

National 5 Chemistry

Learning Outcomes

2017-18

Chemical changes and structure

Rates of reaction

To follow the progress of chemical reactions, changes in mass, volume and other quantities can be measured. Graphs can then be drawn and be interpreted in terms of:

- end-point of a reaction
- quantity of product
- quantity of reactant used
- effect of changing conditions

Rates of reaction can be increased:

- by increasing the temperature
- by increasing the concentration of a reactant
- by increasing surface area/decreasing particle size
- through the use of a catalyst

Catalysts are substances that speed up chemical reactions but can be recovered chemically unchanged at the end of the reaction.

The average rate of a chemical reaction can be calculated, with appropriate units, using the equation: $\text{rate} = \frac{\Delta \text{quantity}}{\Delta t}$

The rate of a reaction can be shown to decrease over time by calculating the average rate at different stages of the reaction.

Atomic structure and bonding related to properties of materials

Periodic Table and atoms

Elements in the Periodic Table are arranged in order of increasing atomic number.

The Periodic Table can be used to determine whether an element is a metal or non-metal.

Groups are columns in the Periodic Table containing elements with the same number of outer electrons, indicated by the group number.

Elements within a group share the same valency and have similar chemical properties because they have the same number of electrons in their outer energy levels.

The electron arrangement of the first 20 elements can be written.

An atom has a nucleus, containing protons and neutrons, and electrons that orbit the nucleus.

Protons have a charge of one-positive, neutrons are neutral and electrons have a charge of one-negative. Protons and neutrons have an approximate mass of one atomic mass unit and electrons, in comparison, have virtually no mass.

The number of protons in an atom is given by the atomic number.

In a neutral atom the number of electrons is equal to the number of protons.

The mass number of an atom is equal to the number of protons added to the number of neutrons.

Isotopes are defined as atoms with the same atomic number but different mass numbers, or as atoms with the same number of protons but different numbers of neutrons.

Nuclide notation is used to show the atomic number, mass number (and charge) of atoms (ions) from which the number of protons, electrons and neutrons can be determined.

Most elements have two or more isotopes. The average atomic mass has been calculated for each element using the mass and proportion of each isotope present. These values are known as relative atomic masses.

Covalent bonding

Covalent bonds form between non-metal atoms.

A covalent bond forms when two positive nuclei are held together by their common attraction for a shared pair of electrons.

Diagrams can be drawn to show how outer electrons are shared to form the covalent bond(s) in a molecule.

7 elements exist as diatomic molecules through the formation of covalent bonds: H₂, N₂,

O₂, F₂, Cl₂, Br₂, I₂.

The shape of simple covalent molecules depends on the number of bonds and the orientation of these bonds around the central atom. These molecules can be described as linear, angular, trigonal pyramidal or tetrahedral.

More than one bond can be formed between atoms leading to double and triple covalent bonds.

Covalent substances can form either discrete molecular or giant network structures.

Covalent molecular substances:

- have strong covalent bonds within the molecules and only weak attractions between the molecules
- have low melting and boiling points as only weak forces of attraction between the molecules are broken when a substance changes state
- do not conduct electricity because they do not have charged particles which are free to move

Covalent molecular substances which are insoluble in water may dissolve in other solvents.

Covalent network structures:

- have a network of strong covalent bonds within one giant structure
- have very high melting and boiling points because the network of strong covalent bonds is not easily broken
- do not dissolve

In general, covalent network substances do not conduct electricity. This is because they do not have charged particles which are free to move.

Ionic compounds

Ions are formed when atoms lose or gain electrons to obtain the stable electron arrangement of a noble gas.

In general, metal atoms lose electrons forming positive ions and non-metal atoms gain electrons forming negative ions.

Ion-electron equations can be written to show the formation of ions through loss or gain of electrons.

Ionic bonds are the electrostatic attraction between positive and negative ions.

Ionic compounds form lattice structures of oppositely charged ions with each positive ion surrounded by negative ions and each negative ion surrounded by positive ions.

Ionic compounds have high melting and boiling points because strong ionic bonds must be broken in order to break up the lattice.

Many ionic compounds are soluble in water. As they dissolve the lattice structure breaks up allowing water molecules to surround the separated ions.

Ionic compounds conduct electricity only when molten or in solution as the lattice structure breaks up allowing the ions to be free to move.

Conduction in ionic compounds can be explained by the movement of ions towards oppositely charged electrodes.

Formulae and reacting quantities

Chemical formulae

Compound names are derived from the names of the elements from which they are formed. Most compounds with a name ending in '-ide' contain the two elements indicated.

The ending '-ite' or '-ate' indicates that oxygen is also present.

Chemical formulae can be written for two element compounds using valency rules and a Periodic Table.

Roman numerals can be used, in the name of a compound, to indicate the valency of an element.

The chemical formula can also be determined from names with prefixes.

The chemical formula of a covalent molecular substance gives the number of each type of atom present in a molecule.

The formula of a covalent network gives the simplest ratio of each type of atom in the substance.

Ions containing more than one type of atom are often referred to as group ions.

Chemical formulae can be written for compounds containing group ions using valency rules and the data booklet.

Ionic formulae give the simplest ratio of each type of ion in the substance and can show the charges on each ion, if required.

In formulae, charges must be superscript and numbers of atoms/ions must be subscript.

Calculations involving the mole and balanced equations

Chemical equations, using formulae and state symbols, can be written and balanced.

The mass of a mole of any substance, in grams (g), is equal to the gram formula mass and can be calculated using relative atomic masses.

Calculations can be performed using the relationship between the mass and the number of moles of a substance.

A solution is formed when a solute is dissolved in a solvent.

For solutions, the mass of solute (grams or g), the number of moles of solute (moles or mol), the volume of solution (litres or l) or the concentration of the solution (moles per litre or mol l⁻¹) can be calculated from data provided.

Given a balanced equation, the mass or number of moles of a substance can be calculated given the mass or number of moles of another substance in the reaction.

Percentage composition

The percentage composition of an element in any compound can be calculated from the formula of the compound.

Acids and bases

pH

The pH scale is an indication of the hydrogen ion concentration and runs from below 0 to above 14.

A neutral solution has equal concentrations of H⁺(aq) and OH⁻(aq) ions.

Water is neutral as it dissociates according to the equation: $\text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{OH}^-(\text{aq})$ producing equal concentrations of hydrogen and hydroxide ions.

At any time, only a few water molecules are dissociated into free ions. The symbol indicates that a reaction is reversible and occurs in both directions.

Acidic solutions have a higher concentration of H⁺(aq) ions than OH⁻(aq) and have a pH below 7.

Alkaline solutions have a higher concentration of OH⁻(aq) ions than H⁺(aq) ions and have a pH above 7.

Dilution of an acidic solution with water will decrease the concentration of H⁺(aq) and the pH will increase towards 7.

Dilution of an alkaline solution with water will decrease the concentration of OH⁻(aq) and the pH will decrease towards 7.

Soluble non-metal oxides dissolve in water forming acidic solutions.

Soluble metal oxides dissolve in water to form alkaline solutions:

metal oxide + water → metal hydroxide

Metal oxides, metal hydroxides, metal carbonates and ammonia neutralise acids and are called bases. Those bases that dissolve in water form alkaline solutions.

Neutralisation reactions

A neutralisation reaction is one in which a base reacts with an acid to form water. A salt is also formed in this reaction.

Equations can be written for the following neutralisation reactions:

a metal oxide + an acid \rightarrow a salt + water

a metal hydroxide + an acid \rightarrow a salt + water

a metal carbonate + an acid \rightarrow a salt + water + carbon dioxide

The name of the salt produced depends on the acid and base used. Hydrochloric acid produces chlorides, sulfuric acid produces sulfates and nitric acid produces nitrates.

Spectator ions are ions that remain unchanged by the reaction.

Reaction equations can be used to identify spectator ions.

For neutralisation reactions, equations can be written omitting spectator ions:

$2\text{H}^+(\text{aq}) + \text{O}_2^-(\text{s}) \rightarrow \text{H}_2\text{O}(\ell)$ for metal oxides

$\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\ell)$ for metal hydroxides

$2\text{H}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{H}_2\text{O}(\ell) + \text{CO}_2(\text{g})$ for aqueous metal carbonates

$2\text{H}^+(\text{aq}) + \text{CO}_3^{2-}(\text{s}) \rightarrow \text{H}_2\text{O}(\ell) + \text{CO}_2(\text{g})$ for insoluble metal carbonates

In an acid-base titration, the concentration of the acid or base is determined by accurately measuring the volumes used in the neutralisation reaction. An indicator can be added to show the end-point of the reaction.

Given a balanced equation for the reaction occurring in any titration:

- the concentration of one reactant can be calculated given the concentration of the other reactant and the volumes of both solutions
- the volume of one reactant can be calculated given the volume of the other reactant and the concentrations of both solutions

Neutralisation reactions can be used to prepare soluble salts

Titration can be used to produce a soluble salt. Once the volumes of acid and alkali have been noted, the reaction can be repeated without the indicator to produce an uncontaminated salt solution. The solution can then be evaporated to dryness.

Insoluble metal carbonates and insoluble metal oxides can be used to produce soluble salts. Excess base is added to the appropriate acid, the mixture is filtered and the filtrate evaporated to dryness.

Nature's Chemistry

Homologous series

Systematic carbon chemistry

A homologous series is a family of compounds with the same general formula and similar chemical properties.

Patterns are often seen in the physical properties of the members of a homologous series.

The subsequent members of a homologous series show a general increase in their melting and boiling points. This pattern is attributed to increasing strength of the intermolecular forces as the molecular size increases. The type of intermolecular force does not need to be identified.

Hydrocarbons are compounds containing only hydrogen and carbon atoms.

Compounds containing only single carbon–carbon bonds are described as saturated.

Compounds containing at least one carbon–carbon double bond are described as unsaturated.

It is possible to distinguish an unsaturated compound from a saturated compound using bromine solution. Unsaturated compounds decolourise bromine solution quickly.

The structure of any molecule can be drawn as a full or a shortened structural formula.

Isomers:

- are compounds with the same molecular formula but different structural formulae
- may belong to different homologous series
- usually have different physical properties

Given a structural formula for a compound, an isomer can be drawn.

Isomers can be drawn for a given molecular formula.

Alkanes

Alkanes:

- are a homologous series of saturated hydrocarbons
- are commonly used as fuels
- are insoluble in water
- can be represented by the general formula C_nH_{2n+2}

Straight-chain and branched alkanes can be systematically named from structural formulae containing no more than 8 carbons in the longest chain.

Molecular formulae can be written and structural formulae can be drawn, from the systematic names of straight-chain and branched alkanes, containing no more than 8 carbons in the longest chain.

Cycloalkanes

Cycloalkanes:

- are a homologous series of saturated, cyclic hydrocarbons
- are used as fuels and solvents
- are insoluble in water
- can be represented by the general formula C_nH_{2n}

Cycloalkanes (C_3 – C_8) can be systematically named from structural formulae. Branched cycloalkanes are not required.

Molecular formulae can be written and structural formulae can be drawn from the systematic names of un-branched cycloalkanes.

Alkenes

Alkenes:

- are a homologous series of unsaturated hydrocarbons
- are used to make polymers and alcohols
- are insoluble in water
- contain the $C=C$ double bond functional group
- can be represented by the general formula C_nH_{2n}

Straight-chain and branched alkenes can be systematically named indicating the position of the double bond, from structural formulae containing no more than 8 carbon atoms in the longest chain.

Molecular formulae can be written and structural formulae can be drawn, from the systematic names of straight-chain and branched alkenes, containing no more than 8 carbons in the longest chain.

Chemical equations can be written for the addition reactions of alkenes, using molecular or structural formulae.

Alkenes undergo addition reactions:

- with hydrogen forming alkanes, known as hydrogenation
- with halogens forming dihaloalkanes
- with water forming alcohols, known as hydration

Everyday consumer products

Alcohols

Alcohols are used as fuels as they are highly flammable and burn with very clean flames.

Alcohols are often used as solvents.

Methanol, ethanol and propanol are miscible with water, thereafter the solubility decreases as size increases.

As alcohols increase in size their melting and boiling points increase due to the increasing strength of the intermolecular forces. The type of intermolecular force does not need to be identified.

An alcohol is a molecule containing a hydroxyl functional group, -OH group.

Saturated, straight-chain alcohols can be represented by the general formula $\text{C}_n\text{H}_{2n+1}\text{OH}$.

Straight-chain alcohols can be systematically named indicating the position of the hydroxyl group from structural formulae containing no more than 8 carbon atoms.

Molecular formulae can be written and structural formulae can be drawn, from the systematic names of straight-chain alcohols, containing no more than 8 carbons

Carboxylic acids

Carboxylic acids are used in the preparation of preservatives, soaps and medicines.

Vinegar is a solution of ethanoic acid, with molecular formula CH_3COOH . Vinegar is used in household cleaning products as it is a non-toxic acid so can be used safely in household situations.

Methanoic, ethanoic, propanoic and butanoic acid are miscible in water, thereafter the solubility decreases as size increases.

As carboxylic acids increase in size their melting and boiling points increase due to the increasing strength of the intermolecular forces. The type of intermolecular force does not need to be identified.

Carboxylic acids can be identified by the carboxyl functional group, -COOH .

Carboxylic acids can be represented by the general formula $\text{C}_n\text{H}_{2n+1}\text{COOH}$.

Straight-chain carboxylic acids can be systematically named from structural formulae containing no more than 8 carbons.

Molecular formulae can be written and structural formulae drawn, from the systematic names of straight-chain carboxylic acids, containing no more than 8 carbons.

Solutions of carboxylic acids have a pH less than 7 and like other acids, can react with metals, metal oxides, hydroxides and carbonates forming salts. Salts formed from straightchain carboxylic acids containing no more than 8 carbons, can be named.

Energy from fuels

A reaction or process that releases heat energy is described as exothermic. A reaction or process that takes in heat energy is described as endothermic.

In combustion, a substance reacts with oxygen releasing energy.

Hydrocarbons and alcohols burn in a plentiful supply of oxygen to produce carbon dioxide and water. Equations can be written for the complete combustion of hydrocarbons and alcohols.

Fuels burn releasing different quantities of energy.

The quantity of heat energy released can be determined experimentally and calculated using, $E_h = cm\Delta T$.

The quantities E_h , c , m or ΔT can be calculated, in the correct units, given relevant data.

Calculations can involve heating substances other than water. It is not necessary to calculate the enthalpy per mole of substance burned.

Chemistry in Society

Metals

Metallic bonding

Metallic bonding is the electrostatic force of attraction between positively charged ions and delocalised electrons. Metallic elements are conductors of electricity because they contain delocalised electrons.

Reactions of metals

Equations, involving formulae, can be written to show the reaction of metals with oxygen, water, and dilute acids:

metal + oxygen \rightarrow metal oxide

metal + water \rightarrow metal hydroxide + hydrogen

metal + dilute acid \rightarrow salt + hydrogen

Metals can be arranged in order of reactivity by comparing the rates at which they react.

Metals can be used to produce soluble salts. Excess metal is added to the appropriate acid, the mixture is filtered and the filtrate evaporated to dryness.

Redox

Reduction is a gain of electrons by a reactant in any reaction.

Oxidation is a loss of electrons by a reactant in any reaction.

In a redox reaction, reduction and oxidation take place at the same time.

Ion-electron equations can be written for reduction and oxidation reactions.

Ion-electron equations can be combined to produce redox equations.

Extraction of metals

During the extraction of metals, metal ions are reduced forming metal atoms.

The method used to extract a metal from its ore depends on the position of the metal in the reactivity series. Equations can be written to show the extraction of metals.

Methods used are:

- heat alone (for extraction of Ag, Au and Hg)
- heating with carbon or carbon monoxide (for extraction of Cu, Pb, Sn, Fe and Zn)
- electrolysis (for extraction of more reactive metals including aluminium)

Electrolysis is the decomposition of an ionic compound into its elements using electricity.

A d.c. supply must be used if the products of electrolysis are to be identified.

Positive ions gain electrons at the negative electrode and negative ions lose electrons at the positive electrode.

Electrochemical cells

Electrically conducting solutions containing ions are known as electrolytes.

A simple cell can be made by placing two metals in an electrolyte.

Another type of cell can be made using two half-cells (metals in solutions of their own ions).

An 'ion bridge' (salt bridge) can be used to link the half-cells. Ions can move across the bridge to complete an electrical circuit.

Electricity can be produced in cells where at least one of the half-cells does not involve metal atoms/ions. A graphite rod can be used as the electrode in such half-cells.

Different pairs of metals produce different voltages. These voltages can be used to arrange the elements into an electrochemical series.

The further apart elements are in the electrochemical series, the greater the voltage produced when they are used to make an electrochemical cell.

Electrons flow in the external circuit from the species higher in the electrochemical series to the one lower in the electrochemical series.

For an electrochemical cell, including those involving non-metals, ion-electron equations can be written for:

- the oxidation reaction
- the reduction reaction
- the overall redox reactions

The direction of electron flow can be deduced for electrochemical cells including those involving non-metal electrodes.

Plastics

Addition polymerisation

Plastics are examples of materials known as polymers.

Polymers are long chain molecules formed by joining together a large number of small molecules called monomers.

Addition polymerisation is the name given to a chemical reaction in which unsaturated monomers are joined, forming a polymer.

The names of addition polymers are derived from the name of the monomer used.

Note: brackets can be used in polymer names to aid identification of the monomer unit.

Representation of the structure of monomers and polymers

A repeating unit is the shortest section of polymer chain which, if repeated, would yield the complete polymer chain (except for the end-groups).

The structure of a polymer can be drawn given either the structure of the monomer or the repeating unit.

From the structure of a polymer, the monomer or repeating unit can be drawn.

Fertilisers

Commercial production of fertilisers

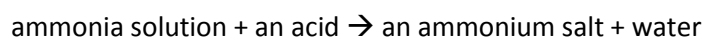
Growing plants require nutrients, including compounds containing nitrogen, phosphorus or potassium.

Fertilisers are substances which restore elements, essential for healthy plant growth, to the soil.

Ammonia and nitric acid are important compounds used to produce soluble, nitrogen-containing salts that can be used as fertilisers.

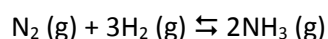
Ammonia is a pungent, clear, colourless gas which dissolves in water to produce an alkaline solution.

Ammonia solutions react with acids to form soluble salts.



Haber and Ostwald processes

The Haber process is used to produce the ammonia required for fertiliser production.



At low temperatures the forward reaction is too slow to be economical. If the temperature is increased, the rate of reaction increases but, as the temperature increases, the backward reaction becomes more dominant. An iron catalyst is used to increase reaction rate.

Ammonia is the starting material for the commercial production of nitric acid.

The Ostwald process uses ammonia, oxygen and water to produce nitric acid. A platinum catalyst is used in this process.

Nuclear chemistry

Radiation

Radioactive decay involves changes in the nuclei of atoms. Unstable nuclei (radioisotopes) can become more stable nuclei by giving out alpha, beta or gamma radiation.

Alpha particles (α) consist of two protons and two neutrons and carry a double positive charge. They have a range of only a few centimetres in air and are stopped by a piece of paper. Alpha particles will be attracted towards a negatively charged plate.

Beta particles (β) are electrons ejected from the nucleus of an atom. They are able to travel over a metre in air but can be stopped by a thin sheet of aluminium. Beta particles will be attracted towards a positively charged plate.

Gamma rays (γ) are electromagnetic waves emitted from within the nucleus of an atom.

They are able to travel great distances in air. They can be stopped by barriers made of materials such as lead or concrete. Gamma rays are not deflected by an electric field.

Nuclear equations

Balanced nuclear equations can be written using nuclide notation.

- In nuclear equations: an alpha particle can be represented as ${}^4_2\text{He}$
- a beta particle can be represented as ${}^0_{-1}\text{e}$
- a proton can be represented as ${}^1_1\text{p}$
- a neutron can be represented as ${}^1_0\text{n}$

In the course of any nuclear reaction:

- The sum of the atomic numbers on the left of the reaction arrow is equal to the sum of the atomic numbers on the right of the reaction arrow.
- The sum of the mass numbers on the left of the reaction arrow is equal to the sum of the mass numbers on the right of the reaction arrow.
- Candidates do not need to show electrical charges when writing balanced equations representing nuclear reactions.

Half-life

Half-life is the time for half of the nuclei of a particular isotope to decay.

The half-life of an isotope is a constant, unaffected by chemical or physical conditions.

Radioactive isotopes can be used to date materials.

The half-life of an isotope can be determined from a graph showing a decay curve.

Calculations can be performed using the link between the number of half-lives, time and the proportion of a radioisotope remaining.

Use of radioactive isotopes

Radioisotopes have a range of uses in medicine and in industry.

Candidates do not need to be able to name the isotope used in a particular application.

Given information on the type of radiation emitted and/or half-lives, the suitability of an isotope for a particular application can be evaluated.

Chemical analysis

Common chemical apparatus

You must be familiar with the use(s) of the following types of apparatus:

- conical flask
- beaker
- measuring cylinder
- delivery tube
- dropper
- test tubes/boiling tubes
- funnel
- filter paper
- evaporating basin
- pipette with safety filler
- burette
- thermometer

General practical techniques

You must be familiar with the following practical techniques:

- simple filtration using filter paper and a funnel to separate the residue from the filtrate
- use of a balance
- methods for the collection of gases including:
 - collection over water (for relatively insoluble gases)
 - downward displacement of air (for soluble gases that are less dense than air)
 - upward displacement of air (for soluble gases that are more dense than air)
 - methods of heating using Bunsen burners and electric hotplates
 - preparation of soluble salts by the reaction of acids with metals, metal oxides, metal hydroxides and metal carbonates
 - preparation of insoluble salts by precipitation testing the electrical conductivity of solids and solutions
 - setting up an electrochemical cell using a salt bridge and either metal or carbon electrodes electrolysis of solutions using a d.c. supply
 - determination of Eh

Analytical methods

Titration is used to determine, accurately, the volumes of solution required to reach the end-point of a chemical reaction. An indicator is normally used to show when the end-point is reached. Titre volumes within 0.2 cm³ are considered concordant.

Solutions of accurately known concentration are known as standard solutions.

Flame tests can identify metals present in a sample.

Simple tests can be used to identify oxygen, hydrogen and carbon dioxide gases.

Precipitation is the reaction of two solutions to form an insoluble salt called a precipitate.

Information on the solubility of compounds can be used to predict when a precipitate will form. The formation of a precipitate can be used to identify the presence of a particular ion.

Reporting experimental work

Labelled, sectional diagrams can be drawn for common chemical apparatus.

Data can be presented in tabular form with appropriate headings and units of measurement.

Data can be presented as a bar, line or scatter graph with suitable scale(s) and labels.

A line of best fit (straight or curved) can be used to represent the trend observed in experimental data.

Average (mean) values can be calculated from data.

Given a description of an experimental procedure and/or experimental results, an improvement to the experimental method can be suggested and justified.