Chemistry Formula Sheet

Chapter by chapter, topic by topic. Written by the PadhoNa team for quick revision.

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CHAPTER 1

Some Basic Concepts of Chemistry

Mole concept

$$n = \frac{\text{mass}}{M} = \frac{N}{N_A} = \frac{V_{\text{gas}}}{22.4\ \text{L}}\ (\text{at STP}), \qquad N_A = 6.022 \times 10^{23}$$

AVERAGE ATOMIC MASS

$$\bar{A} = \frac{\sum(\%\ \text{abundance} \times \text{mass})}{100}$$

Concentration terms

$$M = \frac{n_{\text{solute}}}{V_{\text{soln}}(\text{L})}, \qquad m = \frac{n_{\text{solute}}}{\text{kg solvent}}, \qquad N = M \times n\text{-factor}$$

MOLE FRACTION

$$x_A = \frac{n_A}{n_A + n_B}, \qquad x_A + x_B = 1$$

MOLARITY FROM % (W/W)

$$M = \frac{10 \times d \times \%w}{M_{\text{solute}}}$$

DILUTION / MIXING

$$M_1V_1 = M_2V_2; \qquad M_{\text{mix}} = \frac{M_1V_1 + M_2V_2}{V_1 + V_2}$$

Empirical formula and stoichiometry

MOLECULAR FORMULA

$$\text{molecular formula} = n \times \text{empirical formula}, \qquad n = \frac{\text{molar mass}}{\text{empirical formula mass}}$$

LIMITING REAGENT

$$\text{the reactant with the smallest } \frac{\text{moles}}{\text{coefficient}}$$

EQUIVALENTS

$$\text{equivalents} = n \times n\text{-factor}; \qquad \text{equivalents of A} = \text{equivalents of B in a reaction}$$

Laws of chemical combination

conservation of mass; definite proportions; multiple proportions; Gay-Lussac's gaseous volumes; Avogadro's law

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CHAPTER 2

Structure of Atom

Bohr's model for hydrogen-like species

$$r_n = 0.529\frac{n^2}{Z}\ \text{Å}, \qquad v_n = 2.18\times10^6\frac{Z}{n}\ \text{m s}^{-1}, \qquad E_n = -13.6\frac{Z^2}{n^2}\ \text{eV}$$

RYDBERG

$$\bar{\nu} = \frac{1}{\lambda} = R_H Z^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right), \qquad R_H = 1.097\times10^7\ \text{m}^{-1}$$

NUMBER OF LINES

$$\frac{(n_2 - n_1)(n_2 - n_1 + 1)}{2}$$

Dual nature and uncertainty

$$E = h\nu = \frac{hc}{\lambda}; \qquad \lambda = \frac{h}{p} = \frac{h}{mv}; \qquad \Delta x\,\Delta p \geq \frac{h}{4\pi}$$

PHOTOELECTRIC EFFECT

$$h\nu = h\nu_0 + \tfrac{1}{2}mv^2$$

Quantum mechanical model

QUANTUM NUMBERS

$$n \geq 1; \qquad l = 0\ldots n-1; \qquad m_l = -l\ldots+l; \qquad m_s = \pm\tfrac{1}{2}$$

NODES

$$\text{radial nodes} = n - l - 1, \qquad \text{angular nodes} = l, \qquad \text{total} = n - 1$$

ORBITAL ANGULAR MOMENTUM

$$L = \sqrt{l(l+1)}\,\frac{h}{2\pi}$$

MAGNETIC MOMENT

$$\mu = \sqrt{n(n+2)}\ \text{BM}\ \ (n = \text{unpaired electrons})$$

FILLING ORDER

$$(n+l)\ \text{rule; Aufbau, Pauli, Hund}$$

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CHAPTER 3

Classification of Elements and Periodicity in Properties

Periodic trends

ACROSS A PERIOD (LEFT → RIGHT)

$$\text{atomic radius}\downarrow;\ \text{ionisation enthalpy}\uparrow;\ \text{electronegativity}\uparrow;\ \text{metallic character}\downarrow$$

DOWN A GROUP

$$\text{atomic radius}\uparrow;\ \text{ionisation enthalpy}\downarrow;\ \text{electronegativity}\downarrow$$

EFFECTIVE NUCLEAR CHARGE

$$Z_{\text{eff}} = Z - \sigma\ (\text{screening constant})$$

ELECTRON GAIN ENTHALPY

$$\text{most negative: Cl} > \text{F}\ (\text{small size of F});\qquad \text{noble gases positive}$$

ISOELECTRONIC SPECIES

$$\text{radius falls as nuclear charge rises: } \text{O}^{2-} > \text{F}^{-} > \text{Na}^{+} > \text{Mg}^{2+}$$

Electronic configuration and blocks

$$\text{s-block: } ns^{1-2};\ \text{p-block: } ns^2np^{1-6};\ \text{d-block: } (n-1)d^{1-10}ns^{0-2};\ \text{f-block: } (n-2)f^{1-14}$$

ANOMALOUS CONFIGURATIONS

$$\text{Cr: } 3d^5 4s^1;\qquad \text{Cu: } 3d^{10}4s^1$$

Nomenclature (Z > 100)

$$0\ \text{nil},\ 1\ \text{un},\ 2\ \text{bi},\ 3\ \text{tri},\ 4\ \text{quad},\ 5\ \text{pent},\ 6\ \text{hex},\ 7\ \text{sept},\ 8\ \text{oct},\ 9\ \text{enn} + \text{-ium}$$

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CHAPTER 4

Chemical Bonding and Molecular Structure

Lewis structures and formal charge

FORMAL CHARGE

$$\text{FC} = V - L - \tfrac{1}{2}B \quad (V = \text{valence},\ L = \text{lone-pair electrons},\ B = \text{bonding electrons})$$

VSEPR and hybridisation

STERIC NUMBER

$$\text{SN} = \tfrac{1}{2}\left(V + M - c + a\right)$$

V valence electrons of the central atom, M monovalent atoms around it, c / a positive / negative charge.

HYBRIDISATION FROM SN

$$2\ sp,\ 3\ sp^2,\ 4\ sp^3,\ 5\ sp^3d,\ 6\ sp^3d^2,\ 7\ sp^3d^3$$

REPULSION ORDER

$$\text{lp–lp} > \text{lp–bp} > \text{bp–bp}$$

DIPOLE MOMENT

$$\mu = q \times d; \qquad 1\ \text{D} = 3.336 \times 10^{-30}\ \text{C m}$$

% IONIC CHARACTER

$$\frac{\mu_{\text{observed}}}{\mu_{\text{ionic}}} \times 100$$

Molecular orbital theory

BOND ORDER

$$\text{BO} = \tfrac{1}{2}(N_b - N_a); \qquad \text{BO}\uparrow \Rightarrow \text{bond length}\downarrow,\ \text{bond energy}\uparrow$$

FILLING ORDER

$$\leq 14\ e^-:\ \sigma1s, \sigma^*1s, \sigma2s, \sigma^*2s, \pi2p_x = \pi2p_y, \sigma2p_z, \ldots; \qquad > 14:\ \sigma2p_z \text{ before } \pi2p$$

PARAMAGNETIC EXAMPLES

$$\text{O}_2\ (2\ \text{unpaired}),\ \text{B}_2,\ \text{O}_2^+,\ \text{O}_2^-,\ \text{N}_2^+$$

Ionic bonding and Fajans' rules

$$\text{covalent character}\uparrow \text{ with small cation, large anion, high charge, and } (n-1)d^n ns^0 \text{ cations}$$

Hydrogen bonding

intermolecular: raises boiling point (H_2O, HF, NH_3);

intramolecular: lowers it (o-nitrophenol)

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CHAPTER 5

Thermodynamics

First law and work

$$\Delta U = q + w \quad (w = -P_{\text{ext}}\Delta V \text{ for expansion})$$

REVERSIBLE ISOTHERMAL

$$w = -2.303\, nRT \log \frac{V_2}{V_1}$$

$$\Delta H = \Delta U + \Delta n_g RT, \qquad C_p - C_v = R$$

Enthalpy changes

HESS'S LAW

$$\Delta_r H = \sum \Delta_f H_{\text{products}} - \sum \Delta_f H_{\text{reactants}}$$

FROM BOND ENTHALPIES

$$\Delta_r H = \sum \text{BE}_{\text{bonds broken}} - \sum \text{BE}_{\text{bonds formed}}$$

NEUTRALISATION

$$\Delta H \approx -57.1 \text{ kJ mol}^{-1} \text{ (strong acid + strong base)}$$

Entropy, Gibbs energy and equilibrium

$$\Delta S = \frac{q_{\text{rev}}}{T}; \qquad \Delta G = \Delta H - T\Delta S$$

$$\Delta G^\circ = -RT \ln K = -2.303\, RT \log K; \qquad \Delta G = \Delta G^\circ + RT \ln Q$$

SPONTANEITY

$$\Delta G < 0 \text{ spontaneous}; \qquad T = \frac{\Delta H}{\Delta S} \text{ at the switch}$$

PHASE CHANGE

$$\Delta S = \frac{\Delta H_{\text{trans}}}{T}$$

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CHAPTER 6

States of Matter

Gas laws

$$PV = nRT, \qquad \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}, \qquad d = \frac{PM}{RT}$$

DALTON'S LAW

$$P = \sum p_i, \qquad p_i = x_i P$$

GRAHAM'S LAW

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

$$R = 0.0821 \text{ L atm K}^{-1}\text{mol}^{-1} = 8.314 \text{ J K}^{-1}\text{mol}^{-1}$$

Kinetic theory and real gases

SPEEDS

$$v_{\text{rms}} : v_{\text{avg}} : v_{\text{mp}} = \sqrt{3} : \sqrt{8/\pi} : \sqrt{2}$$

VAN DER WAALS

$$\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$$

COMPRESSIBILITY FACTOR

$$Z = \frac{PV}{nRT}; \qquad Z < 1 \text{ attractions dominate, } Z > 1 \text{ repulsions dominate}$$

CRITICAL CONSTANTS

$$T_c = \frac{8a}{27Rb}, \qquad P_c = \frac{a}{27b^2}, \qquad V_c = 3b; \qquad T_B = \frac{a}{Rb}$$

Liquid state

vapour pressure rises with temperature; boiling when vapour pressure=external pressure

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CHAPTER 7

Chemical Equilibrium

Law of mass action

$$aA + bB \rightleftharpoons cC + dD: \quad K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

$$K_p = K_c(RT)^{\Delta n_g}$$

MANIPULATING K

$$\text{reverse: } \frac{1}{K}; \qquad \times n: \ K^n; \qquad \text{adding reactions: multiply } K$$

Reaction quotient and dissociation

$$Q < K \text{ forward}; \qquad Q = K \text{ equilibrium}; \qquad Q > K \text{ backward}$$

DEGREE OF DISSOCIATION FROM DENSITY

$$\alpha = \frac{D - d}{(n-1)\,d} \quad (D = \text{initial}, d = \text{equilibrium vapour density}, n = \text{particles per molecule})$$

Le Chatelier's principle

$$\text{adding reactant} \rightarrow \text{forward}; \qquad \uparrow P \rightarrow \text{fewer gas moles}; \qquad \uparrow T \rightarrow \text{endothermic direction}$$

VAN 'T HOFF

$$\log \frac{K_2}{K_1} = \frac{\Delta H^\circ}{2.303R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

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CHAPTER 8

Ionic Equilibrium

Acids, bases and pH

$$\text{pH} = -\log[\text{H}^+], \qquad K_w = [\text{H}^+][\text{OH}^-] = 10^{-14}\ (25^\circ\text{C}), \qquad \text{pH} + \text{pOH} = 14$$

WEAK ACID (OSTWALD)

$$\alpha = \sqrt{\frac{K_a}{C}}, \qquad [\text{H}^+] = \sqrt{K_a C}, \qquad \text{pH} = \tfrac{1}{2}(\text{p}K_a - \log C)$$

$$K_a K_b = K_w \ \text{(conjugate pair)}$$

Buffers and salt hydrolysis

HENDERSON

$$\text{pH} = \text{p}K_a + \log\frac{[\text{salt}]}{[\text{acid}]}; \qquad \text{pOH} = \text{p}K_b + \log\frac{[\text{salt}]}{[\text{base}]}$$

WEAK ACID + STRONG BASE SALT

$$\text{pH} = 7 + \tfrac{1}{2}(\text{p}K_a + \log C)$$

STRONG ACID + WEAK BASE SALT

$$\text{pH} = 7 - \tfrac{1}{2}(\text{p}K_b + \log C)$$

WEAK ACID + WEAK BASE SALT

$$\text{pH} = 7 + \tfrac{1}{2}(\text{p}K_a - \text{p}K_b)$$

Solubility product

$$A_x B_y: \quad K_{sp} = x^x y^y\, s^{x+y}$$

$$AB: \ K_{sp} = s^2; \qquad AB_2: \ K_{sp} = 4s^3; \qquad AB_3: \ K_{sp} = 27s^4$$

PRECIPITATION

$$\text{ionic product} > K_{sp} \ \Rightarrow \text{precipitate}$$

COMMON ION

$$\text{solubility falls: e.g. } s = \frac{K_{sp}}{[\text{common ion}]} \text{ for } AB$$

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CHAPTER 9

Redox Reactions

Oxidation number

$$\text{oxidation}=\text{loss of electrons (ON increases)}; \qquad \text{reduction}=\text{gain (ON decreases)}$$

RULES

$$\text{F}=-1;\ \text{O}=-2\ (\text{peroxide}\ -1,\ \text{OF}_2\ +2);\ \text{H}=+1\ (\text{metal hydride}\ -1);\ \sum\text{ON}=\text{charge}$$

Balancing and titrations

N-FACTOR

$$n\text{-factor}=\text{change in ON per formula unit}; \qquad \text{KMnO}_4:\ 5\ (\text{acid}),\ 3\ (\text{neutral}),\ 1\ (\text{strong base});$$

$$\text{K}_2\text{Cr}_2\text{O}_7:\ 6$$

EQUIVALENCE

$$N_1V_1 = N_2V_2; \qquad \text{meq of oxidant}=\text{meq of reductant}$$

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CHAPTER 10

Hydrogen

Hydrogen peroxide

VOLUME STRENGTH

$$\text{volume strength} = 11.2 \times M = 5.6 \times N$$

$$2H_2O_2 \rightarrow 2H_2O + O_2; \qquad \text{acts as oxidant and reductant}$$

Hydrides and water

HARDNESS

$$\text{temporary: } Ca/Mg(HCO_3)_2 \text{ (removed by boiling)}; \qquad \text{permanent: chlorides / sulphates}$$

HYDRIDES

$$\text{ionic (s-block), covalent (p-block), metallic / interstitial (d, f)}$$

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CHAPTER 11

s Block Elements

Alkali metals

reducing power in water: $\mathrm{Li} > \mathrm{Cs} > \mathrm{Rb} > \mathrm{K} > \mathrm{Na}$ (hydration enthalpy of Li^{+})

OXIDES WITH EXCESS O_2

$\mathrm{Li_2O},\ \mathrm{Na_2O_2},\ \mathrm{KO_2}$ (K, Rb, Cs)

flame colours: Li crimson, Na yellow, K violet

Alkaline earth metals and compounds

SOLUBILITY TRENDS

sulphates$\downarrow$ down the group; hydroxides$\uparrow$ down the group

gypsum $\mathrm{CaSO_4 \cdot 2H_2O} \xrightarrow{393\ \mathrm{K}}$ plaster of Paris $\mathrm{CaSO_4 \cdot \frac{1}{2} H_2O}$

DIAGONAL RELATIONSHIP

Li–Mg, Be–Al, B–Si

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CHAPTER 12

p Block Elements (Group 13 and 14)

Group 13

INERT PAIR EFFECT

$$\text{stability of } +1 \text{ rises down the group: } Tl^{+} \text{ more stable than } Tl^{3+}$$

$$BF_3 \text{ is a Lewis acid; diborane } B_2H_6 \text{ has two 3c–2e bridges}$$

BORAX BEAD

$$Na_2B_4O_7 \cdot 10H_2O \xrightarrow{\Delta} NaBO_2 + B_2O_3$$

Group 14

$$\text{catenation: } C \gg Si > Ge \approx Sn; \qquad +2 \text{ state stable for Pb}$$

SILICATES

$$\text{basic unit } SiO_4^{4-} \text{ (tetrahedral)}$$

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CHAPTER 13

General Organic Chemistry

Electronic effects and intermediates

INDUCTIVE (−I)

$$-\mathrm{NO_2} > -\mathrm{CN} > -\mathrm{COOH} > -\mathrm{F} > -\mathrm{Cl} > -\mathrm{Br} > -\mathrm{I} > -\mathrm{OH}$$

+I

$$-\mathrm{C(CH_3)_3} > -\mathrm{CH(CH_3)_2} > -\mathrm{CH_2CH_3} > -\mathrm{CH_3}$$

CARBOCATION STABILITY

$$3^\circ > 2^\circ > 1^\circ > \mathrm{CH_3^+};\ \text{benzyl, allyl stabilised by resonance}$$

CARBANION STABILITY

$$\mathrm{CH_3^-} > 1^\circ > 2^\circ > 3^\circ$$

HYPERCONJUGATION

$$\text{number of } \alpha\text{-H atoms} \Rightarrow \text{more stable carbocation / alkene}$$

Acidity, basicity and aromaticity

HÜCKEL'S RULE

$$(4n+2)\,\pi \text{ electrons, planar, cyclic, fully conjugated} \Rightarrow \text{aromatic;} \qquad 4n\ \pi \Rightarrow \text{antiaromatic}$$

ACIDITY

$$\mathrm{RCOOH} > \mathrm{PhOH} > \mathrm{H_2O} > \mathrm{ROH} > \mathrm{HC{\equiv}CH}$$

electron-withdrawing groups raise acidity; donating groups raise basicity

AMINE BASICITY (AQUEOUS)

$$2^\circ > 1^\circ > 3^\circ > \mathrm{NH_3}\ \text{(methyl amines);} \qquad \text{aniline is much weaker}$$

Isomerism

STEREOISOMERS

$$\max = 2^n\ \ (n = \text{chiral centres; fewer if a meso form exists})$$

DEGREE OF UNSATURATION

$$\mathrm{DU} = C - \frac{H}{2} - \frac{X}{2} + \frac{N}{2} + 1$$

PRIORITY (CIP)

$$\text{higher atomic number first;}\ \ R: \text{clockwise},\ S: \text{anticlockwise (lowest away)}$$

Nomenclature

FUNCTIONAL GROUP PRIORITY

$$\text{COOH} > \text{SO}_3\text{H} > \text{anhydride} > \text{ester} > \text{acid halide} > \text{amide} > \text{CN} > \text{CHO} > \text{C=O} > \text{OH} > \text{NH}_2$$

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CHAPTER 14

Hydrocarbons

Alkanes

WURTZ

$$2\mathrm{RX}+2\mathrm{Na}\xrightarrow{\text{dry ether}}\mathrm{R}\text{–}\mathrm{R}+2\mathrm{NaX}$$

KOLBE ELECTROLYSIS

$$2\mathrm{RCOO}^{-}\rightarrow\mathrm{R}\text{–}\mathrm{R}+2\mathrm{CO}_2+2e^{-}$$

HALOGENATION

$$\text{reactivity: } \mathrm{F}_2>\mathrm{Cl}_2>\mathrm{Br}_2; \qquad \text{selectivity: } 3^{\circ}\mathrm{H}>2^{\circ}>1^{\circ}$$

Alkenes and alkynes

MARKOVNIKOV

$$\mathrm{H}\text{ adds to the carbon with more H}; \qquad \mathrm{HBr}+\text{peroxide: anti-Markovnikov}$$

OZONOLYSIS

$$\mathrm{C}{=}\mathrm{C}\xrightarrow{\mathrm{O}_3,\ \mathrm{Zn}/\mathrm{H}_2\mathrm{O}}\text{two C}{=}\mathrm{O}$$

ALKYNE REDUCTION

$$\text{Lindlar}\rightarrow \textit{cis}\text{-alkene}; \qquad \mathrm{Na}/\text{liq. }\mathrm{NH}_3\rightarrow \textit{trans}\text{-alkene}$$

terminal alkynes are acidic: give precipitates with ammoniacal AgNO_3 and $\mathrm{Cu}_2\mathrm{Cl}_2$

Aromatic hydrocarbons

DIRECTING GROUPS

$$o/p:\ -\mathrm{OH}, -\mathrm{NH}_2, -\mathrm{OR}, -\mathrm{R}, -\mathrm{X}; \qquad m:\ -\mathrm{NO}_2, -\mathrm{CN}, -\mathrm{CHO}, -\mathrm{COOH}$$

FRIEDEL–CRAFTS

$$\mathrm{C}_6\mathrm{H}_6+\mathrm{RCl}\xrightarrow{\mathrm{AlCl}_3}\mathrm{C}_6\mathrm{H}_5\mathrm{R}$$

halogens deactivate the ring but direct o/p

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CHAPTER 15

Environmental Chemistry

Pollution

$$\text{greenhouse gases: } CO_2,\ CH_4,\ N_2O,\ CFCs,\ O_3,\ H_2O$$

OZONE DEPLETION

$$Cl + O_3 \rightarrow ClO + O_2; \qquad ClO + O \rightarrow Cl + O_2$$

$$\text{acid rain } pH < 5.6; \qquad BOD < 5 \text{ ppm for clean water}$$

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CHAPTER 16

Solid State

Unit cells

ATOMS PER CELL

$$\text{SC } 1, \qquad \text{BCC } 2, \qquad \text{FCC } 4; \qquad \text{corner } \tfrac{1}{8},\ \text{face } \tfrac{1}{2},\ \text{edge } \tfrac{1}{4},\ \text{body } 1$$

EDGE AND RADIUS

$$\text{SC } a = 2r; \qquad \text{BCC } \sqrt{3}a = 4r; \qquad \text{FCC } \sqrt{2}a = 4r$$

COORDINATION NUMBER

$$\text{SC } 6, \qquad \text{BCC } 8, \qquad \text{FCC / HCP } 12$$

Packing and density

DENSITY

$$d = \frac{Z\,M}{N_A\,a^3}$$

PACKING EFFICIENCY

$$\text{SC } 52.4\%, \qquad \text{BCC } 68\%, \qquad \text{FCC / HCP } 74\%$$

VOIDS

$$\text{in close packing of } N \text{ spheres: } N \text{ octahedral},\ 2N \text{ tetrahedral}$$

RADIUS RATIO

$$\frac{r^+}{r^-}:\ 0.225\text{–}0.414 \text{ tetrahedral (CN 4)};\ 0.414\text{–}0.732 \text{ octahedral (CN 6)};\ 0.732\text{–}1 \text{ cubic (CN 8)}$$

Defects

$$\text{Schottky: density falls;} \qquad \text{Frenkel: density unchanged;}$$

$$\text{metal excess (F-centres) gives colour}$$

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CHAPTER 17

Solutions

Concentration and Henry's law

HENRY'S LAW

$$p = K_H x$$

PPM

$$\text{ppm} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 10^6$$

Raoult's law

$$p_A = x_A p_A^\circ, \qquad P = x_A p_A^\circ + x_B p_B^\circ, \qquad y_A = \frac{p_A}{P}$$

NON-IDEAL

$$\text{positive deviation: } \Delta H_{\text{mix}} > 0,\ \Delta V_{\text{mix}} > 0; \qquad \text{negative: } \Delta H_{\text{mix}} < 0,\ \Delta V_{\text{mix}} < 0$$

Colligative properties

RELATIVE LOWERING

$$\frac{p^\circ - p}{p^\circ} = i\, x_{\text{solute}}$$

$$\Delta T_b = i K_b m, \qquad \Delta T_f = i K_f m, \qquad \pi = iCRT$$

VAN 'T HOFF FACTOR

$$i = 1 + (n-1)\alpha \ \text{(dissociation)}, \qquad i = 1 - \left(1 - \frac{1}{n}\right)\alpha \ \text{(association)}$$

MOLAR MASS

$$M = \frac{K_b \times w \times 1000}{\Delta T_b \times W}$$

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CHAPTER 18

Electrochemistry

Cells and Nernst equation

$$E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$$

NERNST

$$E = E^\circ - \frac{0.0591}{n}\log Q \ \ (298\ \text{K})$$

$$\Delta G^\circ = -nFE^\circ_{\text{cell}}, \qquad E^\circ_{\text{cell}} = \frac{0.0591}{n}\log K$$

Conductance

$$\kappa = \frac{1}{\rho} = G\,\frac{l}{A}, \qquad \Lambda_m = \frac{\kappa \times 1000}{M}$$

KOHLRAUSCH

$$\Lambda^\circ_m = \nu_+\lambda^\circ_+ + \nu_-\lambda^\circ_-; \qquad \alpha = \frac{\Lambda_m}{\Lambda^\circ_m}$$

STRONG ELECTROLYTES

$$\Lambda_m = \Lambda^\circ_m - A\sqrt{C}$$

Electrolysis

FARADAY'S LAWS

$$w = ZIt = \frac{E}{F}It, \qquad \frac{w_1}{w_2} = \frac{E_1}{E_2}$$

$$1\ \text{F} = 96500\ \text{C mol}^{-1}$$

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CHAPTER 19

Chemical Kinetics

Rate law

$$\text{rate} = k[A]^x[B]^y, \qquad \text{order} = x + y; \qquad \text{units of } k:\ (\text{mol L}^{-1})^{1-n}\,\text{s}^{-1}$$

$$-\frac{1}{a}\frac{d[A]}{dt} = \frac{1}{c}\frac{d[C]}{dt} \ \text{ for } aA \to cC$$

Integrated rate equations

ZERO ORDER

$$[A] = [A]_0 - kt, \qquad t_{1/2} = \frac{[A]_0}{2k}$$

FIRST ORDER

$$k = \frac{2.303}{t}\log\frac{[A]_0}{[A]}, \qquad t_{1/2} = \frac{0.693}{k}$$

$$t_{99.9\%} \approx 10\,t_{1/2}; \qquad n\text{th order: } t_{1/2} \propto [A]_0^{1-n}$$

Temperature dependence

ARRHENIUS

$$k = Ae^{-E_a/RT}; \qquad \log\frac{k_2}{k_1} = \frac{E_a}{2.303R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

a catalyst lowers E_a; rate roughly doubles for every 10 K rise

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CHAPTER 20

Surface Chemistry

Adsorption

FREUNDLICH

$$\frac{x}{m} = kp^{1/n}\ (n > 1), \qquad \log\frac{x}{m} = \log k + \frac{1}{n}\log p$$

physisorption: weak, reversible, multilayer; chemisorption: strong, specific, monolayer

Catalysis

a catalyst changes the path (lower E_a), not ΔH or K

Colloids

HARDY–SCHULZE RULE

coagulating power rises with the charge of the opposite ion: $Al^{3+} > Ba^{2+} > Na^{+}$

gold number: smaller means a better protective colloid

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CHAPTER 21

General Principles and Processes of Isolation of Metals

Concentration and extraction

froth flotation (sulphide ores); leaching (Al, Au, Ag); roasting (sulphides); calcination (carbonates)

ELLINGHAM DIAGRAM

a metal reduces the oxide of any metal above it; $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

Refining

electrolytic (Cu); zone refining (Si, Ge); Mond (Ni via $Ni(CO)_4$); van Arkel (Ti, Zr via iodides)

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CHAPTER 22

p Block Elements (Group 15, 16, 17 and 18)

Group 15

hydride basicity: $NH_3 > PH_3 > AsH_3$; bond angle falls down the group

oxoacids of P: H_3PO_2 (monobasic), H_3PO_3 (dibasic), H_3PO_4 (tribasic)

Group 16

acid strength of hydrides: $H_2O < H_2S < H_2Se < H_2Te$

CONTACT PROCESS

$$2SO_2 + O_2 \xrightarrow{V_2O_5} 2SO_3$$

Group 17

oxidising power: $F_2 > Cl_2 > Br_2 > I_2$; acid strength: $HI > HBr > HCl > HF$

bond energy: $Cl_2 > Br_2 > F_2 > I_2$

OXOACID STRENGTH

$$HClO_4 > HClO_3 > HClO_2 > HClO$$

Group 18

XeF_2 linear; XeF_4 square planar; XeF_6 distorted octahedral; XeO_3 pyramidal

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CHAPTER 23

d and f Block Elements

Properties of transition elements

MAGNETIC MOMENT

$$\mu = \sqrt{n(n+2)}\ \text{BM}$$

coloured ions (d–d transitions); variable oxidation states; catalytic activity

COMMON STATES

Mn: up to $+7$; Sc^{3+}, Ti^{4+}, Zn^{2+}, Cu^{+} colourless

$KMnO_4$ and $K_2Cr_2O_7$

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$$

$Cr_2O_7^{2-}$ (orange) $\rightleftharpoons$ CrO_4^{2-} (yellow) as pH rises

Lanthanoids and actinoids

LANTHANOID CONTRACTION

steady fall in size (poor shielding by 4f); Zr and Hf have almost equal radii

common state $+3$; Ce^{4+} oxidant, Eu^{2+} reductant

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CHAPTER 24

Coordination Compounds

Werner's theory and nomenclature

$$\text{primary valency} = \text{oxidation state}; \qquad \text{secondary valency} = \text{coordination number}$$

EAN

$$\text{EAN} = Z - \text{oxidation state} + 2 \times \text{CN}$$

Isomerism

GEOMETRICAL ISOMERS

$$[\text{MA}_2\text{B}_2] \text{ sq. planar: } 2; \qquad [\text{MA}_4\text{B}_2] \text{ oct: } 2; \qquad [\text{MA}_3\text{B}_3] \text{ oct: } 2 \ (fac, mer)$$

$$\text{structural: ionisation, linkage } (\text{NO}_2^- / \text{ONO}^-), \text{ coordination, hydrate}$$

VBT and crystal field theory

OCTAHEDRAL SPLITTING

$$\text{CFSE} = \left(-0.4\, n_{t_{2g}} + 0.6\, n_{e_g}\right) \Delta_o + nP$$

$$\Delta_t = \tfrac{4}{9} \Delta_o$$

SPECTROCHEMICAL SERIES

$$\text{I}^- < \text{Br}^- < \text{Cl}^- < \text{F}^- < \text{OH}^- < \text{H}_2\text{O} < \text{NH}_3 < \text{en} < \text{CN}^- < \text{CO}$$

$$\Delta_o > P \text{ low spin}; \qquad \Delta_o < P \text{ high spin}$$

Stability

$$\beta_n = K_1 K_2 \cdots K_n; \qquad \text{chelates are more stable (chelate effect)}$$

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CHAPTER 25

Haloalkanes and Haloarenes

SN1, SN2 and elimination

SN2

$$\text{rate} = k[\text{RX}][\text{Nu}^-];\ \text{inversion};\ \ \text{CH}_3\text{X} > 1^\circ > 2^\circ > 3^\circ$$

SN1

$$\text{rate} = k[\text{RX}];\ \text{racemisation};\ \ 3^\circ > 2^\circ > 1^\circ;\ \text{polar protic solvent}$$

LEAVING GROUP

$$\text{I}^- > \text{Br}^- > \text{Cl}^- > \text{F}^-$$

SAYTZEFF

elimination gives the more substituted alkene

Preparation and named reactions

$$\text{Finkelstein: } \text{RCl} + \text{NaI} \rightarrow \text{RI}; \qquad \text{Swarts: } \text{RBr} + \text{AgF} \rightarrow \text{RF}$$

$$\text{Sandmeyer: } \text{ArN}_2^+ \xrightarrow{\text{CuX}} \text{ArX}; \qquad \text{Wurtz–Fittig: } \text{ArX} + \text{RX} + \text{Na} \rightarrow \text{ArR}$$

Haloarenes

less reactive to nucleophiles (C–X has partial double-bond character); EWG at o/p speeds up SNAr

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CHAPTER 26

Alcohols Phenols and Ethers

Alcohols

LUCAS TEST

$$3^\circ \text{ immediate turbidity},\ 2^\circ \text{ in about 5 min},\ 1^\circ \text{ none at room temperature}$$

OXIDATION

$$1^\circ \rightarrow \text{aldehyde} \rightarrow \text{acid}; \qquad 2^\circ \rightarrow \text{ketone}; \qquad 3^\circ \text{ resists}$$

DEHYDRATION

$$3^\circ > 2^\circ > 1^\circ \ (\text{conc. } H_2SO_4)$$

Phenols

$$\text{Reimer–Tiemann: PhOH} \xrightarrow{CHCl_3,\ NaOH} \text{salicylaldehyde}; \qquad \text{Kolbe: PhONa} \xrightarrow{CO_2} \text{salicylic acid}$$

$$\text{phenol} + Br_2(aq) \rightarrow 2,4,6\text{-tribromophenol (white ppt)}$$

Ethers

WILLIAMSON SYNTHESIS

$$RONa + R'X \rightarrow ROR' \ \ (\text{use a } 1^\circ \text{ halide})$$

$$\text{ether} + HI \rightarrow ROH + R'I \ \ (\text{I attaches to the smaller alkyl group, or via SN1 to the } 3^\circ)$$

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CHAPTER 27

Aldehydes and Ketones

Nucleophilic addition

REACTIVITY

$$\mathrm{HCHO} > \mathrm{RCHO} > \mathrm{RCOR'} \text{ (steric and electronic)}$$

$$\mathrm{HCN},\ \mathrm{NaHSO_3},\ \mathrm{RMgX},\ \mathrm{NH_2{-}Z} \text{ (oximes, hydrazones)}$$

Named reactions

ALDOL

$$\text{needs an } \alpha\text{-H; dilute base} \Rightarrow \beta\text{-hydroxy carbonyl}$$

CANNIZZARO

$$\text{no } \alpha\text{-H, conc. base: } \ 2\,\mathrm{HCHO} \rightarrow \mathrm{HCOO^-} + \mathrm{CH_3OH}$$

REDUCTIONS

$$\text{Clemmensen } (\mathrm{Zn{-}Hg/HCl}) \text{ and Wolff–Kishner } (\mathrm{NH_2NH_2/KOH})\text{: } \mathrm{C{=}O \rightarrow CH_2}$$

TESTS

$$\text{Tollens (silver mirror) and Fehling (red ppt): aldehydes;}$$

$$\text{iodoform: } \mathrm{CH_3CO{-}} \text{ and } \mathrm{CH_3CH(OH){-}}$$

Preparation

$$\text{Rosenmund: } \mathrm{RCOCl} \xrightarrow{\mathrm{H_2,\ Pd/BaSO_4}} \mathrm{RCHO}; \qquad \text{Stephen: } \mathrm{RCN} \rightarrow \mathrm{RCHO};$$

$$\text{Etard: toluene} \rightarrow \text{benzaldehyde}$$

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CHAPTER 28

Carboxylic Acids and Their Derivatives

Carboxylic acids

ACIDITY

$$\mathrm{FCH_2COOH > ClCH_2COOH > HCOOH > C_6H_5COOH > CH_3COOH}$$

HVZ

$$\mathrm{RCH_2COOH \xrightarrow{X_2,\ red\ P} RCHXCOOH}$$

DECARBOXYLATION

$$\mathrm{RCOONa \xrightarrow{NaOH/CaO} RH}$$

Acid derivatives

REACTIVITY TO NUCLEOPHILES

$$\mathrm{acid\ chloride > anhydride > ester > amide}$$

$$\mathrm{esterification:\ RCOOH + R'OH \overset{H^+}{\rightleftharpoons} RCOOR' + H_2O}$$

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CHAPTER 29

Amines

Aliphatic and aromatic amines

HOFFMANN BROMAMIDE

$$\mathrm{RCONH_2 + Br_2 + 4NaOH \rightarrow RNH_2} \quad \text{(one carbon fewer)}$$

GABRIEL PHTHALIMIDE

$$\text{gives } 1^\circ \text{ aliphatic amines only}$$

HINSBERG TEST

$$1^\circ : \text{product dissolves in alkali;} \qquad 2^\circ : \text{insoluble;} \qquad 3^\circ : \text{no reaction}$$

CARBYLAMINE TEST

$$1^\circ \text{ amines} + \mathrm{CHCl_3} + \mathrm{KOH} \rightarrow \text{isocyanide (foul smell)}$$

Diazonium salts

$$\mathrm{ArNH_2} \xrightarrow{\mathrm{NaNO_2,\ HCl,\ 0\text{–}5^\circ C}} \mathrm{ArN_2^+ Cl^-}$$

$$\text{Sandmeyer (CuX, CuCN); Gattermann (Cu/HX); } \mathrm{H_3PO_2} \rightarrow \mathrm{ArH}\text{; coupling with phenol} \rightarrow \text{azo dye}$$

Cyanides, isocyanides and nitro compounds

$$\mathrm{RX + KCN \rightarrow RCN;} \qquad \mathrm{RX + AgCN \rightarrow RNC;} \qquad \mathrm{ArNO_2} \xrightarrow{\mathrm{Sn/HCl}} \mathrm{ArNH_2}$$

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CHAPTER 30

Biomolecules

Carbohydrates

glucose $C_6H_{12}O_6$ (aldohexose); fructose (ketohexose); sucrose: non-reducing

α and β anomers differ at C-1; starch: α-glucose; cellulose: β-glucose

Proteins and amino acids

peptide bond –CO–NH–; zwitterion at the isoelectric point

essential amino acids are not made by the body

Nucleic acids and vitamins

DNA: deoxyribose, A–T and G–C; RNA: ribose, uracil instead of thymine

fat-soluble vitamins: A, D, E, K; water-soluble: B, C

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CHAPTER 31

Polymers

Classification and polymerisation

addition (chain growth) vs condensation (step growth); homopolymer vs copolymer

Important polymers

nylon-6,6: hexamethylenediamine + adipic acid; nylon-6: caprolactam

terylene: ethylene glycol + terephthalic acid; Bakelite: phenol + HCHO

Buna-S: butadiene + styrene; Buna-N: butadiene + acrylonitrile;

neoprene: chloroprene

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CHAPTER 32

Chemistry in Everyday Life

Drugs and medicines

analgesics, antipyretics, antibiotics, antiseptics, antacids, tranquillisers

Food and cleansing agents

artificial sweeteners: saccharin, aspartame, sucralose; soaps: sodium salts of fatty acids

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CHAPTER 33

Practical Chemistry

Detection of elements and groups

LASSAIGNE'S TEST

N: Prussian blue; S: violet with sodium nitroprusside; halogens: AgX precipitate

Salt analysis and titrations

group reagents: dil. HCl (Pb^{2+}, Ag^{+}); H_2S in acid (Cu^{2+}, Cd^{2+}); NH_4OH (Fe^{3+}, Al^{3+})

titration: $N_1V_1 = N_2V_2$; phenolphthalein for strong base, methyl orange for strong acid

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CHAPTER 34

Purification and Characterisation of Organic Compounds

Purification methods

crystallisation, sublimation, distillation (fractional, steam, reduced pressure), chromatography

CHROMATOGRAPHY

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

Quantitative analysis

CARBON AND HYDROGEN

$$\%\mathrm{C} = \frac{12}{44} \times \frac{m_{\mathrm{CO_2}}}{m} \times 100, \qquad \%\mathrm{H} = \frac{2}{18} \times \frac{m_{\mathrm{H_2O}}}{m} \times 100$$

DUMAS (N)

$$\%\mathrm{N} = \frac{28}{22400} \times \frac{V_{\mathrm{N_2}}(\mathrm{STP, mL})}{m} \times 100$$

KJELDAHL (N)

$$\%\mathrm{N} = \frac{1.4 \times N \times V}{m}$$

CARIUS (HALOGEN, S)

$$\%\mathrm{X} = \frac{\text{at. mass of X}}{\text{mol. mass of AgX}} \times \frac{m_{\mathrm{AgX}}}{m} \times 100; \qquad \%\mathrm{S} = \frac{32}{233} \times \frac{m_{\mathrm{BaSO_4}}}{m} \times 100$$

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