# Key things to study for each topic in O levels

Disclaimer: This is meant as a summary so not everything that could possibly come out in your exams may be included. This is also a work in progress so there may be errors or items that are left out by accident.

## Atomic structure

### Structure of atom

| Subatomic particle | Symbol | Relative charge | Relative mass |
|---|---|---|---|
| Proton | p | +1 | 1 |
| Neutron | n | 0 | 1 |
| electron | e | –1 | $\frac{1}{1840}$ |

### Isotopes

Definition of isotopes: Isotopes are atoms of the same element with the same number of protons, but different number of neutrons

**Calculation of relative atomic mass**

Q: If chlorine has 2 isotopes with relative masses of 35 and 37 and relative abundance of 75% and 25% respectively, calculate the relative atomic mass of chlorine.

A: Relative atomic mass = 37 x 0.25 + 35 x 0.75 = 35.5

**Calculation of relative abundance**

Q: If boron has 2 isotopes with relative masses of 10 and 11, given that boron has a relative atomic mass of 10.8, calculate the relative abundance of boron-10 and boron-11.

A: Let the relative abundance of boron-10 be x

$10x + 11(1 – x) = 10.8$

$x = 0.2$

Therefore relative abundance of boron-10 is 20% and relative abundance of boron-11 is 80%.

# Chemical bonding

## Template for answering common chemical bonding questions

General template

1. State the structure

2. Describe the structure

3. Relate the relevant part of the structure to the physical property specified in the question

| Structure | Simple covalent | Giant covalent | Giant Ionic lattice | Giant Metallic |
|---|---|---|---|---|
| **Melting and boiling points** | • (substance) has a simple covalent structure.<br>• It consists of discrete molecules held together by weak Van der Waals' forces of attraction.<br>• Very little energy is required to overcome these forces and (substance) has low melting and boiling point. | **Diamond**<br>• Diamond has a giant covalent structure<br>• Each carbon atom is covalently bonded to 4 other carbon atoms in a giant covalent network.<br>• These strong covalent bonds require large amount of energy to overcome.<br>**Graphite**<br>• Graphite has a giant covalent structure.<br>• Each carbon atom is covalently bonded to 3 other carbon atoms in a giant covalent network.<br>• These strong covalent bonds require large amount of energy to overcome. | • (substance) has a giant ionic structure.<br>• It is held together by strong electrostatic forces of attraction between oppositely charged ions in a giant ionic lattice.<br>• A lot of energy is required to overcome these forces and (substance) has high melting and boiling point. | • (substance) has a giant metallic structure.<br>• It is held together by strong electrostatic forces of attraction between the positively charged cations and the 'sea of delocalized' electrons<br>• A lot of energy to overcome those forces. Hence it has a high melting and boiling point. |

| | | | | |
|---|---|---|---|---|
| **Electrical conductivity** | • (substance) has a simple covalent structure.<br>• It consists of molecules that are uncharged/ electrically neutral.<br>• Since it does not contain any mobile ions or electrons/ or mobile charged particles, it cannot conduct electricity. | **Diamond**<br>• Diamond has a giant covalent structure.<br>• Each carbon atom uses up all four of its valence electrons to form covalent bonds with four other carbon atoms to form a giant covalent network.<br>• It does not have any mobile electrons to conduct electricity.<br>**Graphite**<br>• Graphite has a giant covalent structure.<br>• Each carbon atom uses 3 out of 4 of its valence electrons to form covalent bonds with 3 other carbon atoms in a giant covalent network.<br>• Hence each carbon atom has one mobile valence electron that is delocalized between the layers to conduct electricity. | • (substance) has a giant ionic structure.<br>• In **solid state**, the oppositely charged ions can only vibrate about their fixed positions due to the strong electrostatic forces of attraction.<br>• Therefore the ions are not mobile to conduct electricity.<br>• (substance) has a giant ionic structure.<br>• In the **aqueous/molten state**, the electrostatic forces between oppositely charged ions are weakened.<br>• Hence, the ions become mobile and are able to conduct electricity. | • (substance) has a giant metallic structure.<br>• It is held together by electrostatic forces of attraction between the positively charged cations and the ‘sea of delocalized’ electrons.<br>• Hence (substance) has mobile electrons that allow it to conduct electricity. |

| | | | | |
|---|---|---|---|---|
| **Hardness** | NA | **Diamond (same explanation as mp and bp)**<br>• Diamond has a giant covalent structure.<br>• Each carbon atom is covalently bonded to 4 other carbon atoms in a giant covalent network.<br>• These covalent bonds require large amount of force to overcome.<br>**Graphite**<br>• Graphite has a giant covalent structure.<br>• Each carbon atom is covalently bonded to 3 other carbon atoms in a giant covalent network.<br>• Graphite is soft and slippery because the layers of carbon atoms are held by weak Van der Waals' forces of attraction and can slide over each other. | **(same explanation as for mp and bp)**<br>• (substance) has a giant ionic structure.<br>• It is held together by strong electrostatic forces of attraction between oppositely charged ions in a giant ionic lattice,<br>• which require a lot of force is to overcome. | • Pure metals are malleable/ ductile because the orderly layers of same-sized atoms can slide easily over each other without disrupting the structure.<br>• Alloys are harder and stronger than pure metals because alloys have atoms of different sizes. This disrupts the orderly arrangement of atoms and prevent the layers of atoms from sliding over each other easily when a force is applied. |

## Uses of diamond and graphite

| Substance | Uses | Related property |
|---|---|---|
| Diamond | Used as drill bit or cutting tool | Hard |
| Graphite | Used as lubricant and in pencil lead<br>Used as electrodes in electrolysis | Soft<br>Conducts electricity |

## Strength of ionic bonds

- The higher the charge of the ions, the greater the strength of ionic bonds.
- The smaller the size of the ions, the greater the strength of ionic bonds.

**Example:** Why is the melting point of magnesium fluoride higher than that of sodium fluoride?

- $Mg^{2+}$ has a higher charge than $Na^+$.
- $Mg^{2+}$ is smaller than Na+.
- Therefore $Mg^{2+}$ has a higher charge density than $Na^+$.
- More energy is needs to overcome stronger electrostatic forces of attraction between oppositely charged ions.

## Strength of metallic bonds

- The higher the number of delocalised electrons, the greater the strength of metallic bonds.
- The higher the charge of metallic cation, the greater the strength of metallic bonds.
- The smaller the size of metallic cation, the greater the strength of metallic bonds.

**Example:** Why is the melting point of magnesium higher than that of sodim?

- Mg has more valence electrons and therefore more delocalised electrons than sodium.
- $Mg^{2+}$ has a higher charge than $Na^+$.
- $Mg^{2+}$ is smaller than Na+.
- Therefore $Mg^{2+}$ has a higher charge density than $Na^+$.
- More energy is needs to overcome stronger electrostatic forces of attraction between metallic cations and sea of delocalised electrons.

## Hydrogen bonding

### Criteria for hydrogen bonding

1) Hydrogen atom covalently bonded to O, N or F

2) An O, N or F atom with available lone pair(s)

### Effects of hydrogen bonding

1) Higher boiling point compared to most other simple molecules of similar molecular mass.

2) Density of ice is less than density of water.

**Example:** Why is the boiling point of water higher than methane, $CH_4$?

- Water contains hydrogen bonding between water molecules.
- Methane has Van der Waals' forces between methane molecules.
- Hydrogen bonding is stronger than Van der Waals' forces, so more energy is required to overcome the hydrogen bonding in water.

**Example:** Why is ice less dense than water?

- To maximise hydrogen bonding in solid ice, the water molecules are arranged in a more orderly fashion/has an open structure.
- The water molecules in ice are further apart than the randomly arranged molecules in liquid water.

## Strength of Van der Waals' forces

- The higher the Mr, the greater the strength of Van der Waals' forces

**Example:** Why is the boiling point of chlorine higher than that of fluorine?

- Chlorine has a larger relative molecular mass of 71 compared to the relative molecular mass of fluorine which is 38
- The larger the relative molecular mass, the stronger the Van der Waals' forces between discrete molecules.
- More energy is required to overcome the stronger Van der Waals' forces between chlorine molecules.

## Differences between compounds and mixtures

| | Compounds | Mixtures |
|---|---|---|
| Composition | A compound contains two or more elements chemically combined in a fixed composition. | A mixture contains two or more substances physically mixed together in any proportion. |
| Separation | A compound can only be broken down into its elements or into simpler compounds by chemical processes. | The components of a mixture can be separated by physical means. |
| Properties | The physical and chemical properties of a compound are different from its constituent elements. | The chemical properties of a mixture are the same as those of its components. |
| Energy change | Chemical reactions occur when a compound is formed. There is usually an energy change. | No chemical reactions occur when a mixture is formed. There is usually little or no energy change. |

# Ionic equations

## Steps for writing ionic equations

1) Write chemical equation with state symbols

2) Split aqueous ionic compounds and aqueous acids/alkalis into ions (DON'T split solids or molecules like $I_2$)

3) Cancel spectator ions

4) Rewrite ionic equation

## General forms for ionic equations (note that there are exceptions)

**1) acid + metal**

_$H^+$ (aq) + _metal (s) → _$H_2$ (g) + metal cation (aq)

**2) acid + alkali**

$H^+$ (aq) + $OH^-$ (aq) → $H_2O$ (*l*)

**3) acid + base**

_$H^+$ (aq) + _metal oxide (s) → _$H_2O$ (*l*) + _metal cation (aq)

**4) acid + soluble carbonate**

$2H^+$ (aq) + $CO_3^{2-}$ (aq) → $CO_2$ (g) + $2H_2O$ (*l*)

**5) acid + insoluble carbonate**

_$H^+$ (aq) + _metal carbonate (s) → _$CO_2$ (g) + _$H_2O$ (*l*) + _metal cation (aq)

**6) alkali + ammonium salt**

$OH^-$ (aq) + $NH_4^+$ (aq) → $NH_3$ (g) + $H_2O$ (*l*)

**7) precipitation reaction**

cation (aq) + anion (aq) → insoluble salt (s)

**8) metal displacement reaction**

_metal A (s) + _metal cation B (aq) → _metal cation A (aq) + _metal B (s)

**9) halogen displacement reaction**

halogen A (g/aq) + 2halide B (aq) → 2halide A (aq) + halogen B (aq)

# Redox

## Electron transfer

### Steps in constructing half equations

1) Construct ionic equation (if necessary)

2) Identify elements that have experienced a change in their charges

3) Write the relevant half equations

4) Balance the equations by balancing number of atoms

5) Balance the equations by ensuring that sum of the charges on both sides of the equations are equal.

### Identifying substances oxidised/reduced

a) Electrons are added on the left side of the equation → Reactant is reduced because it gained electrons

b) Electrons are on the right side of the equation → Reactant is oxidised because it lost electrons

### Example

$Cu\ (s) + 2AgNO_3\ (aq) \rightarrow Cu(NO_3)_2\ (aq) + 2Ag\ (s)$

1) $Cu\ (s) + 2\ Ag^+\ (aq) \rightarrow Cu^{2+}\ (aq) + 2Ag\ (s)$

2) Both copper and silver have experienced a change in their charges

3) $Cu\ (s) \rightarrow Cu^{2+}\ (aq)$

   $Ag^+\ (aq) \rightarrow Ag\ (s)$

4) Atoms are balanced

5) $Cu\ (s) \rightarrow Cu^{2+}\ (aq) + 2e$

   $Ag^+\ (aq) + e \rightarrow Ag\ (s)$

a) Cu is oxidised as Cu lost electrons to form $Cu^{2+}$ in $Cu(NO_3)_2$

b) $AgNO_3$ is reduced as $Ag^+$ in $AgNO_3$ gained electrons to form Ag

## Oxidation states

### Rules for assigning oxidation states

**1)** The oxidation state of fluorine in compounds is always –1.

**2)** The oxidation state of oxygen in compounds is usually –2, except in peroxides (OS = –1) and $OF_2$ (OS = +2).

**3)** The oxidation state of hydrogen in compounds is usually +1, except in metal hydrides (OS = –1).

**4)** The oxidation state of group **I**, **II** and **III** metals in compounds is usually +1, +2 and +3 respectively.

**5)** The oxidation state of free element is 0.

**6)** The oxidation state of a simple ion is equal to the charge on the ion.

**7)** The sum of oxidation states of all the atoms in a compound is zero.

**8)** The sum of oxidation states of all the atoms in a polyatomic ion is equal to the charge on the ion.

## Answering templates for redox questions

### Gain/loss of H

(substance) is oxidized/reduced because it has lost/gained hydrogen to form (substance).

### Gain/loss of O

(substance) is oxidized/reduced because it has gained/lost oxygen to form (substance).

### Gain/loss of e

(substance) is oxidized/reduced because it has lost/gained electrons to form (substance).

### Increase/decrease in oxidation state

(substance) is oxidized/reduced because the oxidation state of (element) has increased/decreased from (oxidation state) in (substance) to (oxidation state) in (substance).

### Oxidising and reducing agents

(statement explaining why substance is oxidized/reduced). Since (substance) is oxidized/reduced, it is a reducing/oxidizing agent.

### Template for writing observations (for OA and RA)

**Colour change:**

The (colour) (name of chemical) solution turns (colour)

**Gas:**

Effervescence of (colour) (odour) gas that (test for gas).

## Common oxidising and reducing agents

### List of Common Oxidising Agents

| **Oxidising Agent (itself reduced)** | **What happens when it reacts** |
|---|---|
| $KMnO_4$ (aq) with $H_2SO_4$(aq)<br>Acidified potassium manganate (VII) | Purple to colourless ($MnO_4^-$ reduced to $Mn^{2+}$)<br>FYI: $MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O$ |
| $K_2Cr_2O_7$ (aq) with $H_2SO_4$ (aq)<br>Acidified potassium dichromate(VI) | Orange to green ($Cr_2O_7^{2-}$ reduced to $Cr^{3+}$)<br>FYI: $Cr_2O_7^{2-} + 14H^+ + 6e \rightarrow 2Cr^{3+} + 7H_2O$ |
| $H_2O_2$ (aq)<br>Hydrogen peroxide | Remains colourles but causes colour change of a reducing agent ($H_2O_2$ reduced to $H_2O$)<br>FYI: $H_2O_2 + 2H^+ + 2e \rightarrow 2H_2O$ |
| $Cl_2$ (g) | Light greenish-yellow solution turns colourless ($Cl_2$ reduced to $Cl^-$)<br>$Cl_2 + 2e \rightarrow 2Cl^-$ |
| $I_2$ (s) /(aq) | Brown to colourless ($I_2$ reduced to $I^-$)<br>$I_2 + 2e \rightarrow 2I^-$ |
| $Fe^{3+}$ (aq)<br>e.g. $Fe_2(SO_4)_3$, $FeCl_3$, $Fe(NO_3)_3$ | yellow to light green ($Fe^{3+}$ reduced to $Fe^{2+}$)<br>$Fe^{3+} + e \rightarrow Fe^{2+}$ |

### List of Common Reducing Agents

| **Reducing Agent (itself oxidised)** | **What happens when it reacts** |
|---|---|
| KI (aq) | Colourless solution turns brown ($I^-$ oxidised to $I_2$)<br>$2I^- \rightarrow I_2 + 2e$ |
| $H_2O_2$ (aq)<br>Hydrogen peroxide | Remains colourless. Effervescence of colourless odourless gas which relights glowing splint. The gas is oxygen. ($H_2O_2$ oxidized to $O_2$)<br>FYI: $H_2O_2 \rightarrow O_2 + 2H^+ + 2e$ |
| $SO_3^{2-}$(aq), $SO_2$ (g) etc<br>sulfite ion and sulfur dioxide gas | Remains colourless ($SO_3^{2-}$ oxidised to $SO_4^{2-}$)<br>FYI: $SO_3^{2-} \rightarrow SO_4^{2-} + 2e$ |
| $Fe^{2+}$ (aq)<br>e.g. $FeSO_4$, $FeCl_2$, $Fe(NO_3)_2$ | Light green to yellow ($Fe^{2+}$ oxidised to $Fe^{3+}$)<br>$Fe^{2+} \rightarrow Fe^{3+} + e$ |
| $Na_2S_2O_3$ (aq)<br>Sodium thiosulfate | Remains colourless, but causes colour change of an oxidising agent<br>FYI: $2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2e$ |

## Table of colour changes

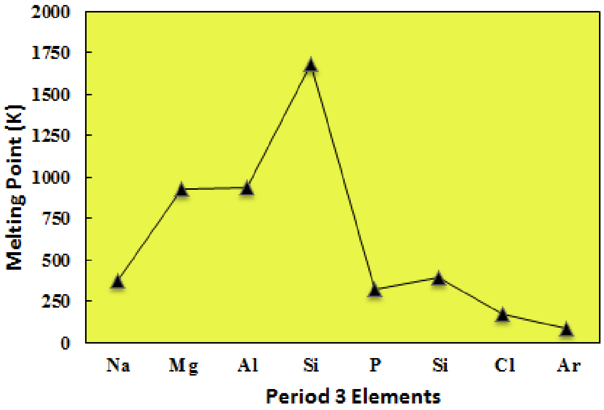
## Table of common colour changes

| | KI | $Na_2S_2O_3$ and $Na_2SO_3$ | $Fe^{2+}$ solutions | $H_2O_2$ |
|---|---|---|---|---|
| Acidified $KMnO_4$ | The purple acidified potassium manganate(VII) solution turns colourless.<br>The colourless potassium iodide solution turns brown<br>**Overall:** The purple acidified potassium manganate(VII) solution turns brown. | The purple acidified potassium manganate(VII) solution turns colourless. | The purple acidified potassium manganate(VII) solution turns colourless.<br>The pale green iron(II) solution turns yellow.<br>**Overall:** The purple acidified potassium manganate(VII) solution turns yellow. | The purple acidified potassium manganate(VII) solution turns colourless.<br>Effervescence of a colourless odourless gas that relights a glowing splint. |
| $Fe^{3+}$ solutions | The yellow iron(III) solution turns pale green.<br>The colourless potassium iodide solution turns brown<br>**Overall:** The yellow iron(III) solution turns brown. | The yellow iron(III) solution turns pale green. | | |
| $I_2$ | | The brown iodine solution turns colourless. | | |
| $Cl_2$ | The colourless potassium iodide solution turns brown with black solids. | | | |
| $H_2O_2$ | The colourless potassium iodide solution turns brown with black solids. | No visible change. | The pale green iron(II) solution turns yellow. | |

# Periodic table

## Trends across period 3

### Trend in melting point across period 3

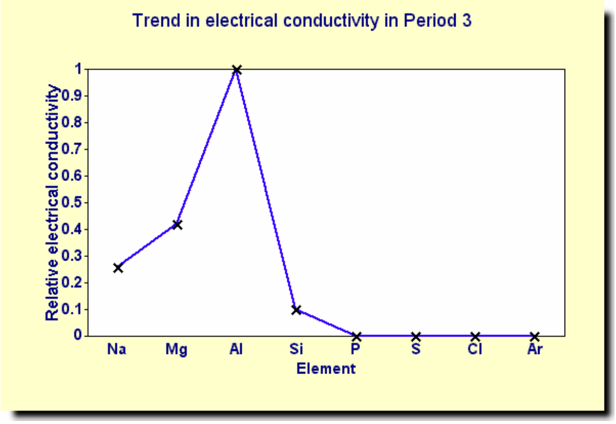


- Na, Mg and A*l* have giant metallic structure
- Melting point increases from Na to Mg to A*l* as the number of delocalised electrons increase
- The charge of the cation increase, while the size of the cation decreases
- Therefore charge density of cation increases
- This increase the electrostatic forces of attraction between the metallic cations and sea of delocalised electrons from Na to Mg to A*l*

- Si has a high melting point as Si has a giant covalent structure.
- A lot of energy is required to break the large number of strong covalent bonds between Si atoms in the vast network

- Phosphorus, sulfur, chlorine have low melting points as they all have simple covalent structure
- While argon exist as monoatomic atoms
- Little energy is required to break the weak Van der Waals' forces between the discrete molecules or atoms.

## Trend in conductivity across period 3



- Na, Mg and Al are able to conduct electricity as they have a giant metallic structure.
- There are strong electrostatic forces of attraction between the metallic cations and sea of delocalised electrons
- The delocalised electrons are mobile to conduct electricity

- The electrical conductivity increases from Na to Mg to Al as the number of delocalised electrons increases

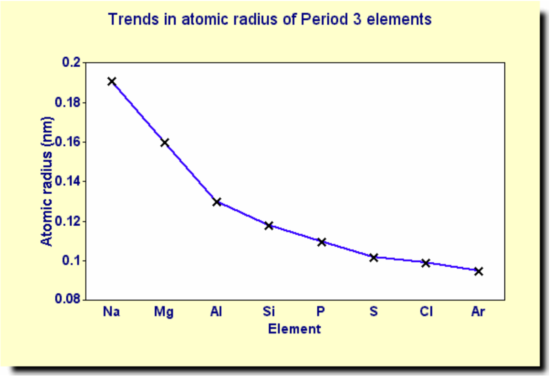
- Si is a metalloid and so it is expected to have the properties of metals and non-metals.
- Si is a semiconductor

- Phosphorus, sulfur, chlorine have simple covalent structure
- While argon exist as monoatomic atoms
- They consist of electrical neutral molecules or atoms
- Therefore there are no mobile ions or electrons to conduct electricity.

## Effective nuclear charge

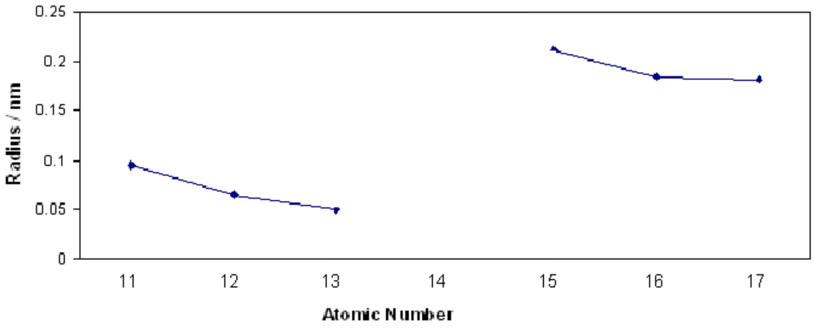
Zeff = Z – S

## Trend in atomic radius across period 3



- Nuclear charge increase as number of protons increase
- Shielding effect is relatively constant (same number of shells)
- Effective nuclear charge increases
- Electrostatic forces of attraction between nucleus and valence electrons increases
- Decrease in atomic radii

## Trend in ionic radius across period 3



- The anions $P^{3-}$, $S^{2-}$, $Cl^{-}$ are larger than the cations $Na^{+}$, $Mg^{2+}$, $Al^{3+}$ because the anions have 1 more quantum shell.
- For the cations, shielding effect is constant because they are isoelectronic (same number of electrons)
- Nuclear charge increases from $Na^{+}$ to $Mg^{2+}$ to $Al^{3+}$ because number of protons increases
- Effective nuclear charge increases
- Electrostatic forces of attraction between nucleus and valence electrons increases
- Ionic radii decreases
- Similar explanation for the anions.

# Group I

## Physical properties

| **Physical Properties**: | **Trends** |
|---|---|
| low melting points | Melting point decreases down the group |
| low densities | • Density generally increase down group<br>• Li, Na and K are less dense than water |
| soft – soft enough to be cut with a knife | |
| shiny and silvery only when freshly cut | |
| good conductors of heat and electricity | |
| malleable (can be beaten into sheets) and ductile (can be drawn into wires) | |

## Trend in melting point down group I

- Down group I, size of the metallic cations increase
- Charge density of metallic cations decrease
- Therefore electrostatic forces of attraction between metallic cations and delocalised electrons decreases,
- Causing the melting point to decrease down group I

## Chemical Properties

### Trend in reactivity

Reactivity of group I metals increase down the group.

### Explanation

- Down the group, the number of protons and number of electron shells increases
- Both the nuclear charge and shielding effect increases
- However, the shielding effect increases more than the nuclear charge
- Therefore effective nuclear charge decreases
- Hence the electrostatic forces of attraction between the valence electrons and the nucleus is weaker,
- making it easier for the element to lose electrons.
- Therefore the reactivity increases down the group.

### Reaction with water

group I metal + water → group I hydroxide (alkali) + hydrogen gas

Observations:

- Lithium/Sodium/Potassium reacts **gently/violently/explosively** with water.
- There is **effervescence** of a **colourless odourless** gas that **extinguishes a lighted splint** with a **pop sound**.
- The lithium/sodium/potassium metal **darts around** and **sizzles** on the **water's surface**.

### Reaction with chlorine

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

## Group VII

### Physical properties

| **Physical Properties**: | **Trends** | **Explanation** |
|---|---|---|
| low melting points<br>States of halogens at rtp:<br>$F_2$: gas<br>$Cl_2$: gas<br>$Br_2$: liquid<br>$I_2$: solid | Melting point increases down the group | • Down the group, the molecular size increases as the atomic size increases.<br>• This results in stronger Van der Waals' forces between the discrete molecules.<br>• More energy is required to overcome the Van der Waals' forces. |
| Coloured<br>Colours of halogens:<br>$F_2$: pale yellow<br>$Cl_2$: greenish yellow<br>$Br_2$: reddish brown<br>$I_2$: black solid<br>brown solution<br>purple vapour | Colours become darker down group | |

## Chemical Properties

### Displacement reactions

A more reactive halogen will displace a less reactive halogen from its aqueous salt.

Observations and explanations

| | Chlorine, $Cl_2$ | Bromine, $Br_2$ | Iodine, $I_2$ |
|---|---|---|---|
| Potassium chloride, $KCl$ | | No visible reaction<br>Bromine is less reactive than chlorine. Hence it cannot displace chlorine from potassium chloride solution. | No visible reaction<br>Iodine is less reactive than chlorine. Hence it cannot displace chlorine from potassium chloride solution. |
| Potassium bromide, $KBr$ | $Cl_2$ (aq) + 2KBr (aq) $\rightarrow$ 2KCl (aq) + $Br_2$ (aq)<br>The colourless potassium bromide solution turns reddish brown.<br>Chlorine is more reactive than bromine. Hence it displaces bromine from potassium bromide solution. | | No visible reaction<br>Iodine is less reactive than bromine. Hence it cannot displace bromine from potassium bromide solution. |
| Potassium iodide, $KI$ | $Cl_2$ (aq) + 2KI (aq) $\rightarrow$ 2KCl (aq) + $I_2$ (aq)<br>The colourless potassium iodide solution turns brown with black solids.<br>Chlorine is more reactive than iodine. Hence it displaces iodine from potassium iodide solution. | $Br_2$ (aq) + 2KI (aq) $\rightarrow$ 2KCl (aq) + $Br_2$ (aq)<br>The colourless potassium iodide solution turns brown with black solids.<br>Bromine is more reactive than iodine. Hence it displaces iodine from potassium iodide solution. | |

### Trend in reactivity

Reactivity of halogens decrease down the group.

Explanation:

- Down the group, the number of protons and number of electron shells increases
- Both the nuclear charge and shielding effect increases
- However, the shielding effect increases more than the nuclear charge
- Therefore effective nuclear charge decreases
- Hence the electrostatic forces of attraction between the valence electrons and the nucleus is weaker,
- making it harder for the element to gain electrons.
- Therefore the reactivity increases down the group.

### Reaction with water

Eg. $Cl_2 + H_2O \rightarrow HCl + HClO$

### Reaction with sodium (see above under chemical properties of group I metals)

## Group 0

### Physical properties

Group 0 elements have low melting and boiling points.

Down group 0, melting points and boiling points increase.

### Explanation

- Down the group, the atomic size increases.
- This results in stronger Van der Waals' forces between the atoms.
- More energy is required to overcome the Van der Waals' forces.
- Hence the melting and boiling points increase down the group.

### Chemical Properties

Group 0 elements are inert/unreactive.

Explanation:

Group 0 elements have a stable noble gas (duplet or octet) electronic configuration.

Therefore they do not need to gain/lose/share electrons.

### Uses

| Noble gas | Uses |
|---|---|
| He | Used in airships and weather balloons due to its low density and low flammability |
| Ne | Used in advertising lights and signs because it is colourless but glows reddish-orange when a current is passed through it |
| Ar | Used in electric bulbs because it will not react with the white-hot filament |

# Transition Metals

## Physical properties

- are shiny and silvery in appearance
- are good conductors of heat and electricity
- are very hard and strong
- are malleable and ductile
- have very high melting points and boiling points
- have high densities

## Chemical Properties

Property 1: Transition metals can form ions with variable oxidation states.

Property 2: Most transition metals form coloured compounds.

Property 3: Transition metals or their compounds are used as catalysts.

Examples of transition metal catalysts in your syllabus (FYI only for now except for $MnO_2$ eg)

| Catalyst | Reaction | Industry |
|---|---|---|
| Iron | Hydrogen + Nitrogen ⇌ Ammonia<br>(Haber process) | manufacture of ammonia for fertilisers and other products |
| Nickel | Alkenes + Hydrogen → Alkanes | manufacture of margarine from vegetable oils |
| manganese (IV) oxide | Hydrogen peroxide → Water + Oxygen | laboratory preparation of oxygen |
| platinum - rhodium alloy | Carbon monoxide + Oxygen → Carbon dioxide<br>Nitrogen oxides → Nitrogen + Oxygen | employed in automobile catalytic converters |

# Mole concept

## Definitions of Ar and Mr

Relative atomic mass = $\frac{\text{average mass of an atom of an element}}{\text{mass of} \frac{1}{12} \text{the mass of a carbon}-12 \text{ atom}}$

Relative molecular mass = $\frac{\text{average mass of a molecule of a substance}}{\text{mass of} \frac{1}{12} \text{the mass of a carbon}-12 \text{ atom}}$

## Equations for mole inter-conversions

1) mass = no of moles x Ar/Mr

2) no of particles = no of moles x (6 x $10^{23}$)

3) volume of gas = no of moles x 24 $dm^3$

4) concentration (mol/$dm^3$) = $\frac{\text{no of moles of solute}}{\text{volume of solution}}$

5) concentration (g/$dm^3$) = $\frac{\text{mass of solute}}{\text{volume of solution}}$

## Definitions of % yield and % purity

% yield = $\frac{\text{experimental yield}}{\text{theoretical yield}}$ x 100%

% purity = $\frac{\text{mass of pure substance}}{\text{mass of sample}}$ x 100%

## Some examples of common mole calculations

### % by mass and mass extracted

Q: Calculate the % by mass of oxygen in sulfuric acid

A: % by mass of oxygen in $H_2SO_4$ = (64/98) x 100% = 65.3%

Q: Calculate the mass of nitrogen in 30 g of ammonium sulfate

A: mass of nitrogen in 30 g of $(NH_4)_2SO_4$ = 30 x (28/132) = 6.36g

## Empirical and molecular formula

Q: A compound with a mass of 42 g contains only boron and 9 g of hydrogen. Relative molecular mass of the compound is 28. Find the molecular formula of the compound.

A:

| | B | H |
|---|---|---|
| Mass/g | 33 | 9 |
| Ar | 11 | 1 |
| No. of moles/mol | 33/11 = 3 | 9/1 = 9 |
| Mole ratio | 3/3 = 1 | 9/3 = 3 |
| Nearest whole number | | |

Empirical formula = $BH_3$
Let molecular formula be $(BH_3)_n$
n = 28/14 = 2
Molecular formula = $B_2H_6$

## % yield

Q: 128 g of sulfur dioxide was reacted with 64 g of oxygen to form sulfur trioxide. 140 g of sulfur trioxide was produced. Calculate the percentage yield of sulfur trioxide.

A: $2SO_2 + O_2 \rightarrow 2SO_3$
no of moles of $SO_2$ = 128/64 = 2 mol
no of moles of $O_2$ = 64/32 = 2 mol
Since 2 moles of $SO_2$ requires 1 mole of $O_2$ for complete reaction, limiting reactant is $SO_2$
Since 2 moles of $SO_2$ forms 2 moles of $SO_3$
no of moles of $SO_3$ = 2 mol
theoretical mass of $SO_3$ = 2 x 80 = 160 g
% yield of $SO_3$ = (140/160) x 100% = 87.5%

## % purity

Q: 3.25 g of impure zinc was reacted with excess dilute hydrochloric acid. 1.1 $dm^3$ of hydrogen gas was produced. Calculate percentage purity of zinc.

A: $Zn + 2HCl \rightarrow H_2 + ZnCl_2$
no of moles of $H_2$ = 1.1/24 = 0.04583 mol (4sf)
1 mole of Zn forms 1 mole of $H_2$
no of moles of Zn = 0.04583 mol
mass of Zn = 0.04583 x 65 = 2.978 g (4sf)
% purity of Zn = (2.978/3.25) x 100% = 91.6% (3sf)

## Back titration

Q: 50.0 $cm^3$ of 0.5 $mol/dm^3$ potassium hydroxide were added to 25 $cm^3$ of ammonium chloride solution and mixed thoroughly. The resulting solution required 22.7 $cm^3$ of 0.22 $mol/dm^3$ nitric acid for complete neutralisation. Calculate the concentration of the ammonium chloride solution.

A: $KOH + HNO_3 \rightarrow H_2O + NaNO_3$
no. of moles of $HNO_3$ = (22.7/1000) x 0.22 = 4.994 x $10^{-3}$ mol
From equation, 1 mole of KOH reacts with 1 mole of $HNO_3$
no. of moles of remaining KOH = 4.994 x $10^{-3}$ mol
no. of moles of KOH initially = (50/1000) x 0.5 = 0.025 mol
no. of moles of KOH reacted = 0.025 – 4.994 x $10^{-3}$ = 0.02000 mol
$NH_4Cl + KOH \rightarrow NH_3 + H_2O + KCl$
From equation, 1 mole of $NH_4Cl$ reacts with 1 mole of KOH
no. of moles of $NH_4Cl$ = 0.02000 mol
concentration of $NH_4Cl$ = 0.02 ÷ (25/1000) = 0.8 $mol/dm^3$

### Calculations involving standard solutions/dilution

Q: 14.7 g of impure anhydrous sodium carbonate was dissolved in 1 $dm^3$ of distilled water to form a sodium carbonate solution. 24.0 $cm^3$ of this sodium carbonate solution required 29.8 $cm^3$ of 0.2 $mol/dm^3$ dilute nitric acid for complete reaction. Calculate the percentage purity of sodium carbonate.

A: $Na_2CO_3 + 2HNO_3 \rightarrow 2NaNO_3 + H_2O + CO_2$
no of moles of $HNO_3$ = 0.2 x (29.8/1000) = 0.00596 mol
Since 1 mole of $Na_2CO_3$ reacts with 2 moles of $HNO_3$
no of moles of $Na_2CO_3$ in 24 cm3 = 0.00596/2 = 0.00298 mol
no of moles of $Na_2CO_3$ in 1 $dm^3$ = 0.00298 x (1000/24) = 0.1241 mol (4sf)
mass of $Na_2CO_3$ = 0.1241 x 106 = 13.15 g (4sf)
% purity of $Na_2CO_3$ = (13.15/14.7) x 100% = 89.5 % (3sf)

# Acids and Bases

## Definitions

**Acid:** An acid is a substance that dissolves and ionises/dissociates in water to form hydrogen ions ($H^+$ ions).

**Basicity:** The basicity of an acid is the total number of hydrogen ions that an acid molecule can form when it dissociates.

**Strong acid:** A strong acid ionises/dissociates completely in water to form ions.

**Weak acid:** A weak acid ionises/dissociate partially in water to form ions.

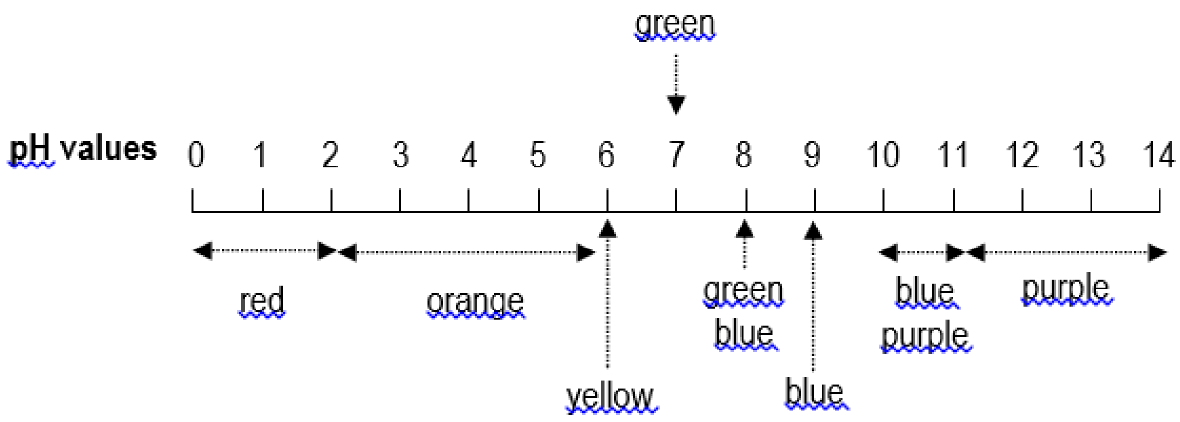
Note: Acids ONLY show acidic properties when dissolved in water. Eg. When hydrogen chloride is dissolved in an organic solvent, it does not display acidic properties.

## Colours of indications

### Examples of 2 common indicators in the syllabus

| **indicator** | **colour in acidic solution (pH < $x$)** | **pH at which colour change occurs ($x$)** | **colour in alkaline solution (pH > $x$)** |
|---|---|---|---|
| litmus | red | 7 | blue |
| methyl orange | red | 4 | yellow |

### Colours of Universal Indicator in Solutions of Various pH Values



## Physical properties of acids

1) Acids taste sour.

2) Acids change the colour of indicators (Universal Indicator, litmus, methyl orange etc.).

3) Solutions of acids dissolved in water can always conduct electricity because they contain mobile ions.

## Chemical properties of acids

1) acid + carbonate → salt + water + carbon dioxide

2) acid + base → salt + water

3) acid + reactive metal → salt + hydrogen

Unreactive metals that do not react with acids are Cu, Ag, Au.

## Physical properties of alkalis

1) Alkalis taste bitter.

2) Alkalis are soapy/slippery.

3) Alkalis change the colours of indicators.

4) Solutions of alkalis dissolved in water are good electrical conductor because they contain mobile ions.

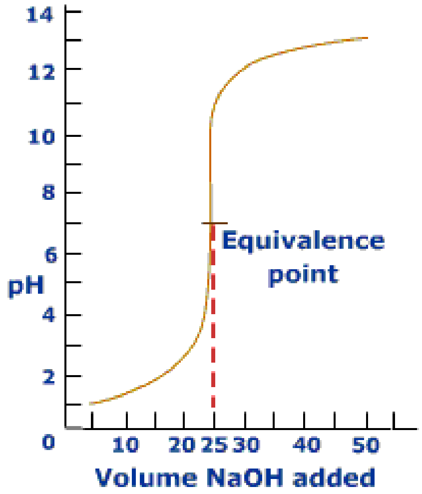
## Chemical properties of alkalis

1) alkali + ammonium salt → ammonia + water + salt

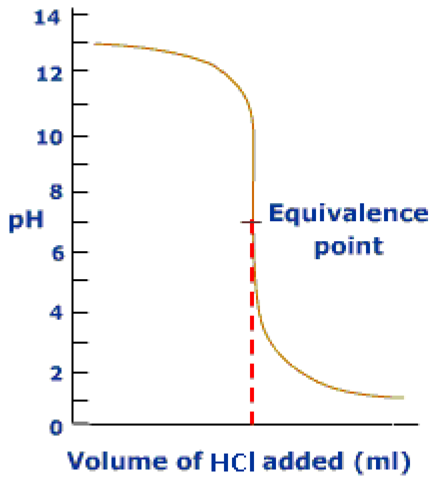
## Titration curves

What a pH curve shows:

- describes how the pH changes during an acid-base titration
- shows the equivalence point – the point where the solutions have been mixed in exactly the right proportions according to the chemical equation
- indicates the choice of a suitable indicator that changes colour near to the equivalence point



Titration curve of strong acid (HCl) with a strong base (NaOH)



Titration curve of strong base (NaOH) with strong acid (HCl)

## Titration curve of HC*l*-$Na_2CO_3$ reaction

In the first part of the reaction, sodium carbonate is reacting with the acid to produce sodium hydrogencarbonate. No carbon dioxide gas is produced.

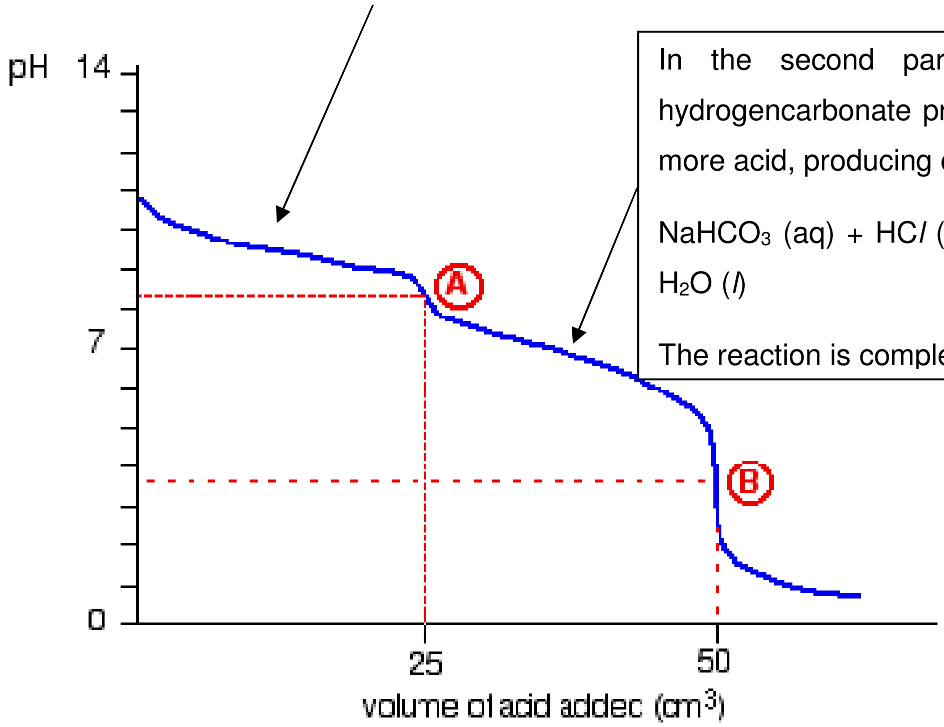
$$Na_2CO_3\ (aq) + HCl\ (aq) \rightarrow NaCl\ (aq) + NaHCO_3\ (aq)$$

The first part of the reaction is complete at A.

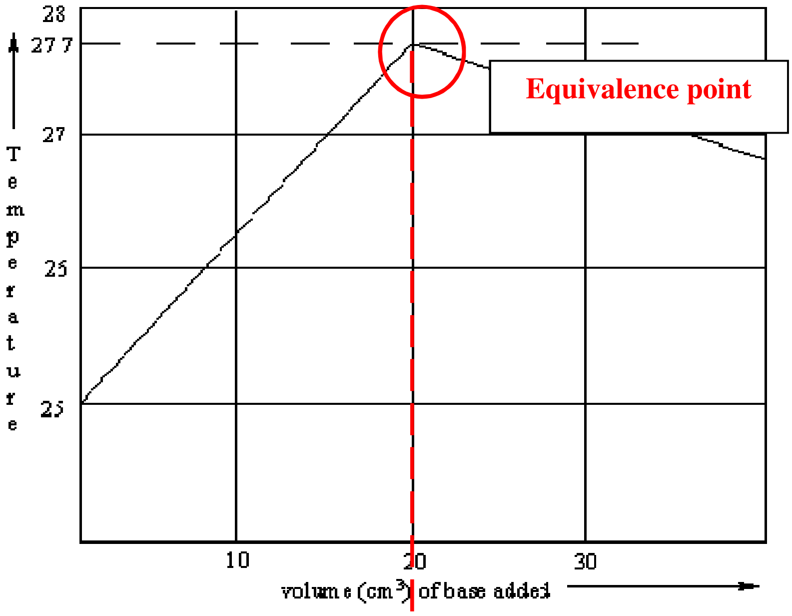
In the second part of the reaction, sodium hydrogencarbonate produced goes on to react with more acid, producing carbon dioxide gas.

$$NaHCO_3\ (aq) + HCl\ (aq) \rightarrow NaCl\ (aq) + CO_2\ (g) + H_2O\ (l)$$

The reaction is complete at B.



## Temperature change vs volume graph



## Nitrogenous fertilisers (placed under topic of ammonia)

## Uses of sulfuric acid and sulfur dioxide

### Uses of Sulfuric Acid

- manufacture of detergents
- manufacture of fertilisers
- battery acid in vehicles

### Uses of Sulfur Dioxide

- bleach / bleaching agent
- food preservative
- in the manufacture of sulfuric acid

## Types of oxides

Definitions:

**Basic** oxides react with acids to form salt and water only.

**Acidic** oxides react with alkalis to form salt and water only.

**Amphoteric** oxides react with both acids and alkalis to form salt and water only.

**Neutral** oxides do not react with either acids or alkalis.

Identifying types of oxides:

Most **metallic** oxides are basic oxides except $ZnO$, $Al_2O_3$ and $PbO$ which are amphoteric oxides

Most **non-metallic** oxides are acidic oxides except $CO$, $NO$ and $H_2O$ which are neutral oxides.

# Salts

## Solubility of salts

| Soluble salts | | Insoluble salts |
|---|---|---|
| All sodium salts<br>All potassium salts } Grp I salts<br>All ammonium salts<br>All nitrates | Except → | |
| All chlorides | ← Except | Silver chloride<br>Lead (II) chloride |
| All sulfates | Except → | Barium sulfate<br>Lead (II) sulfate<br>Calcium sulfate (sparingly soluble) |
| Sodium carbonate<br>Potassium carbonate } All Gp I carbonates<br>Ammonium carbonate | | All other carbonates |

| Soluble bases | | Insoluble bases |
|---|---|---|
| Sodium hydroxide<br>Potassium hydroxide } All Gp I hydroxides<br>Ammonium hydroxide<br>Barium hydroxide<br>Strontium hydroxide<br>Calcium hydroxide (sparingly soluble) | ← Except | All other hydroxides |
| Sodium oxide<br>Potassium oxide } All Gp I oxides<br>Ammonium oxide<br>Barium oxide<br>Strontium oxide<br>Calcium oxide (sparingly soluble) | ← Except | All other oxides |

## Determining method of salt preparation

1) If the salt is insoluble, use precipitation method.

2) If the salt is a soluble group I or ammonium salt, use titration method.

3) If the salt is a soluble salt that is not group I or ammonium salt, use ABCm method.

## Procedure for precipitation method

- Mix aqueous lead(II) nitrate and sulfuric acid solution together and stir
  (One of the aqueous solutions must contain the cation while the other aqueous solution must contain the anion, of the salt to be prepared)

- Lead(II) sulfate is formed as precipitate
- Filter the mixture, retaining the residue (precipitate)
- Wash the residue with lots of distilled water (for 'purity')
- Dry the residue between filter papers (for 'dryness')
- Lead (II) sulfate is obtained

## Procedure for ABCm method

- Add copper (II) carbonate/copper (II) oxide/copper (II) hydroxide to sulfuric acid solution until no further amount of copper (II) carbonate/copper (II) oxide/copper (II) hydroxide can react anymore
- Filter off the excess copper (II) carbonate/copper (II) oxide/copper (II) hydroxide / Filter the mixture and retain the filtrate, aqueous copper (II) sulfate.
- Place the copper (II) sulfate filtrate on an evaporating dish
- Heat/warm the filtrate until saturation
- Let the saturated filtrate cool
- Crystals of copper (II) sulfate are formed (crystallisation) upon cooling
- Filter the mixture to remove the copper (II) sulfate crystals as residue
- Wash the copper (II) sulfate crystals with a small amount of cold distilled water (for 'purity')
- Dry the copper (II) sulfate crystals between filter papers (for 'dryness')
- Copper (II) sulfate is obtained

## Procedure for titration method

- Pipette 20.0 $cm^3$ of sodium hydroxide/sodium carbonate solution into a conical flask
- Add a few drops of methyl orange to sodium hydroxide/sodium carbonate solution
- Add sulfuric acid slowly to the sodium hydroxide/sodium carbonate, with constant swirling, using a burette
- Stop the titration when methyl orange turns from yellow to orange
- Record the volume of sulfuric acid used
- Repeat the previous step again to confirm that the end-point is determined accurately
- Repeat the entire procedure again, using 20.0 $cm^3$ of sodium hydroxide/sodium carbonate and the volume of sulfuric acid used at end-point, without any addition of methyl orange indicator
- Place the sodium sulfate solution on an evaporating dish
- Heat/warm the sodium sulfate solution until saturation
- Saturated solution is cooled
- Crystals of sodium sulfate are formed (crystallisation) upon cooling
- Filter the mixture to remove the sodium sulfate crystals as residue
- Wash the salt crystals with small amount of cold distilled water (for ‘purity’)
- Dry the salt crystals between filter papers (for ‘dryness’)
- sodium sulfate is obtained

# QA

## Test for gases

| Gas | Test and test results |
|---|---|
| $NH_3$ | Turns moist red litmus paper blue |
| $CO_2$ | Forms white ppt with limewater |
| $Cl_2$ | Turns moist blue litmus paper red before bleaching it |
| $H_2$ | Extinguish lighted splint with a pop sound |
| $O_2$ | Relights glowing splint |
| $SO_2$ | Turns purple acidified potassium manganate(VII) solution colourless |
| $H_2O$ | Turns blue anhydrous cobalt(II) chloride paper pink OR<br>Turns white anhydrous copper(II) sulfate blue |

*Refer to table below on properties of gases for colour and odour of gases

## Test for cations

| Cation | Adding aq NaOH | Adding aq $NH_3$ |
|---|---|---|
| $Ca^{2+}$ | White ppt insoluble in excess | No ppt |
| $Zn^{2+}$ | White ppt soluble in excess giving colourless solution | White ppt soluble in excess giving colourless solution |
| $Al^{3+}$ | White ppt soluble in excess giving colourless solution | White ppt insoluble in excess |
| $Pb^{2+}$ | White ppt soluble in excess giving colourless solution | White ppt insoluble in excess |
| $Fe^{2+}$ | Dirty green ppt insoluble in excess | Dirty green ppt insoluble in excess |
| $Fe^{3+}$ | Reddish brown ppt insoluble in excess | Reddish brown ppt insoluble in excess |
| $Cu^{2+}$ | Light blue ppt insoluble in excess | Light blue ppt soluble in excess giving dark blue solution |
| $NH_4^+$ | On warming, a colourless pungent gas that turns moist red litmus paper blue is evolved. | |

## Test for anions

| Anion | Test | Test result |
|---|---|---|
| $CO_3^{2-}$ | Add dilute acid (usually $HNO_3$) | Effervescence of a colourless odourless gas that forms white ppt in limewater |
| $Cl^-$ | Add acidified silver nitrate | White ppt |
| $I^-$ | Add acidified silver nitrate | Pale yellow ppt |
| $SO_4^{2-}$ | Add acidified barium nitrate | White ppt |
| $NO_3^-$ | Add aq NaOH, $Al$, warm | On warming, a colourless pungent gas that turns moist red litmus paper blue is evolved. |

*Acidification is done using dilute nitric acid.

## Differentiating between solutions containing lead(II) and aluminium ions

| | $SO_4^{2-}$<br>*(e.g. aq. $H_2SO_4$, aq. $Na_2SO_4$ etc)* | $Cl^-$<br>*(e.g. aq. HCl, aq. NaCl etc)* | $I^-$<br>*(e.g. aq. NaI, aq. KI etc)* |
|---|---|---|---|
| $Pb^{2+}$ (aq) | A white ppt formed. ($PbSO_4$) | A white ppt formed. ($PbCl_2$) | A bright yellow ppt formed. ($PbI_2$) |
| $Al^{3+}$ (aq) | No visible change | | |

## Properties of Gases

| Gas | Colour | Odour | Solubility in water | Density compared to air | Method of collection | Acidity |
|---|---|---|---|---|---|---|
| Hydrogen | Colourless | Odourless | Not soluble | Less dense | Displacement of water | Neutral |
| Oxygen | Colourless | Odourless | Very slightly soluble | Slightly denser | Displacement of water | Neutral |
| Carbon dioxide | Colourless | Odourless | Slightly soluble | Denser | Downward delivery | Acidic |
| Chlorine | Greenish yellow | Choking | Soluble | Denser | Downward delivery | Acidic/bleaching |
| Sulfur dioxide | Colourless | Choking | Very soluble | Denser | Downward delivery | Acidic |
| Ammonia | Colourless | Pungent | Extremely soluble | Less dense | Upward delivery | Alkaline |
| Nitrogen | | | Not soluble | Slightly less dense | Displacement of water | Neutral |
| Nitrogen monoxide | | | Not soluble | Slightly denser | Displacement of water | Neutral |
| Nitrogen dioxide | | | Slightly soluble | denser | Downward delivery | Acidic |
| Hydrogen chloride | | | Very soluble | Denser | Downward delivery | Acidic |

- ✓ $M_r$ of air is about 28.9

# Summary for colours of substances

## General trends for colours

### Metals

- Most metals are grey except for copper (reddish brown/pink) and gold (gold).

### Group I, II and III compounds

- Most group I, II and III compounds are white solids that form colourless solutions when dissolved in water.
- Exceptions occur when anions are responsible for the colour, eg $KMnO_4$/$K_2Cr_2O_7$

### Group VII halogens

| | In solution | In organic solvent | In different states |
|---|---|---|---|
| Chlorine | greenish yellow | greenish yellow | greenish yellow gas |
| Bromine | reddish brown | reddish brown | reddish brown liquid |
| Iodine | brown | purple | black solid, purple vapour |

### Colours of halides

| Halide | Colour | Halide | Colour |
|---|---|---|---|
| $AgCl$ | white | $PbCl_2$ | white |
| $AgBr$ | cream | $PbBr_2$ | white |
| $AgI$ | pale yellow | $PbI_2$ | bright yellow |

### Colours of hydroxides, oxides, carbonates, and others

| Ions | Solutions | Hydroxides | Oxides | Carbonates | Others |
|---|---|---|---|---|---|
| $Cu^{2+}$ | blue | light blue | black | green | anhydrous $CuSO_4$ (white) |
| $Fe^{2+}$ | pale green | dirty green | black | green | |
| $Fe^{3+}$ | yellow | reddish brown | reddish brown | *brown | |
| $Zn^{2+}$ | colourless | white | yellow when hot, white when cold | white | |
| $Pb^{2+}$ | colourless | white | orange when hot, yellow when cold | white | |
| $Ag^{+}$ | colourless | *brown | *black | *yellow | |

* means FYI only, no need to remember those colours

### Other common coloured substances

| Substance | Colour |
|---|---|
| Manganese compounds | $MnO_2$ (black), $Mn^{2+}$ compounds (colourless), $KMnO_4$ (purple) |
| Chromium compounds | $K_2Cr_2O_7$ (orange), $Cr^{3+}$ compounds (green) |
| C | black |
| $CoCl_2$ | Hydrated (pink), anhydrous (blue) |
| $Fe_3O_4$ | black |

# Metals

## Physical properties of metals (refer to chemical bonding section)

## Common alloys

| Alloy | Elements in alloy |
|---|---|
| Brass | Cu + Zn |
| Bronze | Cu + Sn |
| Steel | Fe + C |
| Stainless steel | Fe + C + Ni + Cr |

## Explanation questions for alloys

**Why are pure metals soft?**

- Easy for orderly layers of same sized atoms to slide over one another.

**Why are alloys harder than pure metals?**

- Alloys consist of atoms of different size.
- The orderly arrangement of atoms is disrupted.
- The layers of atoms cannot slide over each other easily when a force is applied.
- Therefore, alloys are harder and stronger than pure metals.

## Reactivity series

### Reaction of metals with acid, steam and water

**Answering template for observations:**

**Reaction with cold water**

- (metal) reacts explosively/violently/readily/very slowly with cold water.
- Effervescence of a colourless odourless gas that extinguishes a burning splint with a 'pop' sound. (Production of hydrogen gas)
- (group I metal) darts around quickly and sizzles on the surface of the water. *Note that this is only relevant for group I metals

**Reaction with steam**

- (metal) reacts violently/readily/slowly with steam.
- (observation particular to the metal. E.g. for Mg a bright white glow is produced, for Zn an oxide that is yellow when hot and white when cold is formed, for Fe the iron will appear red hot when reacting with steam.)

**Reaction with acid**

- (metal) reacts explosively/violently/very quickly/moderately fast/slow/very slowly with acid
- Effervescence of a colourless odourless gas that extinguishes a burning splint with a 'pop' sound.

**Details in table on next page**

# Reaction of metals with acid, steam and water

| ***Metals*** | ***Reaction with Cold Water*** | ***Reaction with Steam*** | ***Reaction with dilute HCl*** |
|---|---|---|---|
| **Potassium** | ***Reacts explosively***. Potassium ***darts around*** and ***sizzles*** on the surface of the water. ***Effervescence*** of ***colourless odourless gas*** that ***extinguish lighted splint with 'pop' sound***.<br>$2K (s) + 2H_2O (l) \rightarrow$ ***$2KOH (aq) + H_2 (g)$*** | Too explosive | Explosive reaction. ***Effervescence*** of ***colourless odourless gas*** that ***extinguish lighted splint with 'pop' sound***.<br>(Not safe to be performed in the lab)<br>$2K (s) + 2HCl (aq) \rightarrow$ ***$2KCl (aq) + H_2 (g)$*** |
| **Sodium** | ***Reacts violently***. Sodium ***darts around*** and ***sizzles*** on the surface of the water. ***Effervescence*** of ***colourless odourless gas*** that ***extinguish lighted splint with 'pop' sound***.<br>$2Na (s) + 2H_2O(l) \rightarrow$ ***$2NaOH (aq) + H_2 (g)$*** | | Explosive reaction. ***Effervescence*** of ***colourless odourless gas*** that ***extinguish lighted splint with 'pop' sound***.<br>(Not safe to be performed in the lab)<br>$2Na (s) + 2HCl (aq) \rightarrow$ ***$2NaCl (aq) + H_2 (g)$*** |
| **Calcium** | Reacts ***readily***. ***Effervescence*** of ***colourless odourless gas*** that ***extinguish lighted splint with 'pop' sound***.<br>$Ca (s) + 2H_2O(l) \rightarrow$ ***$Ca(OH)_2 (aq) + H_2 (g)$*** | | Reacts ***violently, Effervescence*** of ***colourless odourless gas*** that ***extinguish lighted splint with 'pop' sound***.<br>$Ca (s) + 2HCl (aq) \rightarrow$ ***$CaCl_2 (aq) + H_2 (g)$*** |
| **Magnesium** | Very ***slow*** reaction. ***Effervescence*** of ***colourless odourless gas*** that ***extinguish lighted splint with 'pop' sound***.<br>$Mg (s) + 2H_2O(l) \rightarrow$ ***$Mg(OH)_2 (aq) + H_2 (g)$*** | Hot Mg reacts ***violently*** with steam. Bright ***white*** glow produced. ***Grey*** solid turns ***white***.<br>$Mg (s) + H_2O(g) \rightarrow$ ***$MgO (s) + H_2 (g)$*** | ***Very fast*** reaction. ***Effervescence*** of ***colourless odourless gas*** that ***extinguish lighted splint with 'pop' sound***.<br>$Mg (s) + 2HCl (aq) \rightarrow$ ***$MgCl_2 (aq) + H_2 (g)$*** |
| **Aluminium** | ---- | ---- | ---- |
| **(Carbon)** | | | |
| **Zinc** | No reaction with cold water.<br>*(For iron, rusting occurs slowly in the presence of air.) | Hot Zn reacts ***readily*** in steam. ***Grey*** solid turns ***yellow*** when hot and ***white*** when cold.<br>$Zn (s) + H_2O(g) \rightarrow$ ***$ZnO (s) + H_2 (g)$*** | ***Moderately fast*** reaction. ***Effervescence*** of ***colourless odourless gas*** that ***extinguish lighted splint with 'pop' sound***.<br>$Zn (s) + 2HCl (aq) \rightarrow$ ***$ZnCl_2 (aq) + H_2 (g)$*** |
| **Iron** | | ***Red*** hot iron reacts ***slowly*** to form a ***black*** solid.<br>$3Fe (s) + 4H_2O(g) \rightarrow$ ***$Fe_3O_4 (s) + 4H_2 (g)$*** | ***Slow*** reaction. ***Effervescence*** of ***colourless odourless gas*** that ***extinguish lighted splint with 'pop' sound***.<br>$Fe (s) + 2HCl (aq) \rightarrow$ ***$FeCl_2 (aq) + H_2 (g)$*** |
| **Lead** | | No reaction with steam. | Very ***slow*** reaction. ***Effervescence*** of ***colourless odourless gas*** that ***extinguish lighted splint with 'pop' sound***.<br>$Pb (s) + 2HCl (aq) \rightarrow$ ***$PbCl_2 (s) + H_2 (g)$*** |
| **(Hydrogen)** | | | |
| **Copper** | | | No reaction with dilute acids. |
| **Silver** | | | |

**Exception in reactivity series/oxide layer:**

**Why does (reactive metal, usually aluminium) not react with (steam/acid)? (OR react only after some time if acid is added/after sandpaper is used)**

- (metal) reacts readily with oxygen to form a (metal oxide)
- Metal is covered with oxide layer which is highly adhesive and non-porous
- The layer protects the metal from reacting with (steam/acid)

## Displacement reactions (for solutions)

**Stating observations:**

- A (colour) solid is deposited.
- The (colour) (name of chemical) solution turns (colour)

**Explaining observations:**

- The (more reactive metal) is more reactive than (less reactive metal).
- Therefore (more reactive metal) displaces (less reactive metal) from (salt solution of less reactive metal).

## Stability of metal compounds

More reactive metals form more stable compounds

## Stability of metal carbonates

| Metal Carbonate | Observations upon heating |
|---|---|
| Potassium carbonate | Unaffected by heat; very high thermal stability |
| Sodium carbonate | |
| Calcium carbonate | Eqn: $CaCO_3$ (s) $\rightarrow$ $CaO$ (s) + $CO_2$ (g)<br>Obs: A colourless odourless gas is evolved that forms white precipitate in limewater.<br>The white solid remains white. |
| Magnesium carbonate | Eqn: $MgCO_3$ (s) $\rightarrow$ $MgO$ (s) + $CO_2$ (g)<br>Obs: A colourless odourless gas is evolved that forms white precipitate in limewater.<br>The white solid remains white. |
| Alumnium carbonate | Eqn: $Al_2(CO_3)_3$ (s) $\rightarrow$ $Al_2O_3$ (s) + $3CO_2$ (g)<br>Obs: A colourless odourless gas is evolved that forms white precipitate in limewater.<br>The white solid remains white. |
| Zinc carbonate | Eqn: $ZnCO_3$ (s) $\rightarrow$ $ZnO$ (s) + $CO_2$ (g)<br>Obs: A colourless odourless gas is evolved that forms white precipitate in limewater.<br>The white solid turns yellow when heated and white when cooled. |
| Iron (II) carbonate | Eqn: $FeCO_3$ (s) $\rightarrow$ $FeO$ (s) + $CO_2$ (g)<br>Obs: A colourless odourless gas is evolved that forms white precipitate in limewater.<br>The green solid turns black. |
| Lead (II) carbonate | Eqn: $PbCO_3$ (s) $\rightarrow$ $PbO$ (s) + $CO_2$ (g)<br>Obs: A colourless odourless gas is evolved that forms white precipitate in limewater.<br>The white solid turns orange when heated and yellow when cooled. |
| Copper (II) carbonate | Eqn: $CuCO_3$ (s) $\rightarrow$ $CuO$ (s) + $CO_2$ (g)<br>Obs: A colourless odourless gas is evolved that forms white precipitate in limewater.<br>The green solid turns black. |
| Silver carbonate | Eqn: $2Ag_2CO_3$ (s) $\rightarrow$ $4Ag$ (s) + $2CO_2$ (g) + $O_2$ (g)<br>Obs: A colourless odourless gas is evolved that forms white precipitate in limewater.<br>A colourless odourless gas is evolved that relights a glowing splint.<br>FYI: The yellow solid turns grey. |

**Reduction of metal oxides**

| Metal Oxide | Reaction with C/CO | Reaction with $H_2$ | Electrolysis |
|---|---|---|---|
| Potassium oxide | Heated metal oxides are **not** reduced | Heated metal oxides are **not** reduced | Metal oxides are too stable to undergo chemical reduction.<br>These undergo electrolytic reduction. |
| Sodium oxide | | | |
| Calcium oxide | | | |
| Magnesium oxide | | | |
| Aluminium oxide | | | |
| Zinc oxide | Heated metal oxides are reduced | | Possible for electrolytic reduction; however option not chosen. Why? ***expensive*** |
| Iron(III)oxide | | Heated metal oxides are reduced | |
| Lead(II)oxide | | | |
| Copper(II)oxide | | | |
| Silver oxide | | | |

**Displacement reactions of metal oxides**

More reactive metal will displace a less reactive metal from its oxides.

## Rusting

**Definition:** Rusting is the slow oxidation of iron to form hydrated iron (III) oxide (a reddish-brown solid)

**Conditions for rusting:** oxygen and water

**Factors affecting rate of rusting:**

1) Humidity

2) Presence of acidic pollutants

3) Presence of salts

Note: Rusting is only for iron. Other metals are said to corrode.

## Rust prevention

1) Using protective layer (eg paint, oil)

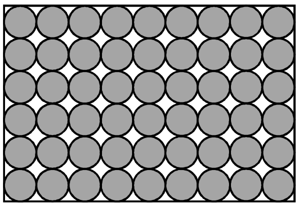
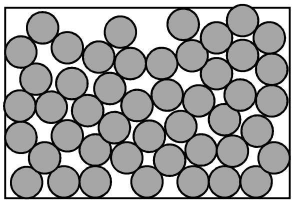
2) Sacrificial protection (eg. Electroplating or dip plating with zinc, attaching zinc blocks to hulls of ships, connecting magnesium blocks to underground pipelines)

## Recycling

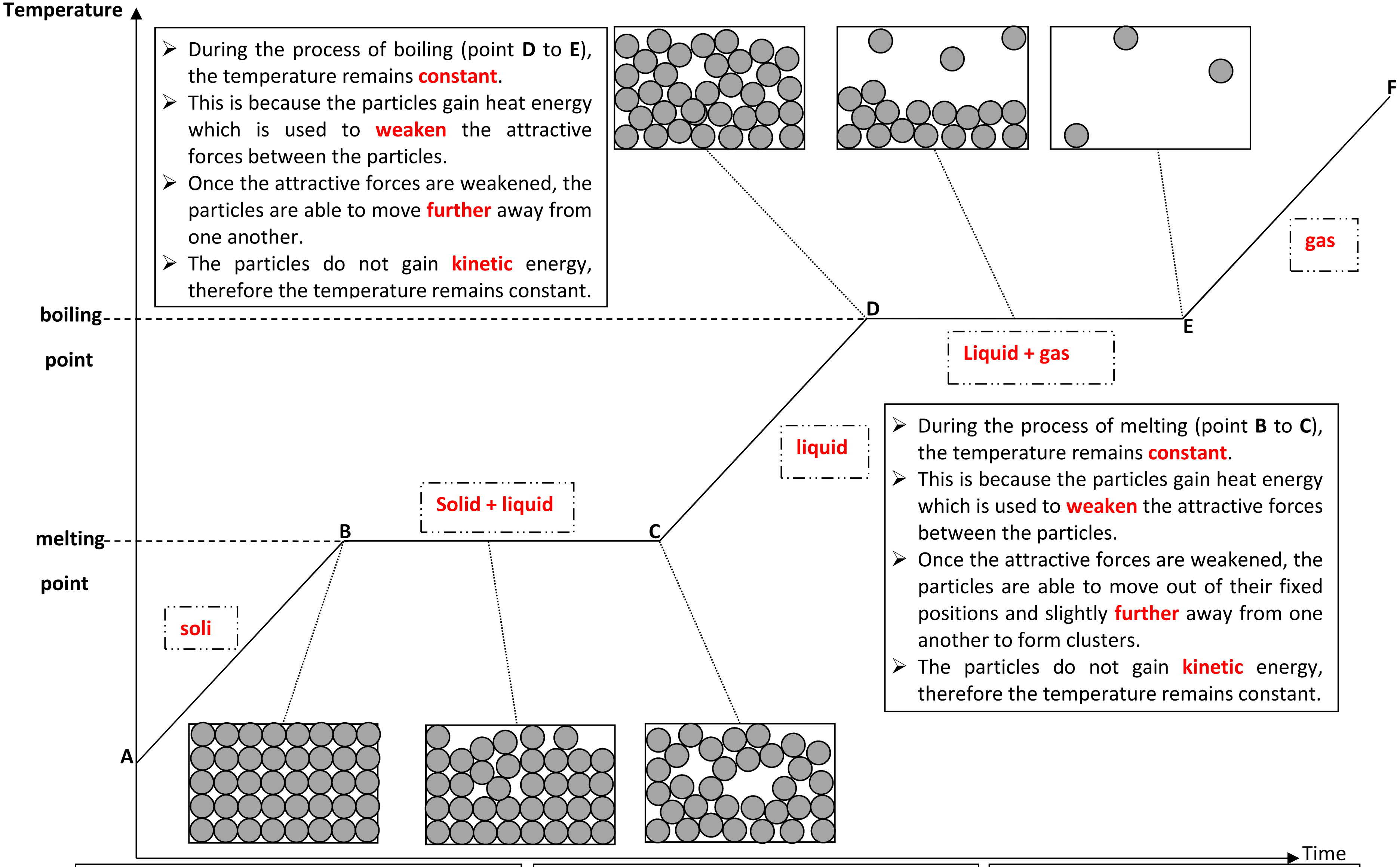
| **Advantages** | **Disadvantages** |
|---|---|
| The finite resources will last longer. | Additional costs incurred during operation. |
| Higher saving of energy – Production of aluminium from scrap aluminium compared to extracting aluminium by electrolysis | ● The cost of transportation of scrap metals to the processing plant. |
| Reduce land and air pollution – mining destroys the environment and produces an enormous amount of waste products. The smelting of ore also causes severe air pollution. | ● The cost to separate and clean scrap metals. |
| Less need for mining – land is freed up for other uses like agriculture and development. | ● The cost to sort the metals into different types. |
| Save landfill sites to dispose of waste products of mining. | |

# Kinetic Particle Theory

## The 3 States of Matter in terms of Kinetic Particle Theory

| | Solid | Liquid | |
|---|---|---|---|
| **Properties** | <br>➢ Fixed Shape<br>• Particles occupy fixed positions<br>➢ Fixed volume/cannot be compressed<br>• Very little empty space in between | <br>➢ No fixed shape<br>• Particles do not occupy fixed positions<br>➢ Fixed volume/cannot be compressed<br>• Little empty space in between | ➢<br>➢ |
| **Arrangement of particles** | ➢ Closely packed in a regular arrangement | ➢ Closely packed in clusters in random arrangement | ➢ |
| **Movement of particles** | ➢ Vibrate in fixed positions | ➢ Slide and roll over each other with particles still in contact with one another | ➢<br>➢ |
| **Heating (with temperature increase)** | ➢ Kinetic energy increases, particles vibrate faster | ➢ Kinetic energy increases, particles roll and slide faster | ➢ |
| **Heating (melting or boiling)** | ➢ Empty spaces between particles increases slightly | ➢ More empty spaces created between particles | ➢ |
| **Forces of attraction between particles** | ➢ Very strong, enough to keep particles closely packed and in fixed positions | ➢ Strong, enough to keep particles close together but allow them to roll and slide randomly | ➢ |

## Heating Curve



- During the process of boiling (point **D** to **E**), the temperature remains **constant**.
- This is because the particles gain heat energy which is used to **weaken** the attractive forces between the particles.
- Once the attractive forces are weakened, the particles are able to move **further** away from one another.
- The particles do not gain **kinetic** energy, therefore the temperature remains constant.

- During the process of melting (point **B** to **C**), the temperature remains **constant**.
- This is because the particles gain heat energy which is used to **weaken** the attractive forces between the particles.
- Once the attractive forces are weakened, the particles are able to move out of their fixed positions and slightly **further** away from one another to form clusters.
- The particles do not gain **kinetic** energy, therefore the temperature remains constant.

- From point **A** to **B**, the particles gain **heat** energy which is converted to **kinetic** energy.
- Therefore, the particles vibrate more quickly but still remain in a **regular** arrangement and in **fixed** positions.

- From point **C** to **D**, the particles gain **heat** energy which is converted to **kinetic** energy.
- Therefore, the particles roll around and slide over one another in clusters at **greater** speeds.

- From point **E** to **F**, the particles gain **heat** energy which is converted to **kinetic** energy.
- Therefore, the particles move freely and randomly at **greater** speeds.

## Factors affecting rate of diffusion

1) **Temperature:** the higher the temperature, the faster the rate of diffusion
2) **Mr:** the higher the Mr, the slower the rate of diffusion
3) **Gravity:** Gravity can aid or slow down diffusion depending on the direction of diffusion

## Examples of questions in kinetic particle theory

1) When the pressure of a gas is increased, the volume decreases. [2]

- Gases can be compressed easily because there are a lot of empty space between particles.
- When the pressure is increased, the gas particles are pushed closer to each other and therefore volume decreases.

2) When the pressure on a solid is increased, there is almost no change in volume. [2]

- Solids cannot be compressed because there is very little space between particles.
- When pressure is increased, the particles cannot be pushed closer to each other and therefore there is almost no change in volume.

3) A solid has more mass than the same volume of gas. [2]

- In solids, there is very little space between particles while for gases, there are a lot of empty space between particles.
- As such, for solids, there will be more particles in the same volume of space as compared to gases and so a solid has more mass than the same volume of gas.

4) A small volume of water produces a much larger volume of steam. [2]

- In water, there is little space between particles while for steam, there are a lot of empty space between particles.
- As such, the particles in steam are further apart than the particles in water, and so a small volume of water will produce a much larger volume of steam.

5) A gas at constant pressure increases in volume when it is gently heated, but a solid does not. [4]

- Particles in a solid can only vibrate in fixed positions.
- When a solid is gently heated, the kinetic energy of the particles increase and they vibrate faster.
- However, the average distance between particles does not increase and so the volume of the solid does not increase.

- Particles in a gas are moving randomly at high speeds.
- When a gas is gently heated, the kinetic particle energy of the particles increase and they move randomly at higher speeds.
- Therefore the average distance between particles increase and the volume of the gas increases.

6) A liquid takes the shape of its container but a solid does not. [1]

- A liquid can take the shape of its container because the particles in a liquid does not occupy fixed positions.
- A solid does not take the shape of its container because the particles in a solid occupy fixed positions.

7) Solid ice loses its shape when it melts. [2]

- Ice has a fixed shaped because the particles in ice occupy fixed positions.
- As ice melts, the intermolecular forces between water molecules are weakened such that the particles are sliding and rolling over each other.
- Since the particles in water do not occupy fixed positions, water does not have a fixed shape.

8) A gas is easier to compress than a solid. [2]

- In solids, there is very little space between particles while for gases, there are a lot of empty space between particles.
- As such, gases are easier to compress as gas particles can move closer to each other easily while it is much more difficult for solid particles to move closer to each other.

# Simple Cell

## General simple cell

| | Anode (–) | Cathode (+) |
|---|---|---|
| Metal | More reactive metal | Less reactive metal |
| Equations | M (s) → $M^{n+}$ + ne | $2H^+$ (aq) + 2e → $H_2$ (g)<br>OR $M^{n+}$ (aq) + ne → M (s) |

*M is a metal, the metal at the anode and cathode may be different.

## Simple Cell Examples

### Zn/Cu simple cell with $H_2SO_4$ electrolyte

| | Anode (–) | Cathode (+) |
|---|---|---|
| Metal | Zn | Cu |
| Equations | Zn (s) → $Zn^{2+}$ + 2e | $2H^+$ (aq) + 2e → $H_2$ (g) |
| Observations | The zinc anode becomes smaller. | Effervescence of a colourless odourless gas that extinguish a lighted splint with a 'pop' sound at the copper cathode. |

### Zn/Cu simple cell with $CuSO_4$ electrolyte

| | Anode (–) | Cathode (+) |
|---|---|---|
| Metal | Zn | Cu |
| Equations | Zn (s) → $Zn^{2+}$ + 2e | $Cu^{2+}$ (aq) + 2e → Cu (s) |
| Observations | The zinc anode becomes smaller. | A reddish brown solid is deposited at the copper cathode.<br>The blue copper(II) sulfate solution turns colourless. |

## Selective discharge at cathode

- If an ion of a metal that is below hydrogen in the reactivity series is present, eg $Ag^+$ and $Cu^{2+}$, the metal ion is discharged to form the metal
- For all other electrolytes, $H^+$ is discharged to form $H_2$.

## Factors affecting voltage reading

- Choice of metal (greater the difference in reactivity = greater voltage)
- Choice of electrolyte (Strong acid/alkali gives greater voltage than weak acid/alkali)

## Fuel Cell (Eg hydrogen fuel cell)

**Overall equation for hydrogen fuel cell**

$2H_2\ (g) + O_2\ (g) \rightarrow 2H_2O\ (l)$

**Where reactants come from**

Oxygen: obtained from fractional distillation of liquid air

Hydrogen: catalytic cracking of long-chain hydrocarbons from petroleum

**Advantages**

1. Infinite lifespan as long as the reactants are supplied continuously.
2. Pollution-free because water is the only product formed.
3. Reactants are renewable.

   Note that this only applies if hydrogen is obtained from water instead of petroleum.

**Disadvantages**

1. Expensive because of large amount of platinum metals used as catalyst required for electrode reaction.
2. The reactant, hydrogen, needs to be liquefied for both transport and storage, which will increase costs.

## Answering template for explanations for observations in a simple cell

| | | |
|---|---|---|
| **Anode** | At the anode, the (metal) electrode is oxidized and loses electrons to form (metal) ions. | |
| **Cathode** | If only 1 type of positive ion in the electrolyte | At the cathode, the (positive) ions are discharged by reduction and gain electrons to form (product). |
| | If more than 1 type of positive ion in the electrolyte, selective discharge occurs | (element) is more reactive than (element). At the cathode, the ions of (the less reactive metal) are selectively discharged by reduction and gain electrons to form (product). |

# Electrolysis

## Electrolysis of molten $NaCl$ using inert electrodes

| | Anode (+) | Cathode (–) |
|---|---|---|
| **Observation** | Effervescence of a greenish yellow choking gas that turns moist blue litmus paper red before bleaching it. | A grey liquid is observed. |
| **Half equation** | $2Cl^- (l) \rightarrow Cl_2 (g) + 2e$ | $Na^+ (l) + e \rightarrow Na (l)$ |
| **Overall equation** | $2NaCl (l) \rightarrow 2Na (l) + Cl_2 (g)$ | |

## Electrolysis of dilute $NaCl$ using inert electrodes

| | Anode (+) | Cathode (–) |
|---|---|---|
| **Observation** | Effervescence of a colourless odourless gas that relights a glowing splint. | Effervescence of a colourless odourless gas that extinguish a lighted splint with a pop sound. |
| **Half equation** | $4OH^- (aq) \rightarrow O_2 (g) + 2H_2O (l) + 4e$ | $2H^+ (aq) + 2e \rightarrow H_2 (g)$ |
| **Overall equation** | $2H_2O (l) \rightarrow 2H_2 (g) + O_2 (g)$ | |

## Electrolysis of concentrated $NaCl$ using inert electrodes

| | Anode (+) | Cathode (–) |
|---|---|---|
| **Observation** | Effervescence of a greenish yellow choking gas that turns moist blue litmus paper red before bleaching it. | Effervescence of a colourless odourless gas that extinguish a lighted splint with a pop sound. |
| **Half equation** | $2Cl^- (aq) \rightarrow Cl_2 (g) + 2e$ | $2H^+ (aq) + 2e \rightarrow H_2 (g)$ |
| **Overall ionic equation** | $2H^+ (aq) + 2Cl^- (aq) \rightarrow H_2 (g) + Cl_2 (g)$ | |
| **Overall equation** | $2H_2O (l) + 2NaCl (aq) \rightarrow H_2 (g) + 2NaOH (aq)$ | |

## Electrolysis of aqueous $CuSO_4$ using inert electrodes

| | Anode (+) | Cathode (–) |
|---|---|---|
| **Observation** | Effervescence of a colourless odourless gas that relights a glowing splint. | A reddish brown solid is deposited |
| **Half equation** | $4OH^- (aq) \rightarrow O_2 (g) + 2H_2O (l) + 4e$ | $Cu^{2+} (aq) + 2e \rightarrow Cu (s)$ |
| **Overall ionic equation** | $2Cu^{2+} (aq) + 4OH^- (aq) \rightarrow 2Cu (s) + O_2 (g) + 2H_2O (l)$ | |
| **Overall equation** | $2CuSO_4 (aq) + 2H_2O (l) \rightarrow 2Cu (s) + O_2 (g) + 2H_2SO_4 (aq)$ | |

## Electrolysis using reactive electrodes

Electrolyte: $CuSO_4$ (aq)

Electrodes: Cu

| | **Anode (+)** | **Cathode (–)** |
|---|---|---|
| **Observation** | The size of the anode decreases. | A reddish brown solid is deposited/The size of the cathode increases. |
| **Half equation** | $Cu\ (s) \rightarrow Cu^{2+}\ (aq) + 2e$ | $Cu^{2+}\ (aq) + 2e \rightarrow Cu\ (s)$ |
| **Overall equation** | NA | |

## Selective discharge

| **Cathode (–)** | **Anode (+)** |
|---|---|
| **1)** For ions of metals below hydrogen in reactivity series: metal ion is reduced.<br>($M^{n+} + ne \rightarrow M$)<br>**2)** For ions of metals above hydrogen in reactivity series: hydrogen ion is reduced.<br>($2H^+ + 2e \rightarrow H_2$) | **1)** If reactive electrode is used: electrode is oxidised.<br>If electrode is inert:<br>**2)** For concentrated halide solution ($I^-$, $Br^-$, $Cl^-$): halide ion is oxidised.<br>(Eg. $2Cl^- \rightarrow Cl_2 + 2e$)<br>**3)** Any other solutions: $OH^-$ is oxidised<br>($4OH^- \rightarrow O_2 + 2H_2O + 4e$) |

## Steps to write overall ionic equation and overall equation

1) Balance the number of moles of electrons in the half equations by multiplying the equations accordingly.
2) Add the two half equations together to form the **overall ionic equation**.
3) Add $H^+$ or $OH^-$ on both sides of the equations to balance any $H^+$ or $OH^-$ present on the left hand side of the equation. Combine the $H^+$ and $OH^-$ to form $H_2O$.
4) Cancel any $H_2O$ present on both sides of the equation.
5) Add back the spectator ions to form the **overall equation**.

**Example: Electrolysis of aqueous $CuSO_4$ using inert electrodes**

1) Anode: $4OH^-\ (aq) \rightarrow O_2\ (g) + 2H_2O\ (l) + 4e$
   Cathode: $2Cu^{2+}\ (aq) + 4e \rightarrow 2Cu\ (s)$
2) Overall ionic equation: $2Cu^{2+}\ (aq) + 4OH^-\ (aq) \rightarrow 2Cu\ (s) + O_2\ (g) + 2H_2O\ (l)$
3) $2Cu^{2+}\ (aq) + 4OH^-\ (aq) + 4H^+\ (aq) \rightarrow 2Cu\ (s) + O_2\ (g) + 2H_2O\ (l) + 4H^+\ (aq)$
   $2Cu^{2+}\ (aq) + 4H_2O\ (l) \rightarrow 2Cu\ (s) + O_2\ (g) + 2H_2O\ (l) + 4H^+\ (aq)$
4) $2Cu^{2+}\ (aq) + 2H_2O\ (l) \rightarrow 2Cu\ (s) + O_2\ (g) + 4H^+\ (aq)$
5) $2CuSO_4\ (aq) + 2H_2O\ (l) \rightarrow 2Cu\ (s) + O_2\ (g) + 2H_2SO_4\ (aq)$

## Answering template for explanations for observations in an electrolytic cell

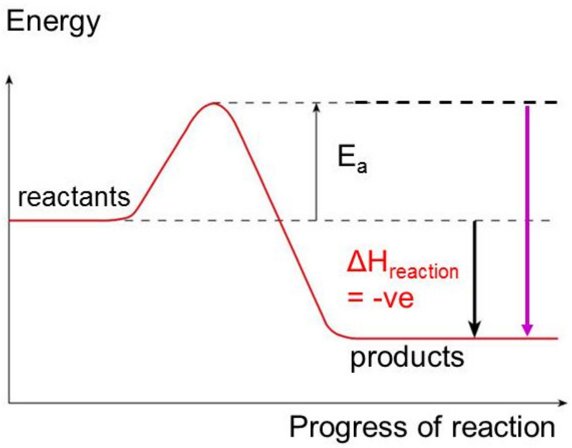
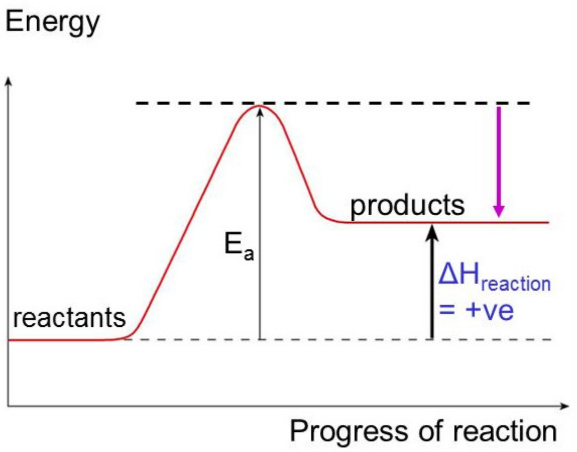
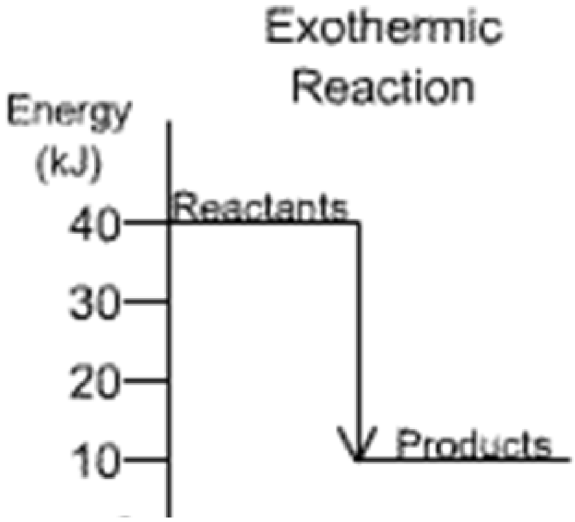
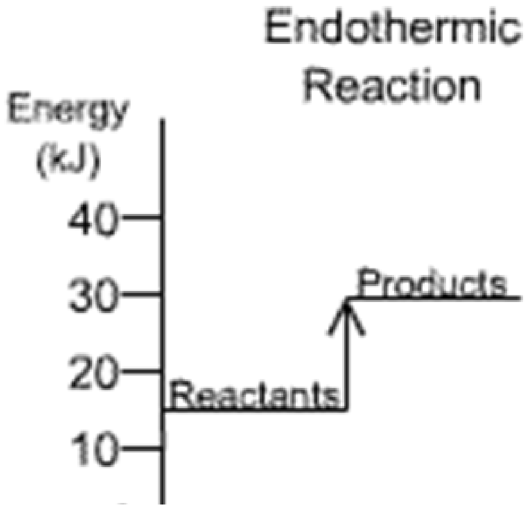
| | | |
|---|---|---|
| **Anode** | If there is **no** selective discharge (i.e. only 1 type of negative ion in the electrolyte) | At the anode, the (negative) ions are discharged / oxidised and lose electrons to form (product). |
| | If there is selective discharge (i.e. more than 1 type of negative ion in the electrolyte) | At the anode, the (negative) ions are selectively discharged / selectively oxidised / are discharged/oxidised instead of (another anion) and lose electrons to form (product). |
| | If a reactive anode is used | At the anode, the (metal) electrode is oxidised and loses electrons to form (metal) ions. |
| **Cathode** | If there is **no** selective discharge (i.e. only 1 type of positive ion in the electrolyte) | At the cathode, the (positive) ions are discharged / reduced and gain electrons to form (product). |
| | If there is selective discharge (i.e. more than 1 type of positive ion in the electrolyte) | (element) is more reactive than (another element). At the cathode, the ions of (the less reactive metal) are selectively discharged / selectively reduced / are discharged/reduced instead of the ions of the (more reactive metal) and gain electrons to form (product). |

## Uses of electrolysis

- Electroplating: to improve appearance and increase resistance to corrosion
- Electrolytic refining
- Extraction of reactive metals from their ores

# Energy Changes

## Energy profile and energy level diagrams

| Exothermic Processes | Endothermic Processes |
|---|---|
| Energy profile diagram:<br><br> | Energy profile diagram:<br><br> |
| Energy level diagram:<br><br> | Energy level diagram:<br><br> |

**Things to take note of when drawing energy profile diagrams**

- Label x axis as progress of reaction
- Label y axis as energy
- Label reactants and products (write formula/names if given in question)
- Label Ea (use single headed arrow)
- Label ΔH (give value if known, otherwise indicate if it is positive or negative, use single headed arrow as well)

**Things to take note of when drawing energy level diagrams**

- x axis is not present

## Standard template to explain why reactions are exothermic or endothermic

**Example:**

$2H_2 + O_2 \rightarrow H_2O$

The total energy absorbed to break the bonds in 2 moles of $H_2$ and 1 mole of $O_2$ is lesser than the total energy released to form bonds in 2 moles of $H_2O$. Therefore, energy is released to the surroundings (exothermic reaction).

## Examples for calculating enthalpy change and energy change

Q: If the H–H bond energy is 436 kJ/mol, the O=O bond energy is 496 kJ/mol, and the O–H bond energy is 460 kJ/mol, calculate the enthalpy change for the following reaction:

$2H_2 (g) + O_2 (g) \rightarrow 2H_2O (g)$

A: $\Delta H_{\text{reaction}} = 2(+436) + 1(+496) + 4(-460)$

$= (+1368) + (-1840) = -472$ kJ/mol

Q: If the mass of hydrogen reacted is 2g, calculate the energy change for the above reaction.

A: moles of $H_2$ = 2/2 = 1 mol

energy change = (1/2) x –472 = –236 kJ

Note: A sign is required for enthalpy and energy changes. No sign is required for bond energy, energy released, and energy absorbed.

Unit for energy is kJ, unit for enthalpy is kJ/mol

## Common examples of exothermic and endothermic reactions

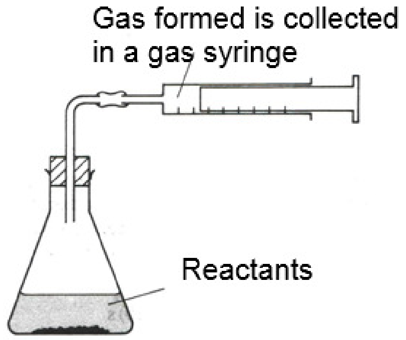
| **Exothermic Processes** | **Endothermic Processes** |
|---|---|
| Types of exothermic reactions according to energy transformation:<br>(A) Chemical energy → Heat energy<br>1. Combustion<br>2. Respiration<br>3. Neutralisation<br>4. Displacement reaction of metals<br>5. Acid + metal reaction<br>6. Addition of water to conc. $H_2SO_4$<br>7. Haber process<br>8. Reduction of iron (III) oxide by carbon monoxide (extraction of iron)<br>9. Addition of water to anhydrous substances like $NaOH$, $Na_2CO_3$, $CaCl_2$, $CuSO_4$<br>(B) Chemical energy → Electrical energy<br>1. Electric cell (Mg – Cu, Zn – Cu)<br>2. Fuel cell ($H_2 - O_2$)<br>(C) Chemical energy → Nuclear energy<br>Fission of Uranium atoms<br>(D) Physical processes<br>Condensation, freezing | Types of endothermic reactions according to energy transformation:<br>(A) Heat energy → Chemical energy<br>1. Addition of water to substances like $NH_4Cl$, $Ca(NO_3)_2$, $KNO_3$.<br>(B) Light energy → Chemical energy<br>1. Photosynthesis (Formation of carbohydrate)<br>2. Photography<br>3. Photochemical reaction ($NO_2 \rightarrow NO + \bar{O}$ ; $\bar{O} + O_2 \rightarrow O_3$)<br>(C) Electrical energy → Chemical energy<br>Electrolysis of molten lead (II) bromide, aqueous sulfuric acid, aqueous sodium chloride, aqueous copper (II) sulfate<br>(D) Physical processes<br>Melting, Boiling |

# Rate of reaction

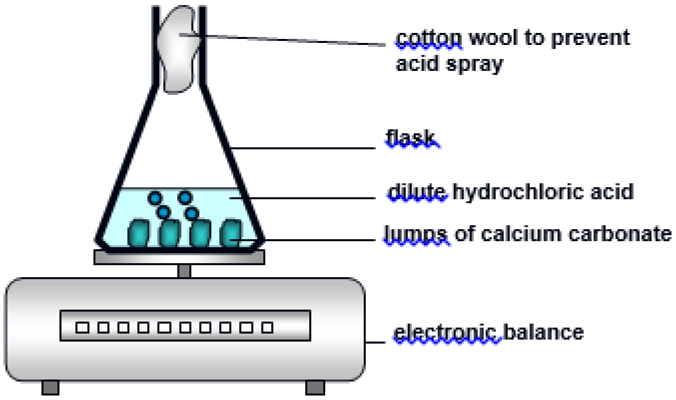
## How rate of reaction can be measured

1. The volume of a gaseous product
2. The change in mass of the reaction mixture during the reaction
3. The time for the colour to appear / disappear or solid to appear / disappear
4. The change in temperature
5. The change in conductivity of a solution
6. Change in pH
7. Change in pressure

## Experimental set-ups for measuring volume of gas



## Experimental set-up for measuring loss in mass



## How different factors affect rate of reaction

| | |
|---|---|
| Concentration | • More particles per unit volume<br>• Increase in frequency of collisions between particles<br>• Increase in frequency of effective collisions between particles<br>• Faster rate of reaction |
| Pressure | • More particles per unit volume<br>• Increase in frequency of collisions between particles<br>• Increase in frequency of effective collisions between particles<br>• Faster rate of reaction |
| Particle Size | • Bigger surface area to unit volume<br>• Increase in frequency of collisions between particles<br>• Increase in frequency of effective collisions between particles<br>• Faster rate of reaction |
| Temperature | • Particles gain kinetic energy and move faster<br>• Increase in proportion or number of particles with energy more than Activation Energy<br>• Increase in frequency of collisions between particles<br>• Increase in frequency of effective collisions between particles<br>• Faster rate of reaction |
| Catalyst | • Provides an alternative pathway with lower Activation Energy<br>• Increase in proportion or number of particles with energy more than this lowered Activation Energy<br>• Increase in frequency of effective collisions between particles<br>• Faster rate of reaction |

# Organic Chemistry

## Definitions

**Homologous series:** A homologous series is a family of organic compounds which conform to the same general formula and each member differs from the next by a $-CH_2$ group. Compounds in the same homologous series contain the same functional group and have similar chemical properties.

**Funtional group:** A functional group is an atom or a group of atoms that gives a molecule its characteristic properties.

**Alkanes:** Alkanes are compounds which conform to the general formula of $C_nH_{2n+2}$. Each member of the alkane homologous series differs from the next by a $-CH_2$ unit.

**Alkenes:** Alkenes are compounds which conform to the general formula of $C_nH_{2n}$. Each member of the alkene homologous series differs from the next by a $-CH_2$ unit.

**Alcohols:** Alcohols are compounds which conform to the general formula of $C_nH_{2n+1}OH$. Each member of the alcohol homologous series differs from the next by a $-CH_2$ unit.

**Carboxylic acids:** Carboxylic acids are compounds which conform to the general formula of $C_nH_{2n+1}COOH$. Each member of the alkane homologous series differs from the next by a $-CH_2$ unit.

**Structural isomers:** Structural isomers are compounds which have the same molecular formulae but different structural formulae.

**Unsaturated:** A unsaturated compound contains C=C bonds (carbon-carbon double bond).

**Polyunsaturated:** A substance is said to be polyunsaturated if it contains multiple carbon-carbon double bond.

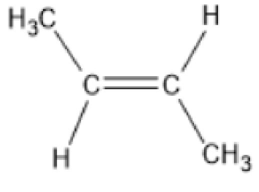
**Macromolecule:** A macromolecule is a long-chain / large molecule that is formed by linking together many small repeating units known as monomers. Different macromolecules have different units and/or different linkages.

**Polymerisation:** The process of joining together a large number of small molecules (monomers) to form macromolecules.

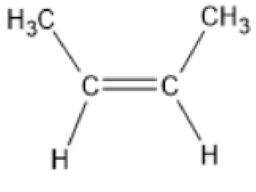
**Addition polymerisation:** Addition polymerization is the process whereby a large number of small repeating units join together without losing any molecules or atoms to form a polymer.

**Condensation polymerisation:** Condensation polymerisation is the process whereby a large number of small repeating units join together with the elimination of small molecules such as $H_2O$, HCl etc to form a polymer.

## Geometric isomers example



and



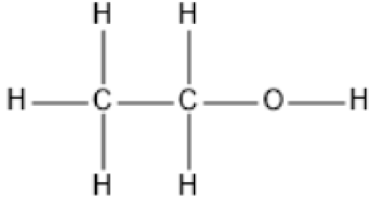
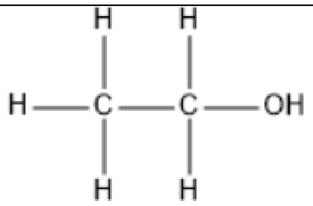
## Naming of organic compounds

The names of organic compounds consist of a prefix, suffix, and occasionally a number to denote the position of the functional group.

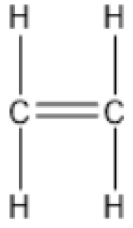
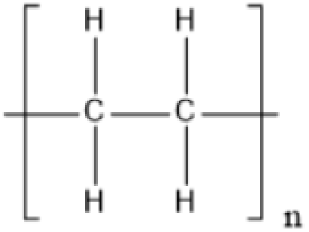
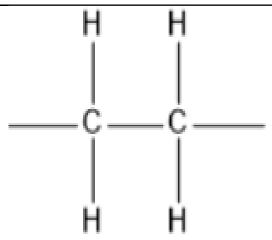
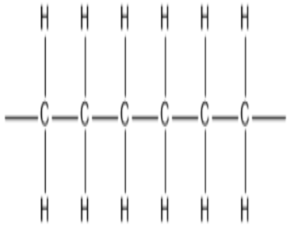
| No of C atoms | Prefix |
|---|---|
| 1 | meth– |
| 2 | eth– |
| 3 | prop– |
| 4 | but– |
| 5 | pent– |
| 6 | hex– |
| 7 | hept– |
| 8 | oct– |
| 9 | non– |
| 10 | dec– |

| Functional group | Suffix |
|---|---|
| alkane | –ane |
| alkene | –ene |
| alcohol | –ol |
| carboxylic acid | –oic |
| ester | –oate |

## Different types of formula/structures

| Full structural formula/displayed formula | Structural formula | Condensed formula |
|---|---|---|
|  |  | $CH_3CH_2OH$ |
| **Formula** | **Molecular formula** | **Empirical formula** |
| $C_2H_5OH$ | $C_2H_6O$ | $C_2H_6O$ |

## Different types of structures for macromolecules

| Monomer | Formula | 1 repeating unit | 3 repeating units/part of the structure |
|---|---|---|---|
|  |  |  |  |

## Physical properties

| Physical property | Properties for different functional groups | Trend |
|---|---|---|
| Melting point/Boiling point | Alkanes and alkenes with 4C or less are gases<br>Alcohols and carboxylic acids are liquids or solids | ↑ as no of C ↑<br>Vdw forces becomes stronger as Mr increases, requiring more energy to overcome |
| Viscoscity | | ↑ as no of C ↑<br>Vdw forces becomes stronger as Mr increases, therefore it is harder for the liquid to flow |
| Solubility in water | Alkanes and alkenes are insoluble<br>Alcohols and carboxylic acids are soluble | ↓ as no of C ↑ |
| Density | Generally less dense than water | ↑ as no of C ↑ |
| Flammability | | Flammability ↓ as no of C ↑, as the number of bonds to be broken ↑, which ↑ Ea |

## Summary of organic chemistry reactions

### Combustion

**Examples:**

**Complete combustion**

$CH_4$ (g) + $2O_2$ (g) → $CO_2$ (g) + $2H_2O$ (*l*)

**Incomplete combustion**

$3CH_4$ (g) + $5O_2$ (g) → $CO_2$ (g) + 2CO (g) + $6H_2O$ (*l*)

$2CH_4$ (g) + $3O_2$ (g) → $CO_2$ (g) + C (s) + $4H_2O$ (*l*)

**Reactants:** oxygen

**Conditions:** –

**Note:** Substances with higher % by mass of C (eg alkenes vs alkanes) have higher tendency to undergo incomplete combustion.

### Substitution reaction of alkane

**Examples:**

$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$

$CH_4 + Br_2 \rightarrow CH_3Br + HBr$

**Reactants:** $Cl_2$ (g) or $Br_2$ (*l*)

**Conditions:** uv light

**Note:** Multiple substitutions can occur to produce $CH_2Cl_2$, $CHCl_3$ and $CCl_4$

## Catalytic cracking of long chain hydrocarbons

**Examples:**

$C_{12}H_{26} \rightarrow C_4H_{10} + C_8H_{16}$

$C_{18}H_{38} \rightarrow C_8H_{16} + C_{10}H_{20} + H_2$

**Reactants:** –

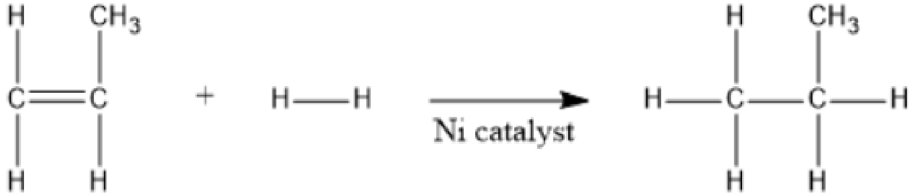
**Conditions:** $Al_2O_3$ or $SiO_2$ as catalyst, high temperature

**Note:**

- Used to produce short chain alkanes to meet the demand for these alkanes, especially petrol
- Used to produce short chain alkenes as raw material to manufacture ethanol and plastics like poly(ethene).
- Used to produce hydrogen, which is an important raw material for the manufacture of ammonia in the Haber Process and the manufacture of margarine, and also as fuel for rockets and hydrogen-oxygen fuel cells.

## Addition of hydrogen (hydrogenation)

**Example:**



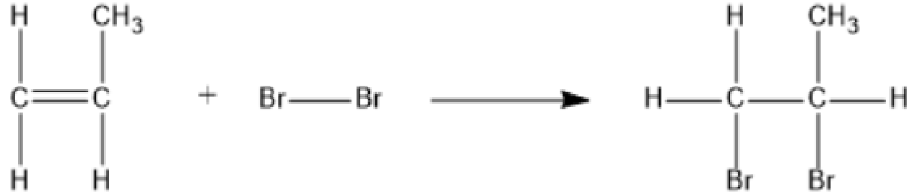
**Reactants:** $H_2$ (g)

**Conditions:** Ni as catalyst, heat

**Note:** Used to manufacture margarine (solid at rtp) from vegetable oil (liquid at rtp)

## Addition of bromine (bromination)

**Example:**



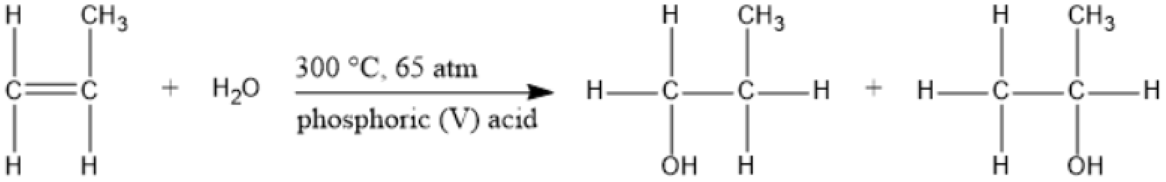
**Reactants:** $Br_2$ (*l*) or $Br_2$ in $CCl_4$

**Conditions:** absence of uv light

**Note:** Can be used as distinguishing test for alkenes.

## Addition of steam (hydration)

**Example:**



**Reactants:** steam

**Conditions:** 300 ℃, 65 atm, phosphoric (V) acid as catalyst

**Note:** The hydrogen atom and hydroxyl group can add to either side of the C=C, forming 2 possible products if an unsymmetrical alkene is reacted.

## Fermentation

**Example:**

$C_6H_{12}O_6$ (aq) → $2CO_2$ (g) + $2C_2H_5OH$ (aq)

**Reactants:** yeast, water

**Conditions:** 37 ℃, no light, anaerobic condition

**Note:**

- Kept at 37 ℃ because yeast's enzymes will be denatured above this temperature.
- Fermentation of sugars produces only a dilute solution of ethanol (up to about 15 %) because enzymes will also be denatured if percentage of ethanol goes beyond 15%. Ethanol can then be obtained from this liquid mixture by fractional distillation.
- Anaerobic condition is used because yeast will adopt aerobic respiration when oxygen is present, resulting in formation of water and carbon dioxide instead of ethanol and carbon dioxide. The ethanol produced may also be oxidised by oxygen to produce ethanoic acid (turns sour).

Ethanol made from fermentation is a carbon-neutral fuel because:

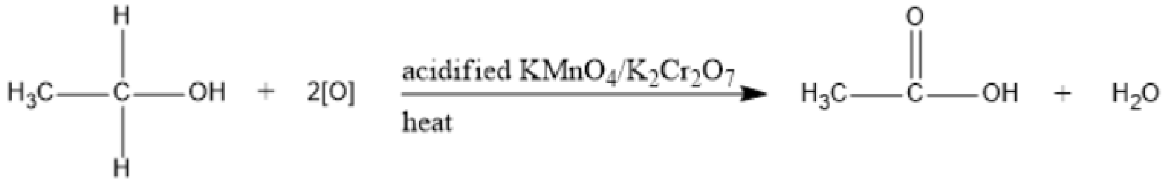
1) Photosynthesis: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
2) Fermentation: $C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_5OH$
3) Combustion: $2C_2H_5OH + 6O_2 \rightarrow 6H_2O + 4CO_2$

Comparison between hydration and fermentation

| | **Addition of steam** | **Fermentation** |
|---|---|---|
| **Time** | Takes shorter time | Takes longer time |
| **% yield** | 100% | 15% ethanol solution |
| **Types of alcohol produced** | Different alcohols can be obtained | Only ethanol |
| **Cost** | Higher | lower |
| **Renewability** | Renewable because ethene comes from petroleum | Renewable because glucose comes from sugar cane |

## Oxidation of alcohols with acidified $KMnO_4/K_2Cr_2O_7$

**Oxidation of primary alcohol example 1:**



$$H_3C{-}CH_2{-}OH + 2[O] \xrightarrow[\text{heat}]{\text{acidified } KMnO_4/K_2Cr_2O_7} H_3C{-}C(=O){-}OH + H_2O$$

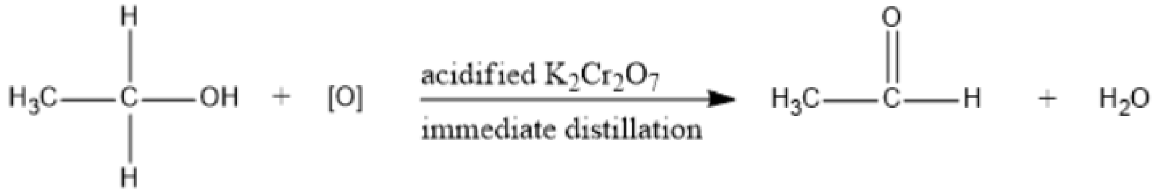
[O] represents oxygen from oxidising agent

**Reactants:** acidified $KMnO_4/K_2Cr_2O_7$

**Conditions:** heat under reflux

**Note:** Can be used as distinguishing test

**Oxidation of primary alcohol example 2:**



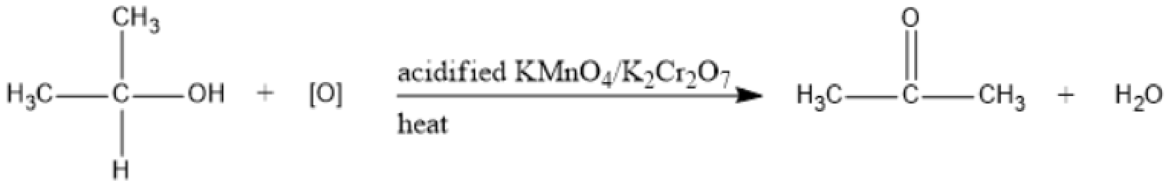
$$H_3C{-}CH_2{-}OH + [O] \xrightarrow[\text{immediate distillation}]{\text{acidified } K_2Cr_2O_7} H_3C{-}C(=O){-}H + H_2O$$

**Reactants:** acidified $K_2Cr_2O_7$

**Conditions:** immediate distillation

**Note:** Can be used as distinguishing test

**Oxidation of secondary alcohol example:**



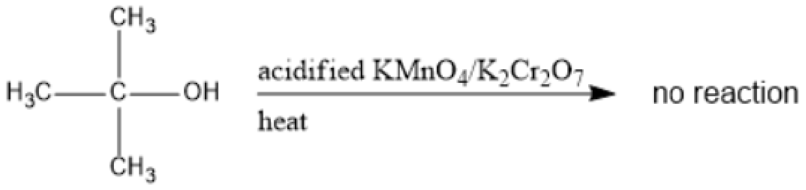
$$H_3C{-}CH(CH_3){-}OH + [O] \xrightarrow[\text{heat}]{\text{acidified } KMnO_4/K_2Cr_2O_7} H_3C{-}C(=O){-}CH_3 + H_2O$$

**Reactants:** acidified $KMnO_4/K_2Cr_2O_7$

**Conditions:** heat under reflux

**Note:** Can be used as distinguishing test

**Oxidation of tertiary alcohol example:**



$$H_3C{-}C(CH_3)_2{-}OH \xrightarrow[\text{heat}]{\text{acidified } KMnO_4/K_2Cr_2O_7} \text{no reaction}$$

### Oxidation of alcohol by oxygen in the air with bacteria

**Example:**

$C_2H_5OH\ (aq) + 2[O] \rightarrow CH_3COOH\ (aq) + H_2O\ (l)$

[O] represents oxygen from oxidising agent

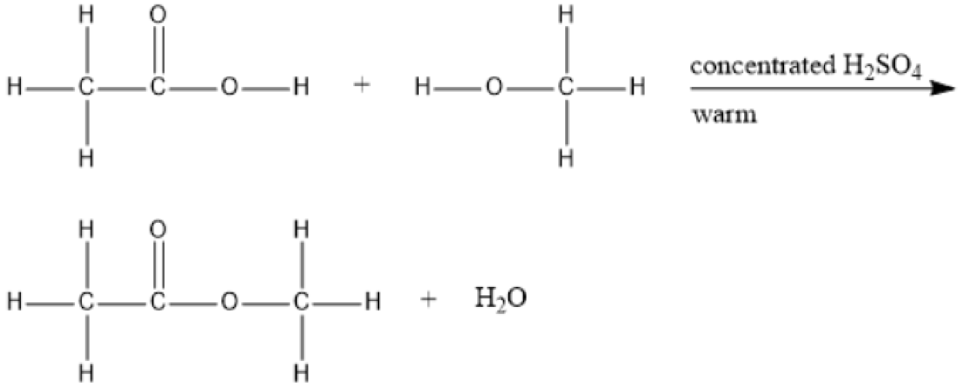
**Reactants:** oxygen in the air

**Conditions:** action by bacteria in the air

**Note:** This causes alcoholic drinks to turn sour if exposed to the air for some time due to oxidation of ethanol to ethanoic acid.

### Esterification

**Example:**



**Reactants:** carboxylic acid with alcohol

**Conditions:** concentrated $H_2SO_4$ as catalyst, warm

**Note:** When naming the ester, the alcohol should be named before the acid. For example, the ester formed above is methyl ethanoate.

### Reaction of carboxylic acid with reactive metal

**Example:**

$2CH_3COOH + Mg \rightarrow (CH_3COO)_2Mg + H_2$

**Reactants:** reactive metal

**Conditions:** –

**Note:** Can be used as distinguishing test for carboxylic acid. Very reactive metals like sodium should not be used.

## Reaction of carboxylic acid with carbonate

**Example:**

$2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + H_2O + CO_2$

**Reactants:** any carbonate

**Conditions:** –

**Note:** Can be used as distinguishing test for carboxylic acid

## Reaction of carboxylic acid with base

**Example:**

$2CH_3COOH + MgO \rightarrow (CH_3COO)_2Mg + H_2O$

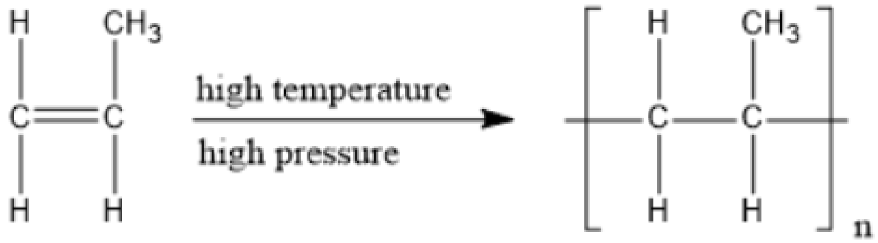
**Reactants:** any base

**Conditions:** –

**Note:** –

## Addition polymerisation

**Example:**



**Reactants:** alkene monomer

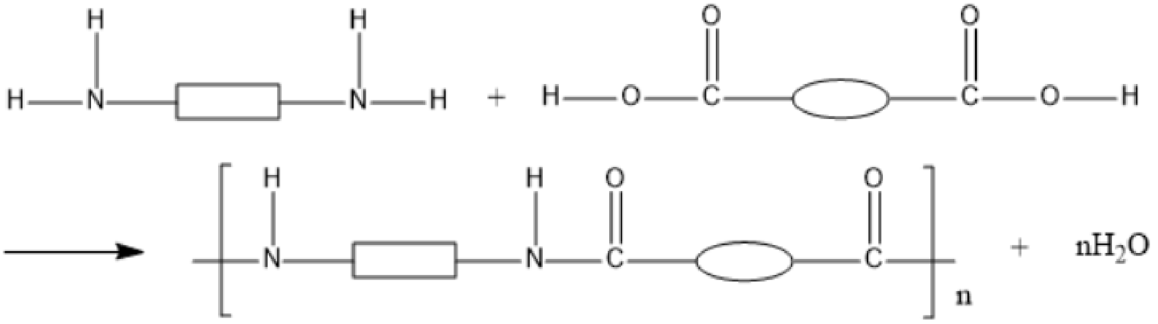
**Conditions:** high temperature and pressure

**Note:** The polymers formed will be a mixture of polymers with different chain lengths, so there will be a range of melting points.

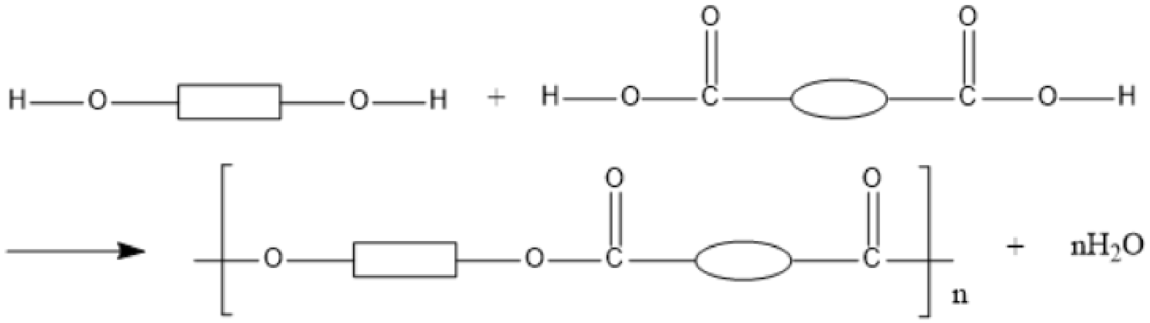
## Condensation polymerisation

**Examples:**

**Formation of Nylon (polyamide)**



**Formation of Terylene (polyester)**



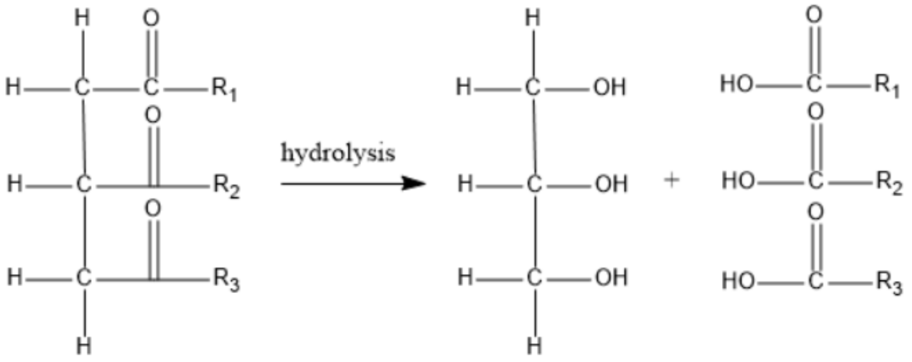
**Reactants:** diamine + dicarboxylic acid, diol + dicarboxylic acid, monomer with 1 alcohol and 1 carboxylic acid group, etc

**Conditions:** –

**Note:** The polymers formed will be a mixture of polymers with different chain lengths, so there will be a range of melting points.

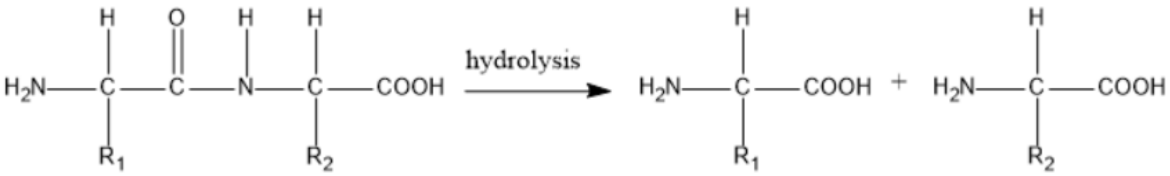
## Hydrolysis of fats and proteins

**Hydrolysis of fats example:**



Note: $R_1$, $R_2$ and $R_3$ are H or any carbon chain

**Hydrolysis of polypeptide example:**



## Summary of distinguishing tests

| Functional Group | Distinguishing test |
|---|---|
| Alkane | NA |
| Alkene | Reddish brown bromine will turn colourless spontaneously if alkene is present. |
| Alcohol | Purple acidified potassium manganate(VII) solution will turn colourless OR orange acidified potassium dichromate(VI) solution will turn green if primary or secondary alcohol is present. |
| Carboxylic acid | If carboxylic acid is present, when sodium carbonate is added, there will be effervescence of a colourless odourless gas that forms a white precipitate in limewater. |
| Ester | If ester is present, there will be a sweet smell. |

## Explanation of how petroleum fractions are separated

1. Petroleum is heated in a furnace and vapourised. The hot vapour will flow up the fractionating column and start to cool down.
2. Each fraction condenses at a different temperature and comes out of the column at different height depending on their boiling points.
3. The hydrocarbons with the lower boiling point range will distill over at the top of the column, where the temperature is lower, while the ones with the higher boiling point range will distil over at the bottom where the temperature is higher.

## Different petroleum fractions and their uses

| Fraction | No. of carbon atoms (n) | Boiling Point Range (ºC) | Uses |
|---|---|---|---|
| Petroleum gas | 1 – 4 | < 40 | Fuel for cooking |
| Petrol (Gasoline) | 5 – 10 | 40 – 75 | Fuel for car engines |
| Naphtha | 7 – 14 | 75 – 150 | Feedstock (raw material) for petrochemicals (E.g. plastics, detergents, alcohol, drugs) |
| Kerosene (Paraffin) | 11 – 16 | 160 – 250 | Fuel for jet engines; cooking and heating |
| Diesel | 16 – 20 | 250 – 300 | Fuel for diesel engines of buses, taxis and lorries |
| Lubricating oil | 20 – 35 | 300 – 350 | Lubricants for machines; making of waxes and polishes |
| Bitumen | >70 | > 350 | Make road surfaces |

## Issues related to fossil fuels

- Petroleum is a finite non-renewable resource and the world's petroleum reserves are depleting.
- The supply of petroleum is being depleted very rapidly, and there is a need for its conservation.
- Petroleum, besides being used as fuel, has other important uses like being used as a raw material for the manufacture of essential chemical compounds like medicine and plastics.
- Combustion of petroleum also contributes to pollution (due to the production of CO and C) and global warming (due to the production of $CO_2$).

## Alternative fuels

**Possible sources of alternative fuels:**

- Palm oil and ethanol (from sugarcane) from plants can be used as fuels for vehicles.
- Methane produced when organic matter (waste material from plants and animals) is allowed to decay in the absence of air.
- Hydrogen which can be obtained from photolysis of water (renewable) or from catalytic cracking of long chain hydrocarbon (non-renewable).

**Advantages of using hydrogen as an alternative fuel:**

1. Clean fuel, producing only water.
2. Renewable, can be manufactured. (Note that this only applies if hydrogen is obtained from water instead of petroleum)
3. Produces more energy per unit mass (reaction is more exothermic).

**Disadvantages of using hydrogen as an alternative fuel:**

1. Hydrogen needs to be liquefied for both transport and storage, which increases costs.

## Uses of ethanol

- In alcoholic drinks
- As a fuel for motor vehicles
- As a solvent in pains, varnishes, deodorants and perfumes

## Uses of esters

- Used as solvent for cosmetics and glue.
- Used in preparation of perfumes and artificial food flavouring because they are sweet smelling.

## Uses of macromolecules

| Macromolecule | Uses + related propeties |
|---|---|
| Poly(ethane) | Used to make plastic bottles, plastic bags and clingfilm |
| Nylon | It is used for making strong ropes, fishing lines, zippers, tents, parachutes and rain coats<br>Nylon is light yet strong; can be stretched without breaking; waterproof. |
| Terylene | It is made into fibre and woven into cloth, used for making clothes and curtains.<br>Terylene is shrink-proof and crease-proof, which makes it easy to wash and dry. |

## Advantages and disadvantages of macromolecules

| Advantages | Disadvantages |
|---|---|
| Light, tough and waterproof | Burn easily; a fire risk in buildings and vehicles |
| Resistant to decay, corrosion and chemical attack | Causes air pollution:<br>When plastics are disposed of by burning, poisonous gases like CO may be produced when there is insufficient oxygen. Plastics like PVC also produce very acidic gases like hydrogen chloride ($HCl$). |
| Can be easily moulded into various shapes | Causes land pollution:<br>Plastics are non-biodegradable (cannot be decomposed by bacteria in the soil). They will not rot when buried underground. Accumulation of plastic waste takes up space and causes land pollution. |

# Air

## Common pollutants

| Pollutant | Source | Effects on environment | Effects on humans | Solutions |
|---|---|---|---|---|
| Oxides of nitrogen (NO and $NO_2$) | • Lightning activities<br>• When combustion of fuel occurs in internal combustion engines, the high temperature of the engine causes nitrogen and oxygen in the air to react.<br>• $N_2 + O_2 \rightarrow 2NO$<br>• $N_2 + 2O_2 \rightarrow 2NO_2$ | • Nitrogen monoxide NO<br>• Neutral oxide<br>• But oxidised easily to $NO_2$<br>• Nitrogen dioxide $NO_2$<br>• Acidic oxide<br>• Formation of acid rain: nitrogen dioxide dissolves in rain water and is oxidised by atmospheric oxygen to form nitric acid<br>• Overall equation: $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$<br>Effects of acid rain:<br>• Acid rain will corrode buildings made of cement, reactive metals and limestone.<br>• When acid rain falls onto land, it causes the soil pH to decrease, making it unsuitable for growing crops. It also leeches important nutrients from the soil and reduces the fertility of the soil.<br>• When acid rain falls into rivers and lakes, the water bodies become acidic, affecting plant and marine life. | • $NO_2$ is a poisonous and choking gas that irritates and attacks the lungs, causing respiration problems | • Removed by redox reactions in the catalytic converters in vehicles<br>• $2NO \rightarrow N_2 + O_2$<br>• $2NO_2 \rightarrow N_2 + 2O_2$<br>• $2NO + 2CO \rightarrow N_2 + 2CO_2$<br>• $2NO_2 + 4CO \rightarrow N_2 + 4CO_2$<br>• Using calcium carbonate to reduce the effects of acid rain on soil pH<br>• $CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O$ |

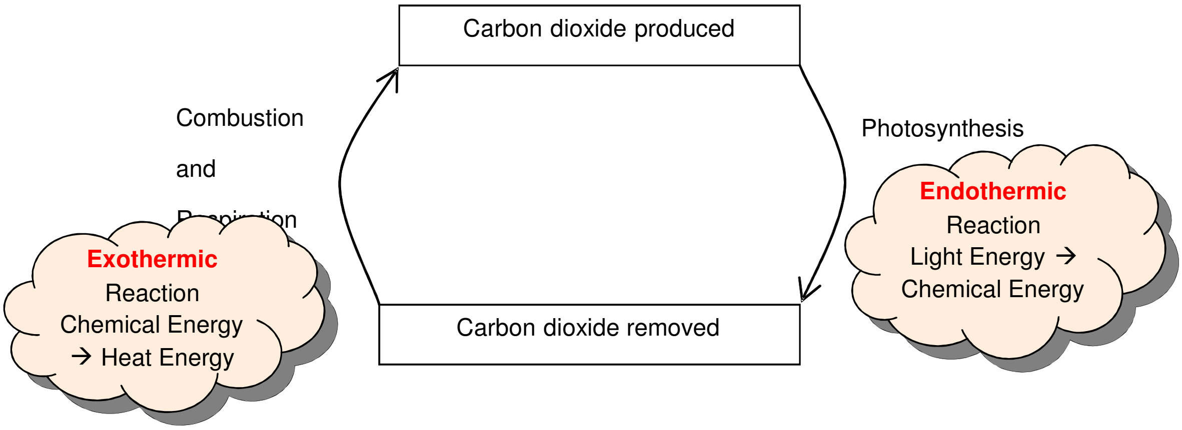
| | | | | |
|---|---|---|---|---|
| Sulfur dioxide | • Volcanic activity<br>• Combustion of fossil fuels like coal in power stations and factories | • ***Same as nitrogen dioxide $NO_2$***<br>• Formation of acid rain: sulfur dioxide dissolves in rain water to form sulfurous acid ($SO_2 + H_2O \rightarrow H_2SO_3$), which is then oxidized by atmospheric oxygen to form sulfuric acid ($2H_2SO_3 + O_2 \rightarrow 2H_2SO_4$)<br>• Overall equation: $2SO_2 + 2H_2O + O_2 \rightarrow 2H_2SO_4$ | • ***Same as nitrogen dioxide $NO_2$*** | • Using calcium carbonate or calcium oxide in flue gas desulfurization (in power stations and factories)<br>• Flue gas is the exhaust / waste gases (after burning coal for energy) from power stations and factories<br>• $CaCO_3 + SO_2 \rightarrow CaSO_3 + CO_2$ OR $CaO + SO_2 \rightarrow CaSO_3$<br>• $2CaSO_3 + O_2 \rightarrow 2CaSO_4$<br>• Using calcium carbonate to reduce the effects of acid rain on soil pH<br>• $CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$ |
| Ozone | | | • At sea level, toxic at high concentration<br>• Breathing it can be dangerous especially for young children, the elderly and people with asthma | |
| Unburnt hydrocarbons | • Incomplete combustion of hydrcarbon-containing fuels in internal combustion engines e.g. petrol, diesel | | • Results in photochemical reactions which produces ozone and causes difficulty in breathing | • Removed by the reactions in the catalytic converters in vehicles<br>• Unburnt hydrocarbons are oxidised in a redox reaction to form carbon dioxide and water. |

| | | | | |
|---|---|---|---|---|
| Carbon monoxide | • Incomplete combustion of carbon-containing substances e.g. petrol, diesel, ethanol | | • Poisonous gas<br>• Combines with haemoglobin in red blood cells to form a very stable compound, carboxyhaemoglobin<br>• Reaction is irreversible and it reduces the red blood cells' ability to transport oxygen around the body, eventually leading to death | • Removed by the redox reactions in the catalytic converters in vehicles<br>• $2CO + O_2 \rightarrow 2CO_2$ |
| Methane | | • Greenhouse gas<br>• Traps infrared radiation and contributes to global warming<br>Possible consequences of global warming:<br>• Melting of large quantities of ice in the North Pole and South pole will cause the levels of oceans to rise and flood low-lying countries<br>• Rapid evaporation of water from the earth's surface may cause areas that are currently covered by vegetation to become deserts, resulting in a decrease in crop yields<br>• Carbon dioxide that was dissolved in the oceans will be driven out into the atmosphere, adding further to the greenhouse effect | | |

## Composition of dry air

| Gas | % composition |
|---|---|
| Nitrogen | 78 |
| Oxygen | 21 |
| Rare gases (mainly argon) | 1 |
| Carbon dioxide | 0.03 |

## Carbon dioxide and carbon cycle



## Process producing $CO_2$

### Combustion (of fuels)

E.g.: $C + O_2 \rightarrow CO_2$

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

### Respiration (by plants and animals)

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

## Process removing $CO_2$

### Photosynthesis

$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Carbon dioxide, like methane, is also a <u>greenhouse</u> gas and will contribute to <u>global warming</u>.

## Ozone layer

### Function

The ozone layer acts as a kind of shield, filtering out excess harmful UV radiation from the sun.

### How ozone is depleted

CFCs (chlorofluorocarbons), which are usually used as propellants for aerosol sprays and coolants in refrigerators and air conditioners, are very unreactive at sea level. But once they move up to the stratosphere, they will decompose, under strong UV radiation, to form chlorine atoms which destroy ozone.

$Cl + O_3 \rightarrow ClO + O_2$

### Consequence of ozone layer depletion

Excess UV radiation will reach the surface of the earth, leading to a drastic increase in the cases of skin cancer, genetic mutation and eye damage (cataracts).

## Catalytic converter

- Contains rhodium and platinum catalyst

Reactions in catalytic converter:

- $2CO + O_2 \rightarrow 2CO_2$
- $2NO \rightarrow N_2 + O_2$
- $2NO_2 \rightarrow N_2 + 2O_2$
- $2NO + 2CO \rightarrow N_2 + 2CO_2$
- $2NO_2 + 4CO \rightarrow N_2 + 4CO_2$
- Complete combustion of unburnt hydrocarbons to form carbon dioxide and water

# Ammonia

## Haber process

**Condition:**

- Temperature: 450°C
- Pressure: 200 atm
- Catalyst: Iron

**Equation:** $N_2\ (g) + 3H_2 \rightleftharpoons 2NH_3\ (g)$

Obtaining the reactants:

- Nitrogen is obtained from liquid air by fractional distillation.
- Hydrogen is obtained from catalytic cracking of long-chain hydrocarbons in petroleum.

## Use of ammonia to synthesise nitrogenous fertilisers

### Natural source of nitrogen

- From lightning and when plants and animals die and decay.

### Nitrogenous ferilisers

- Nitrogeneous fertilisers are added to soil to provide nitrogen for plants to make proteins for growth so that crop yield can be increased.

### Synthesis of some Nitrogenous Fertilisers from ammonia

- $2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$ (ammonium sulfate)

- $NH_3 + HNO_3 \rightarrow NH_4NO_3$ (ammonium nitrate)

- $3NH_3 + H_3PO_4 \rightarrow (NH_4)_3PO_4$ (ammonium phosphate)

### Choice of Nitrogenous Fertilisers

Some factors that need to be considered when choosing a fertiliser:

- how soluble is it (how quickly can it release its nitrogen for plant use) (ammonium fertilisers release nitrogen slower because ammonium ions must first be oxidised to nitrate.

- its percentage by mass of nitrogen content

- its cost per unit mass

## Displacement of ammonia from nitrogenous fertilisers by calcium hydroxide

### Why calcium hydroxide is added to soil

- Agricultural land often becomes too acidic for growth of food crops.
- The acidity can be caused by acid rain and/or excessive use of fertilisers.
- Farmers use calcium hydroxide to neutralise the acidity to provide a more suitable pH for plant growth to increase crop yield.

## Reaction of calcium hydroxide with nitrogenous fertilisers

- Calcium hydroxide can react with nitrogenous fertilisers to displace ammonia.
- Ionic Equation: $OH^- (aq) + NH_4^+ (aq) \xrightarrow{\textit{heat from sunlight}} NH_3 (g) + H_2O (l)$
- Since ammonia is a gas, it escapes from the soil when warmed and this causes loss of nitrogen from the soil.

## Alternative to calcium hydroxide

- Calcium carbonate

# Chemical equilibrium

## Definitions

**Dynamic equilibrium:** A reversible reaction in which the rates of forward and backward reactions have become equal and there is no change in the concentration of the reactants and products.

**Le Chatelier's Principle:** Le Chatelier's Principle states that when a system in equilibrium is subjected to a change in conditions which disturbs the equilibrium, the position of equilibrium will shift in a way so as to reduce that change.

**Reversible reaction:** A reversible reaction is one which can proceed in both directions

## Template for answering questions on equilibrium shift

- (change)
- Forward/backward reaction is exothermic/endothermic (for temperature change)/number of moles of gas is more/less on left/right (for gas) (NA for adding/removing reactants/products)
- Equilibrium will shift to the left/right
- To (change due to equilibrium shift) in order to minimise the (initial change)

### Example

$C_2H_4$ (g) + $H_2O$ (g) $\rightleftharpoons$ $C_2H_5OH$ (*l*)   $\Delta H$ is positive

- If ethane is added,
- the equilibrium will shift to the right
- to decrease the amount of ethane to minimise the increase in amount of ethane

- When steam is added,
- the equilibrium will shift to the right
- to decrease the amount of ethane to minimise the increase in amount of steam

- When ethanol is removed,
- the equilibrium will shift to the right
- to increase the amount of ethanol to minimise the decrease in amount of ethanol

- When temperature is increased,
- since the reaction in endothermic,
- the equilibrium will shift to the right
- to decrease the temperature to minimise the increase in temperature

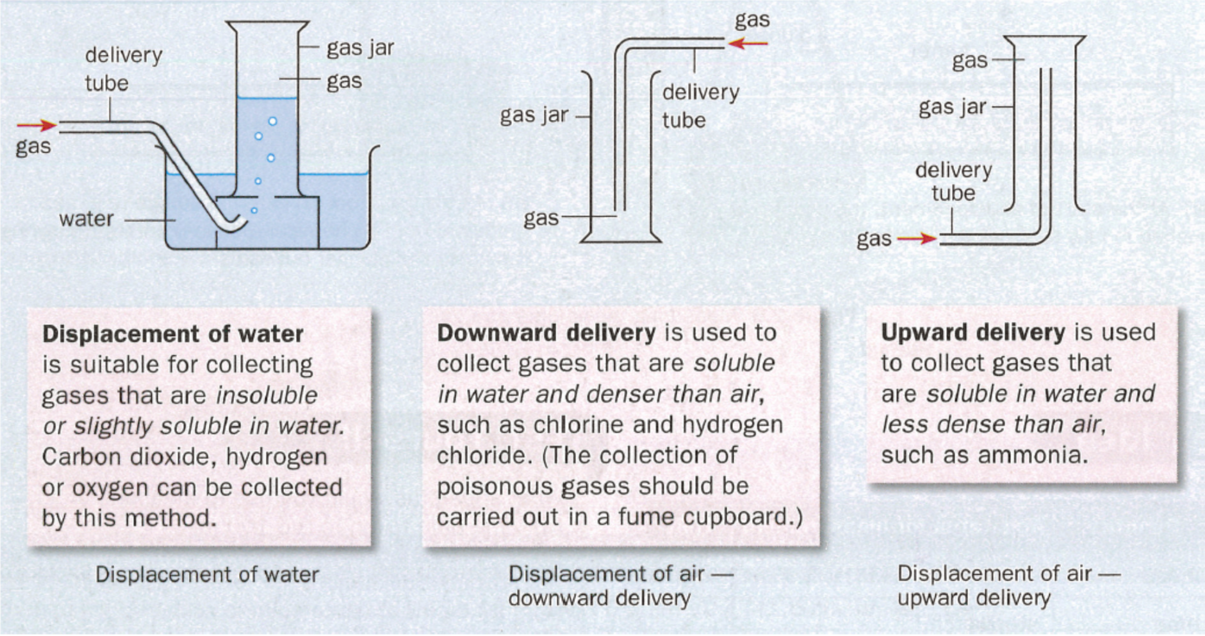
- When pressure is increased,
- since there are less moles of gas on the right,
- the equilibrium will shift to the right
- to decrease the pressure in order to minimise the increase in pressure.

# Separation techniques

## Precision of different instruments for measuring volumes

| Apparatus | Precision |
|---|---|
| Measuring cylinder | Measures to the nearest $cm^3$, e.g. 45 $cm^3$ |
| Burette | Accurately measures the volume of a liquid to the nearest 0.1 $cm^3$ |
| Pipette | Accurately measures out **fixed** volumes of liquids, e.g. 20.0 $cm^3$ or 25.0 $cm^3$ |

## Methods of collecting gases (refer to part on QA for properties of gases)



**Displacement of water** is suitable for collecting gases that are *insoluble or slightly soluble in water.* Carbon dioxide, hydrogen or oxygen can be collected by this method.

**Downward delivery** is used to collect gases that are *soluble in water and denser than air,* such as chlorine and hydrogen chloride. (The collection of poisonous gases should be carried out in a fume cupboard.)

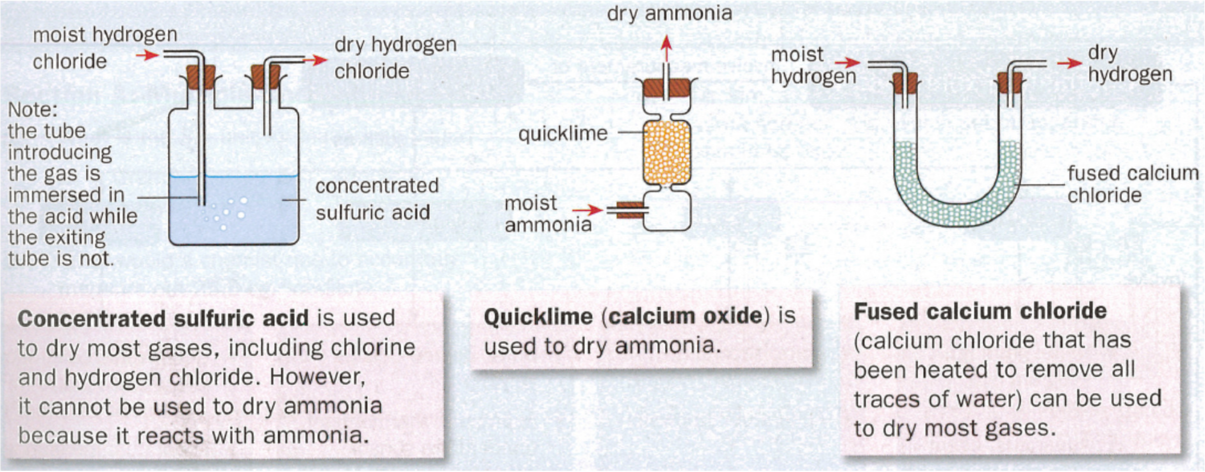
**Upward delivery** is used to collect gases that are *soluble in water and less dense than air,* such as ammonia.

Displacement of water

Displacement of air — downward delivery

Displacement of air — upward delivery

## Drying agents



Note: the tube introducing the gas is immersed in the acid while the exiting tube is not.

**Concentrated sulfuric acid** is used to dry most gases, including chlorine and hydrogen chloride. However, it cannot be used to dry ammonia because it reacts with ammonia.

**Quicklime (calcium oxide)** is used to dry ammonia.

**Fused calcium chloride** (calcium chloride that has been heated to remove all traces of water) can be used to dry most gases.

## Purity and MP/BP

- Pure substances have fixed melting and boiling point.
- Impure substances will melt/boil over a range of temperature.
- Impurities decrease melting point but increase boiling point.

## Uses of different separating techniques

| Separating technique | Use of separating technique |
|---|---|
| Filtration | Separate insoluble solid from a liquid<br>Eg separate sand and water, sand and $CuSO_4$ solution |
| Evaporation | Obtain soluble solid (solute) from a liquid (solvent)<br>Cannot be used if solid decompose upon heating or become anhydrous salt upon heating<br>Eg obtain $NaCl$ from $NaCl$ solution |
| Crystallisation | Separate soluble solid (solute) from a liquid (solvent)<br>Can be used to obtain hydrated salt<br>Eg obtain $CuSO_4$ from $CuSO_4$ solution |
| Sublimation | Separate two or more solid substances, one of which can sublime<br>Substance that sublime: dry ice (CO2), iodine, ammonium chloride<br>Eg obtain $I_2$ from sand and $I_2$ |
| Simple distillation | Obtain liquid (solvent) from a solution<br>Eg Obtain water from $NaCl$ solution |
| Fractional distillation | Separate two or more miscible liquids<br>Eg separate water and ethanol |
| Separating funnel | Separate 2 immiscible liquids<br>Eg separate water and oil |
| Paper chromatography | Separate 2 solutes in a mixture<br>Eg dyes in ink, different amino acids |

## $R_f$ value

$$R_f \text{ value} = \frac{\text{distance moved by the substance}}{\text{distance moved by the solvent}}$$

Record $R_f$ values to 3sf

## Additional details/common questions for paper chromatography

**Principle of chromatography:** Different solutes have different solubilities in different solvents.

**Chromatogram:** Filter paper with separated components on it.

**Why should the base line be drawn using a pencil instead of a pen?**

- the solvent will not separate the pencil mark, unlike ink which contains soluble dyes
- the separated dyes from the ink will smudge, thus interfering with dyes from the test sample

**What are the advantages of using chromatography?**

- only a small amount of sample is required e.g. $1 \times 10^{-12}$ g of sample
- inexpensive to set up and conduct, in the case of paper chromatography

**How can chromatography be applied to colourless substances?**

- Use ultraviolet (UV) light to ‘see’ the invisible dyes/ components (some substances are coloured under uv light, but colourless in white light)
- Use a locating agent e.g. ninhydrin solution/ spray (ninhydrin forms a purple stain with amino acids which are originally colourless)

**Why should the solvent front be near the end of the paper at the end of the experiment?**

To ensure maximum separation of the components in the sample. Rf value calculated is more accurate.

**Why should the spots and dyes on the starting line be small?**

To ensure that there will not be any overlapping of the components

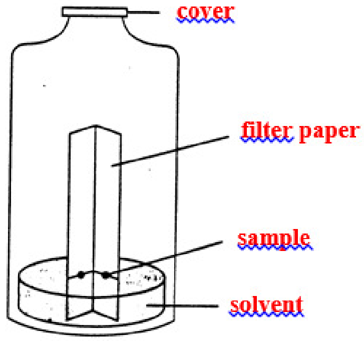
**Why should the start line be above the solvent level?**

So that the sample will not dissolve in the solvent before the components in the sample can be separated.

**Why does the container need to be closed with a lid?**

To minimize solvent evaporation and drying up before process is completed.

**Describe with the aid of a diagram, how a chromatogram can be set up.**



- Ensure the start line/base line is drawn in pencil and above the solvent level before the experiment starts.
- After the chromatogram has developed, indicate, with a pencil, the position of the solvent front and wait for it to dry.
- If necessary, use a locating agent to make the chromatogram visible.