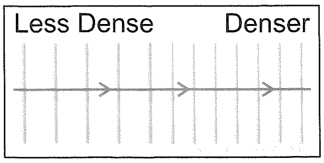
Refraction

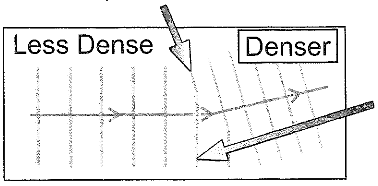
Waves can be Refracted

1) Reflection isn't all that happens when a wave meets a boundary. Usually, some of it is **refracted** too — it passes through the boundary and **changes direction**.
2) Waves travel at **different speeds** in **different media**.
   E.g. — electromagnetic waves, like light, usually travel slower in denser media.

If a wave hits a boundary 'face on', it **slows down** without changing direction.



But if the wave hits at an angle, this bit **slows down first**...



...while this bit carries on at the same speed until it meets the boundary. The wave **changes direction**.

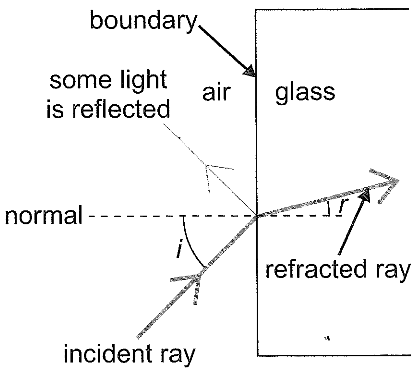
When an electromagnetic wave enters a **denser** medium, it bends **towards** the normal.
When one enters a **less dense** medium, it bends **away** from the normal.

The Refractive Index is a Ratio of Speeds

The **refractive index** of a medium, n, is the **ratio** of the speed of light in a **vacuum** to the speed of light in **that medium**. **Every** transparent material has a refractive index and different materials have **different refractive indices**.

You can Calculate the Refractive Index using Snell's Law

When an **incident ray** travelling in **air** meets a boundary with **another material**, the **angle of refraction** of the ray, r, depends on the **refractive index** of the material and the **angle of incidence**, i.



This is called **Snell's Law**. **refractive index (n)** = $\dfrac{\sin i}{\sin r}$

EXAMPLE: The angle of incidence of a beam of light on a glass block is 65°. The angle of refraction is 35°. What is the refractive index of the block?

$$n = \frac{\sin i}{\sin r} = \frac{\sin 65}{\sin 35} = 1.580... = \mathbf{1.6}$$

You can **rearrange** Snell's Law to find an angle of refraction or incidence, e.g. $r = \sin^{-1}\left(\frac{\sin i}{n}\right)$.

This page has a high refractive index — it's really slowed me down...

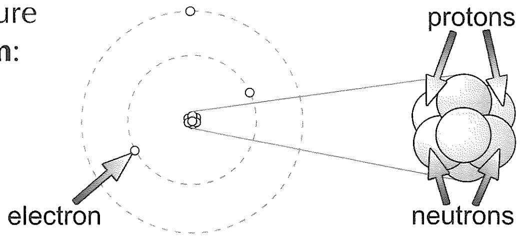
1) A wave hits a boundary between two media head on. Describe what happens to the wave.
2) A wave hits a boundary between two media at an angle. Describe what happens to the wave.
3) A light wave travelling in air hits a transparent material at an angle of 72° to the normal to the boundary. The angle of refraction is 39°. What is the refractive index of the material?
4) A light wave hits the surface of the water in a pond at 23° to the normal. The refractive index of the pond water is 1.3. What is the angle of refraction?

Atomic Structure

Atoms are **Made Up** of **Three** Types of **Particle**

1) According to the **nuclear model**, the atom is made up of electrons, protons and neutrons.
2) The **nucleus** is at the **centre** of the atom. It contains **protons** (which have a **positive** charge) and **neutrons** (which have **no charge**), giving the nucleus an **overall positive charge**. Protons and neutrons are both known as **nucleons**.
3) The nucleus is **tiny** but it makes up **most** of the **mass** of the atom. The rest of the atom is mostly **empty space**, containing only the negative **electrons** which orbit **around** the nucleus.

Here's the structure of a **lithium atom**:



	relative mass	relative charge
proton	1	+1
neutron	1	0
electron	0.0005	–1

Atomic Structure can be **Represented** Using **Nuclide Notation**

1) The **proton number** (or atomic number), **Z**, is the number of **protons** in an atom.
2) The **nucleon number** (or mass number), **A**, is the total number of **protons** and **neutrons**.
3) An element can be **described** by its **proton** and **nucleon numbers**:

nucleon number → $^{A}_{Z}X$ ← element symbol
proton number →

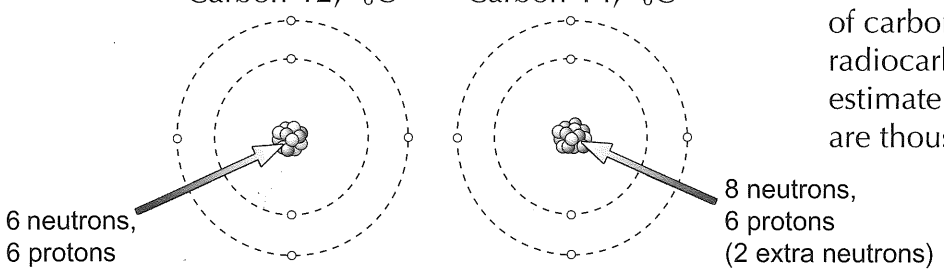
For example, lithium has 4 neutrons and 3 protons, so its symbol is $^{7}_{3}Li$.

Isotopes are **Different Forms** of the **Same Element**

1) Isotopes are atoms with the **same number** of **protons** but a **different number** of **neutrons**.
2) This means they have the **same proton number**, but **different nucleon numbers**.
3) Many isotopes are **unstable** and give off **radiation** (see next page).

EXAMPLE: Carbon-12 and carbon-14 are two isotopes of carbon.

Carbon-12, $^{12}_{6}C$ Carbon-14, $^{14}_{6}C$



The radioactive decay of carbon-14 is used in radiocarbon dating to estimate the age of things that are thousands of years old.

Radiocarbon dating — what physicists do on Valentine's Day...

1) How many protons and neutrons are there in each of the following nuclei?
   a) $^{241}_{95}Am$ b) $^{239}_{94}Pu$ c) $^{90}_{38}Sr$ d) $^{60}_{27}Co$ e) $^{226}_{88}Ra$
2) What is an isotope of an element?

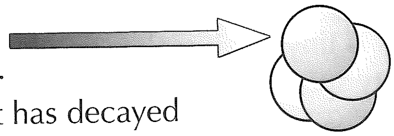
Nuclear Radiation

If an atom is **unstable**, it can undergo **radioactive decay** and give off **nuclear radiation**. By decaying, a nucleus emits **particles** or **energy**, making it **more stable**.

There are **three** kinds of nuclear radiation you need to know about:

*In **Alpha Decay** (Symbol α), an Alpha Particle is Emitted*

1) An **alpha particle** is emitted from the **nucleus**. It is made up of **two protons** and **two neutrons**.
2) As a result, the **proton number** of the atom that has decayed goes **down by 2** and the **nucleon number** goes **down by 4**.



EXAMPLE: The alpha decay of radium-226.

$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}\alpha$ Proton and nucleon numbers are both conserved during all forms of radioactive decay:

Nucleon number: 226 = 222 + 4 Proton number: 88 = 86 + 2

*In **Beta Decay** (Symbol β), an **Electron** is Emitted*

1) A **neutron** in the nucleus turns into a **proton** and an **electron**. The electron is **emitted** from the nucleus and is called a **beta particle**.
2) As a result the **proton number** of the nucleus goes **up by 1**, but the **nucleon number doesn't change**.

EXAMPLE: The beta decay of radium-228.

$^{228}_{88}Ra \rightarrow ^{228}_{89}Ac + ^{0}_{-1}\beta$ Nucleon number: 228 = 228 + 0
Proton number: 88 = 89 – 1

***Gamma Decay** (Symbol γ) Emits **Electromagnetic** Radiation*

1) High-energy **electromagnetic radiation**, called **gamma radiation** is **emitted** from the nucleus.
2) The **number** of **protons** and **neutrons** in the nucleus **stays the same**.

EXAMPLE: The gamma decay of iodine-131.

$^{131}_{53}I \rightarrow ^{131}_{53}I + ^{0}_{0}\gamma$ Proton and nucleon numbers don't change.

You beta learn this radiation stuff — I promise it's not alpha nothing...

1) What is an alpha particle made up of?
2) Describe what happens during the emission of beta and gamma radiation.
3) Complete the following decay equations by filling in any missing radiation symbols, proton numbers or nucleon numbers:
   a) $^{242}_{94}Pu \rightarrow ^{\_}_{\_}U + ^{4}_{2}\alpha$ b) $^{\_}_{\_}K \rightarrow ^{40}_{20}Ca + ^{0}_{-1}\beta$ c) $^{222}_{86}Rn \rightarrow ^{218}_{84}Po + ^{\_}_{\_}\_$ d) $^{14}_{6}C \rightarrow ^{\_}_{\_}N + ^{0}_{-1}\beta$

Planning an Experiment and Collecting Data

Scientists do *Experiments* to *Answer Questions*

You need to **plan experiments** carefully to make sure you get the **best results** possible:

1) Make a **prediction** or **hypothesis** — a testable statement about what you think will happen.
2) Identify your **variables** (see below).
3) Think about any **risks**, and how you can minimise them.
4) Select the right **equipment** for the job — if you're measuring a time interval in minutes you might use a **stopwatch**, but if it's in milliseconds you may need to get a **computer** to measure the time for you, as your reaction time could interfere with your results.
5) Decide what **data** you need to collect and how you'll do it.
6) Write a clear, detailed **method** describing exactly what you're going to do.

You Need to Know What Your *Variables* Are

A variable is anything that has the **potential to change** in an experiment.

The **independent variable** is the thing **you change** in an experiment.

The **dependent variable** is the thing you **measure** in an experiment.

All the **other variables** must be kept the **same** to make it a **fair test**. These are **control variables**.

EXAMPLE: An experiment investigates how the height an object is dropped from affects the time it takes to fall. Identify the variables in this experiment.

The **independent variable** is the **height** you drop the object from — it's what you change.
The **dependent variable** is the **time** the object takes to fall — it's what you measure.
Everything else in the experiment should be **controlled**, so no other variables change.
For example, the **same object** should be used throughout the experiment (so its size and mass don't change), the **conditions** in the room you do the experiment in should be constant, and you shouldn't change your measuring **equipment** halfway through.

Repeating an Experiment Lets You Calculate a *Mean*

Normally, you'll get a slightly different result every time you do an experiment, due to small **random errors** you can't control. E.g. — holding your head in a slightly different place each time you take a measurement from a ruler will cause random errors in the length you read off.

You can **reduce the effect** of these random errors on your results by **repeating** your experiment and taking an average, or **mean**, of your results.

To find the mean:
1) **Add together** the **results** of each repeat.
2) **Divide** this total by the number of **repeats** you did.

Independent variables — not keen on accepting help...

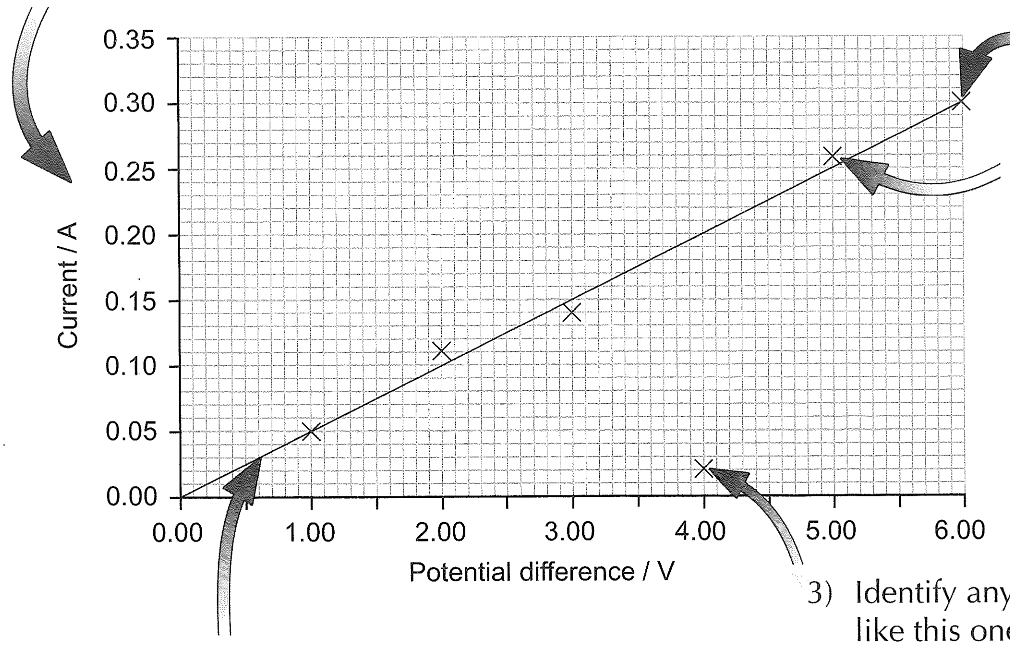
1) A scientist investigates how changing the potential difference across a circuit component affects the current through it. He measures the current three times at each potential difference.
   a) Identify the independent and dependent variables in this investigation.
   b) For a potential difference of 4 V, the scientist records currents of 0.13 A, 0.17 A and 0.12 A. Calculate the mean current through the component when the potential difference is 4 V.

Analysing Your Data

You can Present Your Results on a **Graph**

Graphs are the easiest way to see any **patterns** or **trends** in your results.

1) Usually the **independent variable** goes on the ***x*-axis** (along the bottom) and the **dependent variable** goes on the ***y*-axis** (up the side). Make sure you **label** both axes **clearly** with the quantity and **units**. Pick a **sensible scale** — both axes should go up in sensible steps, and should spread the data out over the full graph (rather than bunching it up in a corner).



2) Plot your points using a **sharp pencil**. This will help make sure they're as **accurate** as possible.

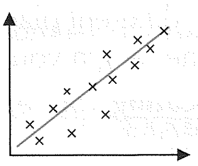
3) Identify any **anomalous results**, like this one — it's way off the general trend, and looks like it was caused by a mistake. **Ignore** anomalous results when drawing your **line of best fit**.

4) Draw a **line of best fit** for your results. Around half the data points should be above your line of best fit and half below it. The line could be **straight** or **curved**, depending on your data.

Graphs Can Show Different Kinds of **Correlation**

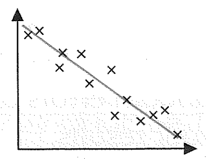
The **correlation** describes the relationship between the variables. Data can show:

POSITIVE CORRELATION:



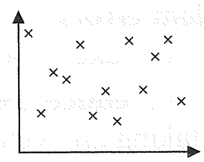
As one variable increases, the other increases.

NEGATIVE CORRELATION:



As one variable increases, the other decreases.

NO CORRELATION:



No relationship between the variables.

Remember, just because two variables are correlated it doesn't mean a change in one is **causing** a change in the other — there could be a third variable affecting them both.

Anomalouse results — unusual results in the insect breeding program...

1) The table on the right gives the speed of a cyclist as he accelerates from rest. Plot a graph of his speed against time, and draw a line of best fit.

time / s	0.0	2.0	4.0	6.0	8.0	10.0
speed / ms^{-1}	0.0	0.7	1.8	2.6	3.2	4.2

Conclusions and Uncertainty

Draw **Conclusions** that Your Results **Support**

You should draw a conclusion that **explains** what your data shows.

1) Your conclusion should be limited to what you've **actually done** and found out in your experiment. For example, if you've been investigating how the force applied to a spring affects how much it stretches, and have only used forces between 0 and 5 N, you can't claim to know what would happen if you used a force of 10 N, or if you used a different spring.
2) You also need to think about how much you can **believe** your conclusion, by evaluating the **quality** of your results (see below). If you can't trust your results, you can't form a **strong conclusion**.

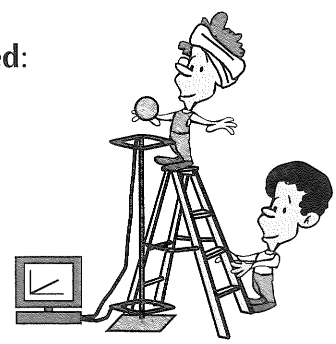
You can Never Measure Anything **Exactly**

1) There will always be **errors** and **uncertainties** in your results caused by lots of different things, including **human error** (e.g. your reaction time). The more errors there are in your results, the **lower the quality** of your data. This will affect the strength of your **conclusion** (see above).
2) All measurements will have some uncertainty due to the equipment used. For example, if you measure a length with a ruler, you can only measure it to the nearest millimetre, as that's the **smallest difference** marked on the ruler's scale. If you measure a length with a ruler as 14 mm you can write this as **14 ± 0.5 mm** to show that you could be up to half a millimetre out either way.
3) If you have a value without a ± sign, the number of **significant figures** gives you an estimate of the **uncertainty**. For example, 72 ms^{-1} has **2 significant figures**, so without any other information you know this value must be 72 **± 0.5** $\mathbf{ms^{-1}}$ — if the value was less than 71.5 ms^{-1} it would have been rounded to 71 ms^{-1}, if it was greater than 72.5 ms^{-1} it would have been rounded to 73 ms^{-1}.

Think About How to **Improve** Your Experiment

You should always think about how your experiment could be **improved**:

1) Did the experiment actually **test** what it was supposed to? Could you make it more **relevant** to the question?
2) Was there anything you could have done to prevent some of the **errors** in your results?
3) Would different **apparatus** or a different **method** have given you **better results**?



In conclusion, I need a cup of tea...

1) A student records how long it takes for a car to stop when the brakes are fully applied. He uses a stopwatch, and gets a measurement of 7.628 ± 0.0005 seconds.
   a) What is the smallest difference the stopwatch can measure?
   b) The student says from his result he can accurately report the time taken for the car to stop to 4 significant figures. Is he correct? Explain your answer.