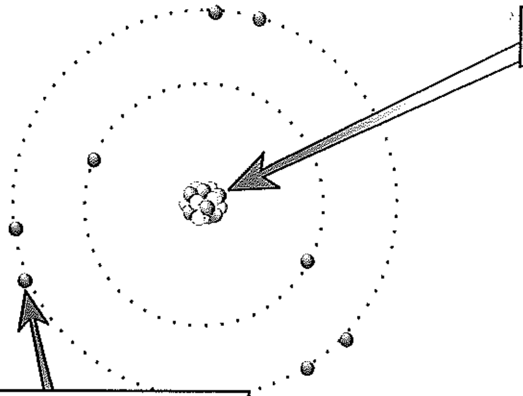
Atoms

Hello, good evening and welcome to Chemistry. This section covers all of Chemistry's essential gory details — about atoms, their innards, and what they get up to with each other when no one's looking.

Structure of the Atom — There's Nothing to It

The structure of atoms is quite simple. Just learn and enjoy, my friend.



The Nucleus

1) It's in the middle of the atom. It contains protons and neutrons. (It's the number of protons in an atom that decides what element it is.)
2) The nucleus has an overall positive charge, because protons are positively charged and neutrons have no charge.
3) Almost the whole mass of the atom is concentrated in the nucleus. But size-wise it's tiny compared to the atom as a whole.

The Electrons

1) They move around the nucleus in energy levels called shells. (Each shell is only allowed a certain number of electrons.)
2) They have a negative charge (electrons and protons have equal but opposite charges).
3) They're tiny compared to the nucleus (they have virtually no mass), but as they move around they cover a lot of space. (The size of their orbits determines how big the atom is.)

Number of Protons Equals Number of Electrons

1) Neutral atoms have no charge overall.
2) This is because the number of protons always equals the number of electrons in a neutral atom, and the charge on the electrons is the same size as the charge on the protons, but opposite.
3) The number of neutrons isn't fixed but is usually about the same as the number of protons.

Know Your Particles

1) Protons are heavy and positively charged.
2) Neutrons are heavy and neutral (no charge).
3) Electrons are tiny and negatively charged.

PARTICLE	RELATIVE MASS	RELATIVE CHARGE
Proton	1	+1
Neutron	1	0
Electron	1/2000	–1

Each Element has an Atomic Number and a Mass Number

1) The atomic number says how many protons there are in an atom, and it's unique to that element.
2) The atomic number also tells you the number of electrons.
3) The mass number is the total number of protons and neutrons in the atom. So if you want to find the number of neutrons in an atom, just subtract the atomic number from the mass number.

On a periodic table you might see "Relative atomic mass" instead of "Mass Number" see p.58 for more

MASS NUMBER
Total number of protons and neutrons. → 16

ATOMIC NUMBER (or PROTON NUMBER) → 8
Number of protons, which is equal to the number of electrons.

$^{16}_{8}O$

Basic atom facts — they don't take up much space...

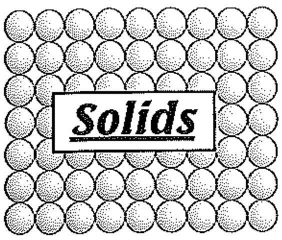
Atoms are tiny. And the atom's nucleus is REALLY tiny. An atom might measure 0.1 nanometres across — that's 0.000 000 000 1 metres, or a hundred-millionth of a centimetre. Wow. That's little.

Solids, Liquids and Gases

You can explain quite a bit of the stuff in Chemistry, if you can get your head round this lot.

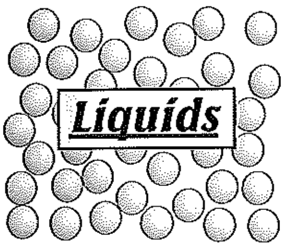
States of Matter — Depend on the Forces Between Particles

All stuff is made of particles (molecules or atoms) that are constantly moving, and the forces between these particles can be weak or strong, depending on whether it's a solid, liquid or a gas.



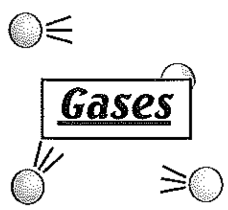
1) There are strong forces of attraction between particles, which holds them in fixed positions in a very regular lattice arrangement.
2) The particles don't move from their positions, so all solids keep a definite shape and volume, and don't flow like liquids.
3) The particles vibrate about their positions — the hotter the solid becomes, the more they vibrate (causing solids to expand slightly when heated).

If you heat the solid (give the particles more energy), eventually the solid will melt and become liquid.



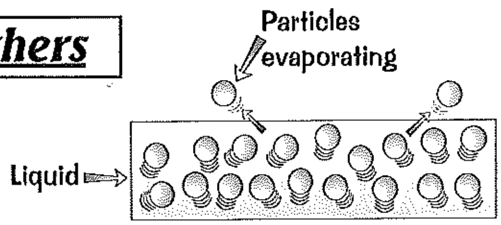
1) There is some force of attraction between the particles. They're free to move past each other, but they do tend to stick together.
2) Liquids don't keep a definite shape and will flow to fill the bottom of a container.
3) The particles are constantly moving with random motion. The hotter the liquid gets, the faster they move. This causes liquids to expand slightly when heated.

If you now heat the liquid, eventually it will boil and become gas.



1) There's next to no force of attraction between the particles — they're free to move. They travel in straight lines and only interact when they collide.
2) Gases don't keep a definite shape or volume and will always fill any container. When particles bounce off the walls of a container they exert a pressure on the walls.
3) The particles move constantly with random motion. The hotter the gas gets, the faster they move. Gases either expand when heated, or their pressure increases.

Some Liquids are More Volatile Than Others



1) When a liquid is heated, the heat energy is transferred to the particles, which makes them move faster.
2) Some particles move faster than others.
3) Fast-moving particles at the surface will overcome the forces of attraction from the other particles and escape. This is evaporation.
4) How easily a liquid evaporates is called its volatility.

Evaporation is why you can smell stuff, even solids and liquids. A few particles have enough energy to evaporate and the smell receptors in your nose detect them — and hey presto — you smell the substance. Perfumes, air fresheners, etc. are usually volatile liquids so they evaporate enough for you to smell them.

Eau de sweaty sock — thankfully not very volatile...

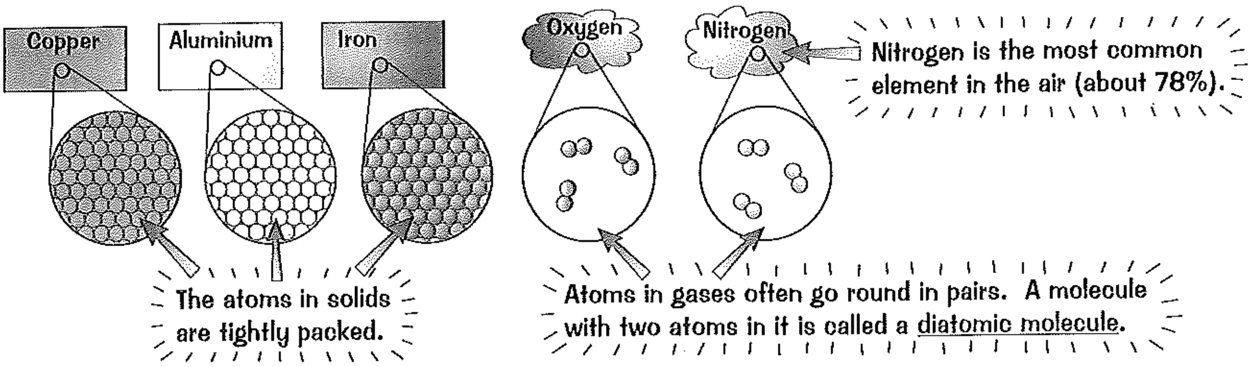
Take another smelly chemical — petrol. The molecules in petrol are held together (otherwise it wouldn't be a liquid), but they must be constantly escaping (evaporating) in order for you to smell it. That's why you shouldn't have naked flames at a petrol station... the vapour from the pumps could explode.

Elements, Compounds and Mixtures

There are only about 100 or so different kinds of atoms, which doesn't sound too bad.
But they can join together in loads of different combinations, which makes life more complicated.

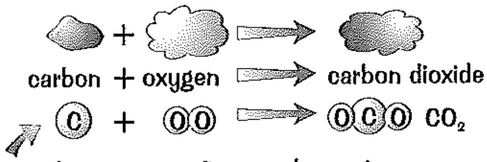
Elements Consist of One Type of Atom Only

Quite a lot of everyday substances are elements:

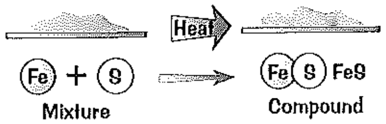


Compounds are Chemically Bonded

A compound is a substance that is made of two or more different elements which are chemically joined (bonded) together.

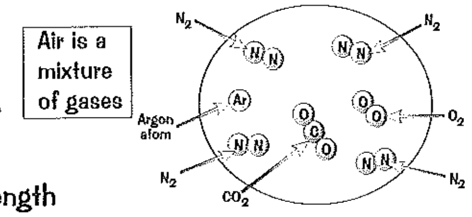


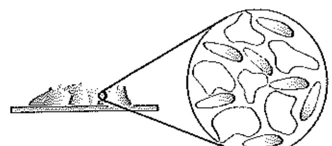
1) For example, carbon dioxide is a compound formed from a chemical reaction. One carbon atom reacts with two oxygen atoms to form a molecule of carbon dioxide, with the formula CO_2.
2) It's very difficult to separate the two original elements out again.
3) The properties of a compound are often totally different from the properties of the original elements.
4) For example, if a mixture of iron and sulfur is heated, the iron and sulfur atoms react to form the compound iron sulfide (FeS). Iron sulfide is not much like iron (e.g. it's not attracted to a magnet), nor is it much like sulfur (e.g. it's not yellow in colour).



Mixtures are Easily Separated — Not Like Compounds

1) Unlike in a compound, there's no chemical bond between the different parts of a mixture. The parts can be separated out by physical methods such as distillation (see page 17).
2) Air is a mixture of gases, mainly nitrogen, oxygen, carbon dioxide and argon. The gases can all be separated out fairly easily.
3) The properties of a mixture are just a mixture of the properties of the separate parts.
4) A mixture of iron powder and sulfur powder will show the properties of both iron and sulfur. It will contain grey magnetic bits of iron and bright yellow bits of sulfur.
5) Crude oil is a mixture of different length hydrocarbon molecules — see page 17.




Iron and sulfur mixed together, but unreacted.

Not learning this stuff will only compound your problems...

Mixtures and compounds. To most people they sound like basically the same thing. Not to GCSE examiners, I'm afraid. If you understand the difference between the mixture of iron powder and sulfur powder, and the compound iron sulfide, it'll make all this stuff easier to remember.

The Periodic Table

In the 1800s chemists were keen to try and find patterns in the elements they knew about. And the more elements that were identified, the clearer those patterns became...

Dmitri Mendeleev Arranged the Elements in Groups

1) In 1869, a Russian scientist called Dmitri Mendeleev arranged the 50 or so known elements in order of atomic mass to make a Table of Elements.
2) Mendeleev's table placed elements with similar chemical properties in the same vertical groups — but he found that he had to leave gaps in his table to make this work.
3) The gaps in Mendeleev's table of elements were really clever because they predicted the properties of undiscovered elements.
4) Since then new elements have been found which fit into the gaps in Mendeleev's table. Over the last hundred years or so the table has been refined to produce the periodic table we know (and love) today...

Mendeleev's Table of the Elements

H																
Li	Be											B	C	N	O	F
Na	Mg											Al	Si	P	S	Cl
K	Ca	*	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	*	*	As	Se	Br
Rb	Sr	Y	Zr	Nb	Mo	*	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I
Cs	Ba	*	*	Ta	W	*	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi		

The Periodic Table Puts Elements with Similar Properties Together

1) The periodic table is laid out (in order of atomic number nowadays) so that elements with similar properties form columns.
2) These vertical columns are called groups and Roman numerals are often used for them.
3) If you know the properties of one element, you can predict properties of other elements in that group.
4) For example the Group I elements are Li, Na, K, Rb, Cs and Fr. They're all metals and they react the same way. E.g. they all react with water to form an alkaline solution and hydrogen gas.
5) You can also make predictions about reactivity. E.g. in Group I, the elements react more vigorously as you go down the group. And in Group VII, reactivity decreases as you go down the group.
6) There are 100ish elements, which all materials are made of. If it wasn't for the periodic table organising everything, you'd have a heck of a job remembering all those properties.

	Group I	Group II											Group III	Group IV	Group V	Group VI	Group VII	Group 0
								1 H Hydrogen 1										4 He Helium 2
2	7 Li Lithium 3	9 Be Beryllium 4											11 B Boron 5	12 C Carbon 6	14 N Nitrogen 7	16 O Oxygen 8	19 F Fluorine 9	20 Ne Neon 10
3	23 Na Sodium 11	24 Mg Magnesium 12											27 Al Aluminium 13	28 Si Silicon 14	31 P Phosphorus 15	32 S Sulfur 16	35.5 Cl Chlorine 17	40 Ar Argon 18
4	39 K Potassium 19	40 Ca Calcium 20	45 Sc Scandium 21	48 Ti Titanium 22	51 V Vanadium 23	52 Cr Chromium 24	55 Mn Manganese 25	56 Fe Iron 26	59 Co Cobalt 27	59 Ni Nickel 28	63.5 Cu Copper 29	65 Zn Zinc 30	70 Ga Gallium 31	73 Ge Germanium 32	75 As Arsenic 33	79 Se Selenium 34	80 Br Bromine 35	84 Kr Krypton 36
5	86 Rb Rubidium 37	88 Sr Strontium 38	89 Y Yttrium 39	91 Zr Zirconium 40	93 Nb Niobium 41	96 Mo Molybdenum 42	99 Tc Technetium 43	101 Ru Ruthenium 44	103 Rh Rhodium 45	106 Pd Palladium 46	108 Ag Silver 47	112 Cd Cadmium 48	115 In Indium 49	119 Sn Tin 50	122 Sb Antimony 51	128 Te Tellurium 52	127 I Iodine 53	131 Xe Xenon 54
6	133 Cs Caesium 55	137 Ba Barium 56	57-71 Lanthanides	179 Hf Hafnium 72	181 Ta Tantalum 73	184 W Tungsten 74	186 Re Rhenium 75	190 Os Osmium 76	192 Ir Iridium 77	195 Pt Platinum 78	197 Au Gold 79	201 Hg Mercury 80	204 Tl Thallium 81	207 Pb Lead 82	209 Bi Bismuth 83	210 Po Polonium 84	210 At Astatine 85	222 Rn Radon 86
7	223 Fr Francium 87	226 Ra Radium 88	89-103 Actinides															

Relative atomic mass (total number of protons & neutrons) → 4

He Helium

Atomic number (number of protons) → 2

Key: reactive metals; transition metals; other metals; non-metals; noble gases; separates metals from non-metals

Elementary my dear Mendeleev...

One important thing to understand on this page is that a scientific theory (such as "elements can be grouped in a table according to their properties") can be used to make predictions (such as "there are gaps in the table so there must be some undiscovered elements to fill those gaps"). Got that... good.

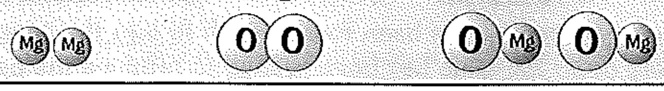
Balancing Equations

All chemical reactions can be shown using an equation. Unfortunately, getting equations right takes a bit of practice. So make sure you get a bit of practice — don't just skate over them.

Atoms Aren't Lost or Made in Chemical Reactions

1) During chemical reactions, things don't appear out of nowhere and things don't just disappear.
2) You still have the same atoms at the end of a chemical reaction as you had at the start. They're just arranged in different ways.
3) Balanced symbol equations show the atoms at the start (the reactant atoms) and the atoms at the end (the product atoms) and how they're arranged. For example:

Word equation:	magnesium	+	oxygen	→	magnesium oxide
Balanced symbol equation:	2Mg	+	O_2	→	2MgO



4) Because atoms aren't gained or lost, the mass of the reactants equals the mass of the products. So, if you react 6 g of magnesium with 4 g of oxygen, you'd end up with 10 g of magnesium oxide.

Balancing the Equation — Match Them Up One by One

1) There must always be the same number of atoms of each element on both sides — they can't just disappear.
2) You balance the equation by putting numbers in front of the formulas where needed. Take this equation for reacting sulfuric acid (H_2SO_4) with sodium hydroxide (NaOH) to get sodium sulfate (Na_2SO_4) and water (H_2O):

$$H_2SO_4 + NaOH \rightarrow Na_2SO_4 + H_2O$$

The formulas are all correct but the numbers of some atoms don't match up on both sides. E.g. there are 3 H's on the left, but only 2 on the right. You can't change formulas like H_2O to H_3O. You can only put numbers in front of them:

Method: Balance Just ONE Type of Atom at a Time

The more you practise, the quicker you get, but all you do is this:

1) Find an element that doesn't balance and pencil in a number to try and sort it out.
2) See where it gets you. It may create another imbalance — if so, just pencil in another number and see where that gets you.
3) Carry on chasing unbalanced elements and it'll sort itself out pretty quickly.

I'll show you. In the equation above you soon notice we're short of H atoms on the RHS (Right-Hand Side).

1) The only thing you can do about that is make it $2H_2O$ instead of just H_2O:

$$H_2SO_4 + NaOH \rightarrow Na_2SO_4 + 2H_2O$$

2) But that now causes too many H atoms and O atoms on the RHS, so to balance that up you could try putting 2NaOH on the LHS (Left-Hand Side):

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$$

3) And suddenly there it is! Everything balances. And you'll notice the Na just sorted itself out.

Balancing equations — weigh it up in your mind...

REMEMBER WHAT THOSE NUMBERS MEAN: A number in front of a formula applies to the entire formula. So, $3Na_2SO_4$ means three lots of Na_2SO_4. The little numbers in the middle or at the end of a formula only apply to the atom immediately before. So the 4 in Na_2SO_4 just means 4 O's, not 4 S's.

Properties of Metals

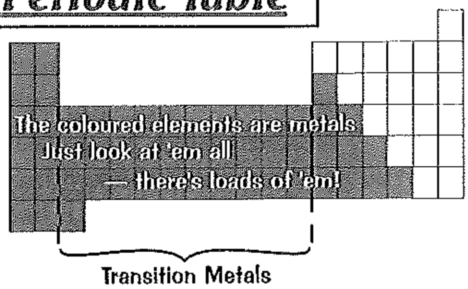
Metals are all similar but slightly different. They have some basic properties in common, but each has its own specific combination of properties, which means you use different ones for different purposes.

Metals are on the Left and Middle of the Periodic Table

Most of the elements are metals — so they cover most of the periodic table.

In fact, only the elements on the far right are non-metals.

The so-called transition metals are found in the centre block of the periodic table. Many of the metals in everyday use are transition metals — such as titanium, iron and nickel.



Metals are Strong and Bendy, and They're Great Conductors

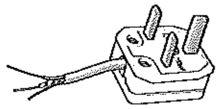
All metals have some fairly similar basic properties.

1) Metals are strong (hard to break), but they can be bent or hammered into different shapes.
2) They're great at conducting heat.
3) They conduct electricity well.

Metals (and especially transition metals) have loads of everyday uses because of these properties...

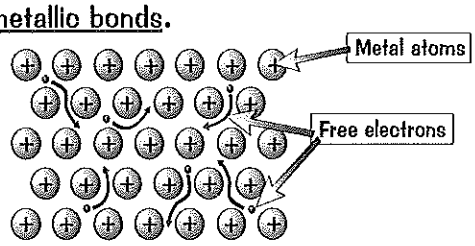
Transition metals have loads of everyday uses — partly because they're not crazily reactive like, say, potassium (which would catch fire if it got rained on).

- Their strength and 'bendability' makes them handy for making into things like bridges and car bodies.
- Metals are ideal if you want to make something that heat needs to travel through, like a saucepan base.
- And their conductivity makes them great for making things like electrical wires.



It's the Structure of Metals That Gives Them Their Properties

1) All metals have the same basic properties. These are due to the special type of bonding in metals.
2) Metals consist of a giant structure of atoms held together with metallic bonds.
3) These special bonds allow the outer electron(s) of each atom to move freely.
4) This creates a "sea" of free electrons throughout the metal, which is what gives rise to many of the properties of metals.
5) This includes their conduction of heat and electricity.



A Metal's Exact Properties Decide How It's Best Used

1) The properties above are typical properties of metals. Not all metals are the same though — and it's their exact properties that determine how they're used.
2) If you wanted to make an aeroplane, you'd probably use metal as it's strong and can be bent into shape, but you'd also need it to be light — so aluminium would be a good choice.
3) And if you were making replacement hips, you'd pick a metal that won't corrode when it comes into contact with water — it'd also have to be light, and not too bendy. Titanium has all of these properties so it's used for stuff like this.

Metal fatigue? — yeah, I've had enough of this page too...

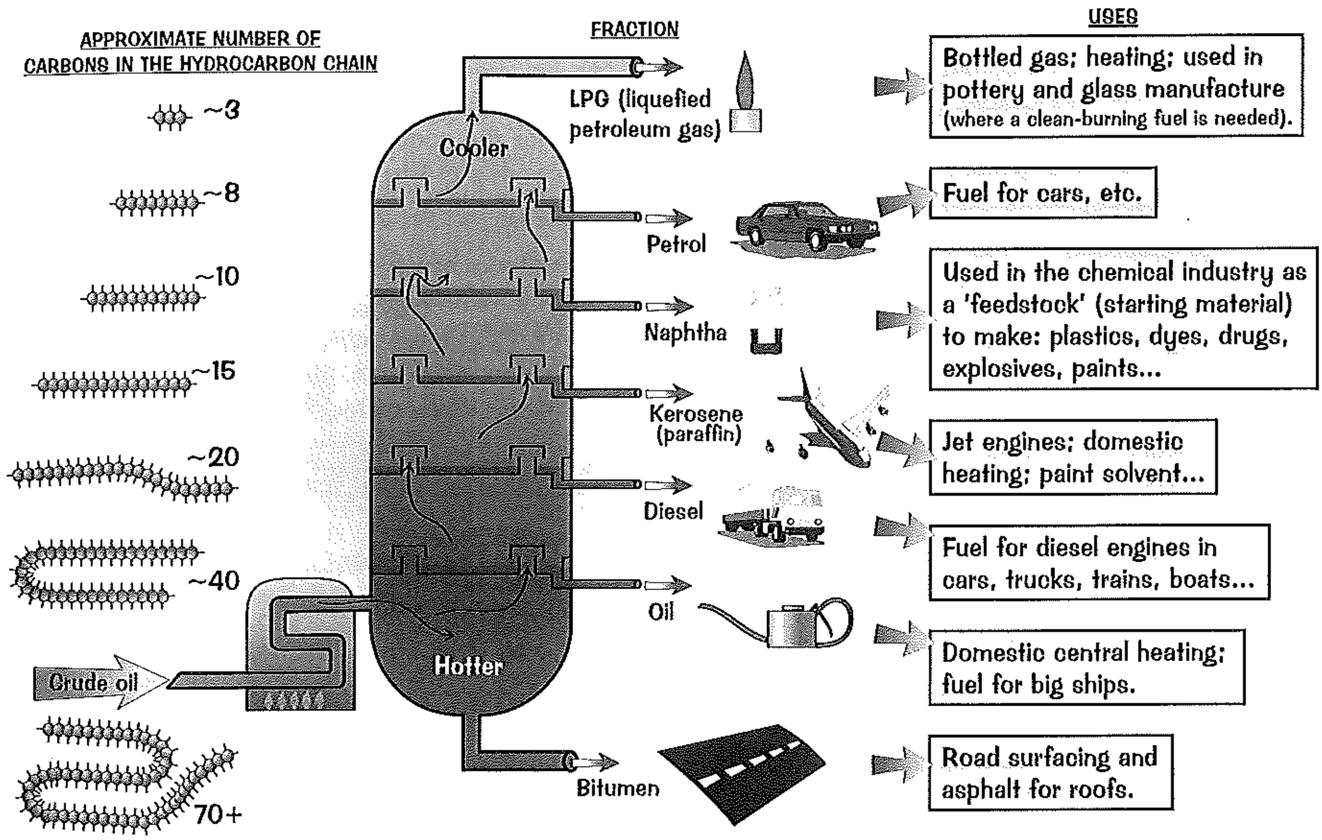
So, all metals conduct electricity and heat and can be bent into shape. But lots of them have special properties too. You have to decide what properties you need and use a metal with those properties.

Fractional Distillation of Crude Oil

Crude oil is formed from the buried remains of plants and animals — it's a fossil fuel. Over millions of years, with high temperature and pressure, the remains turn to crude oil, which can be drilled up.

Crude Oil Can be Split into Separate Hydrocarbons

1) Crude oil is a mixture of hydrocarbons — molecules which are made of just carbon and hydrogen.
2) Fractional distillation splits crude oil into fractions (groups of compounds with carbon chains of similar length).
3) Heated crude oil is piped in at the bottom of a fractionating column.
The various fractions are constantly tapped off at the different levels where they condense.



Fractional distillation is an example of a physical process — there are no chemical reactions.

The Properties of Hydrocarbon Molecules Depend on Their Size

The big hydrocarbon molecules are the first to condense, because they have higher boiling points. As the molecules get smaller, they condense higher up the fractionating column. The smaller the molecule...

1) ...the lower the boiling point — the substance stays as a gas at lower temperatures.
2) ...the more flammable it is — it sets fire more easily.
3) ...the less viscous it is — it's less 'gloopy' and flows more easily.
4) ...the more volatile it is — it evaporates more readily.

The vapours of the more volatile hydrocarbons are very flammable and pose a serious fire risk.
So don't smoke at the petrol station. (In fact, don't smoke at all, it's stupid.)

The diesel engine was named after its inventor — Rudolf Engine...

Crude oil is useful stuff, there's no doubt about it. But using it is not without its problems (see page 19 for more about fuels). For example, oil is shipped around the planet, which can lead to slicks if there's an accident. Also, burning oil is thought to cause climate change, acid rain and global dimming. And oil is going to start running out one day, which will lead to big difficulties.

Alkanes and Alkenes

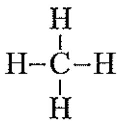
Crude oil contains both alkanes and alkenes (although mostly alkanes). They have different properties, and it's all down to their structure.

Alkanes Have All C–C Single Bonds

1) Alkanes are made up of chains of carbon atoms joined by single covalent bonds, and surrounded by hydrogen atoms.
2) Different alkanes have chains of different lengths. The first four alkanes are methane (natural gas), ethane, propane and butane.

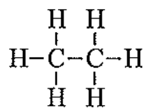
Covalent bonds are when atoms share electrons. Carbon atoms like to make 4 bonds altogether. Hydrogen atoms like to make 1.

1) Methane: CH_4

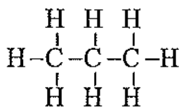


(natural gas)

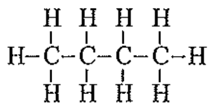
2) Ethane: C_2H_6



3) Propane: C_3H_8



4) Butane: C_4H_{10}



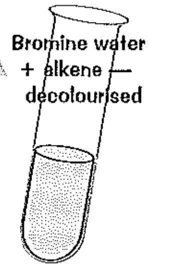
3) All alkanes have the formula: C_nH_{2n+2}
4) They're called saturated hydrocarbons because they have no spare bonds left (i.e. no double bonds that can open up and have things join onto them — see below).
5) You can tell the difference between an alkane and an alkene by adding the substance to bromine water. An alkane won't decolourise the bromine water. This is because it has no spare bonds, so it can't react with the bromine.
6) Alkanes won't form polymers — again, no spare bonds.
7) They burn cleanly, producing carbon dioxide and water.

Alkenes Have a C=C Double Bond

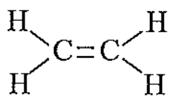
1) Alkenes have chains of carbon atoms with one or more double covalent bonds.
2) They're called unsaturated hydrocarbons because double bonds can open up and let things join on.

A double bond means that atoms are sharing two pairs of electrons. A double bond counts as two of a carbon atom's four bonds.

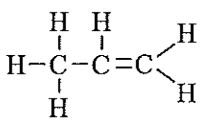
3) This is why they will decolourise bromine water. They form bonds with the bromine.
4) Alkenes are more reactive — due to the double bond all poised and ready to just pop open. They can form polymers by opening up their double bonds to 'hold hands' in a long chain. (See page 22 for more info on polymers.)
5) The first three alkenes are ethene, propene and butene.



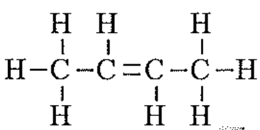
1) Ethene: C_2H_4



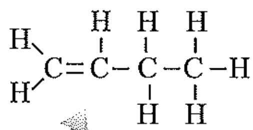
2) Propene: C_3H_6



3) Butene: C_4H_8



or



There are different forms of butene.

6) All alkenes containing one double bond have the formula: C_nH_{2n}
7) They tend to burn with a smoky flame, producing soot (carbon).

Alkane anybody who doesn't learn this lot properly...

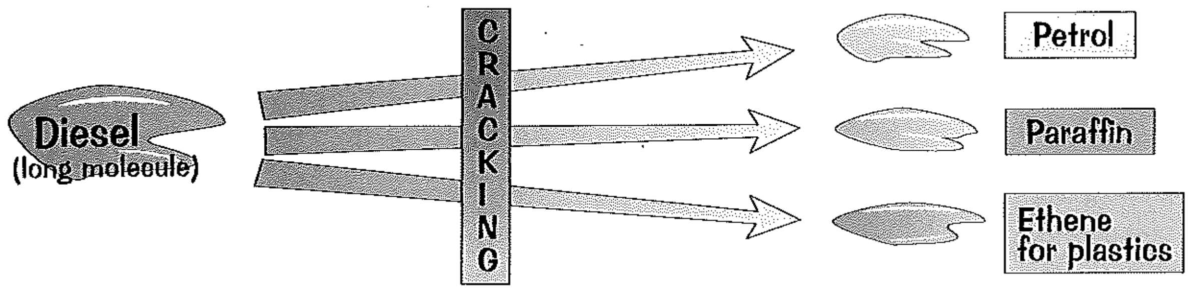
Don't get alkenes confused with alkanes — that one letter makes all the difference. Alkenes have a C=C bond, alkanes don't. The first part of their names is the same though. "Meth-" means "one carbon atom", "eth-" means "two C atoms", "prop-" means "three C atoms", "but-" means "four C atoms", etc.

Cracking Crude Oil

After the distillation of crude oil (see page 17), you've still got both short and long hydrocarbons, just not all mixed together. But there's more demand for some products, like petrol, than for others, like bitumen.

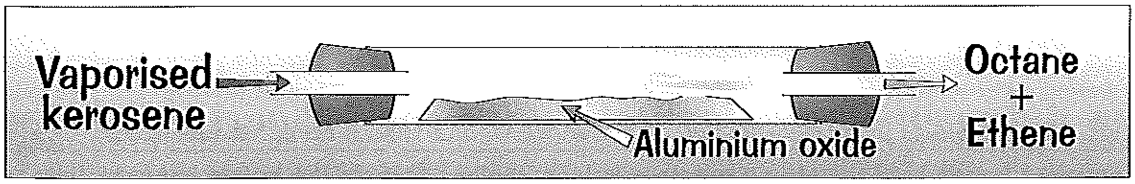
Cracking Means Splitting Up Long-Chain Hydrocarbons...

1) Long-chain hydrocarbons form thick, gloopy liquids like tar which aren't all that useful, so...
2) ... a lot of the longer molecules produced from fractional distillation are turned into smaller ones by a process called cracking.
3) Some of the products of cracking are useful as fuels, e.g. petrol for cars and kerosene (which is also known as paraffin) for jet fuel.
4) Cracking also produces short alkenes like ethene, which are needed for making plastics (see p22).



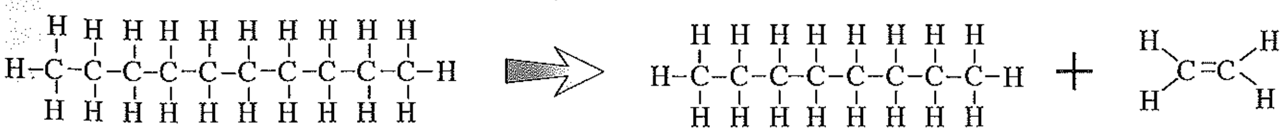
...by Passing Vapour Over a Hot Catalyst

1) Cracking is a thermal decomposition reaction — breaking molecules down by heating them.
2) The first step is to heat the long-chain hydrocarbon to vaporise it (turn it into a gas).
3) Then the vapour is passed over a powdered catalyst at a temperature of about 400 °C – 700 °C.
4) Aluminium oxide is the catalyst used.
5) The long-chain molecules split apart or "crack" on the surface of the specks of catalyst.



6) Most of the products of cracking are alkanes and alkenes (see page 20).

Long-chain hydrocarbon molecule ⟹ Shorter ALKANE molecule + ALKENE



E.g. Kerosene (ten C atoms) (Too much of this in crude oil) ⟹ Octane (eight C atoms) (useful for petrol) + ethene (for plastics)

Get cracking — there's a lot to learn...

It's up to chemists to make sure we have the chemicals we need — and to do their best to make the most efficient use of substances from the Earth. Here, 'efficient' means not wasting raw materials, and also not making more waste than is necessary. It's a tough job, but someone's got to do it.

Making Polymers

Plastics are made up of lots of molecules joined together. They're like long chains.

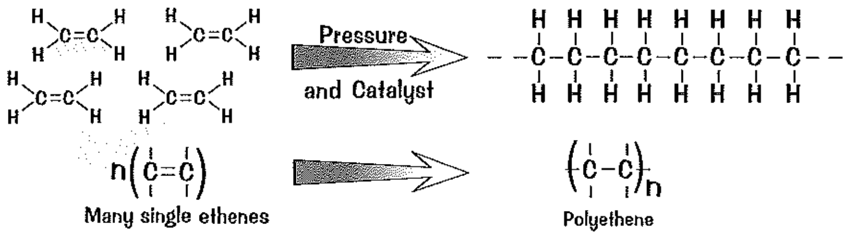
Plastics are Long-Chain Molecules Called Polymers

1) Plastics are formed when lots of small molecules called monomers join together to give a polymer.
2) They're usually carbon based (and the monomers are very often alkenes — see p20).

Addition Polymers are Made Under High Pressure

1) The monomers that make up addition polymers have a double covalent bond (i.e. they're unsaturated).
2) Under high pressure and with a catalyst (see p76), many unsaturated small molecules open up those double bonds and "join hands" (polymerise) to form long saturated chains called polymers.

Ethene becoming polyethene or "polythene", is the easiest example:

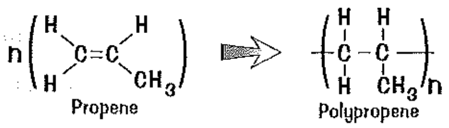


You'll need to be able to draw the formula of an addition polymer, given the formula of its monomer. Dead easy — the carbons just all join together in a row with no double bonds between them.

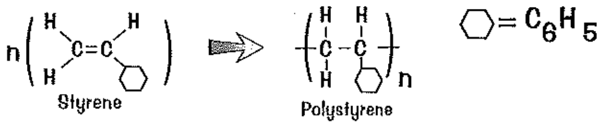
The 'n' just means there can be any number of monomers (and polymer units).

The name of the plastic comes from the type of monomer it's made from — you just stick the word "poly" in front of it:

Propene can form polypropene:



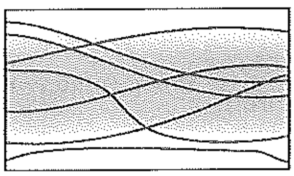
A molecule called styrene will polymerise into polystyrene:



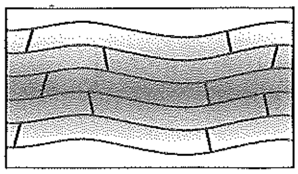
Forces Between Molecules Determine the Properties of Plastics

Strong covalent bonds hold the atoms together in long chains. But it's the bonds between the different molecule chains that determine the properties of the plastic.

Weak Forces:
Long chains held together by weak forces are free to slide over each other. This means the plastic can be stretched easily, and will have a low melting point.



Strong Forces:
Plastics with stronger bonds between the polymer chains have higher melting points and can't be stretched, as the crosslinks hold the chains firmly together.



Revision — it's all about stringing lots of facts together...

Which monomer a polymer is made from affects the properties of the plastic, as do the exact conditions the plastic is made under (e.g. pressure, temperature). And the properties of the plastic affect what the plastic can be used for (more about the uses of plastics on p23, by the way).

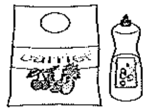
Uses of Polymers

Plastics are fantastically useful. You can make novelty football pencil sharpeners and all sorts.

Polymers' Properties Decide What They're Used For

Different polymers have different physical properties — some are stronger, some are stretchier, some are more easily moulded, and so on. These different physical properties make them suited for different uses.

- Strong, rigid polymers such as high density polyethene are used to make plastic milk bottles.
- Light, stretchable polymers such as low density polyethene are used for plastic bags and squeezy bottles. Low density polyethene has a low melting point, so it's no good for anything that'll get very hot.

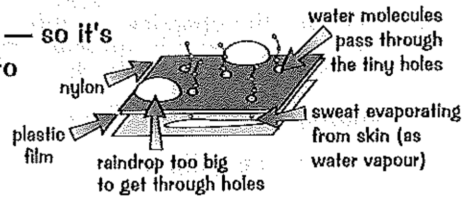


- PVC is strong and durable, and it can be made either rigid or stretchy. The rigid kind is used to make window frames and piping. The stretchy kind is used to make synthetic leather.
- Polystyrene foam is used in packaging to protect breakable things, and it's used to make disposable coffee cups (the trapped air in the foam makes it a brilliant thermal insulator).
- Heat-resistant polymers such as melamine resin and polypropene are used to make plastic kettles.

Polymers are Often Used to Make Clothes

1) Nylon is a synthetic polymer often used to make clothes. Fabrics made from nylon aren't waterproof on their own, but they can be coated with polyurethane to make tough, waterproof outdoor clothing.
2) One big problem is that the polyurethane coating doesn't let water vapour pass through it. So if you get a bit hot (or do a bit of exercise), sweat condenses on the inside. This makes skin and clothes get wet and uncomfortable — the material isn't breathable.
3) Breathable fabrics have all the useful properties of nylon/polyurethane ones, but they also let sweat out. If you sweat in a breathable material, water vapour can escape — so no condensation.

1) Breathable fabrics are made by combining a thin film of a plastic with a layer of another fabric, such as polyester or nylon.
2) The plastic film has tiny holes which let water vapour pass through — so it's breathable. But it's waterproof, since the holes aren't big enough to let big water droplets through and the plastic repels liquid water.
3) This material is great for outdoorsy types — they can hike about in the rain without getting wet or soaked in sweat.



Non-biodegradable Plastics Cause Disposal Problems

1) Most polymers aren't 'biodegradable' — they're not broken down by microorganisms, so they don't rot. This property is actually kind of useful until it's time to get rid of your plastic.
2) It's difficult to get rid of plastics — if you bury them in a landfill site, they'll still be there years later. Landfill sites fill up quickly, and they're a waste of land. And a waste of plastic.
3) When plastics are burnt, some of them release gases such as acidic sulfur dioxide and poisonous hydrogen chloride and hydrogen cyanide. So burning's out, really. Plus it's a waste of plastic.
4) The best thing is to reuse plastics as many times as possible and then recycle them if you can. Sorting out lots of different plastics for recycling is difficult and expensive, though.
5) Chemists are working on a variety of ideas to produce biodegradable polymers.

Polymers — great until you don't need them any more...

If you're making a product, you need to pick your plastic carefully. It's no good trying to make a kettle out of a plastic that melts at 50 °C — you'll end up with a messy kitchen, a burnt hand and no cuppa. You'd also have a bit of difficulty trying to wear clothes made of brittle, unbendy plastic.

Ethanol

There are different kinds of alcohol, but the one that's in beer, wine and so on is ethanol.

Ethanol Can be Made by Fermentation

1) Fermentation is the process of using yeast to convert sugars into ethanol. Carbon dioxide is also produced. Which my Dad discovered when his homebrew exploded one year.

This is the formula for glucose — a common sugar.

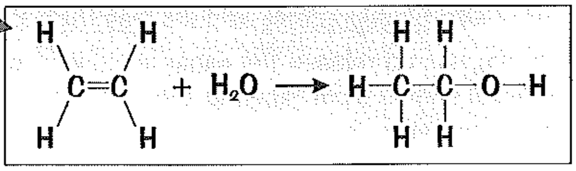
$$C_6H_{12}O_6 \xrightarrow{\text{yeast}} 2C_2H_5OH + 2CO_2$$

The products are ethanol and carbon dioxide.

2) The yeast cells contain an enzyme called zymase. (Enzymes are naturally occurring catalysts.)
3) Fermentation happens fastest at a temperature of about 30 °C. At lower temperatures, the reaction is very slow. If it's too hot, the enzyme in the yeast is destroyed.
4) It's important to prevent oxygen getting to the fermentation process. If oxygen is present, a different reaction happens and you don't get ethanol.
5) When the concentration of alcohol reaches about 10 to 20%, the fermentation reaction stops, because the yeast gets killed off by the alcohol.
6) Different types of alcoholic drinks are made using sugars from different sources — usually from grains, fruits or vegetables, e.g. barley is used to make beer and grapes are used for making wine.
7) The fermented mixture can be distilled to produce more concentrated alcohol. Brandy is distilled from wine, whisky is distilled from fermented grain and vodka's distilled from fermented grain or potatoes.
8) The ethanol produced this way can also be used as quite a cheap fuel in countries which don't have oil reserves for making petrol (see below).

Ethene Can be Reacted with Steam to Produce Ethanol

1) Ethene (C_2H_4) will react with steam (H_2O) to make ethanol.



2) The reaction needs a temperature of 300 °C and a pressure of 70 atmospheres.
3) Phosphoric acid is used as a catalyst.
4) At the moment this is a cheap process, because ethene's fairly cheap and not much of it is wasted.
5) The trouble is that ethene's produced from crude oil, which is a non-renewable resource and which will start running out fairly soon. This means using ethene to make ethanol will become very expensive.

Alcohol Can be Used as a Fuel

1) Ethanol can be used as fuel. It burns to give just CO_2 and water.
2) Cars can be adapted to run on a mixture of about 10% ethanol and 90% petrol — 'gasohol'. Some countries (e.g. Brazil) make extensive use of gasohol. It's best used in areas where there's plenty of fertile land for growing the crops needed, and good crop-growing weather.
3) Using gasohol instead of pure petrol means that less crude oil is being used. Another advantage is the crops needed for ethanol production absorb CO_2 from the atmosphere in photosynthesis while growing. This goes some way towards balancing out the release of CO_2 when the gasohol is burnt.
4) But distilling the ethanol after fermentation needs a lot of energy, so it's not a perfect solution.

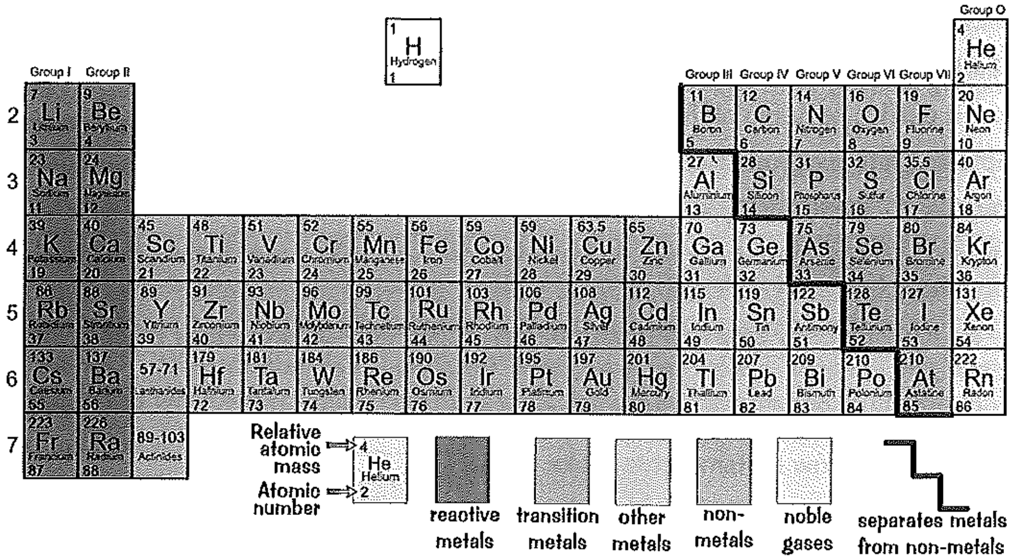
Excessive ethanol drinking — when a tipple becomes a topple...

People have been making alcohol for thousands of years. It could explain why there are so many ancient ruins all over the place — maybe the Romans were always too drunk to finish the job properly...

The Periodic Table and Electron Shells

Here's your old friend from Section One, back again — because you need to know it really well.

The Periodic Table is a Table of All Known Elements



Hopefully you already know (from page 7) that:

1) the periodic table contains all of the 100 or so known elements...
2) ...in order of ascending atomic number...
3) ...and arranged into columns (groups) that share similar properties.

But that's really only half the story. Read on.

The atomic number is the number of protons, which conveniently also tells you the number of electrons. *See page 4 for more.*

Elements in a Group Have the Same Number of Outer Electrons

1) The elements in each group all have the same number of electrons in their outer shell. Group I elements have one outer electron, Group VII elements have seven outer electrons, and so on.
2) That's why they have similar properties. And that's why they're arranged in this way.
3) When only 50 or so elements were known, the periodic table was made by looking at the properties of the elements and arranging them in groups — the same groups that they are in today.
4) This next idea is extremely important to chemistry — so make sure you understand it:
   The properties of the elements are decided entirely by how many electrons they have.
   So atomic number is very significant, because it's equal to the number of electrons each atom has.
   But it's the number of electrons in the outer shell which is the really important thing.

Electron Shells are What Chemistry is All About

The fact that electrons form shells around atoms is the basis for the whole of chemistry. If they just whizzed round the nucleus any old how and didn't care about shells, there'd be no chemical reactions. No nothing in fact — because nothing would happen. The atoms would just sit there. But amazingly, they do form shells (if they didn't, we wouldn't even be here to wonder about it), and the electron arrangement of each atom determines the whole of its chemical behaviour. Phew. I mean electron arrangements explain practically the whole Universe. Pretty amazing.

I've got a periodic table — Queen Anne legs and everything...

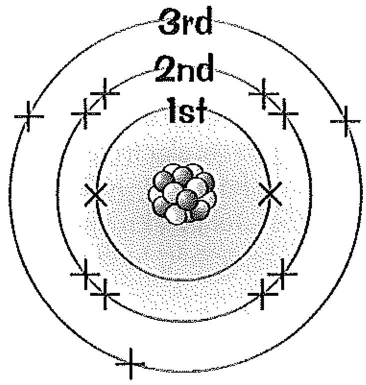
Physicists can produce new elements in particle accelerators, but they're all radioactive. Most only last a fraction of a second before they decay. They haven't even got round to giving most of them proper names yet, but then even "element 114" sounds pretty cool when you say it in Latin — ununquadium...

Electron Shells

I said it on the last page, but as it's got such a huge wow factor, I'll say it again — the fact that electrons occupy "shells" around the nucleus is what causes the whole of chemistry. And don't you forget it.

Electron Shell Rules:

1) Electrons always occupy shells (sometimes called energy levels).
2) The lowest energy levels are always filled first — these are the ones closest to the nucleus.
3) Only a certain number of electrons are allowed in each shell:
   1st shell: 2 2nd Shell: 8 3rd Shell: 8
   (This isn't strictly true, but it works for the first 20 elements so it's all you need to know for now.)
4) Atoms are much happier when they have full electron shells — like the noble gases in Group 0 (see p53).
5) In most atoms the outer shell is not full and this makes the atom want to react to fill it.

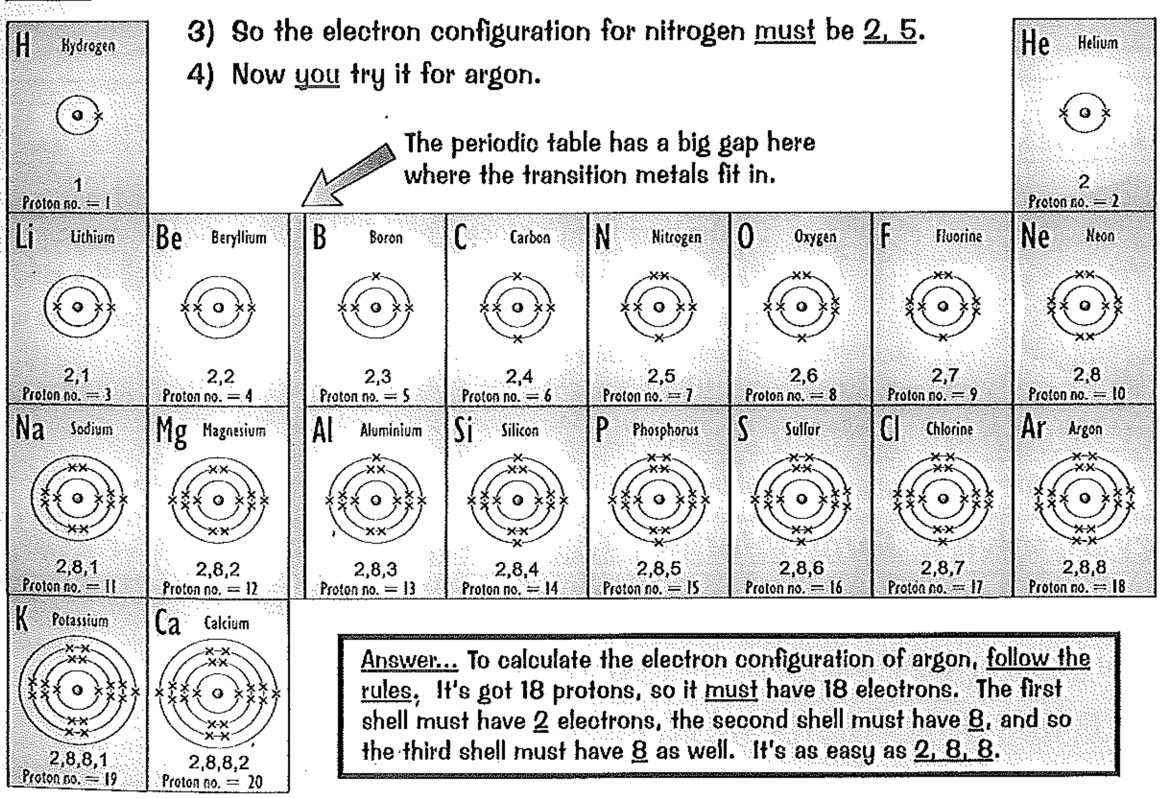


3rd shell still filling

Follow the Rules to Work Out Electron Configurations

You need to know the electron configurations for the first 20 elements (things get a bit more complicated after that). But they're not hard to work out. For a quick example, take nitrogen. Follow the steps...

1) The periodic table tells us nitrogen has seven protons... so it must have seven electrons.
2) Follow the 'Electron Shell Rules' above. The first shell can only take 2 electrons and the second shell can take a maximum of 8 electrons.
3) So the electron configuration for nitrogen must be 2, 5.
4) Now you try it for argon.



Answer... To calculate the electron configuration of argon, follow the rules. It's got 18 protons, so it must have 18 electrons. The first shell must have 2 electrons, the second shell must have 8, and so the third shell must have 8 as well. It's as easy as 2, 8, 8.

One little duck and two fat ladies — 2, 8, 8...

You need to know enough about electron shells to draw out that whole diagram at the bottom of the page without looking at it. Obviously, you don't have to learn each element separately, just learn the pattern. Cover the page and, using a periodic table, find the atom with the electron configuration 2, 8, 6.

Ionic Bonding

Ionic Bonding — Transferring Electrons

In ionic bonding, atoms lose or gain electrons to form charged particles (called ions) which are then strongly attracted to one another (because of the attraction of opposite charges, + and −).

A Shell with Just One Electron is Well Keen to Get Rid...

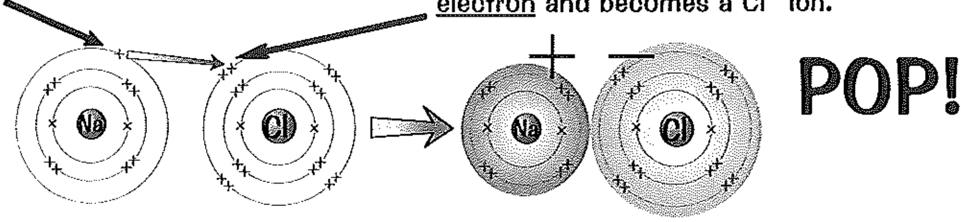
All the atoms over at the left-hand side of the periodic table, e.g. sodium, potassium, calcium etc. have just one or two electrons in their outer shell. And they're pretty keen to get shot of them, because then they'll only have full shells left, which is how they like it. So given half a chance they do get rid, and that leaves the atom as an ion instead. Now ions aren't the kind of things that sit around quietly watching the world go by. They tend to leap at the first passing ion with an opposite charge and stick to it like glue.

A Nearly Full Shell is Well Keen to Get That Extra Electron...

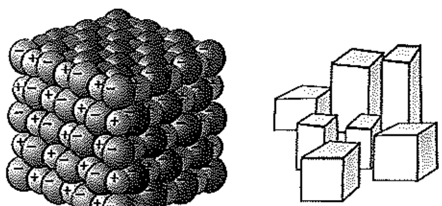
On the other side of the periodic table, the elements in Group VI and Group VII, such as oxygen and chlorine, have outer shells which are nearly full. They're obviously pretty keen to gain that extra one or two electrons to fill the shell up. When they do of course they become ions (you know, not the kind of things to sit around) and before you know it, pop, they've latched onto the atom (ion) that gave up the electron a moment earlier. The reaction of sodium and chlorine is a classic case:

The sodium atom gives up its outer electron and becomes an Na^+ ion.

The chlorine atom picks up the spare electron and becomes a Cl^- ion.



Giant Ionic Structures Don't Melt Easily, but When They Do...



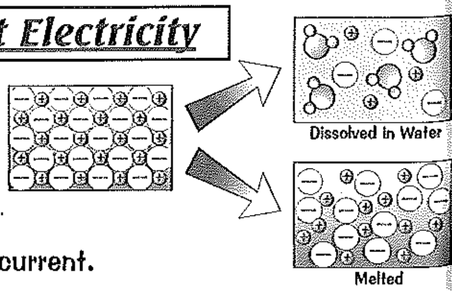
1) Ionic bonds always produce giant ionic structures.
2) The ions form a closely packed regular lattice arrangement.
3) There are very strong chemical bonds between all the ions.
4) A single crystal of salt is one giant ionic lattice, which is why salt crystals tend to be cuboid in shape.

1) They Have High Melting Points and Boiling Points

This is due to the very strong chemical bonds between all the ions in the giant structure.

2) They Dissolve to Form Solutions That Conduct Electricity

When dissolved the ions separate and are all free to move in the solution, so obviously they'll carry electric current. Dissolved lithium salts are used to make rechargeable batteries.



3) They Conduct Electricity When Molten

When it melts, the ions are free to move and they'll carry electric current.

Giant ionic lattices — all over your chips...

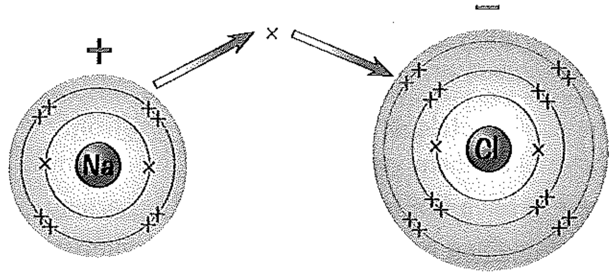
Because they conduct electricity when they're dissolved in water, ionic compounds are used to make some types of battery. In the olden days, most batteries had actual liquid in, so they tended to leak all over the place. Now they've come up with a sort of paste that doesn't leak but still conducts. Clever.

Ions and Formulas

Groups I & II and VI & VII are the Most Likely to Form Ions

1) Remember, atoms that have lost or gained an electron (or electrons) are ions.
2) The elements that most readily form ions are those in Groups I, II, VI and VII.
3) Group I and II elements are metals and they lose electrons to form +ve ions or cations.
4) Group VI and VII elements are non-metals. They gain electrons to form –ve ions or anions.
5) Make sure you know these easy ones:

Cations		Anions	
Gr I	Gr II	Gr VI	Gr VII
Li^+	Be^{2+}	O^{2-}	F^-
Na^+	Mg^{2+}		Cl^-
K^+	Ca^{2+}		Br^-



6) When any of the above cations react with the anions, they form ionic bonds.
7) Only elements at opposite sides of the periodic table will form ionic bonds, e.g. Na and Cl, where one of them becomes a cation (+ve) and one becomes an anion (–ve).

Remember, the + and – charges, e.g. Na^+ for sodium, just tell you what type of ion the atom WILL FORM in a chemical reaction. In sodium metal there are only neutral sodium atoms, Na. The Na^+ ions will only appear if the sodium metal reacts with something like water or chlorine.

A useful way of representing ions is to give the ion's name, then its electron configuration and the charge on the ion. For example, the electronic structure of the sodium ion Na^+ can be represented by Na $[2, 8]^+$. That's the electron configuration followed by the charge on the ion. Simple enough.

You Need to Know These Chemical Formulas

You need to be able to write down the right chemical formulas for ionic compounds.
That means you have to learn the stuff in the table below, and know how to use it.
The main thing to remember is that in compounds the total charge must always add up to zero.

Positive Ions						Negative Ions	
Lithium	Li^+	Barium	Ba^{2+}	Zinc	Zn^{2+}	Chloride	Cl^-
Sodium	Na^+	Magnesium	Mg^{2+}	Manganese(II)	Mn^{2+}	Hydroxide	OH^-
Potassium	K^+	Iron(II)	Fe^{2+}	Aluminium	Al^{3+}	Oxide	O^{2-}
		Copper(II)	Cu^{2+}	Iron(III)	Fe^{3+}	Carbonate	CO_3^{2-}

Some metals (e.g. copper, iron and manganese) can form different ions with different charges. The number in brackets after the name tells you the size of the positive charge on the ion. If you ever see them in compounds written without a number, assume 'manganese' is manganese(II) and 'copper' is copper(II).

EXAMPLE: Find the formula for zinc carbonate.
A zinc ion has a +2 charge and a carbonate ion has a –2 charge. So the formula of zinc carbonate must be: $ZnCO_3$

EXAMPLE: Find the formula for aluminium oxide.
An aluminium ion is Al^{3+} and an oxide ion is O^{2-}. To balance the total charge you need two aluminium ions to every three oxide ions. Al_2O_3

Any old ion, any old ion — any, any, any old ion...

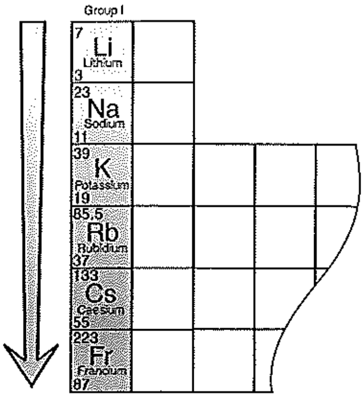
Learn which atoms will form 1^+, 1^-, 2^+ and 2^- ions, and why. Then have a go at these:
1) What ions will each of these elements form? Write out their electron configurations:
a) potassium, b) aluminium, c) beryllium, d) sulfur, e) fluorine. (use a periodic table) Answers on page 124.

Group 1 — Alkali Metals

Time to start getting to know a few of these periodic table groups a little better. First up, alkali metals.

Group 1 Metals are Known as the 'Alkali Metals'

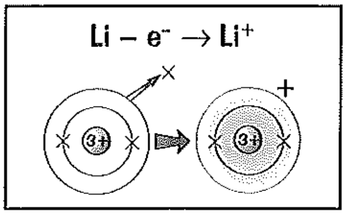
Group 1 metals include lithium, sodium and potassium... know those three names really well. They could also ask you about rubidium and caesium.



> As you go DOWN Group 1, the alkali metals become more reactive — the outer electron is more easily lost, because it's further from the nucleus and more shielded from it by the inner shells.

1) The alkali metals all have ONE outer electron. This makes them very reactive and gives them all similar properties.
2) They all have the following physical properties:
   - Low melting point and boiling point (compared with other metals),
   - Low density — lithium, sodium and potassium float on water,
   - Very soft — they can be cut with a knife.
3) The alkali metals always form ionic compounds. They are so keen to lose the outer electron there's no way they'd consider sharing, so covalent bonding (see p50) is out of the question.

Oxidation is the Loss of Electrons

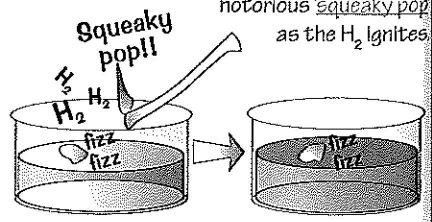


1) Group 1 metals are keen to lose an electron to form a 1^+ ion with a stable electronic structure.
2) The more reactive the metal the happier it is to lose an electron.
3) Loss of electrons is called OXIDATION.

Reaction with Cold Water Produces Hydrogen Gas

1) When lithium, sodium or potassium are put in water, they react very vigorously.
2) They move around the surface, fizzing furiously.
3) They produce hydrogen.
4) The reactivity with water increases down the group — the reaction with potassium gets hot enough to ignite it.
5) Sodium and potassium melt in the heat of the reaction.
6) They form a hydroxide in solution, i.e. aqueous OH^- ions.

A lighted splint will indicate hydrogen by producing the notorious 'squeaky pop' as the H_2 ignites.



2Na	+	$2H_2O$	→	2NaOH	+	H_2
Sodium	+	Water	→	Sodium hydroxide	+	Hydrogen

The solution becomes alkaline, which changes the colour of the pH indicator (see page 65) to purple.

Alkali Metal Compounds Burn with Characteristic Colours

1) Dip a wire loop into some hydrochloric acid to clean it.
2) Put the loop into a powered sample of the compound to be tested, then place the end in a blue Bunsen flame.
3) Alkali metal ions will give pretty coloured flames — the colour of the flame tells you which alkali metal is present.

Lithium:	Red flame
Sodium:	Yellow/orange flame
Potassium:	Lilac flame

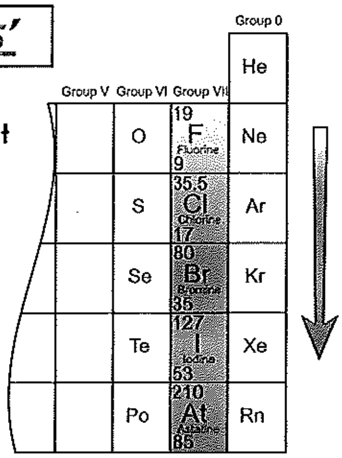
Red and orange and pink and green — or something like that...

Alkali metals are really reactive. They're so reactive, in fact, that they have to be stored in oil — otherwise they react with the air. Learn the trends and characteristics of alkali metals before carrying on.

Group VII — Halogens

Next you'll be meeting the halogens. Besides appearing on this page, these little blighters also crop up on pages in this section about bonding. They can form covalent bonds (see pages 50 and 52) as well as ionic bonds (see pages 46 and 47).

Group VII Elements are Known as the 'Halogens'



Group VII is made up of fluorine, chlorine, bromine, iodine and astatine.

All Group VII elements have 7 electrons in their outer shell — so they've all got similar properties.

> As you go DOWN Group VII, the halogens become less reactive — there's less to pull the extra electron in to fill the outer shell when it's further out and more shielded from the positive nucleus.

Chlorine is a fairly reactive, poisonous, dense green gas.
Bromine is a dense, poisonous, orange liquid.
Iodine is a dark grey crystalline solid.

Reduction is the Gain of Electrons

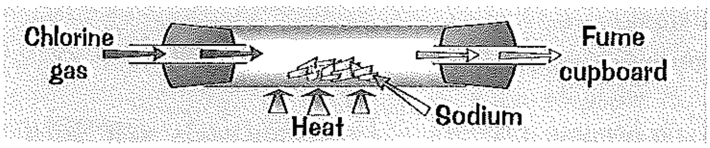
1) Halogens are keen to gain an electron to form a I^- ion with a stable electronic structure.
2) The more reactive the halogen, the happier it is to gain an electron.
3) Gain of electrons is called REDUCTION.

$$Cl_2 + 2e^- \rightarrow 2Cl^-$$

Halogen molecule → Halide ion

The Halogens React with Alkali Metals to Form Salts

They react vigorously with alkali metals to form salts called 'metal halides'.



$$2Na + Cl_2 \rightarrow 2NaCl$$

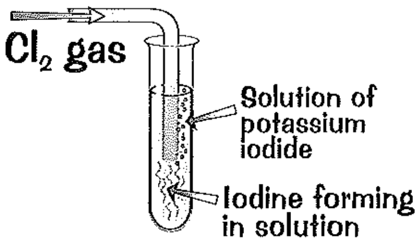
Sodium + Chlorine → Sodium chloride

$$2K + Br_2 \rightarrow 2KBr$$

Potassium + Bromine → Potassium bromide

More Reactive Halogens Will Displace Less Reactive Ones

Chlorine can displace bromine and iodine from a solution of bromide or iodide.
Bromine will also displace iodine because of the trend in reactivity.



$$Cl_2 + 2KI \rightarrow I_2 + 2KCl$$

Chlorine + Potassium iodide → Iodine + Potassium chloride

$$Cl_2 + 2KBr \rightarrow Br_2 + 2KCl$$

Chlorine + Potassium bromide → Bromine + Potassium chloride

Halogens — one electron short of a full shell...

The halogens are another group from the periodic table, and just like the alkali metals (p48) you've got to learn their trends and the equations on this page. Learn them, cover up the page, scribble, check.

Covalent Bonding

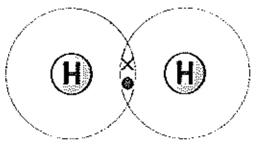
Covalent Bonds — Sharing Electrons

1) Sometimes atoms prefer to make covalent bonds by sharing electrons with other atoms.
2) This way both atoms feel that they have a full outer shell, and that makes them happy.
3) Each covalent bond provides one extra shared electron for each atom.
4) Each atom involved has to make enough covalent bonds to fill up its outer shell.
5) Learn these seven important examples:

You only have to draw the outer shell of electrons.

1) Hydrogen, H_2

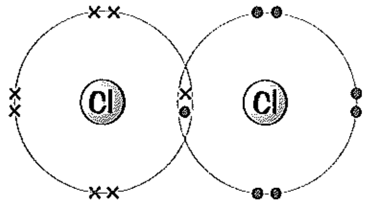
Hydrogen atoms have just one electron. They only need one more to complete the first shell...



or H—H

2) Chlorine, Cl_2

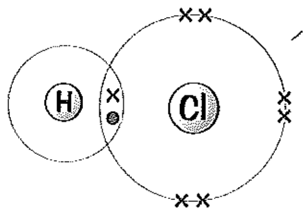
...chlorine atoms also need only one more electron...



or Cl—Cl

...so they often form single covalent bonds to achieve this.

3) Hydrogen Chloride, HCl

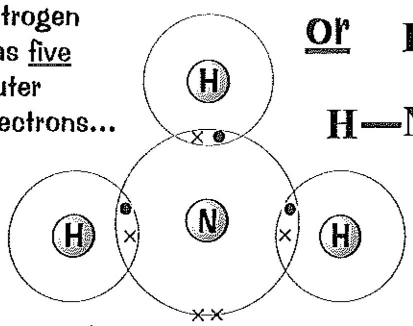


or H—Cl

This is very similar to H_2 and Cl_2. Again, both atoms only need one more electron to complete their outer shells.

4) Ammonia, NH_3

Nitrogen has five outer electrons...



or

```
    H
    |
H — N — H
```

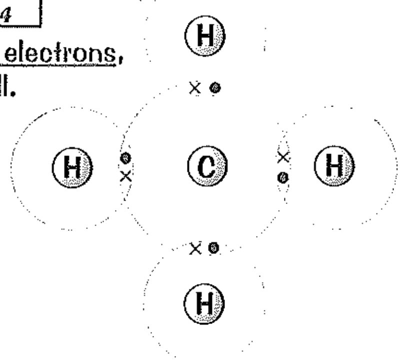
...so it needs to form three covalent bonds to make up the extra three electrons needed.

5) Methane, CH_4

Carbon has four outer electrons, which is half a full shell.

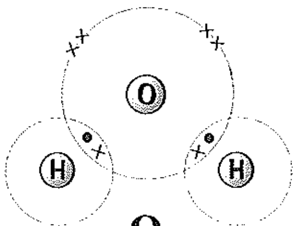
or

```
    H
    |
H — C — H
    |
    H
```



To become a 4^+ or a 4^- ion is hard work, so it forms four covalent bonds to make up its outer shell.

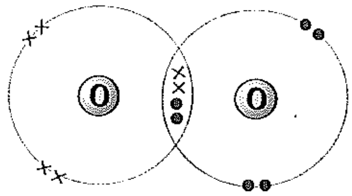
6) Water, H_2O



or

```
  O
 / \
H   H
```

7) Oxygen, O_2



or O=O

Oxygen atoms have six outer electrons. They sometimes form ionic bonds by taking two electrons to complete their outer shell. However, they'll also cheerfully form covalent bonds and share two electrons instead. In water molecules, the oxygen shares electrons with the H atoms and in oxygen gas it shares with another oxygen atom.

Covalent bonding — it's good to share...

Make sure you learn these seven really basic examples and why they work. Every atom wants a full outer shell, and they can get that either by becoming an ion (p46-47) or by sharing electrons. Once you understand that, you should be able to apply it to any example they give you in the exam.

Giant Covalent Structures

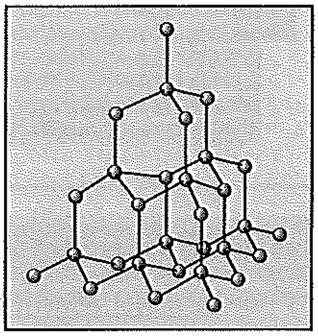
Substances formed from covalent bonds can either be simple molecules (see p52) or giant structures. This page is all about the giant structures, with three examples to learn.

Giant Covalent Structures

1) These are similar to giant ionic structures except that there are no charged ions.
2) All the atoms are bonded to each other by strong covalent bonds.
3) They have very high melting and boiling points.
4) They don't conduct electricity — not even when molten (except for graphite that is — see below).
5) They're usually insoluble in water.
6) Important examples are diamond and graphite, which are both made only from carbon atoms.

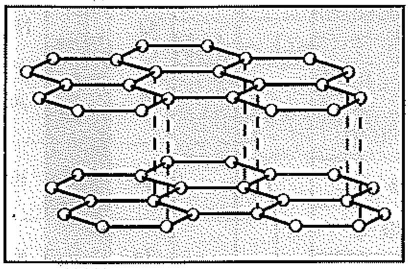
Make Sure You Know These Three Examples

Diamond



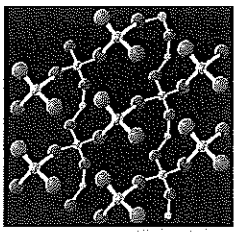
1) Diamonds are sparkly, colourless and clear. Ideal for jewellery.
2) Each carbon atom forms four covalent bonds in a very rigid giant covalent structure, which makes diamond the hardest natural substance. This makes diamonds ideal as cutting tools.
3) All those strong covalent bonds give diamond a very high melting point.
4) It doesn't conduct electricity because it has no free electrons.

Graphite



1) Graphite is black and opaque, but still kind of shiny.
2) Each carbon atom only forms three covalent bonds, creating sheets of carbon atoms which are free to slide over each other. This makes graphite slippery, so it's useful as a lubricant.
3) The layers are held together so loosely that they can be rubbed off onto paper to leave a black mark — that's how pencils work.
4) Graphite's got a high melting point — the covalent bonds need loads of energy to break.
5) Only three out of each carbon's four outer electrons are used in bonds, so there are lots of spare electrons. This means graphite conducts electricity — it's used for electrodes. See p103.

Silicon Dioxide (Silica)



1) Sometimes called silica, this is what sand is made of.
2) Each grain of sand is one giant structure of silicon and oxygen.
3) Silica can be melted down with sodium carbonate (Na_2CO_3) and limestone ($CaCO_3$) to make glass.

Carbon is a girl's best friend...

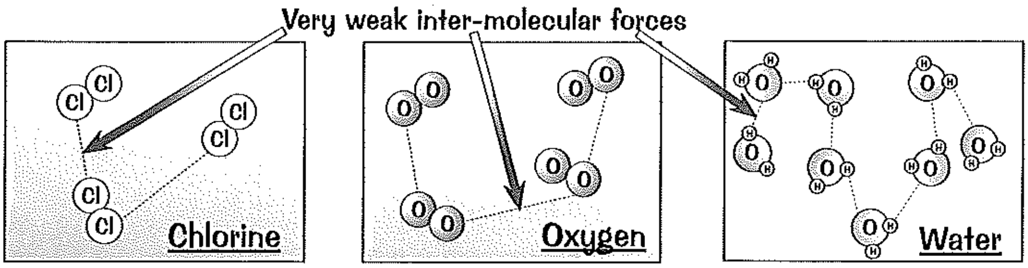
Graphite and diamond are both made purely from carbon — there's no difference at all in the atoms that make them up. The difference in properties (and price) of the two substances is all down to the way the atoms are held together. Different structural forms of the same element like this are called allotropes.

Simple Molecular Covalent Structures

Atoms that bond covalently don't all form giants structures. Some form simple molecular substances.

Simple Molecular Substances

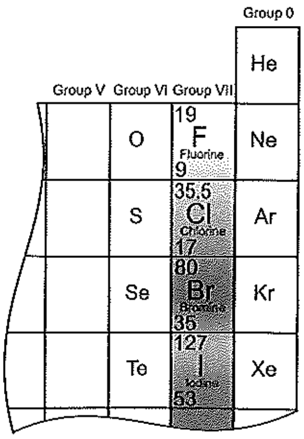
1) The atoms form very strong covalent bonds to form small molecules of two or more atoms.
2) By contrast, the forces of attraction between these molecules are very weak.
3) The result of these feeble inter-molecular forces is that the melting and boiling points are very low, because the molecules are easily parted from each other.
4) Most molecular substances are gases or liquids at room temperature.
5) Molecular substances don't conduct electricity, simply because there are no ions.
6) You can usually tell a molecular substance just from its physical state, which is always kinda 'mushy' — i.e. liquid or gas or an easily-melted solid.



The Halogens are All Simple Molecular

1) The physical properties of the halogens change down the group. Particularly, melting point and boiling point both increase.
2) This is because of the strength of the inter-molecular forces.

	Properties				
Group VII Elements	Atomic number	Colour	Physical state at room temperature	Melting point	Boiling point
Fluorine	9	yellow	gas	–220 °C	–188 °C
Chlorine	17	green	gas	–102 °C	–34 °C
Bromine	35	red-brown	liquid	–7 °C	59 °C
Iodine	53	dark grey	solid	114 °C	184 °C



3) The pattern in properties in the table can be explained because:
   - the halogens get bigger as you go down the group,
   - the bigger the halogen molecule, the stronger the inter-molecular forces of attraction,
   - the stronger the forces, the more energy it takes to separate the molecules, and so the higher their melting points and boiling points.
4) The little molecules of fluorine and chlorine have the weakest attraction to each other, so it takes very little energy to break them apart. That makes them gases at room temperature. The bigger molecules of bromine have stronger attractions, so it's a liquid at room temperature. Iodine's molecules are larger still, its inter-molecular forces are the strongest of the four, and it's a solid.

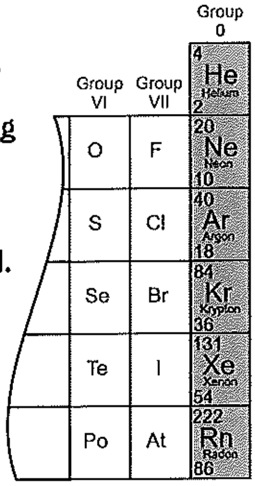
Simple molecules? — not so sure about that...

So, simple molecules are held together by weedy, pathetic inter-molecular forces. But these forces get gradually less weedy as the molecules get bigger. That's why the halogens get more solid down the group. It's also why the hydrocarbons (see page 17) get less runny as they get bigger.

Group 0 — The Noble Gases

The noble gases — stuffed full of every honourable virtue. They don't form covalent bonds or ionic bonds, making them — well, a bit dull really.

Group 0 Elements are All Inert, Colourless Gases



1) Group 0 elements are called the noble gases and include the elements helium, neon and argon (plus a few others).
2) The noble gases were only discovered just over 100 years ago — it took so long to find them because they have properties that make them hard to observe...
3) All elements in Group 0 are colourless gases at room temperature.
4) They are also more or less inert — this means they don't react with much at all. They don't bond with anything, not even with each other, and so they just wander about as single atoms. The reason for this is that they have a full outer shell. This means they don't want to give up or gain or share electrons.
5) Luckily the noble gases all have a dead handy property that lets you see them — they each give out light if you pass an electric current through them. Each noble gas gives out a particular colour of light.

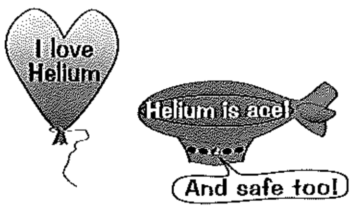
The Noble Gases have Many Everyday Uses...

Neon is used in electrical discharge tubes

Neon lights are used in tacky shop signs — the kind you'd expect to see if you visited Las Vegas. They don't use much current so they're cheap to run, and they give out a bright red light.

Noble Gases are used in Lasers too

There's the famous red helium-neon laser and the more powerful argon laser.



Helium is used in Airships and Party Balloons

Helium has a lower density than air — so it makes balloons float. And it's a lot safer to use than hydrogen (the famous airship Hindenburg was filled with hydrogen and caught fire).

Argon is used in Filament Lamps (Light Bulbs)

It provides an inert atmosphere which stops the very hot filament from burning away.

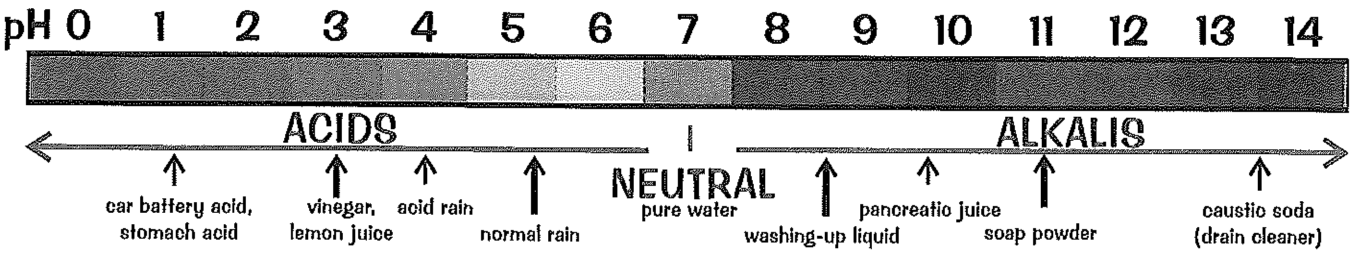
They don't react — that's Noble De use to us chemists...

Well, they don't react so there's a bit less to learn about the noble gases. The main thing to make sure you've grasped is why they don't — because they're quite happy with their full outer shells, thank you.

Acids and Bases

You'll find acids and bases at home, in industry and in the lab — they're an important set of chemicals.

The pH Scale and Universal Indicator



An Indicator is Just a Dye That Changes Colour

The dye in the indicator changes colour depending on whether it's above or below a certain pH. Universal indicator is a very useful combination of dyes which gives the colours shown above. It's very useful for estimating the pH of a solution.

The pH Scale Goes from 0 to 14

1) A very strong acid has pH 0. A very strong alkali has pH 14.
2) A neutral substance has pH 7 (e.g. pure water).

Acids and Bases Neutralise Each Other

An ACID is a substance with a pH of less than 7. Acids form H^+ ions in water.
A BASE is a substance with a pH of greater than 7.
An ALKALI is a base that DISSOLVES IN WATER. Alkalis form OH^- ions in water.

The reaction between acids and bases is called neutralisation. Make sure you learn it:

$$\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}$$

Neutralisation can also be seen in terms of H^+ and OH^- ions like this, so learn this too:

$$H^+ + OH^- \rightarrow H_2O$$

When an acid neutralises a base (or vice versa), the products are neutral, i.e. they have a pH of 7.

Modern Industry Uses Tonnes of Sulfuric Acid

1) Sulfuric acid is used in car batteries, where it's concentrated enough to cause severe burns.
2) It's also used in many manufacturing processes, such as making fertilisers and detergents.
3) You can also use it to clean and prepare metal surfaces, e.g. before painting or welding. A metal surface is usually covered with a layer of insoluble metal oxide. Sulfuric acid reacts with these, forming soluble metal salts which wash away, nice and easily.

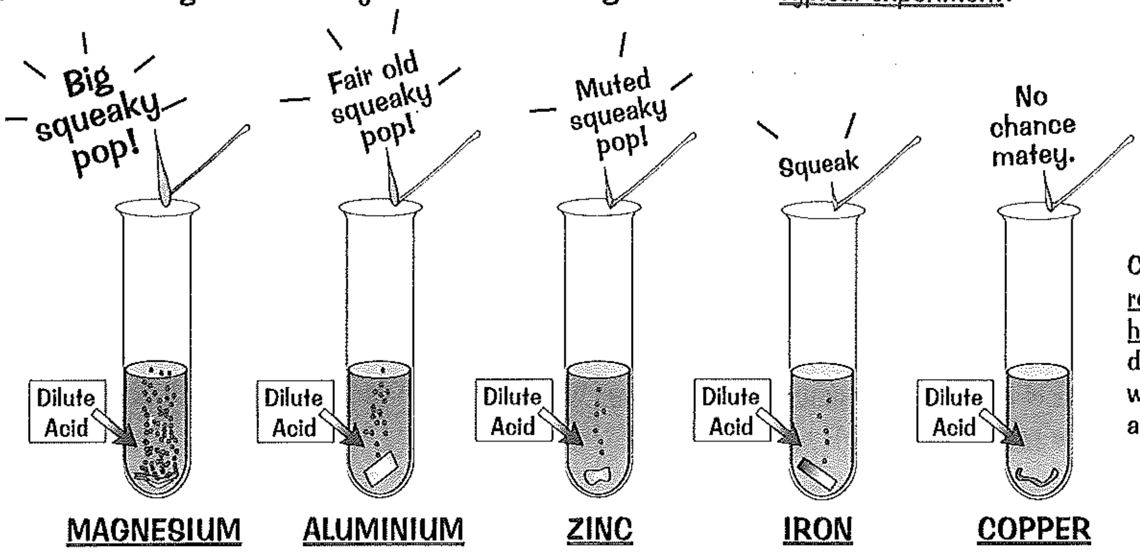
This'll give you a firm base for Chemistry...

There's no getting away from acids and bases in Chemistry, or even in real life. They're everywhere — acids are found in loads of foods, like vinegar and fruit, and as food flavourings and preservatives, while alkalis (particularly sodium hydroxide) are used to help make all sorts of things, from soaps to ceramics.

Acids Reacting with Metals

Acid + Metal → Salt + Hydrogen

That's written big 'cos it's really worth remembering. Here's the typical experiment:



Copper is less reactive than hydrogen so it doesn't react with dilute acids at all.

1) The more reactive the metal, the faster the reaction will go — very reactive metals (e.g. sodium) react explosively.
2) Copper does not react with dilute acids at all — because it's less reactive than hydrogen.
3) The speed of the reaction is indicated by the rate at which the bubbles of hydrogen are given off.
4) The hydrogen is confirmed by the burning splint test giving the notorious 'squeaky pop'.
5) The name of the salt produced depends on which metal is used, and which acid is used:

Hydrochloric Acid Will Always Produce Chloride Salts:

$2HCl + Mg \rightarrow MgCl_2 + H_2$ (Magnesium chloride)

$6HCl + 2Al \rightarrow 2AlCl_3 + 3H_2$ (Aluminium chloride)

$2HCl + Zn \rightarrow ZnCl_2 + H_2$ (Zinc chloride)

Sulfuric Acid Will Always Produce Sulfate Salts:

$H_2SO_4 + Mg \rightarrow MgSO_4 + H_2$ (Magnesium sulfate)

$3H_2SO_4 + 2Al \rightarrow Al_2(SO_4)_3 + 3H_2$ (Aluminium sulfate)

$H_2SO_4 + Zn \rightarrow ZnSO_4 + H_2$ (Zinc sulfate)

Chloride and sulfate salts are generally soluble in water
(the main exceptions are lead chloride, lead sulfate and silver chloride, which are insoluble).

Nitric Acid Produces Nitrate Salts When NEUTRALISED, But...

Nitric acid reacts fine with alkalis, to produce nitrates, but it can play silly devils with metals and produce nitrogen oxides instead, so we'll ignore it here. Chemistry's a really messy subject sometimes, innit.

Nitric acid, tut — there's always one...

Okay, so this stuff isn't exactly a laugh a minute, but at least it's fairly straightforward learning. Metals that are less reactive than hydrogen don't react with acid, and some metals like sodium and potassium are too reactive to mix with acid — your beaker would explode.

Neutralisation Reactions

Metal Oxides and Metal Hydroxides are Bases

1) Some metal oxides and metal hydroxides dissolve in water. These soluble compounds are alkalis.
2) Even bases that won't dissolve in water will still react with acids.
3) So, all metal oxides and metal hydroxides react with acids to form a salt and water.

Acid + Metal Oxide → Salt + Water

Acid + Metal Hydroxide → Salt + Water

(These are neutralisation reactions, of course.)

Hydrochloric acid	+	Copper oxide	→	Copper chloride	+	Water
2HCl	+	CuO	→	$CuCl_2$	+	H_2O
Sulfuric acid	+	Potassium hydroxide	→	Potassium sulfate	+	Water
H_2SO_4	+	2KOH	→	K_2SO_4	+	$2H_2O$
Nitric acid	+	Sodium hydroxide	→	Sodium nitrate	+	Water
HNO_3	+	NaOH	→	$NaNO_3$	+	H_2O

Acids and Carbonates Produce Carbon Dioxide

These are very like the ones above — they just produce carbon dioxide as well.

Acid + Carbonate → Salt + Water + Carbon dioxide

Hydrochloric acid	+	Sodium carbonate	→	Sodium chloride	+	Water	+	Carbon dioxide
2HCl	+	Na_2CO_3	→	2NaCl	+	H_2O	+	CO_2
Hydrochloric acid	+	Calcium carbonate	→	Calcium chloride	+	Water	+	Carbon dioxide
2HCl	+	$CaCO_3$	→	$CaCl_2$	+	H_2O	+	CO_2

Acids and Ammonia Produce Ammonium Salts

And lastly... **Acid + Ammonia → Ammonium salt**

Hydrochloric acid	+	Ammonia	→	Ammonium chloride
HCl	+	NH_3	→	NH_4Cl
Sulfuric acid	+	Ammonia	→	Ammonium sulfate
H_2SO_4	+	$2NH_3$	→	$(NH_4)_2SO_4$
Nitric acid	+	Ammonia	→	Ammonium nitrate
HNO_3	+	NH_3	→	NH_4NO_3

This last reaction with nitric acid produces ammonium nitrate fertiliser, much appreciated for its double dose of nitrogen (essential for healthy plant growth).

Acid + Revision → Insomnia Cure...

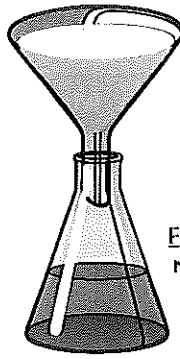
Some of these reactions are really useful, and some are just for fun (who said Chemistry was dull). Try doing different combinations of acids and alkalis, acids and carbonates, acids and ammonia. Balance them. Cover the page and scribble all the equations down. If you make a mistake, try again.

Making Salts

Most chloride, sulfates and nitrates are soluble in water (the main exceptions are lead chloride, lead sulfate and silver chloride). Most oxides, hydroxides and carbonates are insoluble in water.

Making Soluble Salts from Insoluble Bases

1) You need to pick the right acid, plus a metal carbonate or metal hydroxide, as long as it's insoluble. You can't use sodium, potassium or ammonium carbonates or hydroxides, as they're soluble (so you can't tell whether the reaction has finished — see below).
2) You add the carbonate or hydroxide to the acid until all the acid is neutralised. (The excess carbonate or hydroxide will just sink to the bottom of the flask when all the acid has reacted.)
3) Then filter out the excess carbonate, and evaporate off the water — and you should be left with a pure, dry salt.



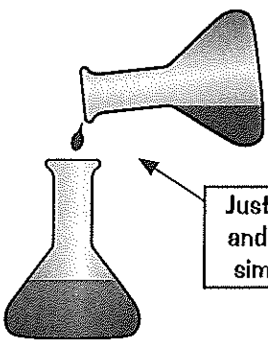
Filtering — to get rid of the excess carbonate or hydroxide.

E.g. you can use copper carbonate and nitric acid to make copper nitrate:

$$CuCO_{3\,(s)} + 2HNO_{3\,(aq)} \longrightarrow Cu(NO_3)_{2\,(aq)} + CO_{2\,(g)} + H_2O_{(l)}$$

Ammonia itself is a base, but it's SOLUBLE, as are all other ammonium bases. This means making soluble ammonium salts, such as ammonium nitrate, is a bit tricky. You can't just add an excess of base and filter out what's left — you have to add exactly the right amount of base to just neutralise the acid. You need to use an indicator to show when the reaction's finished. Then repeat using exactly the same volumes of base and acid so the salt isn't contaminated with indicator. All this is quite fiddly. But ammonium nitrate is a great fertiliser, so it's all worthwhile in the end (if you want nice big crops to grow that is).

Making Insoluble Salts — Precipitation Reactions



1) If the salt you want to make is insoluble, you can use a precipitation reaction (see page 70).
2) You just need to pick the right acid and nitrate, then mix them together. E.g. if you want to make lead chloride (which is insoluble), mix hydrochloric acid and lead nitrate.
3) Once the salt has precipitated out (and is lying at the bottom of your flask), all you have to do is filter it from the solution, wash it and then dry it on filter paper.

E.g. $Pb(NO_3)_{2\,(aq)} + 2HCl_{(aq)} \longrightarrow PbCl_{2\,(s)} + 2HNO_{3\,(aq)}$

4) Precipitation reactions can be used to remove poisonous ions (e.g. lead) from drinking water. Calcium and magnesium ions can also be removed from water this way — they make water "hard", which stops soap lathering properly.

Making Salts by Displacement

Have a look at page 12 for more on displacement.

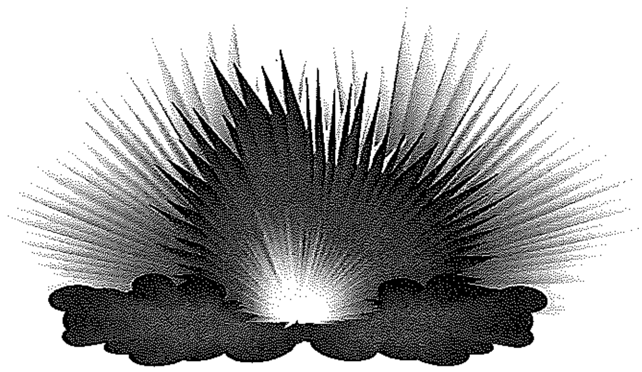
1) If you put a more reactive metal like magnesium into a salt solution of a less reactive metal, like copper sulfate, then the magnesium will take the place of the copper — and make magnesium sulfate.
2) The "kicked-out" (or displaced) metal then coats itself onto the more reactive metal.
3) Once the magnesium has been completely coated with copper, the reaction stops, so this isn't a very practical way to make a salt.

Get two beakers, mix 'em together — job's a good 'un...

It's hard to find the precise neutral point using universal indicator. There's quite a wide range of greens between blue and yellow. There are more accurate indicators though — see page 86 for more on these.

Rates of Reaction

Reactions Can Go at All Sorts of Different Rates



1) One of the slowest is the rusting of iron (it's not slow enough though — what about my little MGB).
2) A moderate speed reaction is a metal (like magnesium) reacting with acid to produce a gentle stream of bubbles.
3) A really fast reaction is an explosion, where it's all over in a fraction of a second.

The Rate of a Reaction Depends on Four Things:

1) Temperature
2) Concentration — (or pressure for gases)
3) Catalyst
4) Size of particles — (or surface area)

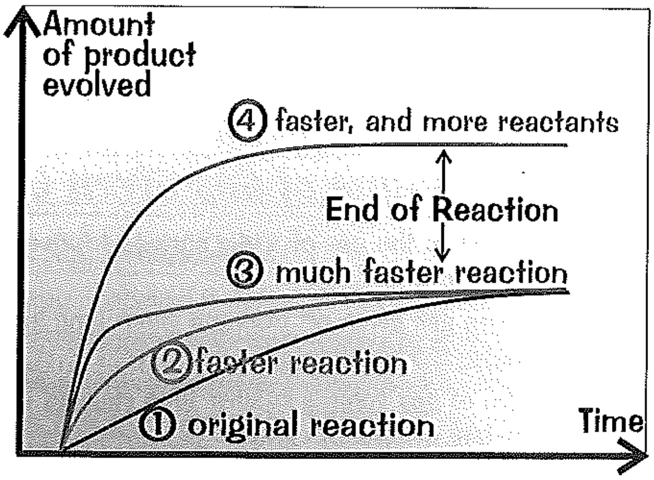
LEARN THEM!

Typical Graphs for Rate of Reaction

The plot below shows how the speed of a particular reaction varies under different conditions. The quickest reaction is shown by the line that becomes flat in the least time. The line that flattens out first must have the steepest slope compared to all the others, making it possible to spot the slowest and fastest reactions.

1) Graph 1 represents the original fairly slow reaction. The graph is not too steep.
2) Graphs 2 and 3 represent the reaction taking place quicker but with the same initial amounts. The slope of the graphs gets steeper.
3) The increased rate could be due to any of these:

> a) increase in temperature
> b) increase in concentration (or pressure)
> c) catalyst added
> d) solid reactant crushed up into smaller bits



4) Graph 4 produces more product as well as going faster. This can only happen if more reactant(s) are added at the start. Graphs 1, 2 and 3 all converge at the same level, showing that they all produce the same amount of product, although they take different times to get there.

How to get a fast, furious reaction — crack a wee joke...

Industrial reactions generally use a catalyst and are done at high temperature and pressure. Time is money, so the faster an industrial reaction goes the better... but only up to a point. Chemical plants are quite expensive to rebuild if they get blown into lots and lots of teeny tiny pieces.

Measuring Rates of Reaction

Three Ways to Measure the Speed of a Reaction

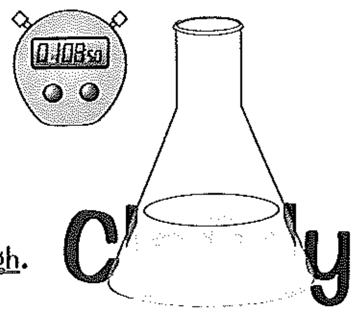
The speed of a reaction can be observed either by how quickly the reactants are used up or how quickly the products are formed. It's usually a lot easier to measure products forming.

The rate of reaction can be calculated using the following equation:

$$\text{Rate of Reaction} = \frac{\text{Amount of reactant used or amount of product formed}}{\text{Time}}$$

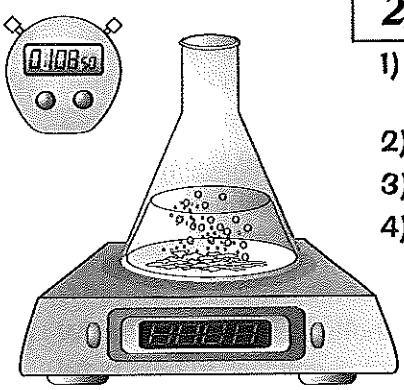
There are different ways that the speed of a reaction can be measured. Learn these three:

1) Precipitation



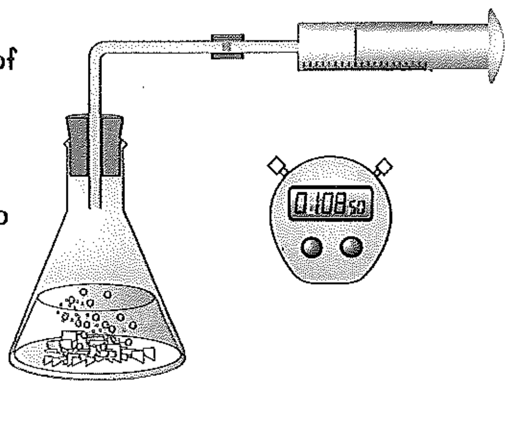
1) This is when the product of the reaction is a precipitate which clouds the solution.
2) Observe a marker through the solution and measure how long it takes for it to disappear.
3) The quicker the marker disappears, the quicker the reaction.
4) This only works for reactions where the initial solution is rather see-through.
5) The result is very subjective — different people might not agree over the exact point when the mark 'disappears'.

2) Change in Mass (Usually Gas Given Off)



1) Measuring the speed of a reaction that produces a gas can be carried out on a mass balance.
2) As the gas is released the mass disappearing is measured on the balance.
3) The quicker the reading on the balance drops, the faster the reaction.
4) Rate of reaction graphs are particularly easy to plot using the results from this method.
5) This is the most accurate of the three methods described on this page because the mass balance is very accurate. But it has the disadvantage of releasing the gas straight into the room.

3) The Volume of Gas Given Off



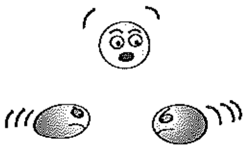
1) This involves the use of a gas syringe to measure the volume of gas given off.
2) The more gas given off during a given time interval, the faster the reaction.
3) A graph of gas volume against time elapsed could be plotted to give a rate of reaction graph.
4) Gas syringes usually give volumes accurate to the nearest millilitre, so they're quite accurate. You have to be quite careful though — if the reaction is too vigorous, you can easily blow the plunger out of the end of the syringe.

OK have you got your stopwatch ready *BANG!* — oh...

Each method has its pros and cons. The mass balance method is only accurate as long as the flask isn't too hot, otherwise you lose mass by evaporation as well as by the reaction. The first method isn't very accurate, but if you're not producing a gas you can't use either of the other two. Ah well.

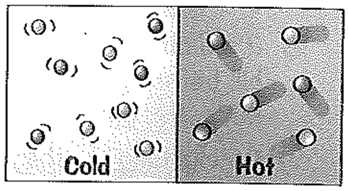
Collision Theory

Reaction rates are explained perfectly by collision theory. It's really simple. It just says that the rate of a reaction simply depends on how often and how hard the reacting particles collide with each other. The basic idea is that particles have to collide in order to react, and they have to collide hard enough (with enough energy).



More Collisions Increases the Rate of Reaction

All four methods of increasing the rate of reactions can be explained in terms of increasing the number of successful collisions between the reacting particles:

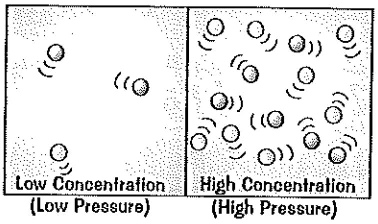


1) HIGHER TEMPERATURE increases collisions

When the temperature is increased the particles all move quicker. If they're moving quicker, they're going to have more collisions.

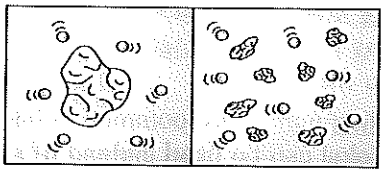
2) HIGHER CONCENTRATION (or PRESSURE) increases collisions

If a solution is made more concentrated it means there are more particles of reactant knocking about between the water molecules, which makes collisions between the important particles more likely. In a gas, increasing the pressure means the particles are more squashed up together so there are going to be more collisions.



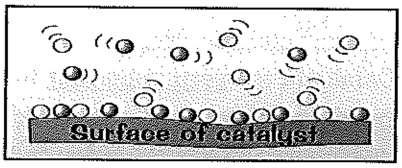
3) LARGER SURFACE AREA increases collisions

If one of the reactants is a solid then breaking it up into smaller pieces will increase its surface area. This means the particles around it in the solution will have more area to work on, so there'll be more useful collisions.



4) CATALYSTS increase the number of SUCCESSFUL collisions

A solid catalyst works by giving the reacting particles a surface to stick to. They increase the number of SUCCESSFUL collisions by lowering the activation energy (see next page).



Faster Collisions Increase the Rate of Reaction

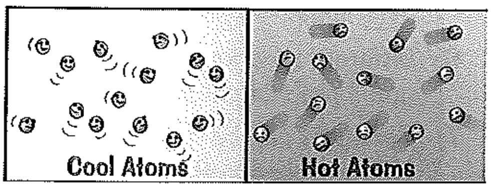
Higher temperature also increases the energy of the collisions, because it makes all the particles move faster.

Faster collisions are ONLY caused by increasing the temperature

Reactions only happen if the particles collide with enough energy.

At a higher temperature there will be more particles colliding with enough energy to make the reaction happen.

This initial energy is known as the activation energy, and it's needed to break the initial bonds.



Collision theory — the lamppost ran into me...

Once you've learnt everything off this page, the rates of reaction stuff should start making a lot more sense to you. The concept's fairly simple — the more often particles bump into each other, and the harder they hit when they do, the faster the reaction happens.

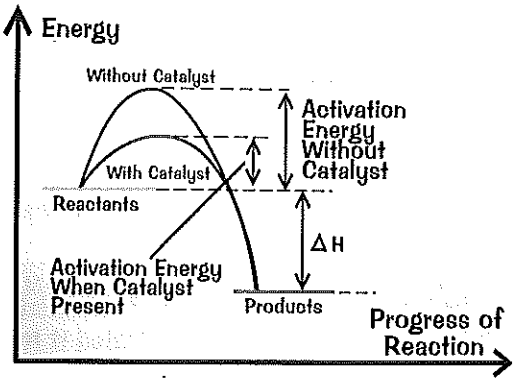
Catalysts

Many reactions can be speeded up by adding a catalyst.

A catalyst is a substance which changes the speed of a reaction, without being changed or used up in the reaction.

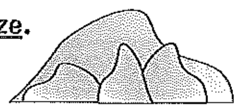
1) Catalysts Lower the Activation Energy

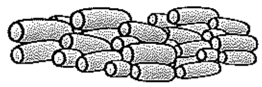
1) The activation energy is the minimum amount of energy needed for a reaction to happen.
2) It's a bit like having to climb up one side of a hill before you can ski/snowboard/sledge/fall down the other side.
3) Catalysts lower the activation energy of reactions, making it easier for them to happen.
4) This means a lower temperature can be used.

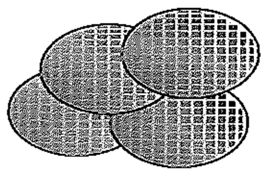


2) Solid Catalysts Work Best When They Have a Big Surface Area

1) Catalysts are usually used as a powder or pellets or a fine gauze.
2) This gives them a very large surface area to enable the reacting particles to meet up and do the business.


Catalyst Powder


Catalyst Pellets


Catalyst Gauzes

3) Transition metals are common catalysts in many industrial reactions, e.g. nickel can be used instead of aluminium oxide for cracking hydrocarbons (see p21) and iron catalyses the Haber process (see p81).

3) Catalysts Help Reduce Costs in Industrial Reactions

1) Catalysts are very important for commercial reasons — most industrial reactions use them.
2) Catalysts increase the rate of the reaction, which saves a lot of money simply because the plant doesn't need to operate for as long to produce the same amount of stuff.
3) Alternatively, a catalyst will allow the reaction to work at a much lower temperature. That reduces the energy used up in the reaction (the energy cost), which is good for sustainable development and can save a lot of money too.
4) There are disadvantages to using catalysts, though.
5) They can be very expensive to buy, and often need to be removed from the product and cleaned. They never get used up in the reaction though, so once you've got them you can use them over and over again.
6) Different reactions use different catalysts, so if you make more than one product at your plant, you'll probably need to buy different catalysts for them.
7) Catalysts can be 'poisoned' by impurities, so they stop working, e.g. sulfur can poison the iron catalyst used in the Haber process. That means you have to keep your reaction mixture very clean.

Catalysts are like great jokes — they can be used over and over...

And they're not only used in industry... every useful chemical reaction in the human body is catalysed by a biological catalyst (an enzyme). If the reactions in the body were just left to their own devices, they'd take so long to happen, we couldn't exist. Quite handy then, these catalysts.