The Scientific Method

This section isn't about how to 'do' science — but it does show you the way most scientists work.

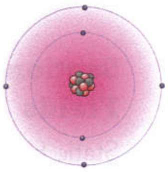
Scientists Come Up With Hypotheses — Then Test Them

1) Scientists try to explain things. They start by observing something they don't understand.
2) They then come up with a hypothesis — a possible explanation for what they've observed.
3) The next step is to test whether the hypothesis might be right or not. This involves making a prediction based on the hypothesis and testing it by gathering evidence (i.e. data) from investigations. If evidence from experiments backs up a prediction, you're a step closer to figuring out if the hypothesis is true.

About 100 years ago, scientists hypothesised that atoms looked like this.

Several Scientists Will Test a Hypothesis

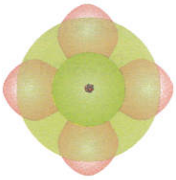
1) Normally, scientists share their findings in peer-reviewed journals, or at conferences.
2) Peer-review is where other scientists check results and scientific explanations to make sure they're 'scientific' (e.g. that experiments have been done in a sensible way) before they're published. It helps to detect false claims, but it doesn't mean that findings are correct — just that they're not wrong in any obvious way.
3) Once other scientists have found out about a hypothesis, they'll start basing their own predictions on it and carry out their own experiments. They'll also try to reproduce the original experiments to check the results — and if all the experiments in the world back up the hypothesis, then scientists start to think the hypothesis is true.
4) However, if a scientist does an experiment that doesn't fit with the hypothesis (and other scientists can reproduce the results) then the hypothesis may need to be modified or scrapped altogether.



After more evidence was gathered, scientists changed their hypothesis to this.

If All the Evidence Supports a Hypothesis, It's Accepted — For Now

1) Accepted hypotheses are often referred to as theories. Our currently accepted theories are the ones that have survived this 'trial by evidence' — they've been tested many times over the years and survived.
2) However, theories never become totally indisputable fact. If new evidence comes along that can't be explained using the existing theory, then the hypothesising and testing is likely to start all over again.



Now we think it's more like this.

Theories Can Involve Different Types of Models

1) A representational model is a simplified description or picture of what's going on in real life. Like all models, it can be used to explain observations and make predictions. E.g. the Bohr model of an atom is a simplified way of showing the arrangement of electrons in an atom (see p.49). It can be used to explain electron excitations in atoms.

Scientists test models by carrying out experiments to check that the predictions made by the model happen as expected.

2) Computational models use computers to make simulations of complex real-life processes, such as climate change. They're used when there are a lot of different variables (factors that change) to consider, and because you can easily change their design to take into account new data.
3) All models have limitations on what they can explain or predict. E.g. the Big Bang model (a model used to describe the beginning of the Universe) can be used to explain why everything in the Universe is moving away from us. One of its limitations is that it doesn't explain the moments before the Big Bang.

I'm off to the zoo to test my hippo-thesis...

The scientific method has developed over time, and many people have helped to develop it. From Aristotle to modern day scientists, lots of people have contributed. And many more are likely to contribute in the future.

Communication & Issues Created by Science

Scientific developments can be great, but they can sometimes raise more questions than they answer...

It's Important to Communicate Scientific Discoveries to the General Public

Some scientific discoveries show that people should change their habits, or they might provide ideas that could be developed into new technology. So scientists need to tell the world about their discoveries.

Radioactive materials are used widely in medicine for imaging and treatment (see p.56). Information about these materials needs to be communicated to doctors so they can make use of them, and to patients, so they can make informed decisions about their treatment.

Scientific Evidence can be Presented in a Biased Way

1) Reports about scientific discoveries in the media (e.g. newspapers or television) aren't peer-reviewed.
2) This means that, even though news stories are often based on data that has been peer-reviewed, the data might be presented in a way that is over-simplified or inaccurate, making it open to misinterpretation.
3) People who want to make a point can sometimes present data in a biased way. (Sometimes without knowing they're doing it.) For example, a scientist might overemphasise a relationship in the data, or a newspaper article might describe details of data supporting an idea without giving any evidence against it.

Scientific Developments are Great, but they can Raise Issues

Scientific knowledge is increased by doing experiments. And this knowledge leads to scientific developments, e.g. new technologies or new advice. These developments can create issues though. For example:

Economic issues: Society can't always afford to do things scientists recommend (e.g. investing in alternative energy sources) without cutting back elsewhere.

Personal issues: Some decisions will affect individuals. For example, someone might support alternative energy, but object if a wind farm is built next to their house.

Social issues: Decisions based on scientific evidence affect people — e.g. should fossil fuels be taxed more highly? Would the effect on people's lifestyles be acceptable...

Environmental issues: Human activity often affects the natural environment. For example, building a dam to produce electricity will change the local habitat so some species might be displaced. But it will also reduce our need for fossil fuels, so will help to reduce climate change.

Science Can't Answer Every Question — Especially Ethical Ones

1) We don't understand everything. We're always finding out more, but we'll never know all the answers.
2) In order to answer scientific questions, scientists need data to provide evidence for their hypotheses.
3) Some questions can't be answered yet because the data can't currently be collected, or because there's not enough data to support a theory.
4) Eventually, as we get more evidence, we'll answer some of the questions that currently can't be answered, e.g. what the impact of global warming on sea levels will be. But there will always be the "Should we be doing this at all?"-type questions that experiments can't help us to answer...

Think about new drugs which can be taken to boost your 'brain power'.

- Some people think they're good as they could improve concentration or memory. New drugs could let people think in ways beyond the powers of normal brains.
- Other people say they're bad — they could give you an unfair advantage in exams. And people might be pressured into taking them so that they could work more effectively, and for longer hours.

Tea to milk or milk to tea? — Totally unanswerable by science...

Science can't tell you whether or not you should do something. That's for you and society to decide. But there are tons of questions science might be able to answer, like where life came from and where my superhero socks are.

Risk

By reading this page you are agreeing to the risk of a paper cut or severe drowsiness...

Nothing is Completely Risk-Free

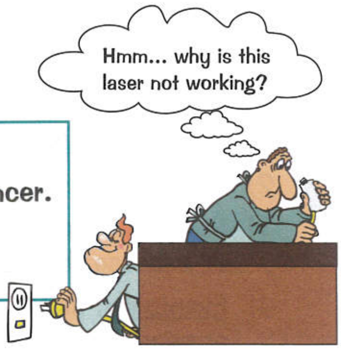
1) A hazard is something that could potentially cause harm.
2) All hazards have a risk attached to them — this is the chance that the hazard will cause harm.
3) The risks of some things seem pretty obvious, or we've known about them for a while, like the risk of causing acid rain by polluting the atmosphere, or of having a car accident when you're travelling in a car.
4) New technology arising from scientific advances can bring new risks, e.g. scientists are unsure whether nanoparticles that are being used in cosmetics and suncream might be harming the cells in our bodies. These risks need to be considered alongside the benefits of the technology, e.g. improved sun protection.
5) You can estimate the size of a risk based on how many times something happens in a big sample (e.g. 100 000 people) over a given period (e.g. a year). For example, you could assess the risk of a driver crashing by recording how many people in a group of 100 000 drivers crashed their cars over a year.
6) To make decisions about activities that involve hazards, we need to take into account the chance of the hazard causing harm, and how serious the consequences would be if it did. If an activity involves a hazard that's very likely to cause harm, with serious consequences if it does, it's considered high risk.

People Make Their Own Decisions About Risk

1) Not all risks have the same consequences, e.g. if you chop veg with a sharp knife you risk cutting your finger, but if you go scuba-diving you risk death. You're much more likely to cut your finger during half an hour of chopping than to die during half an hour of scuba-diving. But most people are happier to accept a higher probability of an accident if the consequences are short-lived and fairly minor.
2) People tend to be more willing to accept a risk if they choose to do something (e.g. go scuba diving), compared to having the risk imposed on them (e.g. having a nuclear power station built next door).
3) People's perception of risk (how risky they think something is) isn't always accurate. They tend to view familiar activities as low-risk and unfamiliar activities as high-risk — even if that's not the case. For example, cycling on roads is often high-risk, but many people are happy to do it because it's a familiar activity. Air travel is actually pretty safe, but a lot of people perceive it as high-risk.
4) People may over-estimate the risk of things with long-term or invisible effects, e.g. ionising radiation.

Investigations Can be Hazardous

1) Hazards from science experiments might include:
   - Lasers, e.g. if a laser is directed into the eye, this can cause blindness.
   - Gamma radiation, e.g. gamma-emitting radioactive sources can cause cancer.
   - Fire, e.g. an unattended Bunsen burner is a fire hazard.
   - Electricity, e.g. faulty electrical equipment could give you a shock.



2) Part of planning an investigation is making sure that it's safe.
3) You should always make sure that you identify all the hazards that you might encounter. Then you should think of ways of reducing the risks from the hazards you've identified. For example:
   - If you're working with springs, always wear safety goggles. This will reduce the risk of the spring hitting your eye if the spring snaps.
   - If you're using a Bunsen burner, stand it on a heat proof mat. This will reduce the risk of starting a fire.

You can find out about potential hazards by looking in textbooks, doing some internet research, or asking your teacher.

Not revising — an unacceptable exam hazard...

The world's a dangerous place, but if you can recognise hazards, decide how to reduce their risks, and be happy to accept some risks, you can still have fun. Just maybe don't go skydiving with a great white shark on Friday 13th.

Designing Investigations

Dig out your lab coat and dust down your badly-scratched safety goggles... it's investigation time.

Investigations Produce Evidence to Support or Disprove a Hypothesis

1) Scientists observe things and come up with hypotheses to explain them (see p.2). You need to be able to do the same. For example:

Observation: People with big feet have spots. Hypothesis: Having big feet causes spots.

2) To determine whether or not a hypothesis is right, you need to do an investigation to gather evidence. To do this, you need to use your hypothesis to make a prediction — something you think will happen that you can test. E.g. people who have bigger feet will have more spots.
3) Investigations are used to see if there are patterns or relationships between two variables, e.g. to see if there's a pattern or relationship between the variables 'number of spots' and 'size of feet'.

Evidence Needs to be Repeatable, Reproducible and Valid

Investigations include experiments and studies.

1) Repeatable means that if the same person does an experiment again using the same methods and equipment, they'll get similar results.
2) Reproducible means that if someone else does the experiment, or a different method or piece of equipment is used, the results will still be similar.
3) If data is repeatable and reproducible, it's reliable and scientists are more likely to have confidence in it.
4) Valid results are both repeatable and reproducible AND they answer the original question. They come from experiments that were designed to be a FAIR TEST...

To Make an Investigation a Fair Test You Have to Control the Variables

1) In a lab experiment you usually change one variable and measure how it affects another variable.
2) To make it a fair test, everything else that could affect the results should stay the same — otherwise you can't tell if the thing you're changing is causing the results or not.
3) The variable you CHANGE is called the INDEPENDENT variable.
4) The variable you MEASURE when you change the independent variable is the DEPENDENT variable.
5) The variables that you KEEP THE SAME are called CONTROL variables.

You could find how current through a circuit component affects the potential difference (p.d.) across the component by measuring the p.d. at different currents. The independent variable is the current. The dependent variable is the potential difference. Control variables include the temperature of the component, the p.d. of the power supply, etc.

6) Because you can't always control all the variables, you often need to use a control experiment. This is an experiment that's kept under the same conditions as the rest of the investigation, but doesn't have anything done to it. This is so that you can see what happens when you don't change anything at all.

The Bigger the Sample Size the Better

1) Data based on small samples isn't as good as data based on large samples. A sample should represent the whole population (i.e. it should share as many of the characteristics in the population as possible) — a small sample can't do that as well. It's also harder to spot anomalies if your sample size is too small.
2) The bigger the sample size the better, but scientists have to be realistic when choosing how big. For example, if you were studying the effects of living near a nuclear power plant, it'd be great to study everyone who lived near a nuclear power plant (a huge sample), but it'd take ages and cost a bomb. It's more realistic to study a thousand people, with a mixture of ages, gender, and race.

This is no high street survey — it's a designer investigation...

Not only do you need to be able to plan your own investigations, you should also be able to look at someone else's plan and decide whether or not it needs improving. Those examiners aren't half demanding.

Collecting Data

You've designed the perfect investigation — now it's time to get your hands mucky and collect some data.

Your Data Should be Repeatable, Reproducible, Accurate and Precise

1) To check repeatability you need to repeat the readings and check that the results are similar. You need to repeat each reading at least three times.
2) To make sure your results are reproducible you can cross check them by taking a second set of readings with another instrument (or a different observer).
3) Your data also needs to be ACCURATE. Really accurate results are those that are really close to the true answer. The accuracy of your results usually depends on your method — you need to make sure you're measuring the right thing and that you don't miss anything that should be included in the measurements. E.g. estimating the volume of an irregularly shaped solid by measuring the sides isn't very accurate because this will not take into account any gaps in the object. It's more accurate to measure the volume using a density bottle (see p.93).
4) Your data also needs to be PRECISE. Precise results are ones where the data is all really close to the mean (average) of your repeated results (i.e. not spread out).

Brian's result was a curate.

Repeat	Data set 1	Data set 2
1	12	11
2	14	17
3	13	14
Mean	13	14

Data set 1 is more precise than data set 2.

Your Equipment has to be Right for the Job

1) The measuring equipment you use has to be sensitive enough to measure the changes you're looking for. For example, if you need to measure changes of 1 cm^3 you need to use a measuring cylinder or burette that can measure in 1 cm^3 steps — it'd be no good trying with one that only measures 10 cm^3 steps.
2) The smallest change a measuring instrument can detect is called its RESOLUTION. E.g. some mass balances have a resolution of 1 g, some have a resolution of 0.1 g, and some are even more sensitive.
3) Also, equipment needs to be calibrated by measuring a known value. If there's a difference between the measured and known value, you can use this to correct the inaccuracy of the equipment.

You Need to Look out for Errors and Anomalous Results

1) The results of your experiment will always vary a bit because of RANDOM ERRORS — unpredictable differences caused by things like human errors in measuring. The errors when you make a reading from a ruler are random. You have to estimate or round the distance when it's between two marks — so sometimes your figure will be a bit above the real one, and sometimes it will be a bit below.
2) You can reduce the effect of random errors by taking repeat readings and finding the mean. This will make your results more precise.
3) If a measurement is wrong by the same amount every time, it's called a SYSTEMATIC ERROR. For example, if you measured from the very end of your ruler instead of from the 0 cm mark every time, all your measurements would be a bit small. Repeating your experiment in the exact same way and calculating a mean won't correct a systematic error.

If there's no systematic error, then doing repeats and calculating a mean can make your results more accurate.

4) Just to make things more complicated, if a systematic error is caused by using equipment that isn't zeroed properly, it's called a ZERO ERROR. For example, if a mass balance always reads 1 gram before you put anything on it, all your measurements will be 1 gram too heavy.
5) You can compensate for some systematic errors if you know about them though, e.g. if your mass balance always reads 1 gram before you put anything on it you can subtract 1 gram from all your results.
6) Sometimes you get a result that doesn't fit in with the rest at all. This is called an ANOMALOUS RESULT. You should investigate it and try to work out what happened. If you can work out what happened (e.g. you measured something totally wrong) you can ignore it when processing your results.

Watch what you say to that mass balance — it's very sensitive...

Weirdly, data can be really precise but not very accurate. For example, a fancy piece of lab equipment might give results that are really precise, but if it's not been calibrated properly those results won't be accurate.

Processing and Presenting Data

Processing your data means doing some calculations with it to make it more useful. Once you've done that, you can present your results in a nice chart or graph to help you spot any patterns in your data.

Data Needs to be Organised

1) Tables are dead useful for organising data.
2) When you draw a table use a ruler and make sure each column has a heading (including the units).

You Might Have to Process Your Data

1) When you've done repeats of an experiment you should always calculate the mean (average). To do this add together all the data values and divide by the total number of values in the sample.
2) You can also find the mode of your results — this is the value that occurs the most in your set of results.
3) The median can be found by writing your results in numerical order — the median is the middle number.

Ignore anomalous results when calculating the mean, mode and median.

EXAMPLE: The results of an experiment show the extension of spring A when a force is applied to it. Calculate the mean, mode and median of the extension for the spring.

Spring	Repeat (cm)					Mean (cm)	Mode (cm)	Median (cm)
	1	2	3	4	5			
A	18	26	22	26	28	(18 + 26 + 22 + 26 + 28) ÷ 5 = 24	26	26

Round to the Lowest Number of Significant Figures

The first significant figure of a number is the first digit that's not zero. The second and third significant figures come straight after (even if they're zeros). You should be aware of significant figures in calculations.

1) In any calculation, you should round the answer to the lowest number of significant figures (s.f.) given.
2) Remember to write down how many significant figures you've rounded to after your answer.
3) If your calculation has multiple steps, only round the final answer, or it won't be as accurate.

EXAMPLE: The mass of a solid is 0.24 g and its volume is 0.715 cm³. Calculate the density of the solid.

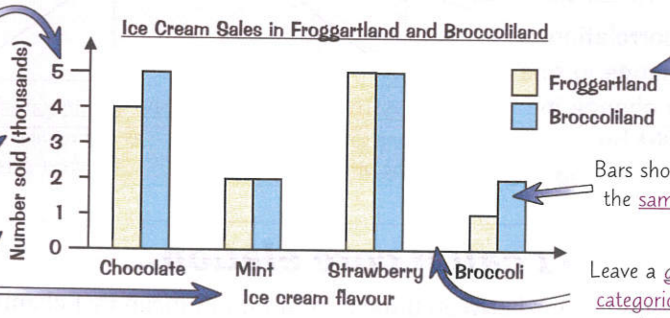
$$\text{Density} = \underbrace{0.24\text{ g}}_{2\text{ s.f.}} \div \underbrace{0.715\text{ cm}^3}_{3\text{ s.f.}} = 0.33566... = 0.34\text{ g/cm}^3\ (2\text{ s.f.})$$

Final answer should be rounded to 2 s.f.

If Your Data Comes in Categories, Present It in a Bar Chart

1) If the independent variable is categoric (comes in distinct categories, e.g. solid, liquid, gas) you should use a bar chart to display the data.
2) You also use them if the independent variable is discrete (the data can be counted in chunks, where there's no in-between value, e.g. number of protons is discrete because you can't have half a proton).
3) You can also plot continuous data (see page 8).

There are some golden rules you need to follow for drawing bar charts:



The scale needs to be linear (there should be equal values for each division).

Remember to include the units.

Label both axes.

If you've got more than one set of data include a key.

Draw it nice and big (covering at least two thirds of the graph paper).

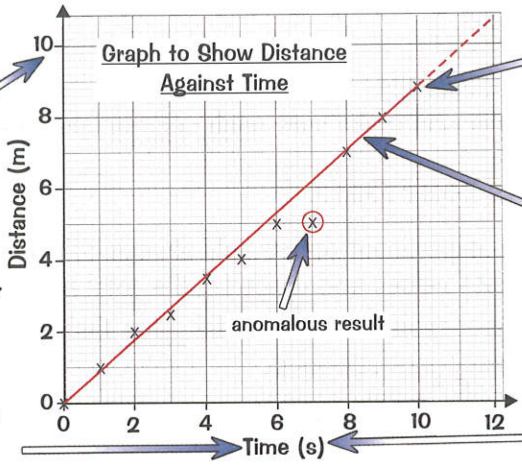
Bars should all be the same width.

Leave a gap between different categories for categoric or discrete data. For continuous data, the bars should be touching.

Graphs can be Used to Plot Continuous Data

If both variables are continuous (numerical data that can have any value within a range, e.g. length, volume, temperature) you can use a graph to display the data.

Here are the rules for plotting points on a graph:

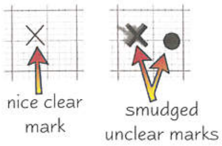


Use the biggest data values you've got to draw a sensible scale on your axes. Here, the longest distance is 8.8 m, so it makes sense to label the y-axis up to 10 m.

The dependent variable goes on the y-axis (the vertical one).

The independent variable goes on the x-axis (the horizontal one).

To plot points, use a sharp pencil and make neat little crosses (don't do blobs).



If you're asked to draw a line (or curve) of best fit, draw a line through or as near to as many points as possible, ignoring any anomalous results. Don't join the crosses up.

Draw it nice and big (covering at least two thirds of the graph paper).

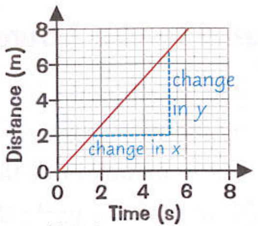
Remember to include the units.

Graphs Can Give You a Lot of Information About Your Data

1) The gradient (slope) of a graph tells you how quickly the dependent variable changes if you change the independent variable.

$$\text{gradient} = \frac{\text{change in } y}{\text{change in } x}$$

This graph shows the distance travelled by a vehicle against time. The graph is linear (it's a straight line graph), so you can simply calculate the gradient of the line to find out the speed of the vehicle.



1) To calculate the gradient, pick two points on the line that are easy to read and a good distance apart.
2) Draw a line down from one of the points and a line across from the other to make a triangle. The line drawn down the side of the triangle is the change in y and the line across the bottom is the change in x.

Change in $y = 6.8 - 2.0 = 4.8$ m Change in $x = 5.2 - 1.6 = 3.6$ s

$$\text{Rate} = \text{gradient} = \frac{\text{change in } y}{\text{change in } x} = \frac{4.8\text{ m}}{3.6\text{ s}} = 1.3\text{ m/s}$$

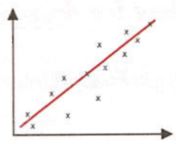
The units of the gradient are (units of y)/(units of x).

You can use this method to calculate other rates from a graph, not just the rate of change of distance (which is speed). Just remember that a rate is how much something changes over time, so x needs to be the time.

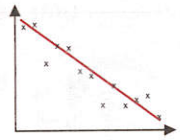
2) To find the gradient of a curve at a certain point, draw a tangent to the curve at that point and then find the gradient of the tangent. See page 14 for details on how to do this.
3) The intercept of a graph is where the line of best fit crosses one of the axes. The x-intercept is where the line of best fit crosses the x-axis and the y-intercept is where it crosses the y-axis.

Graphs Show the Relationship Between Two Variables

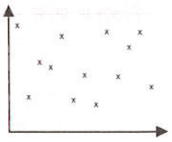
1) You can get three types of correlation (relationship) between variables:
2) Just because there's correlation, it doesn't mean the change in one variable is causing the change in the other — there might be other factors involved (see page 10).



POSITIVE correlation: as one variable increases the other increases.



INVERSE (negative) correlation: as one variable increases the other decreases.



NO correlation: no relationship between the two variables.

I love eating apples — I call it core elation...

Science is all about finding relationships between things. And I don't mean that chemists gather together in corners to discuss whether or not Devini and Sebastian might be a couple... though they probably do that too.

Units and Equations

Graphs and maths skills are all very well, but the numbers don't mean much if you can't get the units right.

S.I. Units Are Used All Round the World

1) It wouldn't be all that useful if I defined volume in terms of bath tubs, you defined it in terms of egg-cups and my pal Sarwat defined it in terms of balloons — we'd never be able to compare our data.
2) To stop this happening, scientists have come up with a set of standard units, called S.I. units, that all scientists use to measure their data. Here are some S.I. units you'll see in physics:

Quantity	S.I. Base Unit
mass	kilogram, kg
length	metre, m
time	second, s
temperature	kelvin, K

Scaling Prefixes Can Be Used for Large and Small Quantities

1) Quantities come in a huge range of sizes. For example, the volume of a swimming pool might be around 2 000 000 000 cm³, while the volume of a cup is around 250 cm³.
2) To make the size of numbers more manageable, larger or smaller units are used. These are the S.I. base unit (e.g. metres) with a prefix in front:

prefix	tera (T)	giga (G)	mega (M)	kilo (k)	deci (d)	centi (c)	milli (m)	micro (μ)	nano (n)
multiple of unit	10^{12}	10^9	1 000 000 (10^6)	1000	0.1	0.01	0.001	0.000001 (10^{-6})	10^{-9}

3) These prefixes tell you how much bigger or smaller a unit is than the base unit. So one kilometre is one thousand metres.
4) To swap from one unit to another, all you need to know is what number you have to divide or multiply by to get from the original unit to the new unit — this is called the conversion factor.
   - To go from a bigger unit (like m) to a smaller unit (like cm), you multiply by the conversion factor.
   - To go from a smaller unit (like g) to a bigger unit (like kg), you divide by the conversion factor.

The conversion factor is the number of times the smaller unit goes into the larger unit.

5) Here are some conversions that'll be useful for GCSE physics:

Mass can have units of kg and g.

$$\begin{tikzcd} kg \arrow[r, bend left, "\times 1000"] & g \arrow[l, bend left, "\div 1000"] \end{tikzcd}$$

Energy can have units of J and kJ.

$$\begin{tikzcd} kJ \arrow[r, bend left, "\times 1000"] & J \arrow[l, bend left, "\div 1000"] \end{tikzcd}$$

Volume can have units of m³ and cm³.

$$\begin{tikzcd} m^3 \arrow[r, bend left, "\times 1\,000\,000"] & cm^3 \arrow[l, bend left, "\div 1\,000\,000"] \end{tikzcd}$$

Density can have units of kg/m³ and g/cm³.

$$\begin{tikzcd} kg/m^3 \arrow[r, bend left, "\div 1000"] & g/cm^3 \arrow[l, bend left, "\times 1000"] \end{tikzcd}$$

6) Numbers can also be written in standard form, e.g. 1×10^2 m = 100 m. Make sure you know how to work with standard form on your calculator.

Always Check The Values in Equations and Formulas Have the Right Units

1) Equations show relationships between variables.
2) To rearrange an equation — whatever you do to one side of the equation also do to the other.

wave speed = frequency × wavelength. You can rearrange this equation to find the frequency by dividing each side by wavelength to give: frequency = wave speed ÷ wavelength.

3) To use a formula, you need to know the values of all but one of the variables. Substitute the values you do know into the formula, and do the calculation to work out the final variable.
4) Always make sure the values you put into an equation or formula have the right units. For example, you might have done an experiment to find the speed of a trolley. The distance the trolley travels will probably have been measured in cm, but the equation to find speed uses distance in m. So you'll have to convert your distance from cm to m before you put it into the equation.
5) To make sure your units are correct, it can help to write down the units on each line of your calculation.

I wasn't sure I liked units, but now I'm converted...

It's easy to get in a muddle when converting between units, but there's a handy way to check you've done it right. If you're moving from a smaller unit to a larger unit (e.g. g to kg) the number should get smaller, and vice versa.

Drawing Conclusions

Congratulations — you're nearly at the end of a gruelling investigation, time to draw conclusions.

You Can Only Conclude What the Data Shows and NO MORE

1) Drawing conclusions might seem pretty straightforward — you just look at your data and say what pattern or relationship you see between the dependent and independent variables.

The table on the right shows the potential difference across a light bulb for three different currents through the bulb:

Current (A)	Potential difference (V)
6	4
9	10
12	13

CONCLUSION: A higher current through the bulb gives a higher potential difference across the bulb.

2) But you've got to be really careful that your conclusion matches the data you've got and doesn't go any further.

You can't conclude that the potential difference across any circuit component will be higher for a larger current — the results might be completely different.

3) You also need to be able to use your results to justify your conclusion (i.e. back up your conclusion with some specific data).

The potential difference across the bulb was 9 V higher with a current of 12 A compared to a current of 6 A.

4) When writing a conclusion you need to refer back to the original hypothesis and say whether the data supports it or not:

The hypothesis for this experiment might have been that a higher current through the bulb would increase the potential difference across the bulb. If so, the data supports the hypothesis.

Correlation DOES NOT Mean Cause

If two things are correlated (i.e. there's a relationship between them) it doesn't necessarily mean a change in one variable is causing the change in the other — this is REALLY IMPORTANT — DON'T FORGET IT. There are three possible reasons for a correlation:

1) CHANCE: It might seem strange, but two things can show a correlation purely due to chance.

For example, one study might find a correlation between people's hair colour and how good they are at frisbee. But other scientists don't get a correlation when they investigate it — the results of the first study are just a fluke.

2) LINKED BY A 3RD VARIABLE: A lot of the time it may look as if a change in one variable is causing a change in the other, but it isn't — a third variable links the two things.

For example, there's a correlation between water temperature and shark attacks. This isn't because warmer water makes sharks crazy. Instead, they're linked by a third variable — the number of people swimming (more people swim when the water's hotter, and with more people in the water you get more shark attacks).

3) CAUSE: Sometimes a change in one variable does cause a change in the other. You can only conclude that a correlation is due to cause when you've controlled all the variables that could, just could, be affecting the result.

For example, there's a correlation between smoking and lung cancer. This is because chemicals in tobacco smoke cause lung cancer. This conclusion was only made once other variables (such as age and exposure to other things that cause cancer) had been controlled and shown not to affect people's risk of getting lung cancer.

I conclude that this page is a bit dull...

...although, just because I find it dull doesn't mean that I can conclude it's dull (you might think it's the most interesting thing since that kid got his head stuck in the railings near school). In the exams you could be given a conclusion and asked whether some data supports it — so make sure you understand how far conclusions can go.

Uncertainties and Evaluations

Hurrah! The end of another investigation. Well, now you have to work out all the things you did wrong.

Uncertainty is the Amount of Error Your Measurements Might Have

1) When you repeat a measurement, you often get a slightly different figure each time you do it due to random error. This means that each result has some uncertainty to it.
2) The measurements you make will also have some uncertainty in them due to limits in the resolution of the equipment you use (see page 6).
3) This all means that the mean of a set of results will also have some uncertainty to it. You can calculate the uncertainty of a mean result using the equation:
4) The larger the range, the less precise your results are and the more uncertainty there will be in your results. Uncertainties are shown using the '±' symbol.

The range is the largest value minus the smallest value.

$$\text{uncertainty} = \frac{\text{range}}{2}$$

EXAMPLE: The table below shows the results of an experiment to determine the resistance of a piece of wire in a circuit. Calculate the uncertainty of the mean.

Repeat	1	2	3	mean
Resistance (Ω)	4.20	3.80	3.70	3.90

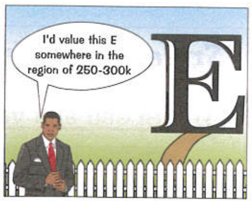
1) First work out the range:
Range = 4.20 – 3.70
= 0.5 Ω

2) Use the range to find the uncertainty:
Uncertainty = range ÷ 2 = 0.5 ÷ 2 = 0.25 Ω

So, uncertainty of the mean = 3.90 ± 0.25 Ω

5) Measuring a greater amount of something helps to reduce uncertainty. For example, in a speed experiment, measuring the distance travelled over a longer period compared to a shorter period will reduce the percentage uncertainty in your results.

Evaluations — Describe How it Could be Improved



An evaluation is a critical analysis of the whole investigation.

1) You should comment on the method — was it valid?
Did you control all the other variables to make it a fair test?
2) Comment on the quality of the results — was there enough evidence to reach a valid conclusion? Were the results repeatable, reproducible, accurate and precise?
3) Were there any anomalous results? If there were none then say so. If there were any, try to explain them — were they caused by errors in measurement? Were there any other variables that could have affected the results? You should comment on the level of uncertainty in your results too.
4) All this analysis will allow you to say how confident you are that your conclusion is right.
5) Then you can suggest any changes to the method that would improve the quality of the results, so that you could have more confidence in your conclusion. For example, you might suggest changing the way you controlled a variable, or increasing the number of measurements you took. Taking more measurements at narrower intervals could give you a more accurate result. For example:

> Springs have an elastic limit (a maximum extension before they stop springing back to their original size). Say you use several identical springs to do an experiment to find the elastic limit of the springs. If you apply forces of 1 N, 2 N, 3 N, 4 N and 5 N, and from the results see that the elastic limit is somewhere between 4 N and 5 N, you could then repeat the experiment with one of the other springs, taking more measurements between 4 N and 5 N to get a more accurate value for the elastic limit.

6) You could also make more predictions based on your conclusion. Then further experiments could be carried out to test them.

When suggesting improvements to the investigation, always make sure that you say why you think this would make the results better.

Evaluation — next time, I'll make sure I don't burn the lab down...

So there you have it — Working Scientifically. Make sure you know this stuff like the back of your hand. It's not just in the lab that you'll need to know how to work scientifically. You can be asked about it in the exams as well.