Cambridge IGCSE · Chemistry 0620

Chemistry 0620 formulas and definitions

All 305 formulas, facts and definitions to learn, by syllabus topic. Formulas the exam gives you are left out.

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1 States of matter

Solid: touching, regular, vibrate about fixed positions; fixed shape and volume; not compressible

Particles in the same volume: solid most, liquid slightly fewer, gas far fewer

Liquid: touching, random, slide past each other; fixed volume, takes the container's shape; not compressible

Gas: far apart, random, move fast in all directions; fills the container; easily compressed

Melting (s → l), freezing (l → s), boiling and evaporating (l → g), condensing (g → l)

Evaporating: below the boiling point, from the surface only; boiling: at the boiling point, throughout the liquid

Below m.p. solid; between m.p. and b.p. liquid; above b.p. gas

Gas at constant pressure: temperature up, volume up

Gas at constant temperature: pressure up, volume down

Diffusion: net movement from high to low concentration, by the random movement of particles

Extended only: lower M_r → faster diffusion; M_r = sum of the relative atomic masses

Extended only: flat parts of a heating or cooling curve = change of state, temperature constant

Extended only: gas pressure comes from particles colliding with the container walls

2 Atoms, elements and compounds

2.1–2.3 Elements, compounds and atomic structure

Proton: charge $+1$, mass 1; neutron: charge 0, mass 1; electron: charge -1, mass $\frac{1}{1840}$

Proton number (atomic number) = number of protons in the nucleus

Mass number (nucleon number) = number of protons + neutrons in the nucleus

Neutrons = mass number – proton number

In an atom, electrons = protons; in an ion, electrons = protons – charge

Shells for proton numbers 1–20 hold 2, then 8, then 8, then the rest

Group number (I–VII) = outer-shell electrons; period number = occupied shells

Noble gases (Group VIII) have a full outer shell

Isotopes: atoms of the same element, same number of protons, different numbers of neutrons

Extended only: isotopes have the same chemical properties: same number of electrons, same configuration

Relative atomic mass A_r = average mass of an element's isotopes, compared with $\frac{1}{12}$ of the mass of a carbon-12 atom

Extended only: $A_r = \frac{\sum(\text{isotope mass} \times \text{abundance})}{100}$

2.4, 2.7 Ionic and metallic bonding

Metals lose electrons → positive ions (cations); non-metals gain electrons → negative ions (anions)

Ion charges: Group I $1+$, II $2+$, III $3+$, V $3-$, VI $2-$, VII $1-$

Ionic bond = strong electrostatic attraction between oppositely charged ions

Ionic compounds: high melting and boiling points; conduct when molten or aqueous, not when solid

Formula of an ionic compound: total positive charge + total negative charge $= 0$

Extended only: giant ionic lattice = regular arrangement of alternating positive and negative ions

Extended only: metallic bonding = electrostatic attraction between positive ions in a giant lattice and a sea of delocalised electrons

Extended only: metals conduct because delocalised electrons move; they are malleable and ductile because layers of ions slide over each other

2.5–2.6 Covalent bonding and giant covalent structures

Covalent bond = a pair of electrons shared between two atoms, giving noble-gas configurations

Bonds formed = $8 - \text{group number}$ (hydrogen: 1)

Single bond: 1 shared pair (2 electrons); double: 2 pairs (4); triple: 3 pairs (6)

Simple molecular: low melting and boiling points; poor conductors

Extended only: low melting point because intermolecular forces are weak; poor conductor because there are no ions and no mobile electrons

Diamond: each C bonded to 4 others, very hard, no conduction, cutting tools

Graphite: each C bonded to 3 others in layers, delocalised electrons, layers slide; lubricant and electrodes

Extended only: SiO_2: each Si bonded to 4 O, each O to 2 Si; hard, high melting point, non-conductor, like diamond

3 Stoichiometry

3.1 Formulae and equations

Diatomic elements: H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2; noble gases are single atoms

Group ions: NH_4^+, OH^-, NO_3^-, SO_4^{2-}, CO_3^{2-}, PO_4^{3-}

Roman numeral = charge on the metal ion: Fe^{2+} iron(II), Fe^{3+} iron(III), Cu^{2+} copper(II)

Ionic formula: total positive charge + total negative charge $= 0$

Molecular formula = number and type of different atoms in one molecule

Extended only: empirical formula = simplest whole-number ratio of the different atoms or ions

Balanced equation: the same number of each kind of atom on both sides; change coefficients, never subscripts

State symbols: (s) solid, (l) liquid, (g) gas, (aq) dissolved in water

Extended only: ionic equation: leave out spectator ions; atoms and charges both balance

Extended only: neutralisation: $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

3.2–3.3 Relative masses and the mole

A_r: average mass of an element's isotopes compared with $\frac{1}{12}$ of the mass of a carbon-12 atom

M_r = sum of the A_r of all the atoms in the formula

Concentration units: g/dm³ and mol/dm³; 1 dm³ = 1000 cm³

Extended only: 1 mol = 6.02×10^{23} particles (the Avogadro constant)

Extended only: $\text{amount (mol)} = \dfrac{\text{mass (g)}}{\text{molar mass (g/mol)}}$

Extended only: number of particles = amount × 6.02×10^{23}

Extended only: volume of gas (dm³) = amount × 24

Extended only: amount (mol) = concentration (mol/dm³) × volume (dm³)

Extended only: concentration (g/dm³) = concentration (mol/dm³) × M_r

Extended only: percentage composition $= \dfrac{\text{number of atoms} \times A_r}{M_r} \times 100$

Extended only: percentage yield $= \dfrac{\text{actual yield}}{\text{theoretical yield}} \times 100$

Extended only: percentage purity $= \dfrac{\text{mass of pure substance}}{\text{mass of sample}} \times 100$

4 Electrochemistry

Electrolysis = decomposition of an ionic compound, molten or in aqueous solution, by an electric current

Anode = positive electrode; cathode = negative electrode; electrolyte = the molten or aqueous substance electrolysed

Metals or hydrogen form at the cathode; non-metals (other than hydrogen) at the anode

Molten binary compound: metal at the cathode, non-metal at the anode

Inert electrodes: graphite (carbon) or platinum; they conduct and do not react

Concentrated aqueous NaCl: hydrogen (cathode), chlorine (anode); dilute sulfuric acid: hydrogen (cathode), oxygen (anode), volumes $2:1$

Electroplating: object = cathode, plating metal = anode, electrolyte = solution of the plating metal's salt

Fuel cell: $2\mathrm{H_2} + \mathrm{O_2} \rightarrow 2\mathrm{H_2O}$; water is the only product; chemical → electrical energy

Extended only: electrons move in the external circuit (anode → cathode); ions move in the electrolyte

Extended only: aqueous cathode: hydrogen, unless the metal is less reactive than hydrogen (copper, silver)

Extended only: aqueous halide at the anode: concentrated → halogen; dilute → oxygen

Extended only: $2\mathrm{H^+} + 2\mathrm{e^-} \rightarrow \mathrm{H_2}$; $\mathrm{Cu^{2+}} + 2\mathrm{e^-} \rightarrow \mathrm{Cu}$; $2\mathrm{Cl^-} \rightarrow \mathrm{Cl_2} + 2\mathrm{e^-}$

Extended only: $4\mathrm{OH^-} \rightarrow 2\mathrm{H_2O} + \mathrm{O_2} + 4\mathrm{e^-}$; $\mathrm{Cu} \rightarrow \mathrm{Cu^{2+}} + 2\mathrm{e^-}$

Extended only: oxidation (electrons lost) at the anode; reduction (electrons gained) at the cathode

5 Chemical energetics

Exothermic: thermal energy transferred **to** the surroundings; temperature of the surroundings **increases**

Endothermic: thermal energy taken in **from** the surroundings; temperature of the surroundings **decreases**

Pathway diagram: products **below** reactants = exothermic; products **above** reactants = endothermic

Temperature change $=$ final temperature $-$ initial temperature; bigger change = more energy transferred

Comparing fuels: energy per gram compared by $\dfrac{\text{temperature rise}}{\text{mass of fuel burned}}$

Extended only: ΔH = enthalpy change = thermal energy transferred during a reaction; negative for exothermic, positive for endothermic

Extended only: reverse reaction: same size of ΔH, opposite sign

Extended only: E_a = minimum energy that colliding particles must have to react; arrow from reactants **up to the peak**

Extended only: ΔH arrow from the reactants level **to** the products level (down for exothermic, up for endothermic)

Extended only: bond breaking is endothermic; bond making is exothermic

Extended only: $\Delta H = \text{bonds broken} - \text{bonds made}$ (each bond energy $\times$ number of those bonds)

6 Chemical reactions

6.1–6.2 Physical and chemical changes and rate of reaction

Chemical change: a new substance forms. Physical change: no new substance (changes of state, dissolving, mixing). Mass is conserved in both

Average rate $= \dfrac{\text{amount of product formed}}{\text{time taken}}$, for example in cm^3/s or g/s

Faster: higher temperature, higher concentration, higher gas pressure, smaller pieces (bigger surface area), catalyst

The final amount of product depends only on the amount of the limiting reactant

Catalyst: increases the rate and is unchanged (same mass) at the end

Concentration unit: mol/dm^3 (or g/dm^3)

Extended only: E_a = the minimum energy that colliding particles need to react

Extended only: concentration, pressure, surface area: more frequent collisions; temperature: more frequent collisions **and** a greater proportion with energy $\geq E_a$

Extended only: a catalyst lowers E_a, so a greater proportion of collisions have energy $\geq E_a$

6.3 Reversible reactions and equilibrium

$\rightleftharpoons$ means a reversible reaction

$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ (blue) $\rightleftharpoons \text{CuSO}_4$ (white) $+5\text{H}_2\text{O}$; heat drives water off; adding water turns it blue and gives out heat

$\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ (pink) $\rightleftharpoons \text{CoCl}_2$ (blue) $+6\text{H}_2\text{O}$; heat drives water off; adding water turns it pink and gives out heat

Extended only: equilibrium (closed system): rate forward $=$ rate reverse; concentrations no longer change

Extended only: higher temperature → endothermic direction; lower → exothermic direction

Extended only: higher pressure → side with fewer gas moles; equal gas moles → no effect

Extended only: add a substance → shifts away from it; remove → shifts towards it; catalyst → no change

Extended only: Haber: $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$; $450\ ^\circ\text{C}$, $20\,000\ \text{kPa}$ / $200\ \text{atm}$, iron; H_2 from methane, N_2 from air

Extended only: Contact: $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$; $450\ ^\circ\text{C}$, $200\ \text{kPa}$ / $2\ \text{atm}$, vanadium(V) oxide; SO_2 from burning sulfur or roasting sulfide ores, O_2 from air

Extended only: the forward reactions in both processes are exothermic

6.4 Redox

Oxidation = gain of oxygen; reduction = loss of oxygen

Redox = oxidation and reduction happening at the same time

Roman numeral = oxidation number of that element, e.g. iron(III) → Fe is $+3$

Extended only: oxidation = loss of electrons = increase in oxidation number

Extended only: reduction = gain of electrons = decrease in oxidation number

Extended only: uncombined element $= 0$; monatomic ion $=$ its charge; compound sums to 0; ion sums to its charge

Extended only: O is -2 in compounds (usually); H $+1$ with non-metals; Group I $+1$; Group II $+2$; halide -1

Extended only: oxidising agent oxidises another substance and is itself reduced (gains electrons)

Extended only: reducing agent reduces another substance and is itself oxidised (loses electrons)

Extended only: acidified $\mathrm{KMnO_4}$: purple → colourless with a reducing agent

Extended only: aqueous KI: colourless → brown (iodine) with an oxidising agent

7 Acids, bases and salts

7.1–7.2 Acids, bases and oxides

acid + metal → salt + hydrogen

acid + base (metal oxide or hydroxide) → salt + water

acid + carbonate → salt + water + carbon dioxide

base + ammonium salt → salt + ammonia + water (on warming)

Salt names: hydrochloric → chloride; sulfuric → sulfate; nitric → nitrate; ethanoic → ethanoate

Litmus red / blue; thymolphthalein colourless / blue; methyl orange red / yellow (acid / alkali)

Acids in water contain $\mathrm{H^+}$; alkalis in water contain $\mathrm{OH^-}$

pH < 7 acidic, $= 7$ neutral, > 7 alkaline; lower pH = more $\mathrm{H^+}$

Neutralisation: $\mathrm{H^+(aq) + OH^-(aq) \rightarrow H_2O(l)}$

Base = oxide or hydroxide of a metal; alkali = soluble base

Extended only: acid = proton donor; base = proton acceptor

Extended only: strong acid = completely dissociated; weak acid = partially dissociated

Extended only: $\mathrm{HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)}$

Extended only: $\mathrm{CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)}$

Metal oxides basic (CuO, CaO); non-metal oxides acidic ($\mathrm{SO_2}$, $\mathrm{CO_2}$)

Extended only: amphoteric oxide reacts with acids and with bases to give a salt and water; Al_2O_3 and ZnO

7.3 Preparation of salts

Solubility rules: Na, K, NH_4 salts and all nitrates soluble; chlorides soluble except $PbCl_2$, AgCl; sulfates soluble except $BaSO_4$, $CaSO_4$, $PbSO_4$; carbonates insoluble except Na, K, NH_4; hydroxides insoluble except Na, K, NH_4 ($Ca(OH)_2$ partly)

Soluble salt: acid + excess metal, base or carbonate → filter → heat to the point of crystallisation → cool → filter → dry

Na, K, NH_4 salts: titrate acid and alkali with indicator → repeat without indicator → crystallise

Extended only: insoluble salt: mix two solutions → filter → wash residue with distilled water → dry

Residue = solid left on the filter paper; filtrate = liquid that passes through

Saturated solution: maximum concentration of solute dissolved in the solvent at a stated temperature

Hydrated = chemically combined with water; anhydrous = contains no water

Extended only: water of crystallisation = water molecules present in hydrated crystals; $CuSO_4 \cdot 5H_2O$, $CoCl_2 \cdot 6H_2O$

moles $= \dfrac{\text{mass}}{M_r}$; moles $= \dfrac{\text{concentration} \times \text{volume in cm}^3}{1000}$

Water of crystallisation: $x = \dfrac{\text{moles of water}}{\text{moles of anhydrous salt}}$

8 The Periodic Table

Elements are in order of increasing proton number; rows = periods, columns = groups

Period number = number of occupied shells; group number (I to VII) = number of outer electrons

Same group → same number of outer electrons → similar chemical properties

Across a period: metals → non-metals (metallic character decreases)

Ion charges: I $1+$, II $2+$, III $3+$, V $3-$, VI $2-$, VII $1-$

Down Group I: melting point decreases, density increases, reactivity increases

Group I metal + water → metal hydroxide + hydrogen, e.g. $2Na + 2H_2O \rightarrow 2NaOH + H_2$

Group I metal + oxygen → oxide, e.g. $4K + O_2 \rightarrow 2K_2O$

Down Group VII: density increases, reactivity decreases

Chlorine pale yellow-green gas; bromine red-brown liquid; iodine grey-black solid

Halogen + halide: $Cl_2 + 2KBr \rightarrow 2KCl + Br_2$; only a more reactive halogen displaces

Extended only: $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$

Transition elements: high density, high melting point, coloured compounds, catalysts

Extended only: transition elements: variable oxidation numbers, e.g. Fe^{2+} and Fe^{3+}

Noble gases: unreactive, monatomic, full outer shell

Below melting point: solid; between melting and boiling point: liquid; above boiling point: gas

9 Metals

9.1–9.3 Properties and uses of metals and alloys

Metals: good thermal and electrical conductors, malleable, ductile, usually high melting and boiling points

Non-metals: poor conductors (except graphite), brittle as solids, usually low melting and boiling points

metal + dilute acid → salt + hydrogen, e.g. $\mathrm{Mg} + 2\mathrm{HCl} \rightarrow \mathrm{MgCl_2} + \mathrm{H_2}$

reactive metal + cold water → metal hydroxide + hydrogen, e.g. $\mathrm{Ca} + 2\mathrm{H_2O} \rightarrow \mathrm{Ca(OH)_2} + \mathrm{H_2}$

metal + steam → metal oxide + hydrogen, e.g. $\mathrm{Mg} + \mathrm{H_2O} \rightarrow \mathrm{MgO} + \mathrm{H_2}$

metal + oxygen → metal oxide (a basic oxide), e.g. $2\mathrm{Ca} + \mathrm{O_2} \rightarrow 2\mathrm{CaO}$

Aluminium: aircraft (low density); overhead cables (low density, good electrical conductor); food containers (resists corrosion)

Copper: electrical wiring (good electrical conductor, ductile)

Alloy = a **mixture** of a metal with other elements

Brass = copper + zinc

Stainless steel = iron + chromium, nickel and carbon; cutlery (hard, resists rusting)

Alloys can be harder and stronger than the pure metals, so they are more useful

Extended only: different-sized atoms → layers can no longer slide over each other → harder, stronger

9.4–9.5 Reactivity series and corrosion

Order: K, Na, Ca, Mg, Al, (C), Zn, Fe, (H), Cu, Ag, Au

Metal + cold water → metal hydroxide + hydrogen (K, Na, Ca), for example $\mathrm{Ca} + 2\mathrm{H_2O} \rightarrow \mathrm{Ca(OH)_2} + \mathrm{H_2}$

Metal + steam → metal oxide + hydrogen: $\mathrm{Mg} + \mathrm{H_2O} \rightarrow \mathrm{MgO} + \mathrm{H_2}$

Metal + dilute acid → salt + hydrogen (metals above hydrogen only), for example $\mathrm{Zn} + 2\mathrm{HCl} \rightarrow \mathrm{ZnCl_2} + \mathrm{H_2}$

Oxide reduced by carbon ⟺ metal is below carbon

Extended: more reactive metal + ions of a less reactive metal → displacement, for example $\mathrm{Mg} + \mathrm{Cu}^{2+} \rightarrow \mathrm{Mg}^{2+} + \mathrm{Cu}$

Extended: more reactive = greater tendency to form positive ions (lose electrons)

Rusting needs water **and** oxygen; rust is hydrated iron(III) oxide, $\mathrm{Fe_2O_3} \cdot x\mathrm{H_2O}$

iron + oxygen + water → hydrated iron(III) oxide

Barrier methods (painting, greasing, plastic coating) exclude oxygen and/or water

Extended: sacrificial metal is more reactive than iron: $\mathrm{Zn} \rightarrow \mathrm{Zn}^{2+} + 2e^{-}$

Extended: galvanising = zinc coating = barrier + sacrificial protection

Extended: aluminium's apparent unreactivity = protective aluminium oxide layer

Air is about 21% oxygen (for rusting-tube volumes)

9.6 Extraction of metals

Hematite = main iron ore, mainly iron(III) oxide $\mathrm{Fe_2O_3}$; bauxite = main aluminium ore, mainly aluminium oxide $\mathrm{Al_2O_3}$

Above carbon → electrolysis of the molten compound; below carbon → heat the oxide with carbon; lower = easier to extract

Raw materials: hematite, coke, limestone (top), hot air (bottom); products: molten iron, slag, waste gases ($\mathrm{CO_2}$, $\mathrm{N_2}$)

Heating: $\mathrm{C + O_2 \rightarrow CO_2}$ (exothermic)

Making the reducing agent: $\mathrm{C + CO_2 \rightarrow 2CO}$

Reduction of the ore: $\mathrm{Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2}$

Thermal decomposition: $\mathrm{CaCO_3 \rightarrow CaO + CO_2}$

Slag: $\mathrm{CaO + SiO_2 \rightarrow CaSiO_3}$ (acid–base)

Extended only: cryolite = solvent for aluminium oxide; lowers the operating temperature and improves conductivity

Extended only: cathode $\mathrm{Al^{3+} + 3e^{-} \rightarrow Al}$; anode $\mathrm{2O^{2-} \rightarrow O_2 + 4e^{-}}$

Extended only: anodes burn away: $\mathrm{C + O_2 \rightarrow CO_2}$

Reduced = loses oxygen; oxidised = gains oxygen

Extended only: reduced = gains electrons or oxidation number decreases; oxidised = loses electrons or oxidation number increases

10 Chemistry of the environment

10.1–10.2 Water and fertilisers

Anhydrous copper(II) sulfate: white → blue with water

Anhydrous cobalt(II) chloride: blue → pink with water

Heating the hydrated salt reverses it: blue $\mathrm{CuSO_4 \cdot 5H_2O}$ → white $\mathrm{CuSO_4}$; pink → blue for cobalt(II) chloride

Pure water melts at exactly 0 °C and boils at exactly 100 °C; impure water melts below 0 °C (over a range) and boils above 100 °C
Distilled water has fewer chemical impurities than tap water
Treatment order: sedimentation → filtration (remove solids) → carbon (tastes and odours) → chlorination (kills microbes)
Must be chlorinated: water that is drunk or used for cooking or food, and swimming pools (not washing a car or clothes, chemical reactions or watering plants)
Sewage → harmful microbes → disease; nitrates and phosphates → deoxygenation → damage to aquatic life
Dissolved oxygen is essential for aquatic life; some metal compounds provide essential minerals
Nitrates come from fertilisers; phosphates from fertilisers and detergents
NPK = nitrogen, phosphorus, potassium; ammonium salts and nitrates are fertilisers
Mass in a new volume $= \text{mass in table} \times \dfrac{\text{new volume}}{\text{table volume}}$

10.3 Air quality and climate

Clean, dry air: about 78% $\mathrm{N_2}$, 21% $\mathrm{O_2}$, the rest noble gases (mainly argon) and $\mathrm{CO_2}$
Volume of a gas in a sample of air $= \dfrac{\text{percentage}}{100} \times \text{volume of air}$
Volume of air needed $= \text{volume of oxygen} \div 0.21$
Complete combustion (plenty of oxygen) → $\mathrm{CO_2}$; incomplete combustion (limited oxygen) → CO and particulates
Sources: $\mathrm{CH_4}$ from decomposing vegetation and animal digestion; NO_x from car engines; $\mathrm{SO_2}$ from fossil fuels containing sulfur
Effects: $\mathrm{CO_2}$, $\mathrm{CH_4}$ → global warming → climate change; CO toxic; particulates → respiratory problems and cancer; NO_x → acid rain, photochemical smog, respiratory problems; $\mathrm{SO_2}$ → acid rain
carbon dioxide + water → glucose + oxygen (chlorophyll, light)
Extended: $6\mathrm{CO_2} + 6\mathrm{H_2O} \rightarrow \mathrm{C_6H_{12}O_6} + 6\mathrm{O_2}$
Extended: $\mathrm{N_2} + \mathrm{O_2} \rightarrow 2\mathrm{NO}$ (both from the air, high engine temperature)
Extended: $2\mathrm{CO} + 2\mathrm{NO} \rightarrow 2\mathrm{CO_2} + \mathrm{N_2}$ (NO reduced, CO oxidised)
Extended: greenhouse gases absorb thermal energy from the Earth, emit or reflect some back to the Earth, reduce thermal energy loss to space
Flue gas desulfurisation: calcium oxide (basic) neutralises sulfur dioxide (acidic)

11 Organic chemistry

11.1–11.2 Organic formulae, functional groups and naming

Alkanes $\mathrm{C}_n\mathrm{H}_{2n+2}$ (ending -ane)

Alkenes $\mathrm{C}_n\mathrm{H}_{2n}$ (ending -ene; functional group C=C)

Alcohols $\mathrm{C}_n\mathrm{H}_{2n+1}\mathrm{OH}$ (ending -ol; functional group $-\mathrm{OH}$)

Carboxylic acids $\mathrm{C}_n\mathrm{H}_{2n+1}\mathrm{COOH}$ (ending -oic acid; functional group $-\mathrm{COOH}$; n does not count the COOH carbon)

Extended: acids and esters $\mathrm{C}_n\mathrm{H}_{2n}\mathrm{O}_2$; ester linkage $-\mathrm{COO}-$; name = alcohol part (-yl) + acid part (-oate)

Consecutive members differ by $-\mathrm{CH}_2-$, so M_r differs by 14

Stems: meth- 1, eth- 2, prop- 3, but- 4 carbon atoms

Bonds: C forms 4, O forms 2, H forms 1

Covalent bonds in an alkane $\mathrm{C}_n\mathrm{H}_{2n+2}$: $3n + 1$ (all single)

Hydrocarbon: a compound of carbon and hydrogen only

Saturated: all C–C bonds single; unsaturated: at least one C=C

Structural isomers: same molecular formula, different structural formulae

11.3–11.4 Fuels and alkanes

Alkanes: $\mathrm{C}_n\mathrm{H}_{2n+2}$, so $M_\mathrm{r} = 14n + 2$

Complete combustion: hydrocarbon + oxygen → carbon dioxide + water

Alkane complete combustion: $\mathrm{C}_n\mathrm{H}_{2n+2} + \dfrac{3n+1}{2}\,\mathrm{O}_2 \rightarrow n\,\mathrm{CO}_2 + (n+1)\,\mathrm{H}_2\mathrm{O}$ (double it when n is even)

Incomplete combustion (limited oxygen): carbon monoxide and/or carbon, and water

Extended: $\mathrm{C}_n\mathrm{H}_{2n+2} + \mathrm{Cl}_2 \rightarrow \mathrm{C}_n\mathrm{H}_{2n+1}\mathrm{Cl} + \mathrm{HCl}$ (ultraviolet light)

Fractions from the top: refinery gas, gasoline, naphtha, kerosene, diesel oil, fuel oil, lubricating oil, bitumen

Up the column: shorter chains, lower boiling point, higher volatility, lower viscosity

Hydrocarbon: a compound of carbon and hydrogen only

Saturated: all C–C bonds single

11.5 Alkenes

Alkenes: $\mathrm{C}_n\mathrm{H}_{2n}$, so $M_\mathrm{r} = 14n$; empirical formula CH_2

Unsaturated: at least one C=C (a carbon–carbon bond that is not single); saturated: all C–C bonds single

Test: aqueous bromine, orange → colourless with a C=C; stays orange if saturated

Extended: addition reaction: only one product is formed

Extended: $\mathrm{C}_n\mathrm{H}_{2n} + \mathrm{Br}_2 \rightarrow \mathrm{C}_n\mathrm{H}_{2n}\mathrm{Br}_2$ (room temperature)

Extended: $\mathrm{C}_n\mathrm{H}_{2n} + \mathrm{H}_2 \rightarrow \mathrm{C}_n\mathrm{H}_{2n+2}$ (nickel catalyst, heat)

$\mathrm{C}_2\mathrm{H}_4 + \mathrm{H}_2\mathrm{O} \rightarrow \mathrm{C}_2\mathrm{H}_5\mathrm{OH}$ (steam, acid catalyst, $300\ ^\circ\mathrm{C}$, $60\ \mathrm{atm}$)

Cracking: long-chain alkane → shorter alkane + alkene (or alkene + hydrogen); high temperature, catalyst

Complete combustion: $\mathrm{C}_n\mathrm{H}_{2n} + \frac{3n}{2}\mathrm{O}_2 \rightarrow n\mathrm{CO}_2 + n\mathrm{H}_2\mathrm{O}$

Extended: $\Delta H =$ bonds broken $-$ bonds made

11.6–11.7 Alcohols and carboxylic acids

Alcohols $\mathrm{C}_n\mathrm{H}_{2n+1}\mathrm{OH}$ (–OH); carboxylic acids $\mathrm{C}_n\mathrm{H}_{2n+1}\mathrm{COOH}$ (–COOH)

Fermentation: $\mathrm{C}_6\mathrm{H}_{12}\mathrm{O}_6 \rightarrow 2\mathrm{C}_2\mathrm{H}_5\mathrm{OH} + 2\mathrm{CO}_2$; reactant aqueous glucose; conditions yeast, 25–$35\ ^\circ\mathrm{C}$, no oxygen

Hydration: $\mathrm{C}_2\mathrm{H}_4 + \mathrm{H}_2\mathrm{O} \rightarrow \mathrm{C}_2\mathrm{H}_5\mathrm{OH}$; steam, acid catalyst, $300\ ^\circ\mathrm{C}$, $60\ \mathrm{atm}$ ($6000\ \mathrm{kPa}$)

Complete combustion: $\mathrm{C}_2\mathrm{H}_5\mathrm{OH} + 3\mathrm{O}_2 \rightarrow 2\mathrm{CO}_2 + 3\mathrm{H}_2\mathrm{O}$

Acid + metal → salt + hydrogen; acid + base → salt + water; acid + carbonate → salt + carbon dioxide + water

Ethanoate ion $\mathrm{CH}_3\mathrm{COO}^-$: $\mathrm{CH}_3\mathrm{COONa}$, $(\mathrm{CH}_3\mathrm{COO})_2\mathrm{Ca}$, $(\mathrm{CH}_3\mathrm{COO})_2\mathrm{Mg}$

Extended: ethanol → ethanoic acid by acidified aqueous potassium manganate(VII), or by bacteria (vinegar)

Extended: acid + alcohol → ester + water (acid catalyst); name = alcohol part (-yl) + acid part (-oate)

Extended: ester $\mathrm{C}_n\mathrm{H}_{2n}\mathrm{O}_2$; unbranched esters with n carbons: $n - 1$

11.8 Polymers

Polymer: a large molecule built up from many small molecules (monomers)

$n\ \mathrm{CH}_2{=}\mathrm{CH}_2 \rightarrow -[\mathrm{CH}_2{-}\mathrm{CH}_2]_n-$ (addition polymerisation; only product)

Extended: addition polymer repeat unit = the two C=C carbons joined by a single bond, same side groups, continuation bonds

Extended: monomers in a section of an addition polymer = main-chain carbons ÷ 2

Extended: polyester: dicarboxylic acid + diol; ester linkage –COO–

Extended: polyamide: dicarboxylic acid + diamine (or amino acids); amide linkage –CONH–

Extended: condensation: one water molecule per linkage formed

Extended: amino acid $\mathrm{H}_2\mathrm{N}{-}\mathrm{CH}(\mathrm{R}){-}\mathrm{COOH}$; $M_\mathrm{r} = 74 + M_\mathrm{r}(\mathrm{R})$

Plastic problems: landfill (non-biodegradable), oceans (accumulate, harm animals), burning (toxic gases)

12 Experimental techniques and chemical analysis

12.1–12.2 Experimental design and titrations

Titre = final burette reading − initial burette reading

Concordant titres: within 0.20 cm³ of each other; mean titre = mean of the concordant titres only

$1\ \text{dm}^3 = 1000\ \text{cm}^3$

Time: stop-watch; temperature: thermometer; mass: balance

Any exact volume of liquid: burette; one fixed exact volume: volumetric pipette; rough volume: measuring cylinder

Gas volume: gas syringe (or upside-down measuring cylinder over water)

End-point with alkali in the flask: methyl orange yellow → orange; thymolphthalein blue → colourless

Saturated solution: no more solute can dissolve (the most possible has dissolved), at a stated temperature

12.3–12.4 Chromatography, separation and purification

$R_f = \dfrac{\text{distance moved by the substance}}{\text{distance moved by the solvent}}$, both measured from the baseline (Extended only)

$0 < R_f < 1$; no units

Insoluble solid from a liquid or solution: **filtration**

Dissolved solid from its solution, as crystals: **crystallisation**

Solvent (such as water) from a solution: **simple distillation**

Liquids with different boiling points: **fractional distillation**

Soluble coloured (or, Extended, colourless) substances: **chromatography**

Impurities **lower** the melting point and **raise** the boiling point, and make both happen over a range

Pure water: melts at 0 °C, boils at 100 °C

12.5 Identification of ions and gases

H_2: lighted splint, pops · O_2: glowing splint, relights

CO_2: limewater turns milky · NH_3: damp red litmus turns blue

Cl_2: damp litmus bleached · SO_2: acidified KMnO_4(aq) purple to colourless

Flame colours: Li^+ red, Na^+ yellow, K^+ lilac, Ca^{2+} orange-red, Ba^{2+} light green, Cu^{2+} blue-green

With NaOH(aq): Al^{3+}, Zn^{2+} white ppt. dissolving in excess; Ca^{2+} white ppt. staying; Cr^{3+} green ppt. dissolving; Fe^{2+} green ppt. staying; Fe^{3+} red-brown ppt.; Cu^{2+} light blue ppt.

With $\mathrm{NH_3(aq)}$: only $\mathrm{Zn^{2+}}$ and $\mathrm{Cu^{2+}}$ precipitates dissolve in excess ($\mathrm{Cu^{2+}}$ gives a dark blue solution); $\mathrm{Ca^{2+}}$ gives little or no ppt.

$\mathrm{NH_4^+}$: warm with NaOH(aq), ammonia given off

$\mathrm{CO_3^{2-}}$: dilute acid, effervescence, gas turns limewater milky

$\mathrm{Cl^-}$ / $\mathrm{Br^-}$ / $\mathrm{I^-}$: dilute $\mathrm{HNO_3}$ then $\mathrm{AgNO_3(aq)}$, white / cream / yellow ppt.

$\mathrm{SO_4^{2-}}$: dilute $\mathrm{HNO_3}$ then $\mathrm{Ba(NO_3)_2(aq)}$, white ppt.

$\mathrm{NO_3^-}$: NaOH(aq) and aluminium foil, warm, ammonia given off

$\mathrm{SO_3^{2-}}$: acidified $\mathrm{KMnO_4(aq)}$ purple to colourless

Extended: $\mathrm{Ag^+(aq) + X^-(aq) \rightarrow AgX(s)}$ for $\mathrm{X = Cl, Br, I}$

Extended: $\mathrm{Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)}$

Extended: $\mathrm{M^{n+}(aq) + nOH^-(aq) \rightarrow M(OH)_n(s)}$, such as $\mathrm{Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)}$