Grignard Reagent

Introduction of Organometallic compounds :

Organometallic compounds are the organic compounds in which a metal atom is directly attached to carbon atom through covalent bond or ionic bond.

For example $\stackrel{\bigcirc}{C} \oplus$ (R-MgX, R₂CuLi, R₂Zn, RNa, RLi)

(Where C is a carbon atom of an organic molecule and M is a metal atom)

If the metal atom is attached to oxygen, nitrogen. sulphur, etc., then such an organic compound is not regarded as an organometallic compound.

The following structural formula do not belong to the family of organometallic compounds.

eg. RONa (Sodium alkoxide). CH₃COONa (Sodium acetate), CH₃COOAg (Silver acetate), RSK (Potassium

mercaptide) RNHK (N-Alkylpotassamide), (CH₃COO)₄Pb (Lead tetraacetate), etc.

Note : It should be noted that $(CH_3)_4Si$ (Tetramethylsilane, TMS) is also not an organometallic compound because silicon is a nonmetal.

Most important examples of organometallic compound are **Grignard's reagents.** In Grignard's reagent, the carbon and magnesium atom are bonded with each other through polar covalent bond and magnesium atom is attached to halogen by ionic bond.

 $C - Mg \overset{\Theta}{X}$ (Functional part of a Grignard's reagent molecule)

1. Grignard reagent

1.1 Preparation :

 $\mathsf{RX} + \mathsf{Mg} \xrightarrow{\mathsf{Dry and pure}} \mathsf{RMgX}$

Ether is used as a solvent because it is a Lewis base that donates its lone pair of electrons to electrondeficient magnesium atom, therefore providing stability to the Grignard's reagent (G.R.) by completing the octet on magnesium atom.



dietherate

Process : To an etherial solution of alkyl halide Mg metal is added at very low temp. (0-5°C). A vigorous reaction takes place, and a solution of G.R. is obtained. It cannot be evaporated to get it in solid state because reaction will be explosive. It is stable only in solution state.

Reactivity order with respect to X (For preparation of RMgX)

$$R - X : R - I > R - Br > R - CI > R - F$$
Most
Commonly
Used
(No G.R. formation)

lodides forms organometallic compounds at the fastest rate.

Examples of Grignard's reagent :

1. Saturated Aliphatic Grignard's reagent

R – MgX (Alkylmagnesium halide)

 $CH_{3} - MgI$ (Methylmagnesium iodide)

2. Unsaturated Aliphatic Grignard's reagent

(i) Alkenyl Grignard's reagent : $CH_2 = CH - CH_2 - MgX$ (Allylmagnesium halide)

(ii) Alkynyl Grignard's reagent : CH₃-C=C-MgX

3. Alicyclic Grignard's reagent

4. Aromatic Grignard's reagent

>-MgX (Phenylmagnesium halide)

C_kH_kCH₂MgCl (Benzylmagnesium halide)

Structural stability of G.R.

If the alkyl part has more stable negative charge, then RMgX is more stable. It will be less reactive (1) CH_3 – CH_2 –MgX; (2) CH_3 =CH–MgX; (3) CH_3C =C–MgX

Ex. (1) CH₃–CH₂–MgX ; Reactivity order : Stability order :

2) $CH_2 = CH - MgX$; (3) $CH_3 C = C - MgX$ 1 > 2 > 3 1 < 2 < 3

1.2 Reactivity of Grignard Reagent :

It has been found out by estimation that there is 35% ionic character in carbon-magnesium bond of Grignard's reagent. Therefore, there is a tendency of forming carbanion by heterolysis of this polar bond as follows.

 $\mathsf{R} \not\leftarrow \overset{\oplus}{\mathsf{Mg}} \overset{\Theta}{\mathsf{X}} \xrightarrow{\mathsf{O}} \overset{\oplus}{\mathsf{R}} \overset{\Theta}{\mathsf{Mg}} \overset{\Theta}{\mathsf{X}}$

If Grignard reagent is regarded as the attacking reagent, then the nucleophilic carbanion of Grignard's reagent will attack on the other compound taken as substrate.

$$\stackrel{\text{\tiny (a)}}{\text{\tiny (R)}} + \sum_{c} C \stackrel{\text{\tiny (a)}}{=} O \longrightarrow R - C \stackrel{\text{\tiny (a)}}{=} O \stackrel{\text{\tiny (a)}}{\longrightarrow} R \stackrel{\text{\tiny (a)}}{=} O \stackrel{\text{\tiny (a)}}{\longrightarrow} R \stackrel{\text{\tiny (a)}}{=} O \stackrel{\text{\tiny (a)}}{\longrightarrow} R \stackrel{\text{\tiny (a)}}{\rightarrow} R \stackrel{\text{\tiny (a)}}{\longrightarrow} R \stackrel{\text{\tiny (a)}}{\rightarrow} R \stackrel{\text{(a)}}{\rightarrow} R \stackrel{\text{\tiny (a)}}{\rightarrow} R \stackrel{\text{\tiny (a)}}{\rightarrow} R \stackrel{\text{\tiny (a)}}{\rightarrow} R$$

1.3 Reactivity order of Grignard's reagent

On having same hydrocarbon radical, the order of reactivity of Grignard's reagent will be as follows : * RMgI > RMgBr > RMgCl

Reactivity order with different alkyl part is

* $RMgX : 3^{\circ} > 2^{\circ} > 1^{\circ} > CH_{3} > C = C > C = C$

Reactivity order with respect to different reactants (Substrate)

* Acidic hydrogen > - CHO > R - CO - R > R - COOR' > R - X

Note : Except X (halogen) all other functional groups must be absent in the alkyl group otherwise G.R. will be destroyed by internal reactions. [- NO₂, - CN must also be absent]

1.4 Chemical Reactions of G.R.

(1) Synthesis of other organometallic compounds

(2) Reaction with acidic Hydrogen (H) atom containting compounds

(3) Grignard Reagent as a nucleophile

- (A) Nucleophilic addition reaction
- (B) S_N2 Th (Substitution nucleophilic bimolecular with tetrahedral intermediate)
- (C) Nucelophilic substitution reaction of GR
- (4) Other reaction of GR

(1) Synthesis of other organometallic compounds

 $R-Mg-X + ZnCl_2 \longrightarrow R_2Zn + MgX(Cl)$

+ HgCl₂ \longrightarrow R₂Hg + MgX(Cl)

- + $SnCl_4 \longrightarrow R_4Sn + MgX(Cl)$
- + $PbCl_4 \longrightarrow R_4Pb + MgX(Cl)$



Note : If $R = CH_3$ in R-Mg-Br then methane gas in released.

The reaction is used for estimation of active hydrogen atoms present in a molecule. The method is called **Zerewitinoff method** for estimation of active hydrogen atoms.

(3) Grignard Reagent as a nucleophile

(A) Nucleophilic addition reaction :

Grignard's reagents form adducts by addition on the following type of π bonds.

$$C = 0$$
, $C = S$, $C = N$ and $-C = N$, $-N = 0$, $S = 0$

Nucleophilic Addition Reaction With

$$\overbrace{\substack{\delta^{-} \quad \delta^{+} \\ R - MgX + - C - (1) \\ G^{0}}}^{\bullet} \xrightarrow{ether} \left[\begin{array}{c} R \\ - C - \\ - \\ G^{0} \end{array} \right] \xrightarrow{H_{2}O / H^{\oplus}} - \begin{array}{c} R \\ - C - \\ - \\ G^{0} \end{array} \right]$$

$$\xrightarrow{adduct} \\ [alkoxide salt]$$
Reactivity order : HCHO > RCHO > RCOR
$$RCHO > ArCHO$$

$$RCOR > RCOAr > ArCOAr$$
(i). E.R.G at >C=O decreases rate

(ii) Crowding of R Group at > C=O, decreases rate

Example of Nucleophilic addition reaction :

- (i) Reaction with aldehyde and ketones
- (ii) Reaction with Carbon dioxide and carbon disulphide
- (iii) Reaction with Sulfur dioxide and Sulfur trioxide
- (iv) Reaction with nitriles and imine
- (v) Reaction with oxygen and Sulfur

(I) Reaction with aldehyde and ketones

| Substrate | Product |
|----------------------|--------------------|
| Formaldehyde | Primary alcohols |
| Aldehydes other than | |
| formaldehyde | Secondary alcohols |
| Ketones | Tertiary alcohols |



(ii) Reaction with Carbon dioxide and carbon disulphide

A carboxylic acid is formed on hydrolysis of the adduct formed by passing carbon dioxide in the etherial solution of a Grignard's reagent.

Alkanonic acid

An analogous reaction of Grignard reagent is observed with carbon disulphide to give alkanedithionic acid.

 $\begin{array}{cccc} R-MgX \ + \ S=C=S & \xrightarrow{ether} & R-C-SMgX \xrightarrow{H^+} & R-C-SH \\ & & & \\ S & & \\ & \\ &$

(iii) Reaction with Sulfur dioxide and Sulfur trioxide



Reaction with nitriles and imine



Aldehyde

(v) Reaction with oxygen and Sulfur

 $R - MgX + O = O \longrightarrow R - O - O - MgX$

 $R - O - O - MgX + R - MgX \longrightarrow 2R - O - MgX$

 $R - O - MaX + HOH \longrightarrow R - O - H + Ma(OH)X$

Primary, secondary and tertiary alcohols can be obtained by above reaction.

Phenol is obtained on hydrolysis of the product obtained by reaction of arylmagnesium bromide with oxygen.

 $C_{e}H_{5}MgBr + O = O \longrightarrow C_{e}H_{5}O - OMgBr$

 $C_{k}H_{k}O - OMgBr + C_{k}H_{k}MgBr \longrightarrow 2C_{k}H_{k} - OMgBr$

 $C_{e}H_{5} - OMgBr + H_{2}O \longrightarrow C_{e}H_{2} - OH + Mg(OH)Br$

Other phenols can be prepared by taking any aryl (Ar) group in place of phenyl group.

For example, on taking p-toluenemagnesium bromide p-cresol is formed.



Applications : G.R. is used to prepare alcohols or phenol from those alkyl halides / aryl halides which do not give normal S_{N} reactions



(B) $S_N 2$ Th (Substitution nucleophilic bimolecular with tetrahedral intermediate)

Characteristic reaction of acid and it's derivatives (acid halide, anhydride, amide and ester). Nucleophilic acyl substitution usually takes place by an **addition-elimination** mechanism.The incoming nucleophile adds to the carbonyl to form a tetrasubstituted intermediate with a tetrahedral carbon.



The tetrahedral intermediate formed, when a nucleophile attacks the carbonyl carbon of a carboxylic acid derivative, is not stable and cannot be isolated.

A pair of nonbonding electrons on the oxygen reforms the π bond, and either L^{\ominus} or Nu^{\ominus} is eliminated with its bonding electrons. Whether L^{\ominus} or Nu^{\ominus} is eliminated depends on their relative basicities. The weaker base is preferentially eliminated because the weaker base is the better leaving group.

$$R = C - L + Nu = R = C - Nu + L$$

$$A$$
basicity of Nu should basicity of L should

ty of Nu should basicity of L´should be

be more than that of \breve{L} less than the basicity of $\breve{N}u$

Thus carboxylic acid derivative will undergo a nucleophilic acyl substitution reaction provided that the incoming nucleophile is a stronger base than the group that is to be replaced. If the incoming nucleophile and the group attached to acyl group in the starting material have similar basicities, the tetrahedral intermediate can expect either group with similar ease. A mixture of starting material and substitution product will result.

Condition for acyl nucleophilic substitution reaction :



(i) L must be better leaving group than Nu^{Θ} , i.e., basicity of Nu^{Θ} should be more than that of L^{Θ} .

(ii) Nu[®] must be a strong enough nucleophilic to attack RCOL.

(iii) Carbonyl carbon must be enough electrophilic to react with Nu^o.





Ex.

Ph – MgX +



Ex.

 $Ph-X + \longrightarrow Mg-X \longrightarrow No reaction$

CHEMISTRY FOR NEET





2. **REDUCTION**

2.1 Introduction :

Reduction covers both the addition of hydrogen (or deuterium) to a double bond and the replacement of an atom or group by hydrogen (or deuterium). In other words, reduction means hydrogenation or hydrogenolysis.

Reduction can be carried out in following ways:

- (i) Catalytic hydrogenation
- (ii) Metal/proton (acid) reduction
- (iii) Metal hydrides reduction
- (iv) Miscellaneous Reductions

2.2 Catalytic hydrogenation :

Hydrogenation using $H_2(gas)$ on metal surface or other suitable catalyst is called catalytic hydrogenation. A catalyst provides a new pathway for the reaction that involves lower free energy of activation.



Heterogeneous hydrogenation catalysts typically involve finely divided platinum, The catalysts used can be divided into two broad classes, (a) Heterogeneous catalysts and (b) Homogeneous catalysts, both of which mainly consist of transition metals and their compounds :

(i) Heterogeneous catalysts : (catalysts insoluble in the reaction medium)

In heterogeneous catalytic hydrogenation catalysts are used in powdered form. Raney nickel (Ni), Palladium on charcol (Pd/C), Platinum metal or its oxide are common heterogeneous catalysts. **Facts of catalysis :**

(i) Substrate molecules are assumed to undergo homolysis into atoms at the surface of the catalyst.

- (ii) The substrate is chemisorbed on the surface of the catalyst and hydrogenation takes place.
- (iii) The process is exothermic,

Note : (If H_2 and D_2 mixture is used with a Pt catalyst, the two isotopes quickly scramble to produce a random mixture of HD, H_2 and D_2 . (No scrambling occurs in the absence of the catalyst.) The product has both D and H atoms).

Catalytic Reduction of Functional Groups Using H,/Pd(C) or H,/Pt or H,/Ni

 $R - CH = CH - R + H_2 \xrightarrow{Ni \text{ or } Pd} R - CH_2 - CH_2 - R + heat$

| Substrate | Product |
|------------------|------------------------------------|
| RCOCI | RCH₂OH |
| RNO ₂ | RNH ₂ |
| RC≡CR | RCH ₂ CH ₂ R |
| RCHO | RCH ₂ OH |
| RCH=CHR | RCH ₂ CH ₂ R |
| RCOR | RCHOHR |
| RC≡N | RCH ₂ NH ₂ |
| | |

- Note: (i) Generally RCOOH, RCOOR, RCONH₂ groups are not reduced by catalytic hydrogenation.
 (ii) Stereochemistry of catalytic hydrogenation : The above reaction is syn addition (addition takes place from the same face of alkene or alkyne).
- (ii) **Homogeneous catalysis :** (catalysts soluble in the reaction medium). It uses reactants and catalyst in the same phase. Both hydrogen atoms **usually** add from the same side of the molecule. Common example : Use of Wilkinsion catalyst Rh $[(C_{e}H_{e})_{2}P]_{2}CI$.

(iii) Lindlar's catalyst : [H₂/Pd, CaCO₃, quinoline]

It is a poisoned palladium catalyst. It is composed of powdered calcium carbonate coated with palladium and poisoned with quinoline. It is used to carry out partial reduction of alkyne to alkene and acid chloride to aldehyde.

Stereochemistry : Syn addition.



(iv) Rosenmund catalyst : [H₂/Pd, BaSO₄, quinoline] Hydrogenation in presence of H₂/Pd/BaSO₄ is called Rosenmund Reduction. It reduces alkyne to alkene and acid halide to aldehyde. It is poisoned palladium catalyst, composed of powdered barium sulphate coated with palladium, poisoned with quinoline or sulphur.

Stereochemistry : Syn addition.

(a)
$$CH_3-C=C-CH_3 \xrightarrow{H_2,Pd, BaSO_4, S} \xrightarrow{H_3C} C=C \xrightarrow{CH_3} H$$

cis-2-butene
(b) $CH_3-C-CI \xrightarrow{H_2,Pd, BaSO_4, S} CH_3-CHO$

Note : Nickel boride Ni₂B **(P-2 catalyst)** (made from Nickel acetate and sodium borohidride) is an excellent alternative catalyst for the conversion of alkyne into alkene.

Stereochemistry : Syn addition.

Ni (OCOCH₃)₂
$$\xrightarrow{\text{NaBH}_4}$$
 Ni₂B.

2.3 Metal/proton (acid) reduction :

Reduction by dissolving metals is based on the fact that the metal acts as a source of electrons. **Step-1** : Metals give electrons to the electrophilic species and form anion **Step-2** : Proton is abstracted from the acidic source.

 $A - B \xrightarrow{\overline{e}} A^{\bullet} + \overline{B}: \text{ or } \overline{A}: + B^{\bullet} \xrightarrow{H^{\bullet}} A^{\bullet} + B - H$ $A = B \xrightarrow{\overline{e}} : \overset{\Theta}{A} - B^{\bullet} \text{ or } A^{\bullet} - \overset{\Theta}{B}: \xrightarrow{H^{\bullet}} A^{\bullet} - BH$

(i) Birch reduction [Na or Li/NH₃(liq.) or (ethyl alcohol)] :

Alkyne and Aromatic Compounds are reduced by Na or Li/NH₃. Alkynes are reduced to trans alkene.

Stereochemistry : anti addition.

$$R - C \equiv C - R \xrightarrow{Na/NH_3} \xrightarrow{R} C \equiv C$$

(anti addition)

Benzene ring is reduced at 1, 4-position.



Typical example of reduction for aromatic system : Presence of alkyl, alkoxy, amines reduces the benzene ring at ortho position.



Presence of nitro, cyano, carboxylic or aldehyded group reduces the benzene ring at ipso position.

(electron withdrawing group



(ii) Bouvealt-Blanc reduction $[Na/C_2H_5OH]$:

Reduction of aldehydes, ketones, esters or cyanide by means of excess of Na/C_2H_5OH or n-butanol is called Bouvealt-Blanc reduction reduction.

 $\begin{array}{c} \text{CH}_{3}\text{CHO} \xrightarrow{\text{Na/C}_{2}\text{H}_{5}\text{OH}} \text{CH}_{3}\text{CH}_{2}\text{OH} \\ \text{Acetaldehyde} \qquad \text{Ethanol} \end{array}$

(iii) Stephen's Reductions : [SnCl₂/HCl] :

When reduction of cyanide is carried out with acidified stannous chloride ($SnCl_2/HCl$) at room temperature, imine hydrochloride is obtained. Which on subsequent hydrolysis with boiling water gives aldehyde. This specific type of reduction of nitrile is called stephen's reduction.



(iv) Clemmensen's Reduction : [Zn-Hg/Conc. HCI]

It is used to prepare alkanes from carbonyl compounds (Aldehyde and ketones in absence of acid sensitive groups).

$$\begin{array}{c} \searrow C = O \xrightarrow{Zn - Hg / HCl} \longrightarrow \bigcirc CH_{2} \\ \downarrow g^{2} \\ R - CHO \xrightarrow{Zn - Hg / conc. HCl} \longrightarrow RCH_{3} + H_{2}O \end{array} \qquad \begin{array}{c} O \\ \parallel \\ (b) R - C - R' \xrightarrow{Zn - Hg / conc. HCl} \longrightarrow RCH_{2}R' + H_{2}O \end{array}$$

Note: Clemmensen reduction is not preferred for compounds which have acid sensitive group. [Like Alcohol, Alkene, Alkyne, Ether].

2.4 Metal hydrides reduction

(a)

Certain complex metal and boron hydrides, are important reagents for reduction.

(i) LiAIH₄ (LAH) Lithium aluminium hydride [LiAIH₄ / Ether or THF] :

LAH is most common and versatile reagent. It is sensitive to protic solvent and therefore used in ether.

| Reagent | LiAlH₄ | LiAlH₄ | LiAlH₄/ Excess | LiAlH₄/ Excess | LiAlH₄ | LiAlH ₄ | LiAlH₄ | LiAlH₄ | LiAlH₄ | LiAIH ₄ |
|----------|------------|------------|-------------------|-------------------|------------------|--------------------|----------|----------|------------|--------------------|
| Reactant | Aldehyde | Ketone | Acid | Acidanhydride | Acid chloride | Ester | Cyanide | Amide | Isocyanide | Nitro |
| Product | 1º alcohol | 2º alcohol | 1º alcohol | 1º alcohol | 1º alcohol | 1º alcohol | 1º amine | 1º amine | 2º amine | 1º amine |

Note : Alkene, alkyne, benzene rings are not reduced by LiAlH₄ in ether but it is reported that

(*) double bond can be reduced by LiAlH_4 / THF in few cases like :

 $Ph-CH=CH-CHO \xrightarrow{(i) \ LiAlH_4-THF} Ph-CH_2-CH_2-CH_2OH$

(ii) Sodium borohydride [NaBH₄ / C₂H₅OH or Ether] :

It is more specific than LAH as a reducing agent. It reduces ketones and aldehydes to the corresponding alcohols without affecting other functional groups, reduces acid chlorides to 1^o alcohols. It does not reduce any other derivative of acid. It is effective even in protic solvent like alcohol.

| Reagent | NaBH₄ | NaBH₄ | NaBH₄ | | | | |
|----------|------------|------------|---------------|--|--|--|--|
| Reactant | Aldehyde | Ketone | Acid chloride | | | | |
| Product | 1º alcohol | 2º alcohol | 1º alcohol | | | | |
| | | | | | | | |

(iii) Diisobutyl Aluminium Hydride [DIBAL-H / Inert solvent] :

Diisobutyl aluminium hydride is parallel to LAH (Lithium aluminium hydride) as a reducing agent but it is more selective.

| Reagent | DiBAL- H/Cold | DiBAL- H/Hydrolysis |
|----------|------------------|------------------------|
| Reactant | Ester | Cyanide |
| Product | Aldehyde | Aldehyde |

(a) Ph-CH=CH—COOC₂H₅
$$\xrightarrow{\text{LiAIH}_4-\text{THF}}$$
 Ph-CH₂-CH₂-CH₂OH + C₂H₅OH
 $\int \text{DIBAL-H}$

(b) By DIBAL-H at ordinary temperature esters are reduced to alcohols but at low temperature esters are reduced to aldehyde.

$$C_{6}H_{5} - C_{6}H_{5}CH_{3} \xrightarrow{\text{DIBAL}-H} C_{6}H_{5}CH_{2}OH$$

$$DIBAL-H \downarrow \text{toluene} -78^{\circ}C$$

$$C_{6}H_{5}CHO$$

(c) LAH reduce RCN to amine but DIBAL is found to be reduce it to aldehyde.

2.5 Miscellaneous Reductions :

(i) By Red P & HI :

Used to prepare alkane from acid, acid derivatives and carbonyl compounds.

| Red P & HI | Red P & HI | Red P & HI | Red P & HI | Red P & HI | Red P & HI |
|---------------|---------------|---------------|---------------|---------------|---------------|
| Reactant | Aldehyde | Ketone | Acid chloride | Acidanhydride | Ester |
| Product | Alkane | Alkane | Alkane | Alkane | Alkane |

(a)
$$R - \underset{O}{C} OH \xrightarrow{Red P + HI}{\Delta} R - CH_{3}$$

(b) $R - \underset{O}{C} - CI \xrightarrow{Red P + HI}{\Delta} R - CH_{3}$
(c) $R - \underset{O}{C} - OEt \xrightarrow{Red P + HI}{\Delta} R - CH_{3}$
(d) $R - \underset{O}{C} - R \xrightarrow{Red P + HI}{\Delta} R - CH_{2} - R$
(e) $CH_{3}CH=O \xrightarrow{Red P + HI}{\Delta} CH_{3}CH_{3}$
(f) $CH_{3} - \underset{O}{C} - CH_{3} \xrightarrow{Red P + HI}{\Delta} CH_{3}CH_{2}CH_{3}$

(ii) Meerwein-Pondorf-Verley reduction (Reduction by isopropyl alcohol and aluminium isopropoxide): It is selective reduction of ketones to alcohol, even in presence of other functional groups using Aluminium isopropoxide in isopropyl alcohol.





Note: Wolff-kishner reduction is not preferred used for compounds which have base sensitive groups. [Halogens, Acid halide, Esters, Anhydride]

OXIDATION 3.

3.1 Introduction

(iii)

- 1. oxidation is defined as the addition of oxygen (electronegative) element to a substance or removal of hydrogen (electropositive) element from a substance.
 - or
- 2. Oxidation of an organic molecule usually corresponds to increasing its oxygen content or decreasing its hydrogen content.

$$\operatorname{RCH}_{2}\operatorname{OH} \xrightarrow{(O)} \operatorname{R} - \operatorname{CH} \xrightarrow{(O)} \operatorname{R} - \operatorname{CH} \xrightarrow{(O)} \operatorname{R} - \operatorname{C} - \operatorname{OH}$$

3. Oxidation of an organic compound may be more broadly defined as a reaction that increases its content of any element more electronegative than carbon.

Replacing hydrogen atoms by chlorine atoms is an oxidation

$$\operatorname{Ar}-\operatorname{CH}_{3} \xleftarrow{(O)} \operatorname{ArCH}_{2} \operatorname{CI} \xleftarrow{(O)} \operatorname{ArCHCI}_{2} \xleftarrow{(O)} \operatorname{ArCCI}_{3}$$

When organic compound is oxidised, oxidising agent used is reduced. When an organic compound is reduced, the reducing agent used must be oxidized.

3.2 **Oxidation of Alkanes**

Different products are formed by the use of different oxidising agents or different reaction conditions.

Chemical oxidation with KMnO, or K₂Cr₂O₇ : Alkanes are usually not affected by oxidising agents like KMnO₄ or K₂Cr₂O₇. However, alkanes having tertiary hydrogen are oxidised by these oxidising agents to an alcohol.

$$(CH_3)_3CH \xrightarrow{KMnO_4} (CH_3)_3COH$$

(Isobutane) (Tertiary butyl ald

cohol)

3.3 Oxidation of alkenes and alkynes

(i) Baeyer reagent [cold dilute alkaline KMnO, solution] :

| Baeyer Reagent | Baeyer Reagent | Baeyer Reagent | |
|----------------|----------------|----------------|--|
| Reactant | Alkene | Alkyne | |
| Product | Vicinal diol | Diketone | |

Stereochemistry : syn addition.

Both-OH groups add from same stereochemical side. Note :- Double bond of Aromatic ring cannot react with Bayer's reagent. C = C < + KMnO₄ + [−] OH, H₂O -**General Reaction** C $(or OsO_4, H_2O_2)$ ÓН ÔН (syn addition) ⁻ OH + MnO₂ \downarrow + H₂O Ex. H₂O ОH HO cis-diol

(ii) Osmium tetraoxide in alkaline medium $[OsO_4 / H_2O_2]$: Similar to Baeyer reagent.

| OsO ₄ /H ₂ O ₂ | OsO₄ /H₂O₂ | OsO4 /H ₂ O ₂ | |
|--|---------------|--|--|
| Reactant | Alkene | Alkyne | |
| Product | Vicinal diol | Diketone | |

Note :- Double bond of Aromatic ring cannot react with Osmium tetraoxide in alkaline medium.

Ex.



Cyclohexene

cis-Cyclohexane-1,2-diol

(iii) Oxidation with peroxyacids

An alkene is converted to an epoxide by a peroxyacid. [a carboxylic acid that has an extra oxygen atom in a - O - O - (peroxy) linkage].

General Reaction
$$>C=C< + R - C - O - O - O - H \rightarrow C - C - C + R - C - O - H (acid)$$

 \sim

Some simple peroxyacids (sometimes called peracids) are shown below :

(a)
$$CH_3 - C - O - O - O - O - H$$

peroxyacetic acid
(b) $H - C - O - O - O - O - H$
Peroxy benzoic acid
(c) $H - C - O - O - O - O - H$
Peroxy benzoic acid
(d) $H - C - O - O - O - O - H$
Peroxy benzoic acid
(d) $H - C - O - O - O - O - H$
CI Metachloro perbenzoic acid
(MCPBA)

Note :- Double bond of Aromatic ring cannot react with these reagent.



Stereochemistry : anti addition in diol formation.



Note : The more highly substituted olifinic bond is more nucleophilic and therefore reacts faster with the peroxyacid than the less substituted double bond.



(iv) Oxidation with acidic KMnO₄ [KMnO₄/H⁺] : Stereochemistry : syn addition. When alkene & alkyne heated with KMnO₄ in acidic or in alkaline medium; following changes takes place.

| KMnO₄/H⁺ | KMnO₄/H⁺ | KMnO₄/H⁺ | KMnO₄/H⁺ | KMnO₄/H⁺ | KMnO₄/H⁺ |
|----------|-------------------|----------------------|------------------------|-------------------|--------------------|
| Reactant | $= CH_2 group$ | .= CH R group | $= CR_1R_2$ group | .≡ CH group | .≡ CR group |
| Product | CO ₂ | RCOOH | $O = CR_1R_2$ group | CO ₂ | RCOOH |
| | Carbon dioxide | Carboxylic acid | Ketone | Carbon dioxide | Carboxylic acid |

- **Ex.** RCH= CH₂ $\xrightarrow{[0]}$ CO₂ + H₂O + RCOOH
- **Ex.** RC= CH $\xrightarrow{[0]}$ CO₂ + H₂O + RCOOH
- **Ex.** $RC \equiv C R \xrightarrow{[0]} 2RCOOH$



(v). Oxidation with ozone (ozonolysis) : Alkene & Alkyne

Like permanganate ozone cleaves double bonds to give Ketones and aldehydes. However, ozonolysis is milder, and both Ketones and aldehydes can be recovered without further oxidation.

| | Reductive Ozonolysis Products (O ₃ / Zn, H ₂ O) | | | | | | | | |
|----------------|---|--------------------------|---|--------------------|-------------|--|--|--|--|
| O₃/ Zn, H₂O | O₃/ Zn, H₂O | O₃/ Zn, H₂O | | | | | | | |
| Reactant | $= CH_2 group$ | .= CH R group | $= CR_1R_2$ group | .≡ CH group | .≡ CR group | | | | |
| Product | НСНО | O.= CH R group | O.= CR ₁ R ₂ group | α-keto aldehyde | diketone | | | | |
| | Formaldehyde | Aldehyde | Ketone | Formic acid | diketone | | | | |

| Oxidative Ozonolysis Products | | | | | | | | |
|---|---|---|---|---|---|--|--|--|
| O ₃ /H ₂ O ₂ | | | |
| Reactant | .= CH ₂ group | .= CH R group | $= CR_1R_2$ group | .≡ CH group | .≡ CR group | | | |
| Product | CO ₂ | RCOOH | O.= CR ₁ R ₂ group | CO ₂ | RCOOH | | | |
| | Carbon dioxide | Carboxylic acid | Ketone | Carbon dioxide | Carboxylic acid | | | |

Ex. $C_{_8}H_{_{10}}(A) \xrightarrow{O_{_3, H_2O}} C_{_4}H_{_6}O_{_2}$ Acid (B). Identify (A) and (B) in the above reaction

Sol.

(В) СООН

Ex. A certain hydrocarbon has the formula $C_{16}H_{26}$. Ozonolysis followed by hydrolysis gives $CH_3(CH_2)_4CO_2H$ and succinic acid as the only product. What is hydrocarbon

(A)

≻-c≡c-<

... Molecular structure must be :

 $CH_3(CH_2)_4C \equiv C - CH_2 - CH_2 - C \equiv C(CH_2)_4 - CH_3$

Oxidation Reaction of Alcohols : 3.4

| Oxidation Product of Alcohol-1 | | | | | | | |
|----------------------------------|---------------------------|-------|----------------------|--|----------|------------|--|
| | Weak oxidising agent | | | Strong oxidising agent | | | |
| | PCC* | PDC** | CrO₃/Inert medium | CrO ₃ in water or H ₂ CrO ₄ | KMnO₄/H⁺ | K₂Cr₂O7/H⁺ | |
| 1º alcohol or Primary alcohol | Aldehyde | | | Carboxylic acid | | | |
| 2º alcohol or Secondary alcohol | | Keto | Ketone Ketone | | | | |
| 3º alcohol or tertiary alcohol | Not oxidised Not oxidised | | | | ed | | |

(a) Pyridinium Chloro Chromate (PCC)

(a) Pyridinium Chloro Chromate (PCC)

$$(\bigcirc_{N}$$
 + HCl + CrO₃ $\xrightarrow{\text{Non aquous solvent}}$ $(\bigcirc_{\oplus N}$.CF.CrO₃

Ĥ (b) Pyridinium dichromate (PDC) = $(2C_6H_5N.CrO_3)$

(c) Collin's Reagent = dilute chromic acid + acetone

(d) Jones reagent = CrO_3 + pyridine

(e) MnO₂ = It is Selectively oxidised reagent & oxidised allylic and benzylic alcohol into aldehyde and ketone.

| Oxidation Product of Alcohol-2 | | | | | | | |
|----------------------------------|--|--|--|--|--|--|--|
| | Very-Very Strong oxidising agent KMnO₄/H+/Heat | Copper & heat as oxidising agent | | | | | |
| 1º alcohol or Primary alcohol | Carboxylic acid | Aldehyde | | | | | |
| 2º alcohol or Secondary alcohol | Mixture of Carboxylic acid | Ketone | | | | | |
| 3º alcohol or tertiary alcohol | Mixture of Carboxylic acid | Dehydrate to alkene | | | | | |
| allylic/benzylic alcohol | | | | | | | |

(b) RCHO > RCH₂OH

$$CH_3 - CH_2 - CH_2 - OH \xrightarrow{Cu/\Delta} CH_3 - CH_2 - CH = O$$
 (dehydrogenation)

$$CH_{3} - CH - CH_{3} \xrightarrow{Cu/\Delta} CH_{3} - CH_{3} - CH_{3} \xrightarrow{(dehydrogenation)} (dehydrogenation)$$

$$CH_{3} - CH_{3} \xrightarrow{CH_{3}} CH_{3} \xrightarrow{Cu/\Delta} CH_{3} - CH_{3} \xrightarrow{(dehydrogenation)} (dehydrogenation) \xrightarrow{(dehydrogenation)} (dehydrogenation)$$

Oppenaur's oxidation

(i) This reaction involves the oxidation of a secondary alcohol with a ketone and base to the corresponding ketone.

(ii) Commonly used bases are aluminium tert-butoxide.

 $\begin{array}{c} \text{Al}(\text{OCMe}_{3})_{3} \\ \text{R}_{2}\text{CHOH} + (\text{CH}_{3})_{2}\text{CO} & \overset{\text{Al}(\text{OCMe}_{3})_{3}}{\overset{\text{CO}}{\longleftarrow}} \\ \text{R}_{2}\text{CO} + \text{CH}_{3}\text{CH}(\text{OH})\text{CH}_{3} \\ \text{2}^{0}\text{Alcohol} & \text{Acetone} \\ \end{array}$

Rate of Oxidation

(a) $RCH_2OH > R_2CHOH > R_3C - OH$ (inert)

Ex. Write the product of following reactions.

$$CH_{3} - CH = CH - CH_{2} - CH_{2} - OH$$

$$(X)$$

$$X \xrightarrow{K_{2}Cr_{2}O_{7}} (H_{3} - CH_{3} - CH_{2} - OH_{2} - CH_{2} - CH_{2} - CH_{2} - CH_{2} - CH_{2}$$

$$X \xrightarrow{PCC} (H_{3} - CH_{3} - CH_{3} - CH_{2} - CH_{2} - CHO$$

$$X \xrightarrow{Oppenauer \ oxidation} (G) CH_{3} - CH_{3} - CH_{3} - CH_{2} - CHO$$

$$X \xrightarrow{CrO_{3} / aq.} (H_{3} - CH_{3} - CH_{3} - CH_{2} - CH_{2} - CHO)$$

$$X \xrightarrow{CrO_{3} / aq.} (CH_{3} - CH_{3} - CH_{3} - CH_{2} - CH_{2} - CHO)$$

$$X \xrightarrow{MnO_{2}} (S) CH_{3} - CH_{3} - CH_{3} - CH_{2} - CH_{2} - OH$$

$$H \xrightarrow{O}$$

(i) Acidic KMnO₄ & $K_2Cr_2O_7$ as oxidising agent :

Aldehydes are oxidised to carboxylic acid having same number of C atoms as aldehyde.

HCHO + [O] \longrightarrow HCOOH ; RCHO + [O] \longrightarrow RCOOH Ketones are oxidised with difficulty. They are oxidised only on heating with a strong oxidising agent.

$$CH_{3} - C - CH_{3} + [O] \xrightarrow{Cr_{2}O_{7}^{2-} + H^{+}} CH_{3}COOH + CO_{2} + H_{2}O$$

In case of mixed or unsymmetrical ketones the >C = O group remains with the smaller alkyl group. (Popoff's rule)

 $\mathsf{CH}_3\mathsf{COCH}_2\mathsf{CH}_3 \xrightarrow{[\mathsf{O}]} 2 \ \mathsf{CH}_3\mathsf{COOH} \ ; \ \ \mathsf{CH}_3\mathsf{COCH}_2\mathsf{CH}_2\mathsf{CH}_3 \xrightarrow{[\mathsf{O}]} \mathsf{CH}_3 \ \mathsf{COOH} + \mathsf{CH}_3 \ \mathsf{CH}_2 \ \mathsf{COOH}$

(i)
$$\operatorname{CrO}_{3} + \operatorname{H}_{2}O \longrightarrow \operatorname{H}_{2}\operatorname{CrO}_{4} = \begin{bmatrix} O \\ HO - Cr - OH \\ U \end{bmatrix}$$

(ii) $\operatorname{R} - \operatorname{C}_{H} - O \xrightarrow{H} + H - O \xrightarrow{H} + O \xrightarrow{H} O \xrightarrow$

Remarks :

- (1) Primary alcohol forms a chromate ester with chromic acid.
- (2) The chromate ester decomposes in 2^{nd} slow step with the elimination of α -hydrogen. So the first oxidation product, an aldehyde is obtained.
- (3) In **aqueous medium**, aldehyde forms a gemdiol (hydrated aldehyde). It is further oxidised to an acid by similar mechanism.
- (4) The following reactivity orders can be explained by this mechanism :

Rate of Oxidation

(a) $R - CH_2OH > R - CD_2OH$ (Bond Energy : C - H < C - D) (b) RCHO > RCDO

(ii) With Tollen's reagent :

RCHO (aldehydes) can be easily oxidised to RCOOH (except HCHO that can be oxidised to CO_2) by weak oxidising agents like ammonical AgNO₃ (**Tollen's reagent**) hence they are better reducing agents.

Aldehydes reduce Tollen's reagent to Ag and appears in the form of silver mirror is called **silver-mirror test.** It is given by all aldehydes and reducing sugars.

RCHO + 2[Ag(NH₃)₂⁺] + 3OH⁻
$$\longrightarrow$$
 RCOO⁻ + 2Ag \downarrow + 4NH₃ + 2H₂O

(iii) With Fehling Solution :

Aldehydes (except benzaldehyde) reduce **Fehling's** solution (Cu^{2+} reduced to Cu^{+}) which is an alkaline solution of cupric (Cu^{2+}) ion complexed with tartrate ion.

$$\mathsf{RCHO} + 2\mathsf{Cu}^{2+} + 3\mathsf{OH}^{-} \xrightarrow{\Delta} \mathsf{RCOO^{-}} + \mathsf{Cu}_2\mathsf{O} \downarrow + 2\mathsf{H}_2\mathsf{O}$$

red ppt.

Aldehydes also reduce Benedict's solution (Cu2+ complexed with citrate ion) to Cu+

3.5 Oxidation reaction of diols

(i) HIO_4 oxidation :

(Oxidation by lead acetate is similar to HIO₄ oxidation)



cyclic periodate ester

Remarks

- (1) HIO_4 (periodic acid) oxidises vicinal diols (1, 2-diols).
- (2) It brings about oxidative cleavage of vicinal diol.
- (3) It can also oxidise α -hydroxy carbonyl compound, α -dicarbonyl compound and α -hydroxy acid.
- (4) HIO_4 forms a cyclic periodate ester as an intermediate. So the two –OH groups should have synconformation.
- (5) In cyclic diols only cis-vicinal diols are oxidised. Trans isomers are not oxidised.

Ex. General reaction

Ex.

3.6 Baeyer–Villiger oxidation General reactions :

> RCHO $\xrightarrow{O. A.}$ RCOOH R-C-R' $\xrightarrow{O. A.}$ R-C-OR'

-C–OR' Priority of shift (O accepting aptitude)

R or R' = H > Ph > 3° > 2° > 1° >Me

O.A. = Oxidizing agent. Proxy acids as an oxidising agent may be one of these

(a)
$$O^{CO_3H} = m$$
-CPBA (Metachloro perbenzoic acid)

(b) $CH_3CO_3H = PAA$ (Peracetic acid)

4. HYDROLYSIS

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(i) Introduction :

Hydrolysis is a chemical reaction or process in which a **molecule splits into two parts** by reacting with a molecule of water, (H_2O). One of the parts gets OH^- from the water molecule and the other part gets H^+ from the water.Such reactions are endothermic.

This is distinct from a hydration reaction, in which water molecules are added to a substance, but no fragmentation of molecule/species occurs.Such a process is exothermic.

(ii) Hydrolysis of an ester :

Hydrolysis of an ester involves breaking off an ester link. It can takes place in



(a) Mild acidic medium : Dilute $H_{2}SO_{4}$, dilute HCl.

(b) Strong alkaline medium : Aqueous NaOH or KOH and heat.

one hydrolysis product contains a hydroxyl functional group, while the other contains a carboxylic acid functional group.



(iii) Hydrolysis of an anhydride :

The hydrolysis of acid anhydride produces two carboxylic acids.



(iv) Hydrolysis of acid halide :

Hydrolysis of an acid halide results into a carboxylic acid and hydrogenhalide. Only the carboxylic acid product has a hydroxyl group derived from the water. Hydrohalic acid product gains the remaining hydrogen ion.

$$R = C + CI \xrightarrow{H \longrightarrow H} R = C - OH + HCI$$

(v) Hydrolysis of acid amide :

Hydrolysis of an amide results into a carboxylic acid and an amine product or ammonia, only the carboxylic acid product has a hydroxyl group derived from the water. The amine product (or ammonia) gains the remaining hydrogen ion.

$$R = C + NH_2 + MH_2 + R = C - OH + NH_3$$

(vi) Hydrolysis of cyanides :

Cyanide on hydrolysis produce ammonia and carboxylc acids. It is carried out in acidic medium generally but hydrolyse in basic medium also.

$$R - C \neq N \xrightarrow{3H \longrightarrow 0} H, H^{+} R = \bigcup_{i=0}^{U} OH_{+} NH_{3}$$

(vii) Hydrolysis of isocyanides :

Isocyanides on hydrolysis produce Primary amines and formic acids. It is carried out in acidic medium.

$$R - N \neq C \xrightarrow{3H \longrightarrow 0} H, H^{+} H \longrightarrow C \longrightarrow 0H + RNH_{2}$$

Note: Alkylisocyanide does not hydrolyse in basic medium.

(viii) Hydrolysis of Ethers :

Ethers has R-O-R group. In strong acidic medium (HI or HBr) in hydrolysis to produce 2 equivalent of alcohols.

(ix) Hydrolysis of Hemiacetals and Acetals :

Hemiacetals and Acetals has R-O-R group.

Hemiacetals are unstable and get hydrolysed to aldehyde/ketones even in aq medium. However acetals /Ketals are stable and hydrolyse only in strong acidic medium (HI or HBr) to produce 2 equivalent of alcohols and one equivalent of aldehyde/ketone. Acetals are often used as protecting groups.



| Functional Groups | Reactant | Bond Broken | Products | Products | Catalysis |
|---------------------------------------|---------------------------|-------------|----------------------------------|-----------------------------------|---------------------|
| Alkyl Halides | R—−CI | C-Hal | R | Alcohol and Hydrogen Halides | Basic |
| Ethers | $R \sim R^{1}$ | C-0 | $R^{O}H^{+}H^{O}R^{1}$ | Alcohols or Phenols | Strong acidic HI |
| Acid Halides | R | C-Hal | R OH + HCI | Acids and Hydrogen Halides | Basic |
| Acid Anhydrides | $R \rightarrow 0$ R^{1} | C-0 | R OH HO R^1 | Acids | Acidic or basic |
| Nitriles/Cyani des | RC | IC≡N | RC + NH ₃ | Acids and Ammonia | Acidic |
| Esters | | C-0 | $R^{1} O^{H} + H_{O}^{R}$ | Acids and Alcohols | Acidic or basic |
| Amides Amides and N-substituted | | C-N | R^{1} O H $+$ H NH R | Acids and Ammonia or Amines | Strong Acidic |
| Isonitriles /isocyanides | | IC≡N | R—NH _{2 +} , он | Formic acid and Primary amines | Acidic |

HYDROLYSIS OF COMMON FUNCTIONAL GROUPS

CHEMISTRY FOR NEET

GRIGNARD REAGENT

| Metal Alkyl Halides | RMgBr | M-C | R—H | Hydrocarbons and Metal Hydroxides | H ₂ O |
|------------------------|-------|-----|-----|---|------------------|
| Metal Alkyls | R—Li | M-C | R—H | Hydrocarbons and Metal Hydroxides | H ₂ O |