Cambridge AS & A Level · Chemistry 9701

Chemistry 9701 formulas and definitions: AS Level

All 219 formulas, facts and definitions to learn, by syllabus topic. Formulas the exam gives you are left out.

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AS Level

Atomic structure

Relative charges $+1, 0, -1$ and relative masses $1, 1, \frac{1}{1836}$ of p, n, e

neutrons $= A - Z$; electrons $= Z - \text{charge}$

Orbitals per sub-shell: s 1, p 3, d 5; electrons: s 2, p 6, d 10; 2 per orbital, opposite spins

Energy order: $1s < 2s < 2p < 3s < 3p < 4s < 3d < 4p$

Cr $[\text{Ar}]\, 3d^5 4s^1$ and Cu $[\text{Ar}]\, 3d^{10} 4s^1$

Transition-element ions lose 4s electrons before 3d

nth IE: $\text{X}^{(n-1)+}(\text{g}) \rightarrow \text{X}^{n+}(\text{g}) + e^-$

Factors: nuclear charge, distance (radius), shielding, spin-pair repulsion

$$A_r = \frac{\sum(\text{relative isotopic mass} \times \text{abundance})}{\sum \text{abundance}}$$

Atoms, molecules and stoichiometry

$n = \dfrac{m}{M}$ (mass in g, molar mass in g mol^{-1})

Number of particles $= n \times L$

Gas: $n = \dfrac{V\ (\text{dm}^3)}{24.0} = \dfrac{V\ (\text{cm}^3)}{24\,000}$ at room conditions

Solution: $n = c \times \dfrac{V\ (\text{cm}^3)}{1000}$; concentration in g dm^{-3} $= c \times M$

$$A_r = \frac{\sum(\text{relative isotopic mass} \times \text{abundance})}{\sum \text{abundance}}$$

$$\text{Percentage by mass of an element} = \frac{\text{number of atoms} \times A_r}{M_r} \times 100$$

$$\text{Percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

Molecular formula = (empirical formula) $\times \dfrac{M_r}{\text{empirical formula mass}}$
x in salt·$x\text{H}_2\text{O} = \dfrac{n(\text{H}_2\text{O})}{n(\text{anhydrous salt})}$
Ions NO_3^-, CO_3^{2-}, SO_4^{2-}, OH^-, NH_4^+, Zn^{2+}, Ag^+, HCO_3^-, PO_4^{3-}
Definitions: unified atomic mass unit, A_r, relative isotopic mass, M_r, mole, empirical formula

Chemical bonding

The definitions in "What you need to know" (items 1, 5, 6, 7, 11)
Electronegativity rises across a period and falls down a group
The larger the electronegativity difference, the more ionic the bond; a smaller difference: polar covalent; zero: non-polar (no exact cut-off)
Single bond = 1 σ; double = 1 σ + 1 π; triple = 1 σ + 2 π
4 regions: sp^3; 3 regions: sp^2; 2 regions: sp
VSEPR shapes and angles: 180°, 120°, 109.5°, 107°, 104.5°, 120° and 90°, 90° (the table above)
Repulsion: lone pair–lone pair > lone pair–bond pair > bond pair–bond pair
lone pairs $= \dfrac{\text{outer electrons} - \text{electrons used in bonds} - \text{charge}}{2}$
Hydrogen bond: H of an N–H or O–H group, to a lone pair on N or O; X–H···Y at 180°
Strength: ionic, covalent, metallic > hydrogen bond > pd-pd > id-id (molecules of similar size)

States of matter

$pV = nRT$
$T\,(\text{K}) = \theta\,(^\circ\text{C}) + 273$
$1\ \text{dm}^3 = 10^{-3}\ \text{m}^3$; $1\ \text{cm}^3 = 10^{-6}\ \text{m}^3$; $1\ \text{kPa} = 1000\ \text{Pa}$
$n = \dfrac{m}{M}$
$M_r = \dfrac{mRT}{pV}$
$M_r = \dfrac{\rho RT}{p}$ (ρ in g m^{-3})
At fixed V and T: $p \propto n$; at fixed n and T: $p_1V_1 = p_2V_2$
Ideal gas: particles have zero volume and no intermolecular forces
Most ideal: high temperature, low pressure, weak intermolecular forces

Chemical energetics

Exothermic: $\Delta H < 0$; endothermic: $\Delta H > 0$

Standard conditions: 298 K and 101 kPa, substances in standard states

Definitions of ΔH_r, ΔH_f, ΔH_c, ΔH_neut (see the table above)

ΔH_f of an element in its standard state $= 0$

$E_\mathrm{a}(\mathrm{reverse}) = E_\mathrm{a}(\mathrm{forward}) - \Delta H$

$\Delta H_\mathrm{r} = \Sigma(\mathrm{bonds\ broken}) - \Sigma(\mathrm{bonds\ made})$

$q = mc\Delta T$

$$\Delta H = -\frac{mc\Delta T}{n}$$

Dilute solutions: density 1.00 g cm^{-3}, so 1 cm^3 has a mass of 1 g

$\Delta H_\mathrm{r} = \Sigma\Delta H_\mathrm{f}(\mathrm{products}) - \Sigma\Delta H_\mathrm{f}(\mathrm{reactants})$

$\Delta H_\mathrm{r} = \Sigma\Delta H_\mathrm{c}(\mathrm{reactants}) - \Sigma\Delta H_\mathrm{c}(\mathrm{products})$

Strong acid + strong alkali: $\Delta H_\mathrm{neut} \approx -57$ kJ mol^{-1}

Electrochemistry

Element $= 0$; sum in a compound $= 0$; sum in an ion $=$ its charge

F $= -1$; Group 1 $= +1$; Group 2 $= +2$; Al $= +3$

H $= +1$ (but -1 in metal hydrides); O $= -2$ (but -1 in peroxides, $+2$ in $\mathrm{OF_2}$)

Cl, Br, I $= -1$ unless bonded to O or F

Oxidation: loss of electrons, oxidation number **increases**

Reduction: gain of electrons, oxidation number **decreases**

Oxidising agent: accepts electrons, is itself reduced

Reducing agent: donates electrons, is itself oxidised

Electrons per formula unit $=$ change in oxidation number $\times$ number of atoms that change

Total increase in oxidation number $=$ total decrease (electrons lost $=$ electrons gained)

Acid half-equations: balance O with $\mathrm{H_2O}$, H with $\mathrm{H^+}$, charge with $\mathrm{e^-}$

$\mathrm{MnO_4^-} + 8\mathrm{H^+} + 5\mathrm{e^-} \rightarrow \mathrm{Mn^{2+}} + 4\mathrm{H_2O}$ and $\mathrm{Cr_2O_7^{2-}} + 14\mathrm{H^+} + 6\mathrm{e^-} \rightarrow 2\mathrm{Cr^{3+}} + 7\mathrm{H_2O}$

Equilibria

For $a\mathrm{A} + b\mathrm{B} \rightleftharpoons c\mathrm{C} + d\mathrm{D}$: $K_c = \dfrac{[\mathrm{C}]^c[\mathrm{D}]^d}{[\mathrm{A}]^a[\mathrm{B}]^b}$ (leave out solids)

$K_p = \dfrac{p_{\mathrm{C}}^{c}\, p_{\mathrm{D}}^{d}}{p_{\mathrm{A}}^{a}\, p_{\mathrm{B}}^{b}}$ (gases only)

Units of K_c: $(\mathrm{mol\ dm^{-3}})^{\Delta n}$; of K_p: $(\mathrm{Pa})^{\Delta n}$, with Δn = powers on top – powers underneath

Concentration $= \dfrac{\text{moles}}{\text{volume in dm}^3}$

Mole fraction $x_{\mathrm{A}} = \dfrac{n_{\mathrm{A}}}{n_{\mathrm{total}}}$; the mole fractions add up to 1

Partial pressure $p_{\mathrm{A}} = x_{\mathrm{A}} \times p_{\mathrm{total}}$; the partial pressures add up to p_{total}

Only temperature changes K; raising T increases K for an endothermic forward reaction and decreases it for an exothermic one

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

Acid = proton donor; base = proton acceptor; strong = fully dissociated, weak = partly dissociated

Haber: Fe, about 450 °C, about 200 atm; Contact: $\mathrm{V_2O_5}$, about 450 °C, 1–2 atm

Reaction kinetics

Rate $= \dfrac{\text{change in concentration (or amount)}}{\text{time}}$, units mol dm^{-3} s^{-1} (or mol s^{-1}, cm^3 s^{-1})

Rate at a moment = gradient of the tangent to the amount–time graph

Activation energy E_{A}: the minimum energy for a collision to be effective

$E_{\mathrm{A}}(\text{reverse}) = E_{\mathrm{A}}(\text{forward}) - \Delta H(\text{forward})$

Concentration $= \dfrac{\text{moles}}{\text{volume in dm}^3}$

Higher concentration or pressure: more collisions per unit time, same proportion effective

Higher temperature: greater proportion of molecules with energy $\geq E_{\mathrm{A}}$; E_{A} unchanged

Catalyst: different mechanism, lower E_{A}; curve, ΔH, K_c and yield unchanged

The Periodic Table: chemical periodicity

Across Period 3: atomic radius ↓, electronegativity ↑, cation radius ↓ $\mathrm{Na^+}$ to $\mathrm{Al^{3+}}$, anion radius ↓ $\mathrm{P^{3-}}$ to $\mathrm{Cl^-}$

Melting point: rises Na → Al, peak at Si, low for P, S, Cl (S > P > Cl)

Conductivity: rises Na → Al, Si semiconductor, P, S, Cl none

Highest oxidation number = number of outer electrons (Na +1 … S +6)

Oxygen: $\mathrm{4Na + O_2 \rightarrow 2Na_2O}$, $\mathrm{2Mg + O_2 \rightarrow 2MgO}$, $\mathrm{4Al + 3O_2 \rightarrow 2Al_2O_3}$, $\mathrm{P_4 + 5O_2 \rightarrow P_4O_{10}}$, $\mathrm{S + O_2 \rightarrow SO_2}$

Chlorine: $\mathrm{2Na + Cl_2 \rightarrow 2NaCl}$, $\mathrm{Mg + Cl_2 \rightarrow MgCl_2}$, $\mathrm{2Al + 3Cl_2 \rightarrow 2AlCl_3}$, $\mathrm{Si + 2Cl_2 \rightarrow SiCl_4}$, $\mathrm{2P + 5Cl_2 \rightarrow 2PCl_5}$

Water: $2Na + 2H_2O \rightarrow 2NaOH + H_2$, $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$ (steam: $Mg + H_2O \rightarrow MgO + H_2$)

Oxides + water: $Na_2O + H_2O \rightarrow 2NaOH$, $MgO + H_2O \rightarrow Mg(OH)_2$, $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$, $SO_2 + H_2O \rightarrow H_2SO_3$, $SO_3 + H_2O \rightarrow H_2SO_4$

pH with water: Na_2O 13–14, MgO 9–10, Al_2O_3 and SiO_2 insoluble (7), P_4O_{10} / SO_3 0–2, SO_2 2–3

Amphoteric: $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$; $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$; $Al(OH)_3 + NaOH \rightarrow NaAl(OH)_4$

$P_4O_{10} + 12NaOH \rightarrow 4Na_3PO_4 + 6H_2O$

Chlorides + water: $SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$; $PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$

pH with water: $NaCl$ 7, $MgCl_2$ 6.5, $AlCl_3$ about 3, $SiCl_4$ and PCl_5 0–2

Group 2

With oxygen: $2M + O_2 \rightarrow 2MO$

With water: $M + 2H_2O \rightarrow M(OH)_2 + H_2$; Mg with steam: $Mg + H_2O \rightarrow MgO + H_2$

With acid: $M + 2HCl \rightarrow MCl_2 + H_2$

Oxide with water: $MO + H_2O \rightarrow M(OH)_2$ (no hydrogen)

Carbonate with acid: $MCO_3 + 2HCl \rightarrow MCl_2 + H_2O + CO_2$

Carbonate on heating: $MCO_3 \rightarrow MO + CO_2$ (1 mol gas per mol)

Nitrate on heating: $2M(NO_3)_2 \rightarrow 2MO + 4NO_2 + O_2$ (2.5 mol gas per mol)

Down the group: reactivity and reducing power ↑, first ionisation energy ↓, radius ↑, melting point ↓

Down the group: hydroxide solubility ↑ (pH of saturated solution ↑), sulfate solubility ↓

Down the group: thermal stability of carbonates and nitrates ↑

All Group 2 carbonates are insoluble; all nitrates and chlorides are soluble

$n = \dfrac{m}{M_r}$; gas volume $= n \times 24.0\ \text{dm}^3$

Group 17

Colours: Cl_2 pale green gas, Br_2 red-brown liquid, I_2 grey-black solid (purple vapour)

Down the group: volatility ↓ (id–id forces ↑, more electrons); X–X and H–X bond strength ↓; HX thermal stability ↓

Oxidising power $Cl_2 > Br_2 > I_2$; reducing power $I^- > Br^- > Cl^-$

Displacement: $Cl_2 + 2I^- \rightarrow 2Cl^- + I_2$

Silver halides: AgCl white (dissolves in dilute NH_3), AgBr cream (dissolves in concentrated NH_3), AgI yellow (insoluble)

With concentrated $\mathrm{H_2SO_4}$: $\mathrm{Cl^-}$ gives HCl only; $\mathrm{Br^-}$ gives HBr, $\mathrm{Br_2}$, $\mathrm{SO_2}$; $\mathrm{I^-}$ gives HI, $\mathrm{I_2}$, $\mathrm{SO_2}$, S, $\mathrm{H_2S}$

Cold NaOH: $\mathrm{Cl_2 + 2NaOH \rightarrow NaCl + NaClO + H_2O}$ (Cl 0 to −1 and +1)

Hot NaOH: $\mathrm{3Cl_2 + 6NaOH \rightarrow 5NaCl + NaClO_3 + 3H_2O}$ (Cl 0 to −1 and +5)

Water: $\mathrm{Cl_2 + H_2O \rightarrow HCl + HOCl}$; HOCl and $\mathrm{ClO^-}$ kill bacteria

$n = \dfrac{m}{M_r}$; $n = c \times V$; gas volume $= n \times 24.0\ \mathrm{dm^3}$

Nitrogen and sulfur

$\mathrm{N_2}$ unreactive: strong triple bond (1 σ + 2 π) and non-polar

Base: $\mathrm{NH_3 + H^+ \rightarrow NH_4^+}$; in water $\mathrm{NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-}$

$\mathrm{NH_3}$ pyramidal, 107°; $\mathrm{NH_4^+}$ tetrahedral, 109.5°, one dative bond, all four N–H bonds identical, 10 electrons

Displacement: $\mathrm{NH_4^+ + OH^- \rightarrow NH_3 + H_2O}$ (acid–base, warm)

Formation: $\mathrm{N_2 + O_2 \rightarrow 2NO}$ (lightning, engines); $\mathrm{2NO + O_2 \rightarrow 2NO_2}$

Converter: $\mathrm{2NO + 2CO \rightarrow N_2 + 2CO_2}$; $\mathrm{NO_x}$ reduced, CO and hydrocarbons oxidised

Smog: $\mathrm{NO_x}$ + unburned hydrocarbons → PAN

Direct acid rain: $\mathrm{4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3}$

Catalysis: $\mathrm{SO_2 + NO_2 \rightarrow SO_3 + NO}$; $\mathrm{NO + \tfrac{1}{2}O_2 \rightarrow NO_2}$; $\mathrm{SO_3 + H_2O \rightarrow H_2SO_4}$

Oxidation numbers of N: $\mathrm{NH_3}$ and $\mathrm{NH_4^+}$ −3, $\mathrm{N_2}$ 0, NO +2, $\mathrm{NO_2}$ +4, $\mathrm{HNO_3}$ +5

$n = \dfrac{m}{M_r}$; $n = c \times V$; gas volume $= n \times 24.0\ \mathrm{dm^3}$

An introduction to AS Level organic chemistry

General formulas: alkane $\mathrm{C_nH_{2n+2}}$; alkene $\mathrm{C_nH_{2n}}$; halogenoalkane $\mathrm{C_nH_{2n+1}X}$; alcohol $\mathrm{C_nH_{2n+1}OH}$; aldehyde and ketone $\mathrm{C_nH_{2n}O}$; acid and ester $\mathrm{C_nH_{2n}O_2}$; amine $\mathrm{C_nH_{2n+1}NH_2}$; nitrile $\mathrm{C_nH_{2n+1}CN}$

Stems: meth 1, eth 2, prop 3, but 4, pent 5, hex 6; endings -ane, -ene, -ol, -al, -one, -oic acid, -nitrile, alkyl alkanoate, alkylamine

sp^3: tetrahedral, 109.5°; sp^2: trigonal planar, 120°; sp: linear, 180°

Single bond = 1 σ; double = 1 σ + 1 π; triple = 1 σ + 2 π

σ bonds in a molecule $= A - 1 + R$ (A atoms, R rings)

Stereoisomers $= 2^n$, n = chiral centres + C=C bonds showing cis/trans

$[\mathrm{O}]$ = one O atom from an oxidising agent; $[\mathrm{H}]$ = one H atom from a reducing agent

Primary / secondary / tertiary: 1 / 2 / 3 carbons joined to the carbon carrying –OH or –X

Hydrocarbons

Alkanes $\mathrm{C}_n\mathrm{H}_{2n+2}$; alkenes (one C=C, no ring) $\mathrm{C}_n\mathrm{H}_{2n}$

Complete combustion: $\mathrm{C}_x\mathrm{H}_y + \left(x + \frac{y}{4}\right)\mathrm{O}_2 \rightarrow x\,\mathrm{CO}_2 + \frac{y}{2}\,\mathrm{H}_2\mathrm{O}$

Free-radical substitution: X_2 + UV light; initiation $\mathrm{X}_2 \rightarrow 2\mathrm{X}\bullet$ (homolytic)

Hydrogenation: $\mathrm{H}_2(\mathrm{g})$, Ni or Pt, heat · steam: $\mathrm{H}_2\mathrm{O}(\mathrm{g})$, $\mathrm{H}_3\mathrm{PO}_4 \cdot \mathrm{HX}(\mathrm{g})$, room temperature · X_2, room temperature, dark

Cracking: heat, $\mathrm{Al}_2\mathrm{O}_3$ catalyst · elimination: NaOH in ethanol, heat · dehydration: heated $\mathrm{Al}_2\mathrm{O}_3$ or concentrated $\mathrm{H}_2\mathrm{SO}_4$

Cold dilute acidified KMnO_4: diol · hot concentrated acidified KMnO_4: $=\mathrm{CR}_2 \rightarrow$ ketone, $=\mathrm{CHR} \rightarrow \mathrm{RCOOH}$, $=\mathrm{CH}_2 \rightarrow \mathrm{CO}_2 + \mathrm{H}_2\mathrm{O}$

Carbocation stability: tertiary > secondary > primary (positive inductive effect of alkyl groups)

One C=C adds one H_2 (24.0 dm³ per mole of C=C), one X_2 or one HX

Bromine water: orange → colourless with C=C

Catalytic converter: $2\mathrm{CO} + 2\mathrm{NO} \rightarrow 2\mathrm{CO}_2 + \mathrm{N}_2$

Halogen compounds

$\mathrm{RX} + \mathrm{OH}^- \rightarrow \mathrm{ROH} + \mathrm{X}^-$ (NaOH(aq), heat)

$\mathrm{RX} + \mathrm{CN}^- \rightarrow \mathrm{RCN} + \mathrm{X}^-$ (KCN in ethanol, heat): one extra carbon

$\mathrm{RX} + 2\mathrm{NH}_3 \rightarrow \mathrm{RNH}_2 + \mathrm{NH}_4\mathrm{X}$ (ethanol, heat, pressure)

$\mathrm{Ag}^+(\mathrm{aq}) + \mathrm{X}^-(\mathrm{aq}) \rightarrow \mathrm{AgX}(\mathrm{s})$: AgCl white, AgBr cream, AgI yellow

Elimination: $\mathrm{RCH_2CH_2X} + \mathrm{NaOH} \rightarrow \mathrm{RCH{=}CH_2} + \mathrm{NaX} + \mathrm{H_2O}$ (NaOH in ethanol, heat)

Primary → $\mathrm{S_N}2$ (one step, transition state); tertiary → $\mathrm{S_N}1$ (two steps, carbocation intermediate); secondary → both

Carbocation stability: tertiary > secondary > primary (positive inductive effect of alkyl groups)

Rate: R–I > R–Br > R–Cl > R–F, because C–X bond energy decreases from F to I

Making RX from ROH: $\mathrm{HX}(\mathrm{g})$; KCl + conc. $\mathrm{H_2SO_4}$ or $\mathrm{H_3PO_4}$; $\mathrm{PCl_3}$ + heat; $\mathrm{PCl_5}$; $\mathrm{SOCl_2}$

Percentage yield $= \dfrac{\text{actual amount}}{\text{theoretical amount}} \times 100$

Hydroxy compounds

Primary: carbinol C bonded to 1 other C; secondary: 2; tertiary: 3

Primary $\xrightarrow{[O]}$ aldehyde (distil) $\xrightarrow{[O]}$ carboxylic acid (reflux); secondary → ketone; tertiary: no reaction

Acidified $\mathrm{K_2Cr_2O_7}$: orange → green; acidified $\mathrm{KMnO_4}$: purple → colourless

$RCH_2OH + 2[O] \rightarrow RCOOH + H_2O$; $RCH_2OH + [O] \rightarrow RCHO + H_2O$

C=O → CH–OH: $2[H]$ ($NaBH_4$ or $LiAlH_4$); COOH → CH_2OH: $4[H]$ + H_2O ($LiAlH_4$ only)

$2ROH + 2Na \rightarrow 2RO^-Na^+ + H_2$: $\frac{1}{2}$ mol H_2 per OH

$ROH + PCl_5 \rightarrow RCl + POCl_3 + HCl$; $ROH + SOCl_2 \rightarrow RCl + SO_2 + HCl$;
$3ROH + PCl_3 \rightarrow 3RCl + H_3PO_3$

$C_nH_{2n+1}OH + \frac{3n}{2}O_2 \rightarrow nCO_2 + (n+1)H_2O$

Dehydration: heated Al_2O_3, or conc. H_2SO_4 or H_3PO_4 and heat

Esterification: acid + alcohol $\rightleftharpoons$ ester + H_2O, conc. H_2SO_4 catalyst, heat

$CH_3CH(OH)R$ + alkaline $I_2 \rightarrow CHI_3$ (yellow precipitate) + $RCOO^-$

Alcohols are less acidic than water: the alkyl group is electron-donating

Percentage yield $= \frac{\text{actual amount}}{\text{theoretical amount}} \times 100$

Carbonyl compounds

Primary alcohol $\xrightarrow{[O],\ \text{distil}}$ aldehyde; secondary alcohol $\xrightarrow{[O]}$ ketone (acidified $K_2Cr_2O_7$ or $KMnO_4$)

$RCH_2OH + [O] \rightarrow RCHO + H_2O$; $RCH(OH)R' + [O] \rightarrow RCOR' + H_2O$

$RCHO + 2[H] \rightarrow RCH_2OH$; $RCOR' + 2[H] \rightarrow RCH(OH)R'$ ($NaBH_4$ or $LiAlH_4$)

$RCOR' + HCN \rightarrow RC(OH)(CN)R'$, KCN catalyst, heat; nucleophilic addition

2,4-DNPH: orange precipitate with any aldehyde or ketone

Tollens': silver mirror; Fehling's: blue to red-brown precipitate; both with aldehydes only

$RCHO + [O] \rightarrow RCOOH$ (aldehydes are easily oxidised, ketones are not)

$CH_3COR + 3I_2 + 4OH^- \rightarrow CHI_3 + RCO_2^- + 3I^- + 3H_2O$: yellow precipitate

Hydroxynitrile has one more carbon than the carbonyl compound; M_r rises by 27.0 (HCN)

Reduction raises M_r by 2.0 (two H atoms)

Carboxylic acids and derivatives

$RCH_2OH + 2[O] \rightarrow RCOOH + H_2O$ (acidified $K_2Cr_2O_7$, heat under reflux)

$RCN + HCl + 2H_2O \rightarrow RCOOH + NH_4Cl$; $RCN + NaOH + H_2O \rightarrow RCOONa + NH_3$

$2RCOOH + Mg \rightarrow (RCOO)_2Mg + H_2$; $RCOOH + Na \rightarrow RCOONa + \frac{1}{2}H_2$

$RCOOH + NaOH \rightarrow RCOONa + H_2O$

$2RCOOH + Na_2CO_3 \rightarrow 2RCOONa + H_2O + CO_2$

$RCOOH + R'OH \rightleftharpoons RCOOR' + H_2O$ (concentrated H_2SO_4 catalyst, heat)

$RCOOH + 4[H] \rightarrow RCH_2OH + H_2O$ ($LiAlH_4$ only, not $NaBH_4$)

$\mathrm{RCOOR' + H_2O \rightleftharpoons RCOOH + R'OH}$ (dilute acid, heat)

$\mathrm{RCOOR' + NaOH \rightarrow RCOONa + R'OH}$ (dilute alkali, heat; goes to completion)

Na reacts with every O–H (COOH and alcohol OH): $\frac{1}{2}\mathrm{H_2}$ each; NaOH, carbonates and Mg react with COOH only

$\mathrm{moles} = \dfrac{\mathrm{mass}}{M_r}$; gas volume $= \mathrm{moles} \times 24.0\ \mathrm{dm^3}$

Nitrogen compounds

$\mathrm{RX + 2NH_3 \rightarrow RNH_2 + NH_4X}$ (ammonia in ethanol, heat under pressure)

$\mathrm{RX + KCN \rightarrow RCN + KX}$ (KCN in ethanol, heat; one more carbon)

$\mathrm{R_2C{=}O + HCN \rightarrow R_2C(OH)CN}$ (HCN, KCN catalyst, heat)

$\mathrm{RCN + 2H_2O + HCl \rightarrow RCOOH + NH_4Cl}$ (dilute acid, heat)

$\mathrm{RCN + NaOH + H_2O \rightarrow RCOONa + NH_3}$ (dilute alkali, heat; then acidify)

Mechanisms: $\mathrm{NH_3}$ or $\mathrm{CN^-}$ with RX is nucleophilic substitution; HCN with C=O is nucleophilic addition

$\mathrm{moles} = \dfrac{\mathrm{mass}}{M_r}$; gas volume $= \mathrm{moles} \times 24.0\ \mathrm{dm^3}$; percentage yield $= \dfrac{\mathrm{actual}}{\mathrm{theoretical}} \times 100$

Polymerisation

$n\,\mathrm{CH_2{=}CH_2 \rightarrow -[CH_2{-}CH_2]_n-}$, poly(ethene)

$n\,\mathrm{CH_2{=}CHCl \rightarrow -[CH_2{-}CHCl]_n-}$, poly(chloroethene), PVC

$n\,\mathrm{CH_2{=}CHCH_3 \rightarrow -[CH_2{-}CH(CH_3)]_n-}$, poly(propene)

Repeat unit: the two C=C carbons joined by a single bond, side groups unchanged, continuation bond at each end

Monomer from a section: cut the chain into pairs of carbons and put back each C=C

Polymerisation: π bond broken, σ bonds formed, C changes from sp² to sp³; polymer is saturated

Polymer and monomer have the same empirical formula; $M_r(\mathrm{chain}) = n \times M_r(\mathrm{monomer})$

Disposal problems: non-biodegradable; burning gives CO (toxic) and, from PVC, HCl (toxic, acidic)

Organic synthesis

The 20 reactions in the table above, with their reagents, conditions and types

The tests and their positive results

Which groups each reagent touches ($\mathrm{NaBH_4}$ vs $\mathrm{LiAlH_4}$, $\mathrm{K_2Cr_2O_7}$ vs $\mathrm{KMnO_4}$, Na vs $\mathrm{Na_2CO_3}$)

New C–C bond: KCN in ethanol (halogenoalkane) or HCN/KCN (aldehyde or ketone), one carbon each

Markovnikov: H adds to the C=C carbon with more H atoms

Hot concentrated $\mathrm{KMnO_4}$: $= \mathrm{CH_2} \rightarrow \mathrm{CO_2} + \mathrm{H_2O}$, $= \mathrm{CHR} \rightarrow \mathrm{RCOOH}$, $= \mathrm{CRR'} \rightarrow \mathrm{RCOR'}$
$[\mathrm{O}]$ and $[\mathrm{H}]$ per group: $\mathrm{COOH} \rightarrow \mathrm{CH_2OH}$ needs $4[\mathrm{H}]$ and gives $\mathrm{H_2O}$
Sodium: 1 mol of O–H groups gives $\frac{1}{2}$ mol $\mathrm{H_2}$

Analytical techniques

$A_r = \dfrac{\sum(\text{isotope mass} \times \text{abundance})}{\sum \text{abundance}}$
$n = \dfrac{100 \times \text{abundance of } [M+1]^+}{1.1 \times \text{abundance of } M^+}$
$\text{abundance of } [M+1]^+ = \dfrac{1.1\,n \times \text{abundance of } M^+}{100}$
$^{35}\mathrm{Cl} : {}^{37}\mathrm{Cl} \approx 3:1$, so one Cl gives $M : [M+2] \approx 3:1$
$^{79}\mathrm{Br} : {}^{81}\mathrm{Br} \approx 1:1$, so one Br gives $M : [M+2] \approx 1:1$
Two Cl: $M : [M+2] : [M+4] \approx 9:6:1$; two Br: $1:2:1$
m/e of $M^+ = M_r$ of the compound (with $^{12}\mathrm{C}$, $^{35}\mathrm{Cl}$, $^{79}\mathrm{Br}$)