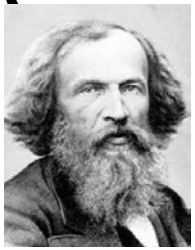
C2 History of the Periodic Table

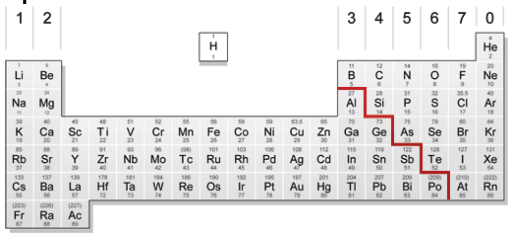


MENDELEEV - 1800s, a chemist put the properties of elements into a table:

- order of increasing atomic mass (number of protons and neutrons)
- Elements with similar properties into vertical columns (called ‘groups’). Horizontal rows are called periods
- sometimes broke the ‘increasing atomic mass rule’
  - he switched tellurium and iodine around so that they would be in the same groups as elements with similar properties
  - left some gaps in his table - realised from the big jumps in atomic mass that there were still some elements to discover. He predicted their properties

THE MODERN PERIODIC TABLE - elements in the modern periodic table are arranged in order of increasing atomic number rather than in order of increasing atomic mass

- In a chemical symbol the atomic number is the bottom number (the smaller one, number of protons) and the mass number is the top number (the bigger one, numbers of protons+neutrons)
- The vertical columns are called groups:
  - numbered 1-7 from left to right The group on the far right is called group 0.
- Diagram of periodic table below:
  - Elements to the left of the jagged line are metals
  - Elements to the right of the line are non-metals



Structure of the Atom

- The 3 subatomic particles are protons, neutrons, electrons.
- The nucleus contain protons and neutrons.
- The masses and charges of subatomic particles are very small and can only be measured relative to the mass of something else - the 'relative mass' and the 'relative charge'
- All atoms contain the same number of protons (+) and electrons(-) so there is no overall charge
- All elements have a different number of protons in their atoms

Relative atomic mass (A_r) - atoms have very small masses - relative atomic mass is used instead of its actual mass in kilograms. A_r is the top number shown in periodic table

- A_r is the relative mass of an atom based on the mass of Carbon atoms.
  - Carbon has a relative atomic mass of 12
  - Mass of a helium atom is one third that of carbon - its relative atomic mass is 4

Isotopes - different atoms of an element with the same number of protons and electrons, but different numbers of neutrons (i.e same atomic number, different mass number)

- The presence of isotopes means that some relative atomic masses aren't whole numbers:
  - The relative atomic mass is the <u>average mass</u> of all the different atoms (isotopes) of an element (relative to carbon), taking their abundance into account

Subatomic particle	Relative mass	Relative charge
Proton	1	+ 1
Neutron	1	0
Electron	Negligible (i.e 0)	- 1

Periodic Table - Questions

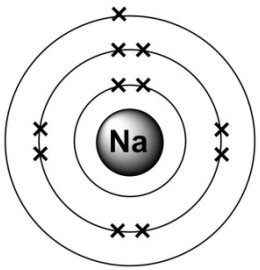
- How did Mendeleev order the elements?
- Why were elements placed in groups?
- How is the modern Table a bit different?
- Where is group 0?
- Explain how the stepped line divides the periodic table.

Structure of Atom - questions

- What is an atom made up of?
- What is the charge of an atom and why?
- Define relative atomic mass
- What is the relative atomic mass of a proton? A neutron? An electron?
- What is the relative charge of a proton? Neutron? Electron?
- What is an isotope?

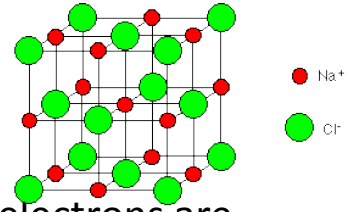
Electron Shells

- Electronic configuration - electrons are arranged in shells around the nucleus of the atom - shown as a circle drawn around the chemical symbol for the atom
- Full outer shells are stable
- Elements which have the maximum number of electrons in their outer shells are said to have 'full outer shells'. The first shell takes 2, the second 8, then 8, then 8…
- Electronic configurations can be worked out using atomic numbers e.g:
  - Atomic number of sodium is 11→it has 11 protons→11 electrons
  - 2 electrons in first shell
  - 8 electrons in second shell
  - 1 electron in third (outer) shell
  - Its electronic configuration can also be written in the form '2.8.1'. The dots separate each shell



- The number of occupied shells is the same as the period number:
  - E.g magnesium is in period 3 of the periodic table…its configuration is '2.8.2'…→has 3 occupied shells
- The number of outer electrons is the same as the group number (apart from elements in group 0 which all have full outer shells):
  - E.g magnesium is in group 2 of the periodic table…its configuration is '2.8.2'…→has 2 electrons in its outer shell

Ionic Compounds



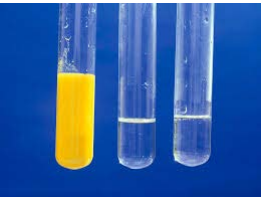
- An ion is an atom or groups of atoms with a positive or negative charge. When electrons are gained or lost, the atoms become ions. Ionic bonds form between +ve and -ve charged ions
- Atoms of most elements have incomplete outer shells. They lose/gain electrons during chemical reactions to obtain full outer shells
- **Cations:** Metal atoms lose their outermost electrons to form positively charged ions. For elements in groups 1 and 2, the number of outer electrons lost is the same as their group number: Sodium is in group 1, (2.8.1), loses 1 electron to become a Na^+ cation (2.8)
- **Anions:** Non-metal atoms gain electrons to form negatively charged ions. For elements in groups 6 and 7, the number of electrons they gain is 8 minus their group number: Oxygen is in group 6 (2.8.6), gains 2 electrons to become an anion (2.8.8)
- **Ionic Compounds**: form when a metal reacts with a non-metal because electrons lost by the metal are transferred to the oppositely charged non-metal
- **Names of ionic compounds:** Ionic compounds end in –ide (e.g NaCl - sodium chlor<u>ide</u>), if they contain oxygen, end in –ate (e.g $Mg(NO_3)_2$ - magnesium nitr<u>ate</u>)
- **Structure of ionic compounds:** ions in an ionic compound are tightly together and arranged in a regular lattice structure, held together by strong electrostatic forces of attraction (ionic bonds).
- **Properties of ionic compounds**: don't conduct electricity when solid (but they do when molten or in a solution) as the ions must be free to move; high boiling and melting points as ionic bonds are very strong and need a lot of energy to break

Electron Shells - questions

- Where are electrons in the atom?
- How many electrons do the first 3 shells take?
- How would you arrange the electrons in an atom with atomic number 11?
- How can you work out which period or row an atom is in?
- What is the connection between the group number and the number of outer shell electrons?

Ionic Compounds - Questions

- What is an ion?
- How do atoms gain full outer shells?
- What is the difference between an anion and a cation?
- How do you name ionic compounds?
- What is the structure of an ionic compound?
- What are the properties of ionic compounds?



Precipitates

Precipitation reactions: a reaction where an insoluble solid (precipitate) is produced from two soluble substances

Lead nitrate + potassium iodide → lead iodide + potassium nitrate

$Pb(NO_3)_{2\ (aq)} + 2KI_{\ (aq)} \rightarrow PbI_{2\ (s)} + 2KNO_{3\ (aq)}$

State symbols show that all substances are dissolved in water (aq) except for lead iodide, which is insoluble (so it's shown as a solid s)

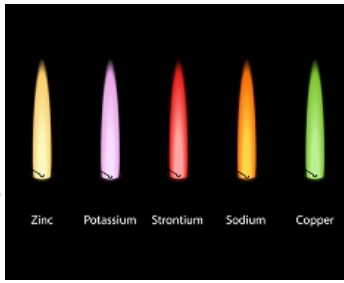
The precipitate is separated from the unreacted ions by filtration, washed on filter paper, dried in an oven.

Diagnosing intestinal problems: patients swallow a drink - 'barium meal' - containing barium sulfate. As it passes through the patient's digestive system, x-ray photos are taken. Barium (like bone) absorbs x-rays, shows up as white on the photos, shows problems with digestive system

Most barium salts are toxic but barium sulphate is insoluble, so can't enter the patient's blood so is safe to swallow

Soluble in water	Insoluble
All common sodium, potassium and ammonium salts	
All nitrates	
Most chlorides	Silver/lead chlorides or iodides
Most sulfates	lead/barium/ calcium sulfates
sodium/ potassium/ ammonium carbonates	Most carbonates
sodium/ potassium/ ammonium hydroxides	Most hydroxides

Ion Tests



Flame tests

- Different metal ions produce different coloured flames when held over a B burner flame

  Sodium (Na^+) = yellow. Potassium (K^+) = lilac. Calcium (Ca^{2+}) = red. Copper (II) (Cu^{2+}) =green/blue

Flame tests led to the discovery of new elements

In the 1800s did flame tests of different samples of mineral water and then used a prism to separate the colours of light given off - 'spectroscopy'. They saw a grey-blue colour that hadn't been seen before and discovered a new element – caesium. A year later rubidium was discovered (gave off a dark red colour in a Bunsen flame)

Precipitation tests to identify anions

Chloride ions (Cl^-) :Add dilute nitric acid and silver nitrate to the solution. If the sample contains chloride ions, a white precipitate of silver chloride will form

https://www.youtube.com/watch?v=vcQXdeL-juM

Sulfate ions (SO_4^{2-}):Add dilute hydrochloric acid and barium chloride to the solution. If solution contains sulfate ions, a white precipitate of barium sulfate will form

https://www.youtube.com/watch?v=kYApk6lwaoI

Test for carbonate ions: Add a dilute acid to the solution. If solution contains carbonate ions (CO_3^-), carbon dioxide gas will be given off, which when bubbled through limewater will turn it milky

https://www.youtube.com/watch?v=197iyKaRhtA

Precipitates - Questions

- What is a precipitation reaction?
- How would you recognise a precipitation reaction from the state symbols?
- Which chlorides are insoluble in water?
- Which hydroxides are soluble in water?
- What is barium meal used for?
- Why doesn’t barium poison us?

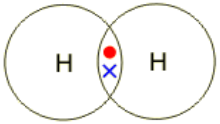
Ion Tests - Questions

- What is the flame colour for the sodium ion?
- How did flame tests lead to discovery of new elements?
- What is the precipitation test for Chloride ions?
- What is the precipitation test for Sulphate ions?
- What is the test for carbonate ions?

Covalent Bonds

- Non-metal compounds held together by pairs of electrons in the outer shell (covalent bonds)
- Electron sharing allows both atoms to have full outer shells (more stable) = formation of molecules
- Shown by dot-cross diagrams (only outer electrons are shown because they form the bonds)

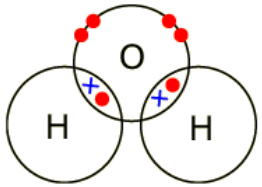
Between atoms of the same element:



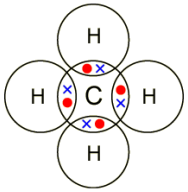
- 2 hydrogen <u>atoms</u> (H) form 1 <u>molecule</u> of hydrogen gas (H_2):
  - Each hydrogen atom contributes one electron to the covalent bond. Both hydrogen atoms have full outer shells. Stable H_2 molecule is formed.
- In diagram they're shown as dots and crosses to show which atom each electron is from

Between atoms of different elements:

- Water (H_2O):

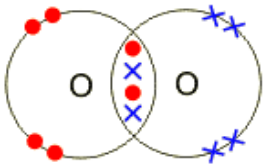


- Methane (CH_4):



Double bonds: Atoms share more than one electron pair if needed for each atom to have a full outer shell. Two pairs of shared electrons form a double bond.

- E.g O=O (O_2):



Properties (simple molecular eg. hydrogen, methane, oxygen, water):

- Low melting and boiling points - (although there are strong covalent bonds between atoms in each molecule) there are only weak intermolecular forces between neighbouring molecules
- Poor conductors of electricity - they haven't gained or lost electrons - no ions can move around

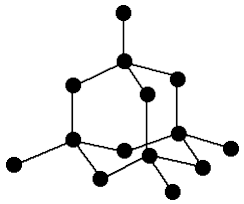
Giant Covalent Structures
Diamond, Graphite, Sand

Giant molecular covalent substances (sand - silicon and oxygen atoms), diamond and graphite (both made of carbon atoms). Billions of atoms all joined together by covalent bonds.

- Most of these substances have high melting and boiling points because all the atoms are joined to other atoms by strong covalent bonds (lots of heat energy is needed to break these bonds)

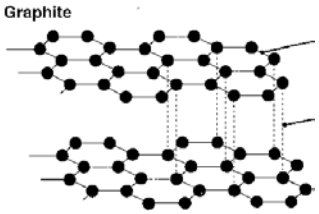
Properties of diamond and graphite:

- Both diamond and graphite have high melting and boiling points because of the strong covalent bonds between the carbon atoms. But they have very different properties, eg. graphite is a form of carbon in layers whereas diamond is a very compact structure.
- **Diamond:**
  - Hard because all the atoms joined with strong covalent bonds. Used to make cutting tools.Doesn't conduct electricity because there are no free ('delocalised') electrons that can move around (all four outer shell electrons in each carbon atom are involved in making bonds)



- **Graphite:** is very soft because although the covalent bonds within the layers are very strong, there are only weak forces between the layer. Graphite is used as a lubricant and for electrodes.

  Conducts electricity because only 3 outer shell electrons in each carbon atom are involved in making bonds. 1 electron from each carbon atom is free to move along the layers (electron is said to be 'delocalised), current can flow.



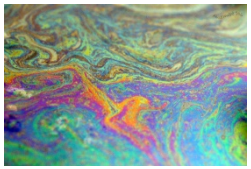
Covalent Bonds - Questions

- What is a covalent bond?
- Why does bonding make the atoms more stable?
- Can you draw the dot-cross diagram for water?
- Why do covalent bonds have low boiling points?
- Why are they poor conductors of electricity?

Giant Covalent - Questions

- What are the similarities and differences between graphite and diamond?
- Name a use of diamond and graphite
- Describe the structure of graphite
- Explain why graphite can conduct electricity, and why diamond can't.
- Why do they both have such a high boiling point?

Immiscible Liquids



Immiscible liquids: Liquids that don't mix completely with each other (e.g oils in water) . Even when shaken up, they soon separate out again

- they can be separated using a separating funnel: tap of funnel is opened so the lower liquid runs out and can be collected in a beaker. Tap is closed before the other (upper) liquid starts running out.

Miscible liquids: If two liquids dissolve in each other, their particles mix completely to make a solution

Once mixed, the only way to separate miscible liquids is by fractional distillation:

- It can separate mixtures of miscible liquids because they have different boiling points:

  The mixture of liquids is heated and the liquids evaporate. Vapours condense in a fractionating column:

  - The fraction with the highest boiling point condenses near the bottom of the column (where it's hotter). The fraction with the lowest boiling point condenses near the top of the column (where it's cooler)

- It can also be used to separate oxygen and nitrogen in air: nitrogen boils at -183°C, oxygen at -196°C. Air first has to be separated into a mixture of liquids:
  - Remove water vapour in the air, it is cooled so that the water can freeze and be removed. The rest is cooled to -200°C (below boiling points of nitrogen and oxygen). Air is a liquid.
  - Nitrogen has a lower boiling point than oxygen. when liquid air is warmed to -185°C, the nitrogen evaporates and rises up the column. The oxygen stays as liquid and is piped out of the bottom of the column

Chromatography

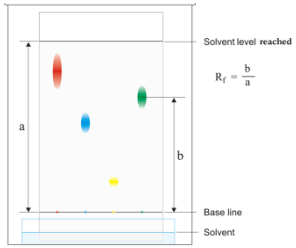
- Inks, paints and foods often contain mixtures of coloured compounds. Some coloured compounds dissolve better in a solvent than others . ‘solvent’ is what substances dissolve into e.g water.
- Mixtures of coloured compounds can be separated by their solubilities through chromatography:
  - In paper chromatography, samples are placed near the bottom of a sheet of special paper (‘base line’ on diagram). The solvent soaks up the paper (solvent must be placed above the bottom edge of the paper but below where the samples are placed)
  - More soluble compounds in a sample are carried up the paper faster (and further) than less soluble ones, separating them. The paper with the separated components on it is called a chromatogram

Rf value:

- the distance the compound has moved up the paper divided by the distance the solvent has moved
- Further up the paper the compound has moved, greater Rf value, more soluble compound

Uses:

- The Food Standards Agency - to separate food colourings – ensures colourings used are safe
- The police - to compare a suspect’s DNA sample to the DNA sample found at the crime scene
- Analysing paints and dyes – museum staff can mix exact copies of old-fashioned paints, to restore old paintings or to identify fakes



Immiscible Liquids - Questions

- What is an immiscible liquid?
- How do you separate them?
- How do you separate a miscible liquid?
- How are oxygen and nitrogen separated?

Chromatography - Questions

- How does the process of chromatography work?
- What is the Rf value?
- What does it mean if the liquid has a higher rf value?
- How would museum staff and police use Chromatography?

Metallic Substances

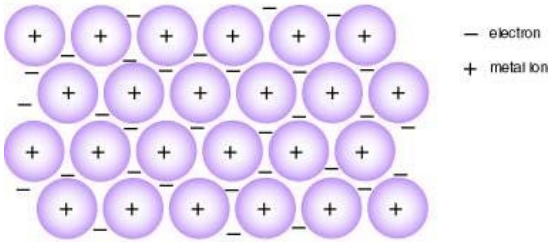
The atoms in metals are held together by metallic bonding (see below) – this gives metals different properties from other types of substances

- Metals are good conductors of electricity and heat
- Metals are solids at room temperature (→metallic bonds are strong), except for mercury, which is a liquid at room temperature
- Metals don't dissolve in water
- Metals are malleable (can be hammered into shape) metals have many uses e.g. they're used to make cars, buildings, tools

Metallic bonding:

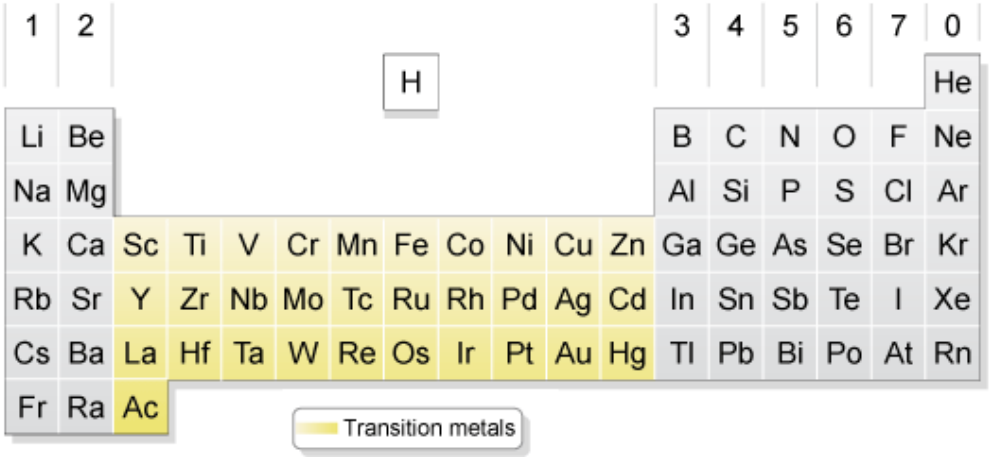
- Metal structure is a giant lattice of positive ions surrounded by a 'sea' of outer shell electrons. The term 'sea of electrons' is used because electrons in the outer shells of metal atoms are free to move through the structure. The electrons aren't located in specific atoms so we say they are 'delocalised electrons'.
- Metals conduct electricity because delocalised electrons move around randomly in all directions between the positive ions. If a potential difference (i.e voltage) is applied across a piece of metal, all the delocalised electrons start to move in the same direction. This movement of electrons is an electric current

- Metals are malleable:
  - If a large force is applied, the layers of positive ions in a metal can slide over each other. The positive ions are still held together by the sea of electrons and the metal spreads out (changes shape) instead of breaking



Transition Metals

- Most metals are transition metals.
- The metals used in the home are typically transition metals such as copper and iron.
- Most transition metals have high melting and boiling points and form coloured compounds.
- Transition metals are in the central block of the periodic table.

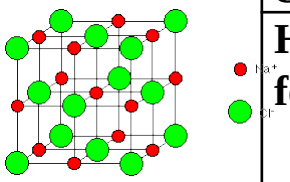


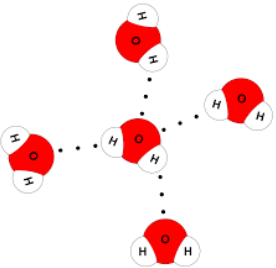
Questions on Metallic Substances

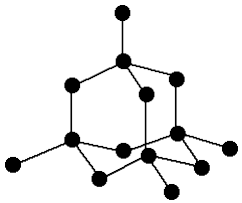
- Give four properties of metals
- What is the word that means metals can be hammered into shape?
- What is the phrase that describes the structure of metals?
- Explain why metals can conduct electricity.
- Explain why metals are malleable.

Questions on Transition Metals

- Where would you find the transition metals?
- Would transition metals have high or low melting points?
- Transition metals form compounds that are …….
- Give a use of a transition metal and suggest why it has been chosen for this purpose.







Type of structure & bonding	Giant Ionic	Simple Molecular Covalent	Giant molecular covalent
How bonds form	metal reacts with a non-metal • Metals lose electrons to become positive cations • Non-metals gain electrons to become negative anions • Oppositely charged ions attract	Between atoms of non-metal elements: Electrons are shared between atoms so they end up with stable, full outer shells	between atoms of non-metal elements Electrons are shared between atoms so they end up with a stable, full outer shells
Examples	sodium chloride	water, oxygen	diamond
Strength of bonds	strong	Strong covalent bonds between atoms, but weak forces holding separate molecules together	Strong across all atoms in a structure
Melting and boiling points	high - solids at room temperature	low – most are liquids or gases at room temperature	high – solids at room temperature
Solubility	many dissolve in water	some dissolve in water	Insoluble in water
Do they conduct electricity?	• yes when molten or in an aqueous solution • no when solid	no	no, except graphite

Alkali Metals

The alkali metals are found in group 1 of the periodic table so they have 1 electron in their outer shell.

To gain a full outer shell they must lose their outer electron so they form ions with a charge of +1

The atoms in alkali metals are held together by metallic bonding and are solids at room temperature, but they have low melting points compared to other metals.

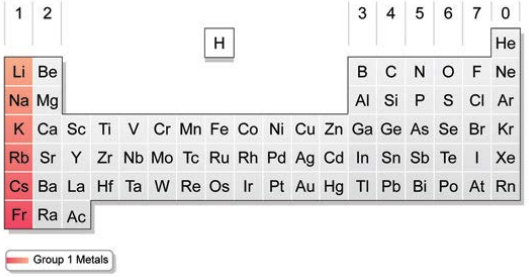
Alkali metals are soft metals and be cut with a knife.

All alkali metals react with water to form a metal hydroxide and hydrogen gas:

lithium + water → lithium hydroxide + hydrogen

$2Li_{(s)} + 2H_2O_{(l)} \rightarrow 2LiOH_{(aq)} + H_{2\,(g)}$

Note: all metal hydroxides are alkaline

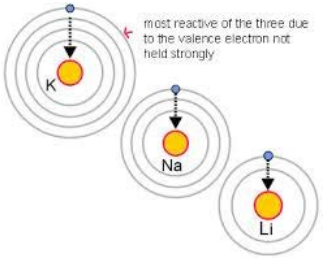


Reactivity

If lithium is dropped in water, it just floats on the water and fizzes (that's the hydrogen being produced) until the reaction is finished. Sodium reacts more strongly with water. Sodium has a lower melting point and reaction produces enough heat to melt the metal so a molten ball of sodium that whizzes around the surface of the water (releasing hydrogen) until the reaction is finished.

Potassium reacts even more strongly and the hydrogen produced during the reaction catches fire, producing a lilac flame so the reactivity of alkali metals increases as you go down group 1.The elements at the bottom of group 1 have more electrons than the elements at the top of the group so they have more electron shells. The electron in the outer shell is further from the nucleus The attraction between the nucleus and the outer electron is weaker when charges are further apart..

- outer electron in a potassium atom (configuration: 2.8.8.1) is not held as strongly as the outer electron in a lithium atom (configuration: 2.1)
- Metals react by losing their outer electron, forming ions with a +1 charge and a full outer shell
- Potassium loses its outer electron more easily and it's more reactive



Questions on Types of Structure and Bonding

- How does an ionic bond form? What does it form between?
- What is a giant structure compared to a simple structure?
- Which type of structures have strong bonds?
- Describe how the melting and boiling point of structures is linked to their structure.
- Which structures are soluble?

Questions on Alkali Metals

Explain why alkali metals become ions with a +1 charge.

Give two properties of alkali metals that are similar to other metals and two properties that are not typical.

Describe what you would see as you added Lithium, Sodium then Potassium to water.

Explain these observations using the structure of the metals.

Halogens

Group 7 so have 7 electrons in their outer shell, to form a full outer shell they gain 1 electron, form ions with a -1 charge.

At room temperature fluorine is a pale yellow gas, Chlorine is a yellow-green gas, Bromine is a brown liquid, Iodine is a grey solid.

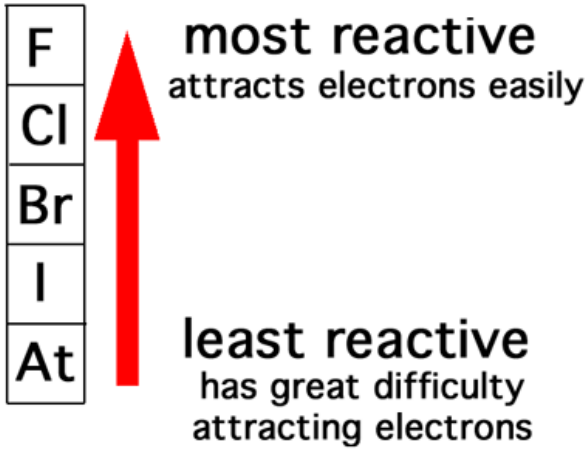
Reactivity: less reactive as you go down group 7, because they react by gaining an electron - this is easier with fewer electron shells (because outer electrons are closer to the nucleus), so fluorine is the most reactive halogen

Halogens React With metals to form metal halides e.g. sodium + chlorine → sodium chloride

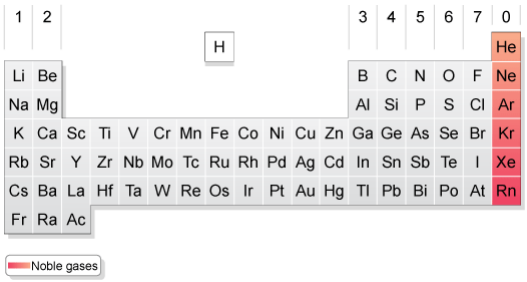
Chlorine→'chloride', fluorine→'fluoride', Iodine→'iodide'

Halogens React With hydrogen: react with hydrogen gas to form hydrogen halides (they form acids when dissolved in water (when hydrogen chloride dissolves in water it forms hydrochloric acid))

Displacement reactions: more reactive halogens can 'displace' less reactive halogens from their compounds. Less reactive halogens cannot 'displace' more reactive halogens from their compounds.



Noble Gases



Group 0 or 8 of the periodic table. They already have full outer shells, compared to other elements so do not need to gain or lose electrons so do not react – they are inert (very unreactive)

Properties: All are gases at room temperature, low boiling points, increase down the group. Particles in a gas are spread far apart, low densities, decreasing down the group

Discovery: Chemists noticed that the density of pure nitrogen made in chemical reactions was less than the density of nitrogen extracted from the air. Experiments were done to find the identity of this dense gas –argon. The other noble gases were discovered soon after.

Uses: useful because unreactive. When electric current is passed through a tube filled with neon under low pressure, coloured light is produced - used in fluorescent lamps and advertising displays

Questions on Halogens

- How many electrons do halogens have in their outer shell?
- What charge will the halide ion have?
- As you go down group 7 what happens to the reactivity. Explain why.
- Give a word equation for a halogen reacting with a metal and reacting with hydrogen.
- What is a displacement reaction? What would you see if the following reacted together?

$$KI + Cl_2 \rightarrow$$

Questions on Noble Gases

- What group are the noble gases?
- Why are noble gases unreactive?
- Name some properties of the noble gases.
- Give a use for noble gases and explain why they can be used in this way.

TEMPERATURE CHANGES

- In chemical reactions heat energy transfers between the reactants and the surroundings

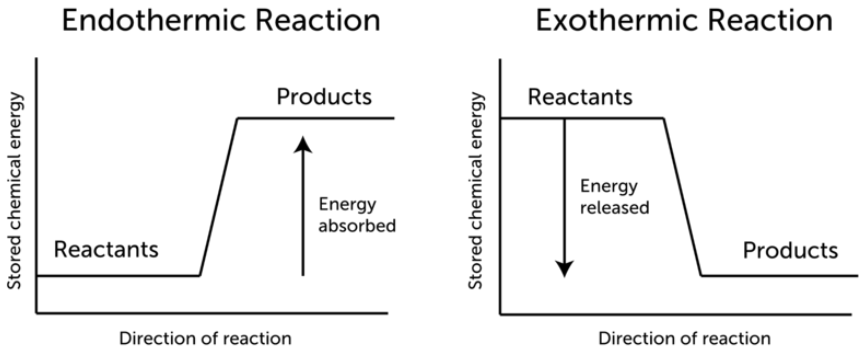
Exothermic reactions

- Exothermic reactions give out heat energy to the surrounding which is shown by the temperature of the reaction mixture and its surroundings increasing.
- Most reactions are exothermic. Examples of exothermic reactions include all combustion reactions and explosions which release their heat energy quickly. e.g combustion of methane:

  methane + oxygen → carbon dioxide + water

Endothermic reactions

- Endothermic reactions take in heat energy from the surroundings so the temperature of the reaction mixture and of the surroundings decreases
- Few chemical reactions are endothermic but examples of endothermic reactions are:
  - Reaction of sodium hydrogencarbonate with hydrochloric acid (if you touch the test tube it feels cold because heat energy is taken from your hand)
  - Dissolving ammonium nitrate in water
  - Photosynthesis (takes in heat energy from the sun)



Making and breaking bonds

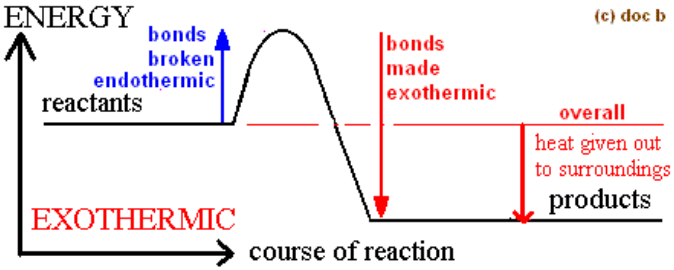
In chemical reactions, bonds in the reactants are broken and new bonds are formed to make the products.

Breaking bonds requires energy so it's an endothermic process (+)

Making bonds releases energy so it's an exothermic process (-)

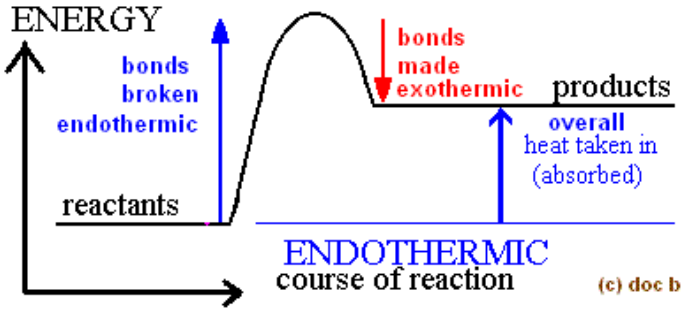
In an exothermic reaction (-)

More heat energy is released making bonds (in the products) than is required to break bonds (in the reactants) so the net result is that heat energy is released (-)



In an endothermic reaction (+)

- More heat energy is required to break bonds (in the reactants) than is released making bonds (in the products) so the net result is that heat energy is taken in (+)
- These energy changes can be shown using diagrams:



Questions on Temperature Changes

- What is an exothermic reaction?
- Draw the energy diagram for an exothermic reaction?
- What will a thermometer do if it is in an exothermic reaction?
- Give an example of an exothermic reaction.
- Now answer all the questions above for an endothermic reaction.

Questions on Bond Breaking and Making

- Chloe says in exothermic reactions bonds are formed. Is she correct?
- Does Bond Breaking require energy to go in or be taken out of the reaction?
- Does Bond Making require energy to go in or be taken out of the reaction?
- If a reaction is overall exothermic and gives out energy what does this tell you about the energy released and absorbed during the bond making and breaking process?

RATES OF REACTION

The rate of a chemical reaction is the speed at which it takes place – or how fast reactants are used up and products are made. In an explosion very fast chemical (exothermic) reactions release lots of heat energy and gas in a short space of time. In the rusting of iron is a slow chemical reaction occurs.

Collision theory

For a reaction to occur, particles of the reactants must collide with each other and if particles collide more frequently, rate of reaction will increase

Not all collisions lead to a reaction – particles must collide with enough energy to break the bonds in the reactants. The more energy particles have, the greater the chance of 'successful collisions'. The rate of reaction will increase if there are more high-energy collisions between particles.

The effect of temperature

The higher the temperature of the reactants, the faster the reaction - e.g eggs cook faster in boiling water than in warm water. As temperature is increased, particles have more energy, they move faster, they have a greater chance of collision and when they do collide there is a greater chance of successful collisions.

Increase in temperature →increased rate of reaction

Sometimes we cool reactions to slow them down e.g some foods are put in a fridge to slow down chemical reactions that make food go off.

The effect of concentration:

The higher the concentration of a reactant in a solution, the faster the reaction. The more concentrated a solution, the more solute particles there are in a given volume therefore it is more likely that reactant particles will collide with one another

Increase in temperature →increased rate of reaction

The effect of surface area:

The greater the surface area of a solid, the faster the rate of reaction. Increasing the surface area increases the number of particles exposed on the surface (that can collide and react) more frequent collisions between reactant particles and hence an increased rate of reaction.

To increase surface area, solids are crushed into lots of small pieces e.g. in power stations, coal is ground up into a fine powder to help it burn faster

CATALYSTS

Catalysts are substances that speed up chemical reactions without being used up in the reactions (note: they are neither reactants nor products)

Catalysts speed up chemical reactions by increasing the probability of successful collisions by providing an alternative pathway for the reaction to occur - i.e when particles collide they don't need as much energy to react

Many chemical processes use catalysts to increase the rate at which products are generated which means that reactions can be done at lower temperatures and pressures than they would otherwise so less energy is used to heat the reactants and it saves money.

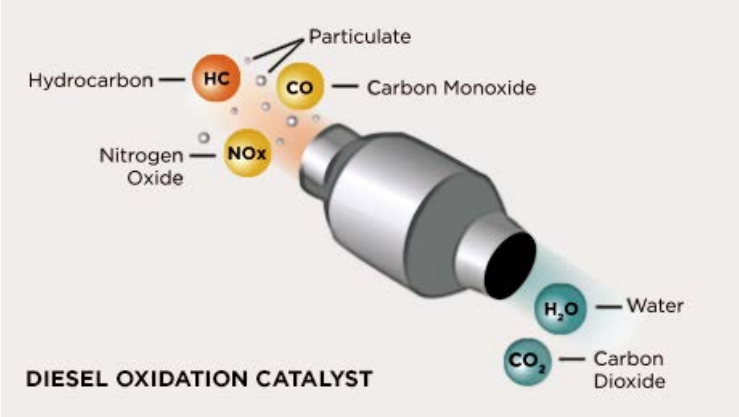
Catalytic converters

The combustion of petrol in car engines produces carbon monoxide (toxic) and unburned hydrocarbons.

Cars are now built with catalytic converters which help to combine carbon monoxide and unburned petrol with oxygen from the air to form carbon dioxide and water vapour.

This reduces pollutants in exhaust gases. Catalytic converters contain the transition metals platinum, rhodium or palladium (all very expensive), which act as catalysts. The catalysts have a high surface area ('honeycomb structure) so the rate at which carbon monoxide and unburned petrol react with oxygen from the air to form carbon dioxide and water vapour is increased.

Catalytic converters work best at high temperatures (as particles collide more frequently and with more energy). When a car engine is first started, a catalytic converter is cool and doesn't work well. However, the hot gases from the engine quickly heat it up.



Questions on Rates of Reaction

- What is the collision theory?
- Do all particles that collide react?
- What is the effect on the rate of reaction of increasing temperature?
- What is the effect on rate of increasing concentration?
- Which has the biggest surface area – powdered calcium carbonate or lumps of calcium carbonate?
- What effect does decreasing the surface area have on the rate of reaction?

Questions on Catalysts

- What is a catalyst?
- How does it work?
- Why does it save money?
- What toxic gases are emitted from a car exhaust?
- What gases are these converted into?
- Why does a large surface area (honeycomb structure) increase the efficiency of a catalyst?

Questions on Atomic and Formula Masses

- Helium has an atomic mass of 4. Magnesium has an atomic mass of 24. How many times heavier is an atom of Magnesium than an atom of Helium?
- Calculate the formula masses of the following:

$CaCO_3$

$LiCl$

CO_2

Glucose - $C_6H_{12}O_6$

Molecular and Empirical Formulae

The true formula for a simple molecular compound is called the 'molecular formula' – this shows the actual number of atoms of each element in a molecule

Substances can also be represented by an empirical formula – this shows the simplest whole number ratio of atoms or ions of each element in a substance.

e.g. Ethene has the molecular formula C_2H_4 and Propene has the molecular formula C_3H_6.

For every molecule of ethene or propene, there are twice as many hydrogen atoms than carbon atoms. The molecular formulae of both ethene and propene can be simplified to CH_2 –the empirical formula.

So ethene and propene have different molecular formulae (C_2H_4 and C_3H_6) but the same empirical formula (CH_2)

Calculating the empirical formula

If you know the mass (in grams) of each element present in a compound, you can use this and the relative atomic mass of each element to calculate the empirical formula of the compound e.g. for calcium chloride:

	Ca	Cl
Mass in g	10.0	**17.8**
Relative atomic mass	40	**35.5**
Step 1. Divide the mass of each element by its relative atomic mass	10.0/40 = 0.25	**17.8/35.5 = 0.5**
Step 2. Divide the answers by the smallest number obtained after step 1 (in this case 0.25) to find the simplest ratio	0.25/0.25 = 1	**0.5/0.25 = 2**
	i.e for every molecule of calcium chloride, there are twice as many chlorine atoms than calcium atoms	
Empirical formula	**$CaCl_2$**	

Quantitative Chemistry

RELATIVE MASSES

The relative atomic mass (A_r) is the mass of an atom compared to that of carbon-12

Calculating the relative formula mass (M_r)

The 'relative formula mass' (M_r) of a substance is the sum of the relative atomic masses (A_r) of all the atoms or ions in its formula:

e.g CO_2 – 1 carbon atom, 2 oxygen atoms:

- A_r of C = 12
- A_r of O = 16 x 2 = 32
- relative formula mass (M_r) of CO_2 = 12 + 32 = 44

e.g $Ca(NO_3)_2$ – 1 calcium atom, 2 nitrogen atoms, 6 oxygen atoms:

- A_r of Ca = 40
- A_r of N = 14 x 2 = 28
- A_r of O = 16 x 6 = 96
- relative formula mass (M_r) of $Ca(NO_3)_2$ = 40 + 28 + 96 = 164

Molecular and Empirical Formulae

- What does the formula CO_2 mean?
- What is the difference between the molecular formula and the empirical formula?
- What is the empirical formula of $C_6H_{12}O_6$?
- What is the empirical formula of Na_2O_2?
- Outline the key steps to calculate the empirical formula given the masses of elements reacting.

PERCENTAGE COMPOSITION

You can use the relative masses to calculate the percentage composition of each element in a compound.

Percentage (by mass) of an element in a compound

= number of atoms of element x A_r/M_r x 100

Calculate the percentage by mass of oxygen in potassium nitrate KNO_3

Number of atoms of oxygen in KNO_3 = 3

Relative atomic mass (A_r) of oxygen = 16

Then calculate the relative formula mass (M_r) of KNO_3

KNO_3 – 1 potassium atom, 1 nitrogen atom, 3 oxygen atoms

A_r of K = 39

A_r of N = 14

A_r of O = 16 x 3 = 48

M_r of KNO_3 = 101

% of oxygen in KNO_3 = (48/101) x 100 = 47.5%

Calculating the Masses of Reactants or Products:

During a chemical reaction, no atoms are lost or made – they are just rearranged to make new substances (the 'products'.) You can use relative masses and the balanced equation for a reaction to calculate the mass of a reactant or product.

E.g potassium nitrate (KNO_3) is decomposed to potassium nitrite (KNO_2) and oxygen (O_2).

what mass of potassium nitrate is needed to make 1.6g of oxygen?

Step 1 – balanced chemical equation: $2KNO_3 \rightarrow 2KNO_2 + O_2$

Step 2 – work out the relative masses of the substances needed in the calculation

- M_r of KNO_3 = 101
- There are two particles of KNO_3 in the balanced equation →we multiply the M_r of KNO_3 by 2…→ 101 x 2 = 202
- Relative mass (only one atom so A_r/M_r it's the same) of O_2 = 32

Step 3 – divide the answers by the smallest relative mass calculated above (in this case 32) to find the ratio:

- $2KNO_3$: 202/32 = 6.3
- O_2: 32/32 = 1
- →ratio of $2KNO_3$:O_2 is 6.3:1

Step 4 – use the ratio to find the answer!

- Ratio is 6.3:1→6.3g of potassium nitrate are needed to make 1g of oxygen
- to find the mass of potassium nitrate needed to make 1.6g of oxygen we multiply 1.6 by 6.3→1.6 x 6.3 = 10.1
- →10.1g of potassium nitrate are needed to make 1.6g of oxygen

Questions on Percentage Composition

- What is the formula for calculating percentage composition?
- What is the percentage of Lithium in LiF?
- What is the percentage of Hydrogen in H_2O?
- What is the percentage of Oxygen in CO_2?
- What is the percentage of Carbon in $C_6H_{12}O_6$?

Questions on Masses of Reactants and Products

$Li + O_2 \rightarrow Li_2O$

How much Lithium oxide can form from 7g of Lithium if there is an excess of oxygen?

$C_2H_4 + O_2 \rightarrow 2CO_2 + 2H_2O$

What mass of ethene is needed to make 8.8g of Carbon dioxide?

YIELDS

The amount of useful product that is obtained from a chemical reaction is called the yield. In theory one might expect all the reactants to turn into products – this is the 'theoretical yield'

The theoretical yield can be calculated from the balanced equation of a reaction and assumes all the reactants are turned into products.

Calculating the theoretical yield

e.g. $2H_2 + O_2 \rightarrow 2H_2O$

1. Calculate the relative formula masses

- $2H_2$ – 4 hydrogen atoms: A_r of H = 1 → A_r of $2H_2$ = 2 x 2 = 4g
- O_2 – 2 oxygen atoms: A_r of O = 16……→ A_r of O_2 = 32g
- $2H_2O$ – 4 hydrogen atoms, 2 oxygen atoms 32 + 4 = 36g

So 36g of water should theoretically be produced when 4g of hydrogen reacts with 32g of oxygen

In practice, however, the 'actual yield' obtained is less than the predicted 'theoretical yield' because

1. reaction may be incomplete – i.e not all reactants are used up
2. some of the product is lost during the practical preparation – e.g when transferring liquids from one container to another
3. there may be other unwanted reactions taking place – e.g some of the reactants may react in different ways to make a different product

The percentage yield compares the actual yield to the theoretical yield (i.e it compares the actual amount of product formed to the predicted amount of product formed calculated from the balanced chemical equation).

Percentage yield = (actual yield / theoretical yield) x 100

e.g. if in the reaction above the actual yield (i.e the amount of water produced) was in fact 30g →percentage yield = (30/36) x 100 = 83.3%

WASTE AND PROFIT

Disposal of waste products

- Many chemical reactions produce substances other than the substance that is wanted - these additional substances are called by-products. Some by-products can be useful e.g sodium hydroxide and hydrogen – by-products of the electrolysis of sodium chloride solution – are useful because they can be sold
- However, many by-products are useless and are called waste products and have to be got rid of.
- Disposal of waste products can be expensive – the waste may have to be transported to a landfill site or it may have to be treated with another substance to make it safe. Waste products can cause environmental problems and cause social problems e.g. house prices could drop if a chemical plant is built near to them and unpleasant smells can be emitted from landfill sites.

Finding the most cost effective process

- As well as taking the environmental impact into account, chemical companies want to use reactions that will make the most money (profit)
- To do this they try to use reactions in which the percentage yield is high which will reduces costs , the reaction takes place quickly – this reduces costs, all the products of the reaction are useful → no waste products
- e.g when ammonia is made there are no waste products:

  $N_2 + 3H_2 \rightarrow 2NH_3$
- e.g. when iron is extracted from iron oxide there is always waste carbon dioxide

  $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

  However, if a use can be found for waste products then a reaction becomes commercially viable (i.e money/profit can be made from it)

Questions on Yields

- What is the theoretical yield?
- Give three reasons why you never get 100% yield?
- If you predict that you will make 12g of propane but only make 4g what is the percentage yield?
- A company makes a drug in a very efficient process which gives 95% yield. If the theoretical yield is 20 g what mass is actually made?

Questions on Waste and Profit

- What is a by-product?
- Name one useful and one useless by-product?
- Why is disposal of waste expensive?
- Do chemical companies want to have a high or low percentage yield? Why?
- What is the best thing you can do with a waste product?