variables that may affect the results of the experiment that need to be controlled or monitored
  - The **dependent variable**: the variable that is measured to determine the outcome of an experiment (the results)
- It is essential that any variable that may affect the outcome of an experiment is controlled in order for the results to be **valid**
- Preliminary research and preliminary studies can be used to identify variables within an experiment and to determine ways of controlling these variables effectively
- The science surrounding the issue/problem being investigated is likely to contain information about different factors or variables that may exist

Example of the science surrounding enzyme rate experiments

- **Enzyme rate experiments** are experiments that are carried out to determine the **effect** of **changing** a particular **factor** on the **rate of a reaction** that is catalysed by an enzyme
- Factors that can be **changed** include:
  - Temperature
  - pH
  - Enzyme concentration
  - Substrate concentration
- The **key** thing with enzyme rate experiments is to ensure that **only one** of these variables is **changed** during a particular experiment
  - This is known as the **independent** variable
- All other variables must be **controlled** (they must stay the **same**)
  - These are known as the **control** variables
- For example, if investigating the effect of **temperature** on the rate of reaction, the **pH**, **enzyme concentration** and **substrate concentration** must be exactly the same (kept constant) each time you run the experiment (at each different temperature you are investigating)
- If these control variables are not kept constant, they could **affect the results** of the experiment
  - This would make the results **unreliable**

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1.1.3 EVALUATING EXPERIMENTAL METHODS

Evaluating Experimental Methods

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- Evaluating experimental methods is an important skill for a scientist
- A good way to evaluate an experimental design is by **repeating the experiment yourself** (using the instructions provided) and determining if you can produce **similar results**
- When analysing and criticising the design of an experiment there are several key things to look out for:
  - **Limitations**
  - **Accuracy**
  - **Precision**
  - **Reliability**
  - **Validity**
- Limitations:
  - A limitation is any **design flaw or fault** that affects the accuracy of the experiment
  - It is crucial that any limitations within an experiment are **identified and removed/corrected**
  - For example, an experiment using a potometer to measure the rate of water uptake in different plant species had a small leak in the system
  - The leak in the apparatus is a limitation as it prevents the accurate measurement of water uptake
  - It can be corrected by ensuring that all fixtures are tightly screwed together or sealed using tape/wax etc
- Accuracy:
  - Accuracy – how **close** a reading/measurement is to its **true value**
  - Faulty instruments or flaws in the experimental method produce systematic errors that are repeated consistently every time the instrument is used or the method is followed. This affects the **accuracy** of all readings obtained
- Precision:
  - Precision – how **similar repeat readings/measurements are to each other**
  - Readings that are tightly clustered together (a small range) are described as precise
  - 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
- Reliability
  - Experiments are repeated many times to ensure the reliability of results
- Validity
  - The other variables in the experiment are identified and controlled in order to ensure the validity of an experiment
- Ideally, the design of an experiment should be **evaluated at the preliminary stage**, this way any corrections or adjustments can be made prior to conducting the actual experiment

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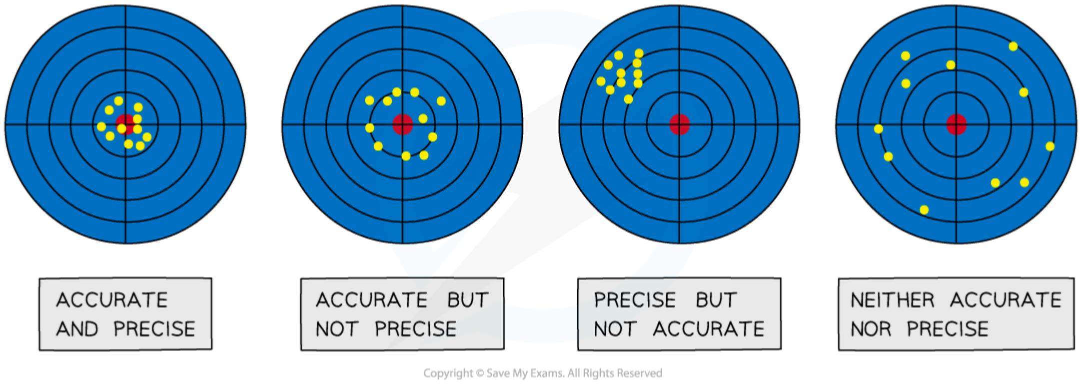

The difference between accuracy and precision explained using a dartboard as a metaphor

Instructions

- Scientists always record instructions for their experiments so that they can be repeated
- The instructions should allow an individual to successfully carry out the experiment **without any additional help** or input
- It is very important to **record all required details** within these instructions
- For example:
    - The apparatus used
    - The quantities of specific reactants/reagents used
    - The species of model organism used

Exam Tip

It is a very common mistake 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.

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1.1.4 USING UNITS

Using Appropriate Units

- It essential that the correct scientific measurements are used when discussing biological experiments
- 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 0.01 m = 1 cm 0.001 m = 1 mm 0.000001 m = 1μm
Volume	Cubic metre	m^3	$10^9 m^3 = 1 km^3$ $0.000001 m^3 = 1 cm^3$ $10^{-9} m^3 = 1 mm^3$ $10^{-18} m^3 = 1 \mu m^3$
Volume	Cubic decimetre	dm^3	$0.001 dm^3 = 1 cm^3$ $0.000001 dm^3 = 1 \mu mm^3$
Area	Square metre	m^2	$10000 m^2 = 1 ha$ $0.0001 m^2 = 1 cm^2$
Mass	Kilogram	kg	1000 kg = 1 tonne 0.001 kg = 1 g 0.000001 kg = 1 mg 10^{-9} kg = 1μg
Time	Second	s	60 s = 1 min 60 min = 1 hour
Pressure	pascal	Pa	1000 Pa = 1 kPa
Energy	joule	J	1000 J = 1 kJ 1000000 J = 1 MJ
Temperature	degrees Celsius	°C	
Amount of substance	mole	mol	0.001 mol = 1 millimole

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

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Exam Tip

Be careful when using the word “amount” in your answers. “Amount” has a very specific meaning in science – “mole”. Instead refer to the mass, volume or concentration of a substance!

Significant Figures

- Significant figures must be used when dealing with quantitative data
- Significant figures are the digits in a number that are **reliable and absolutely necessary** to indicate the quantity of that number
- There are some important **rules** to remember for significant figures
  - All non-zero digits are significant
  - Zeros between non-zero digits are significant
    - 4107 (4.s.f.)
    - 29.009 (5.s.f)
  - Zeros that come before all non-zero digits are not significant
    - 0.00079 (2.s.f.)
    - 0.48 (2.s.f.)
  - Zeros after non-zero digits within a number without decimals are not significant
    - 57,000 (2.s.f)
    - 640 (2.s.f)
  - Zeros after non-zero digits within a number with decimals are significant
    - 689.0023 (7.s.f)
- When rounding to a certain number of significant figures:
  - Identify the significant figures within the number using the rules above
  - Count from the first significant figure to the specified number
  - Use the next number as the ‘rounder decider’
  - If the decider is 5 or greater, increase the previous value by 1

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Worked Example

Write 1.0478 to 3 significant figures.

Step 1: Identify the significant figures

They are all significant figures

Step 2: Count to the specified number (3rd s.f.)

1.0**4**78

Step 3: Round up or down

1.05

Exam Tip

An exam question may sometimes specify how many significant figures the answer should be, make sure you keep an eye out for this!

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1.1.5 PRESENTING EXPERIMENTAL DATA

Presenting Experimental Data

- There are many different types of experiments that can be conducted in biology
- The data collected from biological experiments can vary greatly across the subject
    - For example, the large amounts of numerical data produced from ecological studies is very different to the drawings produced from microscope slides of live specimens
- The nature of an experiment dictates how the data should be presented
    - It is important that scientists can make the correct judgment when deciding how to present data from an experiment

Collecting data

- **Qualitative** experiments involve collecting and recording **observations**
- **Quantitative** experiments involve collecting and recording **numerical data**
- Recording experimental data in a table is important for any type of experiment
    - The table used will vary considerably depending on the specific requirements
- When constructing such a table:
    - Draw lines with a ruler to separate cells
    - Use appropriate headings
    - Use the correct units and symbols (in the headings, not the cells)
    - The independent variable should be in the first column
    - Any dependent variable readings should be in the subsequent columns

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Species	Number of individuals (n)
Northern brown argus butterfly	7
Ladybird	34
Forester moth	6
Wasp	21
Grass spider	12
Bee	37
Hornet	7
Fly	19
Highland Midge	59

Examples of a table that has been correctly constructed for an experiment

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Processing data

- Depending on the type of experiment, data is processed using different methods (before being analysed)
    - Some data does not require any processing, like drawings from life
- Qualitative results can't be processed mathematically (there isn't any numerical data) but the **observations can be analysed**
    - The observations may be compared to a standard or other experimental work
- Quantitative results must be processed using **mathematical skills** prior to analysis
    - Simple calculations work out means and rates
    - Further calculations are done to obtain information surrounding means (standard deviation and standard error)
    - Statistical tests are performed to better understand the results (chi-squared and t-test etc.)
- In addition to these mathematical calculations, the data can be presented in **graphical form**
    - Graphs, bar charts, and histograms can be used to display quantitative data
    - The type of graphical format used depends on the data
        - For qualitative and discrete data, **bar charts** or **pie charts** are most suitable
        - For continuous data, **line graphs** or **scatter graphs** are most suitable
- Any graph drawn should have:
    - The appropriate scale with equal intervals
    - Labelled axes with the correct units
    - Straight lines drawn with a ruler

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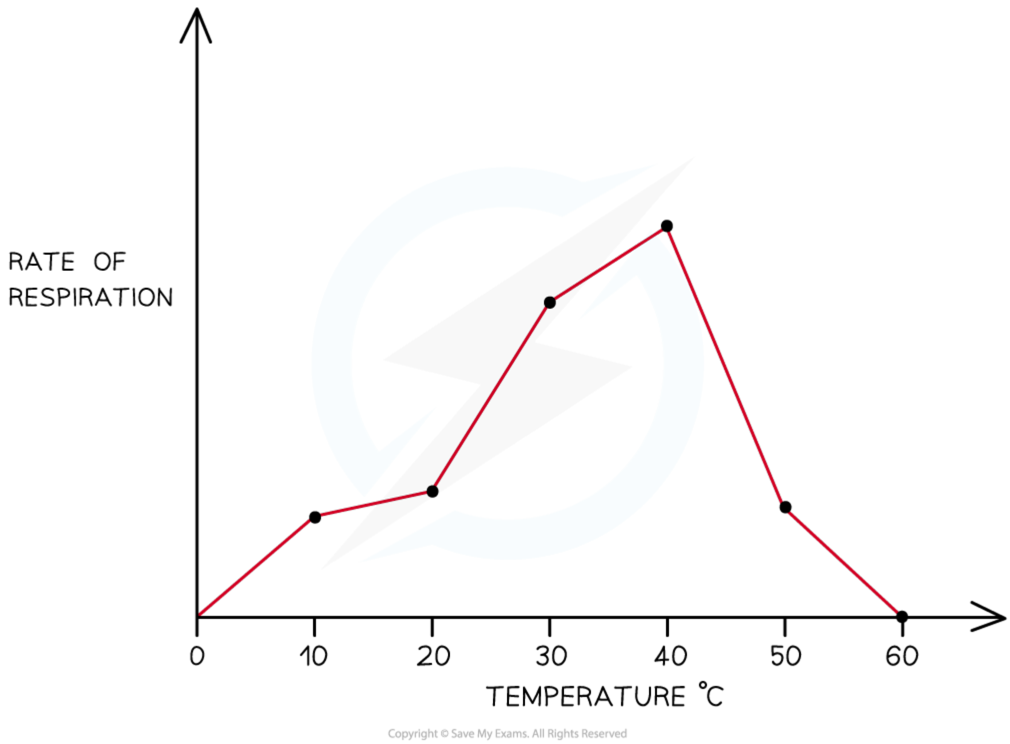

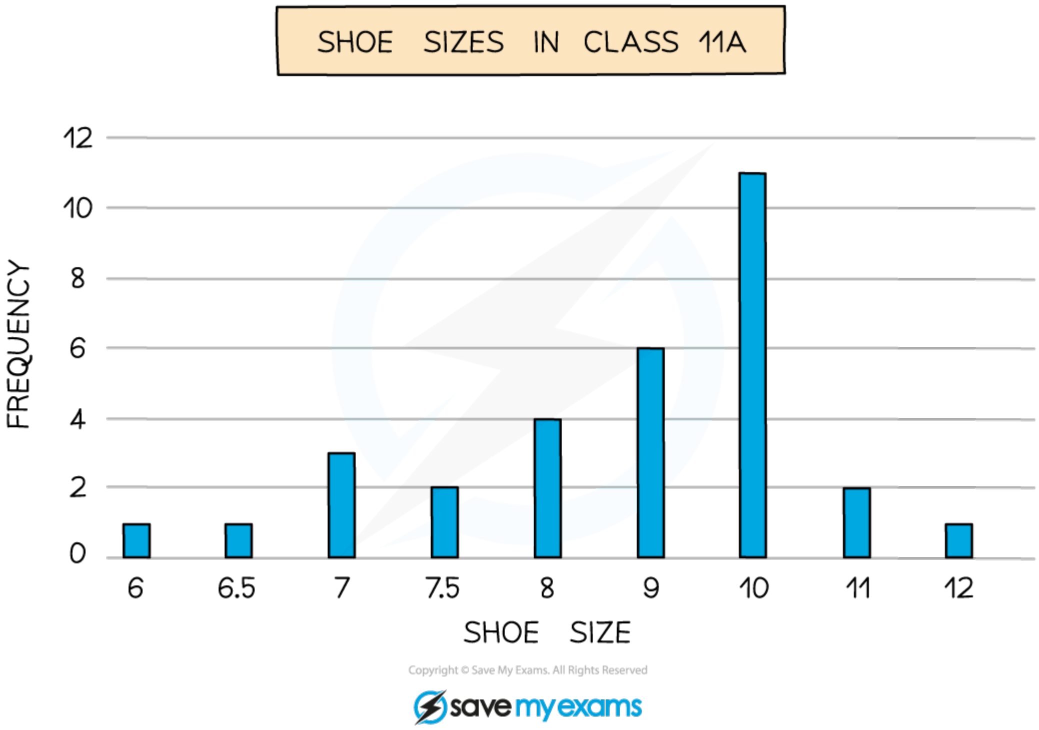

The line graph has been used to display continuous data over time while the bar chart has been used to display grouped data

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Precision & Accuracy

- The certainty of any conclusions made from an experiment are impacted by the precision and accuracy of measurements and data
- It is a very common mistake 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

Precision

- Precise measurements are ones in which there is very little spread about the mean value, in other words, how close the measured values are to each other
- If a measurement is repeated several times, it 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
- **Random errors** cause unpredictable fluctuations in an instrument's readings as a result of **uncontrollable factors,** such as environmental conditions
- This affects the **precision** of the measurements taken**,** causing a wider spread of results about the mean value
- To **reduce** random error:
  - **Repeat** measurements several times and calculate an average from them

Accuracy

- A measurement is considered accurate if it is close to the true value
- Systematic errors arise from the use of faulty instruments used or from flaws in the experimental method
- This type of error is repeated consistently every time the instrument is used or the method is followed, which affects the **accuracy** of all readings obtained
- To **reduce** systematic errors:
  - Instruments should be **recalibrated**, or different instruments should be used
  - Corrections or adjustments should be made to the technique

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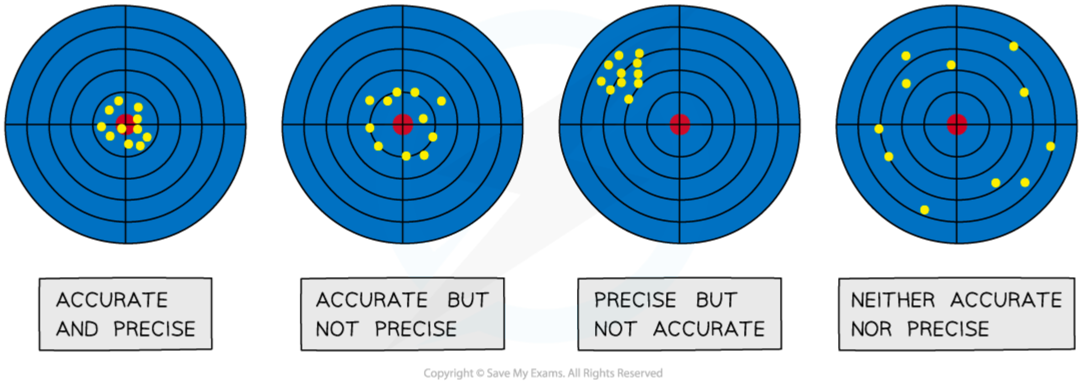

The difference between precise and accurate results

Uncertainty

- 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 as there will always be a degree of uncertainty
- **Uncertainty** is the amount of **error** your measurements might contain
- Results from experiments always contain some error (they are never perfect)
- There will always be a small degree of uncertainty in your readings or measurements
  - This is often because the **accuracy and precision** of the apparatus being used is **limited**
- The **margins of error** of the apparatus are usually displayed on the glassware
- These margins of error can be used to calculate percentage error
  - Percentage error helps to quantify the margin of error and its possible **impact on the results**
- For example, you may want to measure a **reaction rate** by measuring how much of a **product** is **made** in a **given time period** (e.g. using a gas syringe to measure the volume of oxygen produced from the breakdown of hydrogen peroxide by catalase)
  - The gas syringe may only give readings to the nearest **1 cm^3**
  - The gas syringe has a margin of error of **± 0.05 cm^3**
  - A '±' sign tells you the **range** in which the true value lies
  - The real volume produced could be up to 0.05 cm^3 **smaller** or **larger**
- For experiments, you may need to **calculate** the **percentage error** of your measurements
  - As long as you know the **uncertainty value** of your measurements, the percentage error can be calculated using the following formula:

percentage error = (uncertainty value ÷ your measurement) x 100

- A percentage error less than 5% is considered statistically not significant

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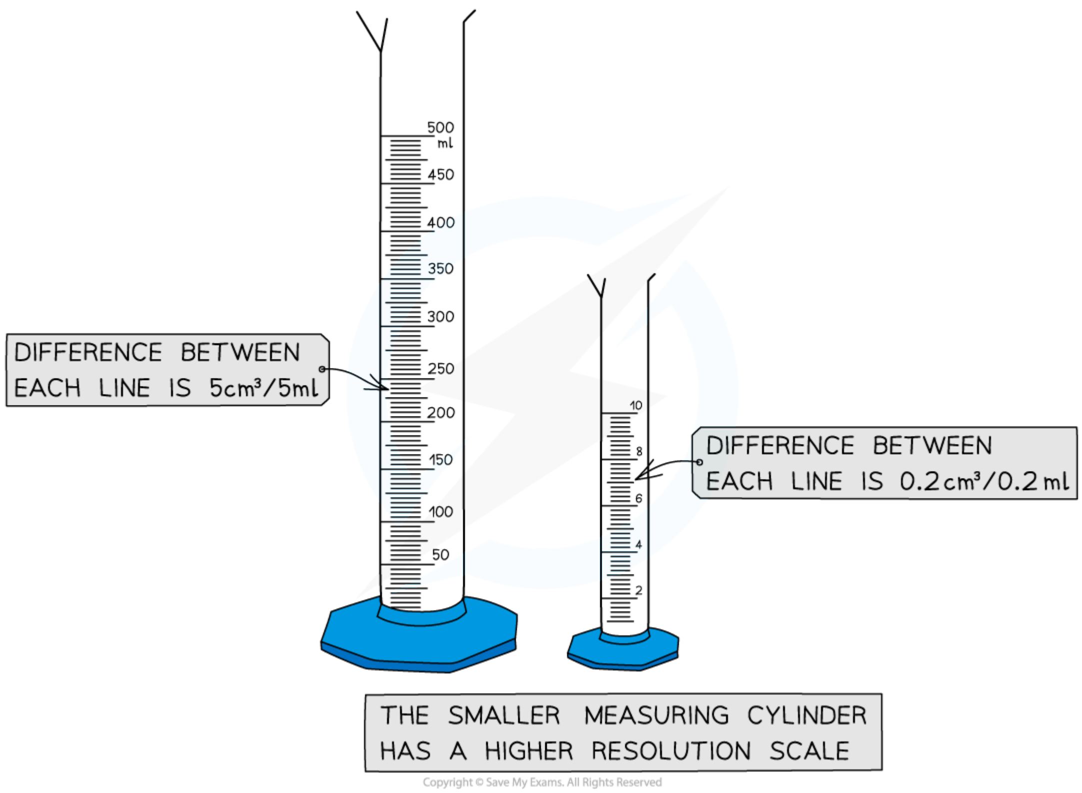
Choosing the apparatus with the right resolution

- Resolution is the smallest change in the quantity being measured of a measuring instrument that gives a perceptible change in the reading
- For example, the resolution of a wristwatch is 1 s, whereas the resolution of a digital stop-clock is typically 10 ms (0.01 s)
- In imaging, resolution can also be described as the ability to see two structures as two separate structures rather than as one fuzzy entity
- When choosing measuring instruments, instruments with an appropriate measuring scale need to be used
- Smaller measuring instruments have **higher resolution scales** due to the **smaller graduations** on the scale. This means they have **smaller margins of error**
- For example, measuring 5 cm^3 of a liquid using a 500 cm^3 measuring cylinder would be very difficult. A 10cm^3 measuring cylinder would be a more appropriate choice as the measuring scale is of a higher resolution



Smaller measuring instruments tend to have higher resolution measurements and a smaller margin of error. Make sure to always choose the appropriate instrument for the experiment

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Worked Example

In an enzyme rate reaction involving the breakdown of hydrogen peroxide by catalase, 50 cm^3 of oxygen was produced, with an uncertainty value of 0.05 cm^3. Calculate the percentage error of this measurement.

Percentage error = (uncertainty value ÷ your measurement) x 100

Percentage error = (0.05 ÷ 50) x 100

Percentage error = 0.001 x 100

Percentage error = 0.1%

Worked Example

In an enzyme rate experiment involving the breakdown of hydrogen peroxide by catalase, a student recorded that 10 cm^3 of oxygen was produced in 5.245 seconds. The student measured this using a stopwatch that counted in milliseconds. Calculate the percentage error of the stopwatch measurements.

Step 1: Calculate the uncertainty value

The stopwatch can measure to the nearest millisecond (**0.001** seconds)

This means the actual time taken could be up to **0.0005** seconds **shorter** or **longer** than this

This means stopwatch measurements have an uncertainty value of **± 0.0005 s**

Step 2: Calculate the percentage error of the student's measurement of 5.245 seconds

Percentage error = (uncertainty value ÷ your measurement) x 100

Percentage error = (0.0005 ÷ 5.245) x 100

Percentage error = 0.000095 x 100

Percentage error = 0.0095% or 0.01%

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Qualitative and Quantitative Results

- There are two types of experiment, which in turn obtain two kinds of results:
- **Qualitative experiments** are used to obtain **qualitative results**
  - **Observations** are recorded **without collecting numerical data**
  - For example, the starch test using iodine is a qualitative test – a colour change is recorded
  - Other common qualitative measurements include smells, tastes, textures, sounds and descriptions of the weather or of a particular habitat
- **Quantitative experiments** are used to obtain **quantitative results**
  - **Numerical data is collected and recorded**
  - For example, recording the percentage cover of a plant species using a quadrat – a numerical value (a percentage) is recorded
  - Other common quantitative measurements include temperature, pH, time, volume, length and mass
  - In order to collect numerical data, a quantitative experiment must use **apparatus** that measures or collects this type of data

Recording qualitative and quantitative results

- Qualitative results are most often recorded in the form of **words**, **short sentences** and **descriptions**, such as describing a colour change, making a note of someone's opinion, describing the appearance or behaviour of an organism, or describing a chemical reaction
- Quantitative results must all be recorded to the **same number of decimal places** but **processed data** can be recorded to the **same number** of decimal places **or to one more decimal place** than the **raw data**
  - For example, the mean of 11, 12 and 14 can be recorded as 12 or 12.3 but not 12.3333333

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Reaching valid conclusions from qualitative and quantitative results

- It could be argued that **qualitative results can be more subjective** (i.e. influenced by the person making the observations), but in fact, both types of results are subject to **bias** and **error**
    - Tools and systems for data gathering and recording are important for both
    - Care should be taken when making qualitative observations to keep them as **objective** as possible (i.e. not allowing observations to be influenced by the person making them)
- In terms of scientific research (and especially in biological experiments sometimes), one type of results is not necessarily better than the other
    - The value of qualitative and quantitative data depends on the thing being observed and the **purpose** of the experiment
    - Sometimes it's important and very useful to use **both**
    - In the example table below, both qualitative and quantitative observations have been recorded whilst observing a field of butterflies and both sets of observations can be useful in **drawing conclusions** (although as always, the validity of any conclusions drawn can be increased by **repeating** the experiments and gathering **more data**)

Qualitative and Quantitative Observations Table

Qualitative observations	Quantitative observations
Some butterflies are a single colour and others are multi-coloured or patterned	Butterflies landed on a single milkweed plant 15 times between 2PM and 2:20PM
Most butterflies fly close to the ground most of the time	At 10°C there is less movement among butterflies compared to 20°C
When the wind gusts many butterflies take flight	One specimen collected had a mass of 2.5 g and a wingspan of 5.3 cm
Some butterflies have antenna that are shaped like hooks	The mean time aloft for 50 butterflies observed was 28.4 seconds

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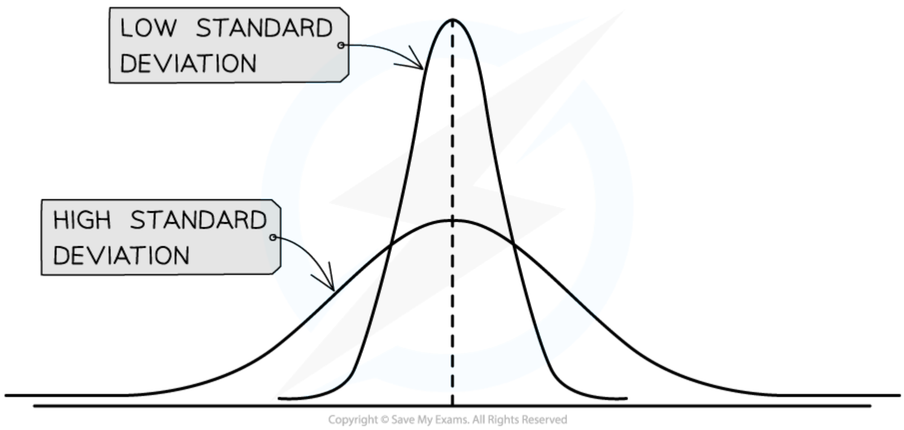
1.1.6 MATHEMATICAL ANALYSIS OF RESULTS

Mathematical Analysis of Results

- Quantitative investigations of variation can involve the interpretation of mean values and their standard deviations
- A **mean** value describes the average value of a data set
- **Standard deviation** is a measure of the spread or dispersion of data around the mean
- A **small** standard deviation indicates that the results lie **close to the mean** (less variation)
- **Large** standard deviation indicates that the results are **more spread out**



Two graphs showing the distribution of values when the mean is the same but one has a large standard deviation and the other a small standard deviation

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Comparison between groups

- When **comparing** the results from **different groups** or samples, using a measure of central tendency, such as the mean, can be quite misleading
- For example, looking at the two groups below
  - Group A: 2, 15, 14, 15, 16, 15, 14
  - Group B: 1, 3, 10, 15, 20, 22, 20
- Both groups have the same mean of 13
- However, most of the values in group A lie close to the mean, whereas in group B most values lie quite far from the mean
- For comparison between groups or samples it is better practice to use standard deviation in conjunction with the mean
- Whether or not the **standard deviations of different data sets overlap** can provide a lot of information:
  - If there is an **overlap** between the standard deviations then it can be said that the results are **not significantly different**
  - If there is **no overlap** between the standard deviations then it can be said that the results are **significantly different**

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Worked Example

A group of scientists wanted to investigate the effects of a specific diet on the risk of coronary heart disease. One group was given a specific diet for 8 weeks, while the other group acted as a control. After the 8 weeks scientists measured the diameter of the lumen of the main artery in the arm of the volunteers. The results of the experiment are shown in Table 1 below:

	Mean maximum diameter of lumen of main artery in the arm (mm)	
	Experimental group (± standard deviation)	Control group (± standard deviation)
Before experiment	0.69 (± 0.02)	0.71 (± 0.02)
After 8 weeks	0.74 (± 0.03)	0.72 (± 0.05)

Use the standard deviations above to evaluate whether the diet had a significant effect?

[2 marks]

Step one: find the full range of values included within the standard deviations for each data set

Experimental group before: 0.67 to 0.71mm
Experimental group after: 0.71 to 0.77mm

Control group before: 0.69 to 0.73mm
Control group after: 0.67 to 0.77mm

Step two: use this information to form your answer

There is an **overlap** of standard deviations in the experimental group before and after the experiment (0.67~0.71mm and 0.71~0.77mm) so it can be said that the difference before and after the experiment is **not significant**; [1 mark]

There is also an **overlap** of standard deviations between the experimental and control groups after the eight weeks (0.71~0.77mm and 0.67~0.77mm) so it can be said that the difference between groups is **not significant**; [1 mark]

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Exam Tip

The standard deviations of a data set are not always presented in a table, they can also be represented by standard deviation **error bars** on a graph.

Plotting & Interpreting Graphs

- Plotting data from investigations in the **appropriate format** allows you to more clearly see the **relationship** between two variables
- This makes the **results** of experiments much easier to **interpret**
- First, you need to consider what **type of data** you have:
    - **Qualitative** data (**non-numerical** data e.g. blood group)
    - **Discrete** data (**numerical** data that can only take **certain values** in a range e.g. shoe size)
    - **Continuous** data (**numerical** data that can take **any value** in a range e.g. height or weight)
- For qualitative and discrete data, **bar charts** or **pie charts** are most suitable
- For continuous data, **line graphs** or **scatter graphs** are most suitable
    - Scatter graphs are especially useful for showing how two variables are **correlated** (related to one another)

Tips for plotting data

- Whatever type of graph you use, remember the following:
    - The data should be plotted with the **independent** variable on the **x-axis** and the **dependent** variable on the **y-axis**
    - Plot data points **accurately**
    - Use **appropriate** linear **scales** on axes
    - Choose scales that enable **all** data points to be plotted **within** the **graph area**
    - **Label axes**, with **units** included
    - Make graphs that **fill the space** the exam paper gives you
    - Draw a **line of best fit**. This may be **straight** or **curved** depending on the **trend** shown by the data. If the line of best fit is a curve make sure it is drawn **smoothly**. A line of best-fit should have a **balance of data points** above and below the line
    - In some cases, the line or curve of best fit should be drawn through the **origin** (but only if the data and trend allow it)

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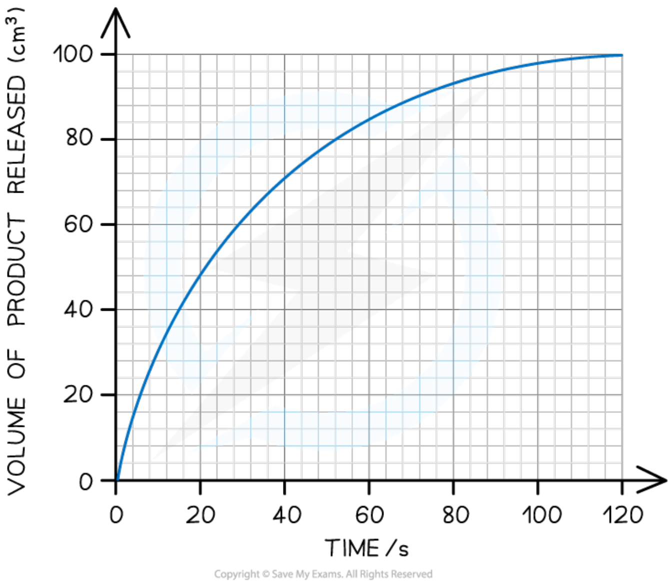
Using a tangent to find the initial rate of a reaction

- For linear graphs (i.e. graphs with a straight-line), the gradient is the same throughout
  - This makes it easy to calculate the rate of change (rate of change = change ÷ time)
- However, many **enzyme rate experiments** produce non-linear graphs (i.e. graphs with a **curved line**), meaning they have an **ever-changing gradient**
  - They are shaped this way because the **reaction rate** is **changing over time**
- In these cases, a **tangent** can be used to find the **reaction rate** at any **one point** on the graph:
  - A tangent is a **straight line** that is drawn so it just **touches** the curve at a **single point**
  - The **slope** of this tangent **matches** the slope of the **curve** at just that point
  - You then simply find the **gradient** of the straight line (tangent) you have drawn
- The **initial** rate of reaction is the rate of reaction at the **start** of the reaction (i.e. where **time = 0**)

Worked Example

The graph below shows the results of an enzyme rate reaction. Using this graph, calculate the initial rate of reaction.



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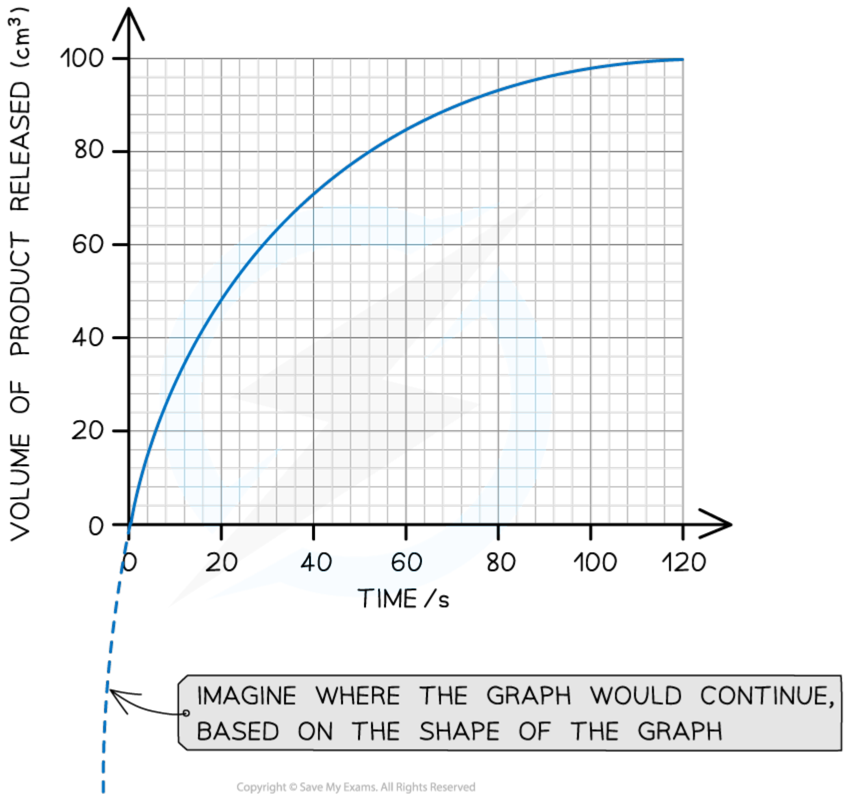
Step 1: Estimate the extrapolated curve of the graph



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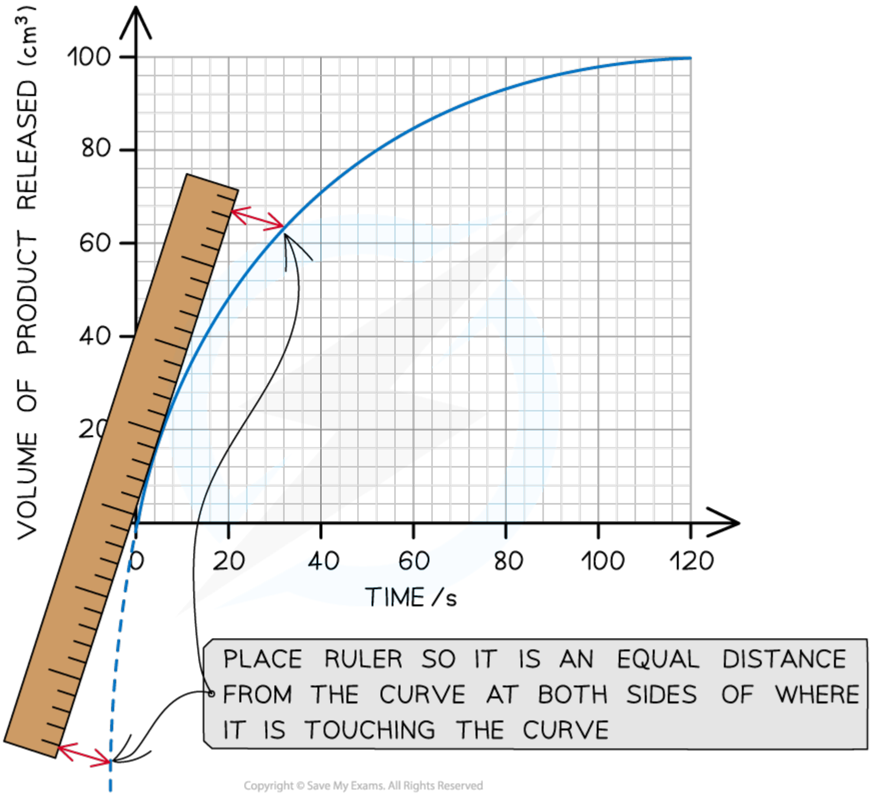
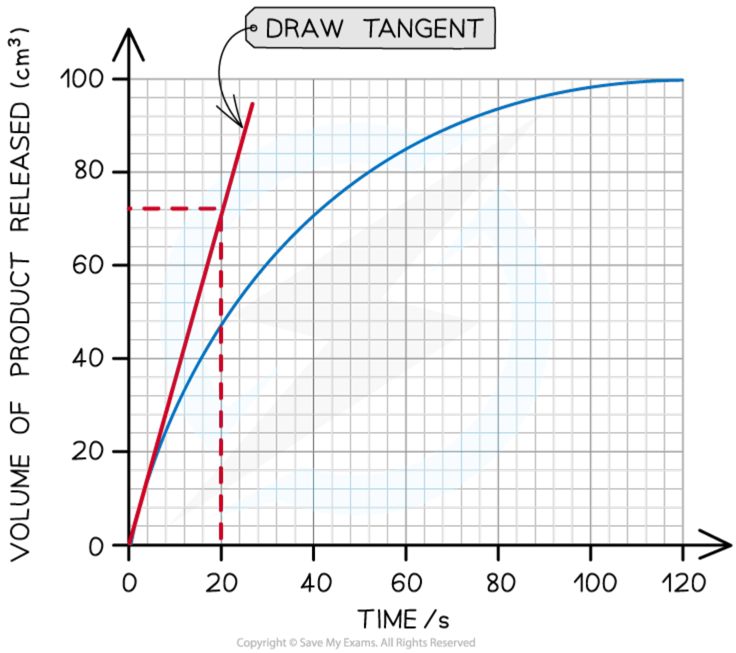
Step 2: Find the tangent to the curve at 0 seconds (the start of the reaction)





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The tangent drawn in the graph above shows that **72 cm^3** of product was produced in the first **20 seconds.**

Step 3: Calculate the gradient of the tangent (this will give you the **initial rate of reaction**):

Gradient = change in y-axis ÷ change in x-axis

Initial rate of reaction = 72 cm^3 ÷ 20 s

Initial rate of reaction = **3.6 cm^3 s^{-1}**

Exam Tip

When drawing tangents: always use a ruler and a pencil; make sure the line you draw is perfectly straight; choose the point where the tangent is to be taken and slowly line the ruler up to that point; try to place your ruler so that none of the line of the curve is covered by the ruler (it is much easier if the curve is entirely visible whilst the tangent is drawn). There is a handy phrase to help you remember how to calculate the gradient of a tangent or line. **Rise over run** means that any increase/decrease vertically should be divided by any increase/decrease horizontally.

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1.1.7 DRAWING CONCLUSIONS

Drawing Conclusions

- **Evaluating experimental results** and **drawing conclusions** from them are two very important skills
- Evaluation of **results** is a **different skill** from evaluation of the experimental **procedure** used to obtain those results
- Conclusions can **only be drawn** from the results once they have been **properly evaluated**
  - For example, during the planning of an experiment, potential **limitations** of the experimental procedure will have been identified
  - Before drawing conclusions, the **impact** that these limitations could theoretically have had (or may actually have had) on the data collected should be evaluated
  - If this evaluation shows these potential impacts to be **negligible,** a **conclusion** can more likely be drawn from the results
  - If it is decided that the limitations could have had a **significant impact** on the data, then it is much harder to draw a conclusion and it should be recognised that any conclusions drawn have a greater chance of being **incorrect**

The importance of precision and accuracy in drawing conclusions

- The **precision** and **accuracy** of experimental apparatus used and measurements taken has an important impact on any conclusions made from the results of an experiment
- **The precision of a measurement:** this is how close the measured values are to each other; if measurements are 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**: this is how close a measured value is to the true value; the accuracy can be increased by repeating measurements and finding a mean average

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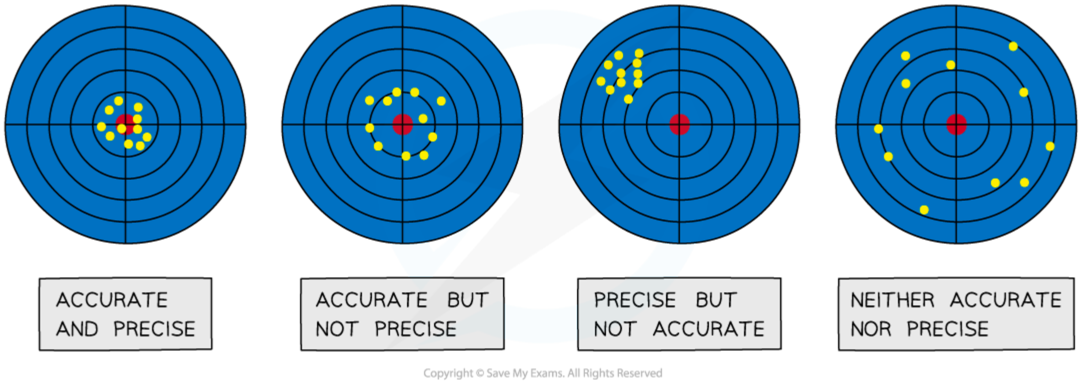

The difference between precise and accurate results

- Most items of apparatus will have a **margin of error** that can be used in **percentage error** calculations
- This percentage error will then give an idea of the magnitude of any error and therefore how much of an **impact** it may have had on the **results**
- If the percentage error is **too high**, any conclusions drawn may be **rejected** or **further testing may be required** by making improvements to the apparatus used or to the experimental procedure in order to reduce the percentage error

Anomalies

- **Experimental errors** (also known as operator errors or 'one off' errors) will **affect the results** of an experiment and can produce **anomalies**
    - These anomalies should be **identified** during the **evaluation of results** and before drawing conclusions
    - Anomalies can be identified by looking for results or data points on a graph that **don't fit with the trend** or with **other replicates** carried out during the experiment
    - These anomalous results will show a larger difference from the mean than the rest of the results (a result is often taken to be anomalous if it differs from the mean result by **more than 10%**)
- The results or 'data' collected from an experiment can be made **more reliable** if the experiment is repeated several times and **anomalies are removed**
    - This, in turn, allows **more valid conclusions to be drawn**

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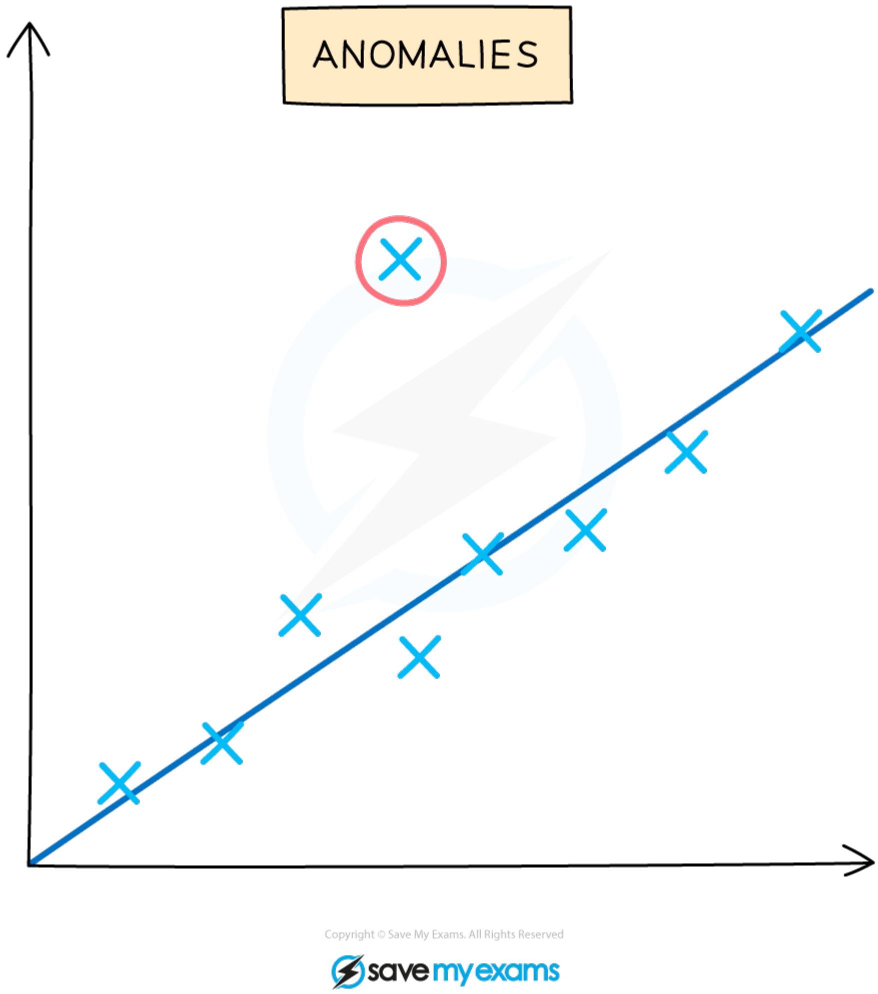

Identifying an anomalous result from a graph