

## Nomenclature and Structural Representation

- Identification of major chain or ring
- Side chains and functional groups added in alphabetical order
- Sums of substituent numbers are minimised.
- Acetone: Propanone
- Formaldehyde: Methanal
- Acetic acid: Ethanoic acid
- Dimethylether: Methoxymethane.

**Def** (Carbon Substitution Levels). Primary C: 3 Hs; Secondary C: 2 Hs; Tertiary C: 1 H; Quaternary C: 0 Hs.

**Def** (Alcohol Substitution Levels). Primary: 2 Hs on C attached to O; Secondary: 1 H on C attached to O; Tertiary: 0 Hs on C attached to O.

**Def** (Amine Substitution Levels). Primary: 2 Hs on N; Secondary: 1 H on N; Tertiary: 0 Hs on N.

**Def** (Aromatic Substitution Positions). Relative to group X: Ortho (1,2), Meta (1,3), Para (1,4).

- Apexes represent Carbon atoms
- Heteroatoms (not H or C) are shown
- H atoms on carbons are omitted
- H atoms on heteroatoms are shown.

## Atomic Properties and Bonding

**Obs** (Molecular Stability). Stability derived from outer electronic configuration of 8 electrons (octet rule) or 2 electrons for Hydrogen.

**Def** (Bond Polarity). Unequal sharing of electrons due to electronegativity differences. Electronegativity increases across a row and up a group (F is highest).

- Polarity operating through  $\sigma$  bonds. Most heteroatoms (O, N, Cl) are  $\delta^-$  relative to Carbon  $\delta^+$ . Metals (Mg, Li) reverse this polarity.

**Thm** (Formal Charge Calculation).

$$FC(X) = (\text{Atomic Group Number}) \\ - (\text{Number of Bonds}) \\ - 2(\text{Number of Lone Pairs})$$

**Thm** (Oxidation Number ( $N_{ox}$ )). For each attached H: -1; For each attached heteroatom (O, N, S, Halogen): +1; Double/triple bonds to heteroatoms count double/triple. Sum for the molecule.

**Obs** (Oxidation vs. Reduction). Oxidation: Change of +2 in total  $N_{ox}$  (e.g., removal of 2H or addition of O). Reduction: Change of -2 in total  $N_{ox}$  (e.g., addition of 2H).

## Acidity and pKa

**Def** (pKa Definition).  $pKa = -\log_{10} Ka$ . Lower pKa indicates a stronger acid. Each unit represents a tenfold change in acidity.

- Alkane: 40
- Amine ( $RNH_2$ ): 30
- Ketone ( $\alpha$ -H): 20
- Alcohol: 16
- Phenol: 10
- Carboxylic Acid: 5.

## 3D Structure and Hybridization

**Def** (sp<sup>3</sup> Hybridization). Mixing of one 2s and three 2p orbitals; 4 equivalent orbitals; 109.5° bond angles; Tetrahedral shape (e.g., Methane, Ammonia, Water).

**Def** (sp<sup>2</sup> Hybridization). Mixing of one 2s and two 2p orbitals; 3

equivalent orbitals at 120°; Trigonal planar shape; Remaining p orbital forms  $\pi$  bond (e.g., Ethene).

**Def** (sp Hybridization). Mixing of one 2s and one 2p orbital; 2 equivalent orbitals at 180°; Linear shape; Two remaining p orbitals form two  $\pi$  bonds (e.g., Ethyne).

**Thm** (VSEPR Theory). Valence Shell Electron Pair Repulsion: Shape is determined by maximizing distance between electron pairs to minimize repulsion.

## Stereochemistry and CIP Rules

**Def** (Configuration vs. Conformation). Configuration: Fixed stereochemical property requiring bond breaking to change. Conformation: Shapes adopted by rotation about single bonds.

- 1. Higher atomic number has priority
- 2. Higher mass isotope has priority
- 3. Move outward to first point of difference
- 4. Multiple bonds count as multiple 'dummy' atoms.

**Def** (E/Z Isomerism). Z (zusammen): High priority groups on same side of double bond. E (entgegen): High priority groups on opposite sides.

**Def** (R/S Configuration). View along C-4 bond (lowest priority in back). Arrow 1  $\rightarrow$  2  $\rightarrow$  3: Clockwise = R (rectus); Counter-clockwise = S (sinister).

- l/d: Sign of optical rotation (levorotatory/dextrorotatory)
- L/D: Absolute configuration relative to glyceraldehyde (common in sugars/amino acids).

## Reaction Mechanisms: Arrow Pushing

- Curly arrows show movement of electron pairs
- Arrows flow head-to-tail
- Sum of charges must be conserved
- Avoid 5 bonds to Carbon.

**Obs** (Formal Charge Movement). Protonation: Charge moves from  $H^+$  to the atom donating the lone pair. Deprotonation: Charge moves from the base to the atom receiving the electron pair.

- 1. Substitution (group replacement)
- 2. Elimination (formation of double bond)
- 3. Addition (adding groups to alkene/alkyne)
- 4. Rearrangement.

## Nucleophilic Substitution

**Thm** (SN<sub>2</sub> Mechanism). Substitution Nucleophilic Bimolecular. Single concerted step; Rate =  $k[\text{Substrate}][\text{Nu}]$ ; Inversion of configuration (Walden inversion); Favored by primary halides.

**Thm** (SN<sub>1</sub> Mechanism). Substitution Nucleophilic Unimolecular. Two-step via carbocation intermediate; Rate =  $k[\text{Substrate}]$ ; Racemisation of configuration; Favored by tertiary halides.

- Good leaving groups stabilize negative charge: Halides (I  $\succ$  Br  $\succ$  Cl), Tosylates (OTs), Mesylates (OMs). OH is a poor leaving group unless protonated.
- SN<sub>1</sub>: Favored by polar protic/aprotic solvents (stabilize ions). SN<sub>2</sub>: Favored by dipolar aprotic solvents (DMF, DMSO) which 'free' the nucleophile.

## Elimination Reactions

**Thm** (E<sub>2</sub> Mechanism). Elimination Bimolecular. One-step; Requires 'anti-periplanar' alignment of H and leaving group; Rate =  $k[\text{Substrate}][\text{Base}]$ .

**Thm** (E<sub>1</sub> Mechanism). Elimination Unimolecular. Two-step via carbocation; Rate =  $k[\text{Substrate}]$ ; Competes with SN<sub>1</sub>.

**Obs** (Base vs. Nucleophile). Alkoxides act as nucleophiles (substitution) or bases (elimination). Hindered substrates and strong bases favor elimination.

## Addition Reactions

**Thm** (Electrophilic Addition to Alkenes). Alkenes react with  $Br_2$  (via cyclic bromonium ion) or  $HBr$  (via carbocation).  $Br_2$  addition is trans/anti.

**Prop** (Markovnikov's Rule). Addition of HX to unsymmetric alkenes forms the more substituted halide via the more stable (more substituted) carbocation.

**Thm** (Hydroboration-Oxidation). i)  $BH_3$ , ii)  $H_2O_2/NaOH$ . Anti-Markovnikov hydration; Syn-addition of H and OH.

**Thm** (Radical Addition of HBr). HBr with peroxides leads to Anti-Markovnikov addition via a bromine radical intermediate.

## Carbonyl Chemistry

**Def** (Tetrahedral Intermediate). Formed by nucleophilic attack on  $C=O$ . If a leaving group is present, it collapses to reform  $C=O$  (Substitution). If no leaving group, it is protonated (Addition).

**Thm** (Wittig Reaction). Reaction of a phosphonium ylid ( $Ph_3P=CH_2$ ) with an aldehyde/ketone to form an alkene and  $Ph_3P=O$ .

**Thm** (Aldol Reaction). Deprotonation at  $\alpha$ -carbon forms an enolate, which attacks another carbonyl to form a  $\beta$ -hydroxy carbonyl compound.

**Def** (Conjugate (Michael) Addition). Nucleophilic attack at the  $\beta$ -carbon of an  $\alpha,\beta$ -unsaturated carbonyl (enone). Driven by electronegativity of Oxygen.

## Oxidation and Reduction Reagents

- $KMnO_4$ ,  $CrO_3$ ,  $OsO_4$  (diols),  $O_3$  (cleavage), Peracids (mCPBA for epoxides).
- $LiAlH_4$  (strong, reduces esters/amides),  $NaBH_4$  (mild, reduces aldehydes/ketones),  $H_2$  with Pd/C (alkenes).
- $H_2$  + Lindlar catalyst  $\rightarrow$  Z-alkene (cis)
- $Li/NH_3$  (reducing metal)  $\rightarrow$  E-alkene (trans).

## Specialized Mechanisms

**Thm** (Diels-Alder Reaction). Concerted [4+2] cycloaddition between a conjugated diene and a dienophile (alkene) to form a cyclohexene ring.

**Thm** (Wacker Oxidation). Conversion of an alkene to a ketone using catalytic  $PdCl_2$ ,  $H_2O$ ,  $O_2$ , and  $CuCl_2$ .

- Electrophilic Aromatic Substitution: 1. Add electrophile ( $NO_2^+$ ) to form cationic intermediate
- 2. Remove proton to restore aromaticity.
- Imine: Ketone + Primary Amine
- Enamine: Ketone + Secondary Amine
- Acetal: Ketone + 2 Alcohols. All are reversible via hydrolysis.