Cambridge AS & A Level · Chemistry 9701

Chemistry 9701 formulas and definitions

All 370 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} $= c \times M$

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

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

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

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
$\text{lone pairs} = \dfrac{\text{outer electrons} - \text{electrons used in bonds} - \text{charge}}{2}$
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 $= 0$

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

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

$q = mc\Delta T$

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

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 $NaBH_4$)

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

$\mathrm{RCOOR'} + \mathrm{NaOH} \rightarrow \mathrm{RCOONa} + \mathrm{R'OH}$ (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

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

Nitrogen compounds

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

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

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

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

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

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

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

Polymerisation

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

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

$n\,\mathrm{CH_2{=}CHCH_3} \rightarrow -[\mathrm{CH_2{-}CH(CH_3)}]_\mathrm{n}-$, 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 sp^2 to sp^3; polymer is saturated

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

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

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

$$n = \frac{100 \times \text{abundance of } [M+1]^+}{1.1 \times \text{abundance of } M^+}$$

$$\text{abundance of } [M+1]^+ = \frac{1.1\,n \times \text{abundance of } M^+}{100}$$

$^{35}\mathrm{Cl} : {}^{37}\mathrm{Cl} \approx 3:1$, 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 $^{12}\mathrm{C}$, $^{35}\mathrm{Cl}$, $^{79}\mathrm{Br}$)

A Level

Chemical energetics

ΔH_{latt}: gaseous ions → 1 mol of ionic solid (always negative)

ΔH_{at}: element in standard state → 1 mol of gaseous atoms (always positive)

EA_1: 1 mol of gaseous atoms + 1 mol of electrons → 1 mol of gaseous 1– ions

ΔH_{hyd}: 1 mol of gaseous ions → aqueous ions (always negative)

ΔH_{sol}: 1 mol of solute → very dilute solution (either sign)

$$\Delta H_{\text{f}} = \Delta H_{\text{at}}(\text{metal}) + \Sigma IE + \Delta H_{\text{at}}(\text{non-metal}) + \Sigma EA + \Delta H_{\text{latt}}$$

ΔH_{at} of a gaseous diatomic element $= \frac{1}{2}\times$ its bond energy

$$\Delta H_{\text{sol}} = \Sigma \Delta H_{\text{hyd}} - \Delta H_{\text{latt}}$$

Entropy: the number of possible arrangements of the particles and their energy in a system

$$\Delta S^{\ominus} = \Sigma S^{\ominus}(\text{products}) - \Sigma S^{\ominus}(\text{reactants})$$

$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ (T in K; ΔS in kJ K^{-1} mol^{-1})

Feasible when $\Delta G < 0$

Temperature where feasibility changes: $T = \Delta H / \Delta S$

$$\Delta S = \frac{\Delta H - \Delta G}{T}$$

$0\ ^\circ\mathrm{C} = 273$ K, so $25\ ^\circ\mathrm{C} = 298$ K

Electrochemistry

$F = Le$

$Q = It$ (Q in C, I in A, t in s)

Moles of electrons $= \dfrac{Q}{F}$; moles of product $= \dfrac{\text{moles of electrons}}{\text{electrons per particle}}$

$E^\ominus_{\text{cell}} = E^\ominus(\text{positive}) - E^\ominus(\text{negative})$; never multiply $E^\ominus$ by a coefficient

Feasible when $E^\ominus_{\text{cell}} > 0$

$E = E^\ominus + \dfrac{0.059}{z} \log \dfrac{[\text{oxidised species}]}{[\text{reduced species}]}$

$\Delta G^\ominus = -nE^\ominus_{\text{cell}}F$ (n = moles of electrons in the equation)

Standard conditions: 1.00 mol dm^{-3} ions, 101 kPa gases, 298 K

Standard hydrogen electrode: $E^\ominus = 0.00$ V

Equilibria

$K_w = [\mathrm{H^+}][\mathrm{OH^-}]$ (the expression)

$\mathrm{pH} = -\log_{10}[\mathrm{H^+}]$; $[\mathrm{H^+}] = 10^{-\mathrm{pH}}$

$\mathrm{pOH} = -\log_{10}[\mathrm{OH^-}]$; pH + pOH $= 14.00$ at 298 K

$K_a = \dfrac{[\mathrm{H^+}][\mathrm{A^-}]}{[\mathrm{HA}]}$, units mol dm^{-3}

$pK_a = -\log_{10} K_a$; $K_a = 10^{-pK_a}$

Weak acid alone: $[\mathrm{H^+}] = \sqrt{K_a \times [\mathrm{HA}]}$

Buffer: $[\mathrm{H^+}] = K_a \times \dfrac{[\mathrm{HA}]}{[\mathrm{A^-}]}$, or $\mathrm{pH} = pK_a + \log_{10}\dfrac{[\mathrm{A^-}]}{[\mathrm{HA}]}$

K_{sp} of $\mathrm{A}_x\mathrm{B}_y = [\mathrm{A}^{y+}]^x[\mathrm{B}^{x-}]^y$, units $(\text{mol dm}^{-3})^{x+y}$

$K_{pc} = \dfrac{[\text{solute in solvent 1}]}{[\text{solute in solvent 2}]}$ at equilibrium, no units

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

Reaction kinetics

$\text{rate} = k[\mathrm{A}]^m[\mathrm{B}]^n$; overall order $= m + n$

Order 0: rate unchanged; order 1: rate $\propto$ [A]; order 2: rate $\propto$ [A]^2

Units of k for overall order n: $\text{mol}^{1-n}\ \text{dm}^{3(n-1)}\ \text{s}^{-1}$ (order 1: s^{-1}; order 2: mol^{-1} dm^3 s^{-1})

First order: $k = \dfrac{0.693}{t_{1/2}}$ $(0.693 = \ln 2)$
Fraction left after n half-lives $= \left(\frac{1}{2}\right)^n$
Rate at time t = gradient of the tangent to the concentration–time graph
First order: gradient of rate against [A] $= k$
Large excess of B: $k' = k[\mathrm{B}]$

Group 2

Thermal stability of nitrates and carbonates **increases** down the group (radius up, charge density down, anion polarised less)

$\mathrm{MCO_3} \rightarrow \mathrm{MO} + \mathrm{CO_2}$
$\mathrm{M(NO_3)_2} \rightarrow \mathrm{MO} + 2\mathrm{NO_2} + \frac{1}{2}\mathrm{O_2}$
$\mathrm{M(HCO_3)_2} \rightarrow \mathrm{MCO_3} + \mathrm{CO_2} + \mathrm{H_2O}$
$\Delta H_{\mathrm{sol}} = \sum \Delta H_{\mathrm{hyd}}(\mathrm{ions}) - \Delta H_{\mathrm{latt}}$
Down the group: ΔH_{latt} and ΔH_{hyd} both become less exothermic
Sulfates (large anion): ΔH_{hyd} falls more, ΔH_{sol} less exothermic, solubility **decreases**
Hydroxides (small anion): ΔH_{latt} falls more, ΔH_{sol} more exothermic, solubility **increases**
$[\mathrm{OH^-}] = 2 \times [\mathrm{M(OH)_2}]$; $\mathrm{pH} = -\log[\mathrm{H^+}]$; $\mathrm{pH} + \mathrm{pOH} = 14.00$ at 298 K

Chemistry of transition elements

Transition element: forms one or more stable ions with incomplete d orbitals
Ions lose 4s electrons before 3d; Cr is $[\mathrm{Ar}]\ 3d^5\ 4s^1$, Cu is $[\mathrm{Ar}]\ 3d^{10}\ 4s^1$
Charge of complex = charge of metal ion + sum of ligand charges
Coordination number = number of dative bonds to the metal (en and $\mathrm{C_2O_4^{2-}}$ count 2, EDTA counts 6)
Linear 180°; square planar 90°; tetrahedral 109.5°; octahedral 90°
Octahedral splitting: 2 higher, 3 lower; tetrahedral: 3 higher, 2 lower
Larger ΔE means higher-frequency light absorbed (no equation needed)
$E^{\ominus}_{\mathrm{cell}} = E^{\ominus}(\mathrm{reduced}) - E^{\ominus}(\mathrm{oxidised})$; feasible if > 0
$\mathrm{MnO_4^-} : \mathrm{Fe^{2+}} = 1:5$; $\mathrm{MnO_4^-} : \mathrm{C_2O_4^{2-}} = 2:5$; $\mathrm{Cu^{2+}} : \mathrm{S_2O_3^{2-}} = 1:1$
$K_{\mathrm{stab}} = \dfrac{[\mathrm{complex}]}{[\mathrm{M}^{n+}][\mathrm{L}]^x}$, no $[\mathrm{H_2O}]$; units $\mathrm{mol}^{-x}\ \mathrm{dm}^{3x}$
K for exchange A $\rightarrow$ B $= K_{\mathrm{stab}}(\mathrm{B}) \div K_{\mathrm{stab}}(\mathrm{A})$

An introduction to A Level organic chemistry

Benzene $\mathrm{C_6H_6}$: planar hexagon, C–C–C and C–C–H angles 120°, every carbon sp^2

σ bond: head-on overlap of orbitals; π bond: sideways overlap of p orbitals; benzene's π electrons are delocalised above and below the ring

Electrophilic substitution: electrophile replaces an H on a benzene ring; addition–elimination: nucleophile adds to C=O of an acyl chloride, then HCl is lost

Amine: 1°, 2°, 3° = 1, 2, 3 carbons on N; amide: $\mathrm{RCONH_2}$ 1°, $\mathrm{RCONHR'}$ 2°, $\mathrm{RCONR'_2}$ 3°

Stereoisomers from n chiral centres $= 2^n$

H count: $2n + 2$ for n carbons, minus 2 for each ring or double bond (benzene ring: minus 8), plus 1 for each N, minus 1 for each halogen

Optically active: rotates the plane of plane-polarised light. Enantiomers: same angle, opposite directions. Racemic mixture: equal amounts of both, no rotation

Hydrocarbons

Benzene: planar, 120°, six sp^2 carbons, σ bonds (head-on overlap) and a delocalised π system (sideways overlap of p orbitals)

Halogenation: $\mathrm{X_2}$ with $\mathrm{AlX_3}$ (or $\mathrm{FeBr_3}$), room temperature, dark → halogenoarene + HX

Nitration: conc. $\mathrm{HNO_3}$ + conc. $\mathrm{H_2SO_4}$, 25–60 °C → nitroarene + $\mathrm{H_2O}$

Alkylation: RCl + $\mathrm{AlCl_3}$, heat; acylation: RCOCl + $\mathrm{AlCl_3}$, heat → + HCl

Electrophiles: $\mathrm{X_2 + AlX_3 \rightarrow X^+ + AlX_4^-}$; $\mathrm{RCl + AlCl_3 \rightarrow R^+ + AlCl_4^-}$;
$\mathrm{HNO_3 + 2H_2SO_4 \rightarrow NO_2^+ + 2HSO_4^- + H_3O^+}$

Catalyst back: $\mathrm{H^+ + AlX_4^- \rightarrow HX + AlX_3}$

Side-chain oxidation: hot alkaline $\mathrm{KMnO_4}$, then dilute acid; ring carbon's chain → –COOH, extra chain carbons → $\mathrm{CO_2}$

Ring hydrogenation: $\mathrm{H_2}$, Pt or Ni, heat; 3 mol $\mathrm{H_2}$ per benzene ring

Side chain: $\mathrm{X_2}$ in UV light (free radical); ring: $\mathrm{X_2}$ with $\mathrm{AlX_3}$ in the dark (electrophilic)

2,4-directing: –$\mathrm{NH_2}$, –OH, –R; 3-directing: –$\mathrm{NO_2}$, –COOH, –COR

Hybridisation: benzene-ring and C=O carbons sp^2; carbons with four single bonds sp^3; C≡N and C≡C carbons sp

Halogen compounds

Making a halogenoarene: $\mathrm{X_2}$ with $\mathrm{AlX_3}$ (or $\mathrm{FeBr_3}$), room temperature, dark, dry

$\mathrm{X_2 + AlX_3 \rightarrow X^+ + AlX_4^-}$ and $\mathrm{H^+ + AlX_4^- \rightarrow HX + AlX_3}$

$\mathrm{C_6H_6 + X_2 \rightarrow C_6H_5X + HX}$ (electrophilic substitution)

An alkyl group on the ring sends the halogen to positions 2 and 4

Chloroalkane + NaOH(aq), heat → alcohol (nucleophilic substitution); chloroarene: no reaction

Reason: Cl lone pair (p orbital) delocalised into the ring → C–Cl partial double bond → stronger

Ease of hydrolysis: acyl chloride > chloroalkane > chloroarene

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

Hydroxy compounds

$\mathrm{ROH + R'COCl \rightarrow R'COOR + HCl}$: room temperature, nucleophilic addition–elimination

Phenylamine $\xrightarrow{\mathrm{NaNO_2 + HCl(aq),\ <10\ ^\circ C}}$ diazonium salt $\xrightarrow{\text{warm with } \mathrm{H_2O}}$ phenol $+\mathrm{N_2}$

$\mathrm{2C_6H_5OH + 2Na \rightarrow 2C_6H_5ONa + H_2}$; $\mathrm{C_6H_5OH + NaOH \rightarrow C_6H_5ONa + H_2O}$

Phenol + $\mathrm{Na_2CO_3(aq)}$: no reaction

$\mathrm{C_6H_5OH + 3Br_2 \rightarrow C_6H_2Br_3OH + 3HBr}$: bromine water, room temperature, white precipitate

Dilute $\mathrm{HNO_3}$, room temperature → 2-nitrophenol + 4-nitrophenol

Diazonium salt + phenol in NaOH(aq), below 10 °C → azo dye ($\mathrm{-N{=}N-}$)

OH on a ring is 2,4,6-directing

Acidity: carboxylic acid > phenol > water > alcohol

Reason: O lone pair (p orbital) overlaps with the ring → O–H weakened, anion stabilised, ring electron density increased

Carboxylic acids and derivatives

Alkylbenzene $\xrightarrow{\text{hot alkaline } \mathrm{KMnO_4}\text{, then dilute acid}}$ benzoic acid (one COOH per side chain)

$\mathrm{RCOOH + SOCl_2 \rightarrow RCOCl + SO_2 + HCl}$

$\mathrm{RCOOH + PCl_5 \rightarrow RCOCl + POCl_3 + HCl}$

$\mathrm{3RCOOH + PCl_3 \rightarrow 3RCOCl + H_3PO_3}$ (heat)

$\mathrm{HCOOH + [O] \rightarrow CO_2 + H_2O}$ (Tollens', Fehling's, acidified $\mathrm{KMnO_4}$ or $\mathrm{K_2Cr_2O_7}$)

$\mathrm{HOOCCOOH + [O] \rightarrow 2CO_2 + H_2O}$ (warm acidified $\mathrm{KMnO_4}$)

$\mathrm{RCOCl + HX \rightarrow RCOX + HCl}$, where HX is $\mathrm{H_2O}$, $\mathrm{R'OH}$, $\mathrm{C_6H_5OH}$, $\mathrm{NH_3}$, $\mathrm{R'NH_2}$ or $\mathrm{R'_2NH}$; room temperature

Mechanism: nucleophilic addition–elimination

Acidity: carboxylic acid > phenol > water > alcohol

Chloro acids: more Cl, Cl nearer COOH, or Cl instead of Br → stronger acid

Ease of hydrolysis: acyl chloride > alkyl chloride > aryl chloride

Nitrogen compounds

$\mathrm{RX} + 2\mathrm{NH_3} \rightarrow \mathrm{RNH_2} + \mathrm{NH_4X}$ (ethanol, sealed tube, heat; excess $\mathrm{NH_3}$)

$\mathrm{RX} + \mathrm{R'NH_2} \rightarrow \mathrm{RNHR'} + \mathrm{HX}$ (ethanol, sealed tube, heat)

$\mathrm{RCN} + 4[\mathrm{H}] \rightarrow \mathrm{RCH_2NH_2}$ ($\mathrm{LiAlH_4}$ in dry ether, or $\mathrm{H_2}$/Ni)

$\mathrm{RCONH_2} + 4[\mathrm{H}] \rightarrow \mathrm{RCH_2NH_2} + \mathrm{H_2O}$ ($\mathrm{LiAlH_4}$ in dry ether)

$\mathrm{RCOCl} + \mathrm{R'NH_2} \rightarrow \mathrm{RCONHR'} + \mathrm{HCl}$ (room temperature)

$\mathrm{RNH_2} + \mathrm{H_2O} \rightleftharpoons \mathrm{RNH_3^+} + \mathrm{OH^-}$

Basicity: secondary amine > primary amine > $\mathrm{NH_3}$ > phenylamine > amide

$\mathrm{ArNO_2} + 6[\mathrm{H}] \rightarrow \mathrm{ArNH_2} + 2\mathrm{H_2O}$ (hot Sn and conc. HCl, then NaOH(aq))

$\mathrm{C_6H_5NH_2} + 3\mathrm{Br_2} \rightarrow \mathrm{C_6H_2Br_3NH_2} + 3\mathrm{HBr}$ (room temperature, white precipitate)

$\mathrm{NaNO_2} + \mathrm{HCl} \rightarrow \mathrm{HNO_2} + \mathrm{NaCl}$

$\mathrm{ArNH_2} + \mathrm{HNO_2} + \mathrm{H^+} \rightarrow \mathrm{ArN_2^+} + 2\mathrm{H_2O}$ (below 10 °C)

$\mathrm{ArN_2^+} + \mathrm{H_2O} \rightarrow \mathrm{ArOH} + \mathrm{N_2} + \mathrm{H^+}$ (warm)

Coupling: $\mathrm{ArN_2^+}$ + phenol in NaOH(aq) → $\mathrm{Ar{-}N{=}N{-}C_6H_4OH}$ (4-position)

Amide hydrolysis: acid → $\mathrm{RCOOH} + \mathrm{R'NH_3^+}$; alkali → $\mathrm{RCOO^-} + \mathrm{R'NH_2}$

Isoelectric point: the pH at which the amino acid is a zwitterion (no overall charge)

Electrophoresis: pH < isoelectric point → cathode; pH = isoelectric point → stays; pH > isoelectric point → anode

Polymerisation

Ester linkage $-\mathrm{CO}-\mathrm{O}-$: diol + dicarboxylic acid (loses $\mathrm{H_2O}$) or dioyl chloride (loses HCl); or one hydroxycarboxylic acid

Amide linkage $-\mathrm{CO}-\mathrm{NH}-$: diamine + dicarboxylic acid (loses $\mathrm{H_2O}$) or dioyl chloride (loses HCl); or one aminocarboxylic acid; peptide link between amino acids

Condensation monomers need two reacting groups each; a molecule with one group ends the chain

Repeat unit from two monomers = one residue of each; from one monomer = one residue; continuation bond at each end

Monomers from a section: cut C(=O)–O or C(=O)–N, add OH to the C=O and H to the O or N

C=C only → addition; two condensing groups → condensation; O or N in the main chain → condensation

Poly(alkenes): inert, non-polar C–C and C–H bonds, cannot be hydrolysed, so they persist

Photodegradable polymers: groups such as C=O absorb UV light and the chain breaks

Polyesters and polyamides: hydrolysed by acid or alkali, so biodegradable

Repeat-unit formula = monomers' formulae – small molecules lost; chain $M_r \approx n \times M_r(\text{repeat unit})$

Organic synthesis

The 24 reactions in the table, with reagents, conditions and types (and the AS ones)

Directing: $-\mathrm{NH_2}$, $-\mathrm{OH}$, $-\mathrm{R}$ to 2, 4; $-\mathrm{NO_2}$, $-\mathrm{COOH}$, $-\mathrm{COR}$ to 3

Reducing agents: $\mathrm{NaBH_4}$ only C=O of aldehydes and ketones; $\mathrm{LiAlH_4}$ also COOH, amides and nitriles; Sn/HCl only $-\mathrm{NO_2}$

$\mathrm{ArNO_2} + 6[\mathrm{H}] \rightarrow \mathrm{ArNH_2} + 2\mathrm{H_2O}$; $\mathrm{RCN} + 4[\mathrm{H}] \rightarrow \mathrm{RCH_2NH_2}$; $\mathrm{RCONH_2} + 4[\mathrm{H}] \rightarrow \mathrm{RCH_2NH_2} + \mathrm{H_2O}$

Ease of hydrolysis: acyl chloride $>$ halogenoalkane $>$ aryl chloride

Acidity: alcohol $<$ water $<$ phenol $<$ carboxylic acid; basicity: amide $<$ phenylamine $<$ $\mathrm{NH_3}$ $<$ alkylamine

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

Analytical techniques

$R_f = \dfrac{\text{distance moved by the spot}}{\text{distance moved by the solvent front}}$, both from the baseline

Retention time = time from injection to detection

Percentage of a component $= \dfrac{\text{its peak area}}{\text{total peak area}} \times 100$

TLC: stationary phase aluminium oxide (or silica) on a support; mobile phase a polar or non-polar solvent

GLC: stationary phase a high-boiling non-polar liquid on a solid support; mobile phase an unreactive gas ($\mathrm{N_2}$, He)

n hydrogens on adjacent carbons $\Rightarrow n + 1$ lines: singlet, doublet, triplet, quartet, then multiplet

Relative peak areas = ratio of numbers of hydrogens

TMS, $\mathrm{Si(CH_3)_4}$, defines $\delta = 0$

$\mathrm{ROH} + \mathrm{D_2O} \rightleftharpoons \mathrm{ROD} + \mathrm{HOD}$: O–H and N–H peaks disappear