→ Organometallic compounds :-

- Organic derivatives of a metal having at least one metal-carbon bond are called organometallic compounds.
- The nature of metal - carbon bond is depends largely upon the difference in electronegativities of the metal and the carbon.

$$\underset{\text{Covalent}}{C-M} \longleftrightarrow \underset{\text{Ionic}}{C^{\ominus}:M^{\oplus}} \equiv C^{-\delta}-M^{+\delta}$$

- If metal is more electropositive, then the more ionic is the C-M bond.

→ Organomagnesium compounds : The Grignard reagents :-

- The alkyl or arylmagnesium halide, R (or Ar) - Mg - X also known as Grignard reagents.
- Victor Grignard introduced Grignard reagents as synthetic reagents in organic chemistry.

→ Formation :-

- A Grignard reagent is prepared by adding an alkyl or aryl halide to a flask containing suspension of magnesium turnings in dry ether.

$$R-X + Mg \xrightarrow{\text{Ether}} R-Mg-X$$

$$Ar-X + Mg \xrightarrow{\text{Ether}} Ar-Mg-X$$

- Other solvents like THF, tertiary amines, ethylene glycol, dimethyl ether have also been used.
- The best solvent is THF as it increases the reactivity of organic halides towards magnesium.

- If the preparation of a particular Grignard reagent is difficult, addition of one or two drops of methyl iodide or crystal of iodine will initiate the reaction. This technique is known as entertainment technique.
- The ease of the formation of Grignard reagent depends on many factors including nature of alkyl or aryl group and the halogen atom.

For a given halogen increase in the number of carbon atoms makes the formation of the Grignard reagent rather difficult and for a particular alkyl group the ease of formation follows the order. $I > Br > Cl$

The alkyl (aryl) magnesium fluorides are practically unknown.

→ Precautions:-

- The apparatus should be dried.
- The aryl or alkyl halide, magnesium and ether should be free from even traces of moisture.
- Ether is also free from alcohol.
- The reaction should be carried out in atomosphere of dry nitrogen (free from O_2 and CO_2).

The above precautions are absolutely essential. because grignard reagent decomposed by moisture and reacts with O_2 and CO_2 to form alcohols and carboxylic acids respectively.

— Mechanism:-

- The mechanism of formation of Grignard reagent is uncertian.
- According to Gomberg and Beckmann the reaction takes place by free radical mechanism.

- The reaction is initiated by $\dot{M}gx$ which is produced by interaction of Mg with MgX_2 also formed in situ.

$$R-X + Mg + X-R \longrightarrow R-R + MgX_2$$

$$MgX_2 + Mg \longrightarrow 2\dot{M}gX$$

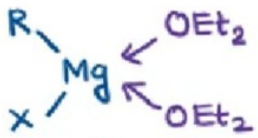
$$R-X + \dot{M}gX \longrightarrow \dot{R} + MgX_2$$

$$\dot{R} + \dot{M}gX \longrightarrow RMgX$$

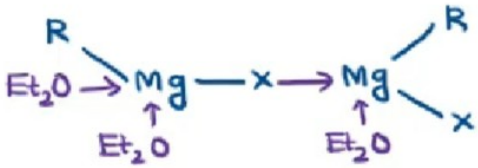
This mechanism also explains the role of iodine as initiator (entertainment technique) which may form magnesium iodide by reacting with magnesium.

→ Structure:→

- Grignard reagents are represented by the general formula R-Mg-X.
- Attempt to isolate these compounds show that they contain ether, commonly known as ether of crystallisation.
- The following three alternative formulation have been proposed.



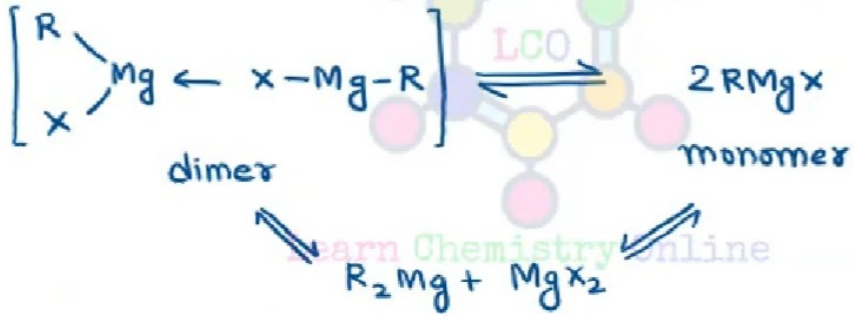
I
monomer



II
dimer

III
dimer

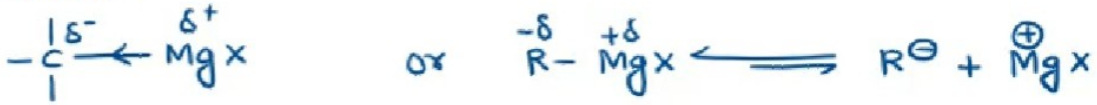
- Structure I shows the simplest structure of monomeric form which is formed by coordinating with two molecules of ether.
- In structure II, the halogen atom coordinates with the magnesium atom of other.
- In structure III, the compound is considered as existing in a 1:1 complex of dialkyl or diaryl magnesium and magnesium halide. The halogen atoms of magnesium halide coordinate with magnesium atom of dialkyl or diaryl magnesium.
- In addition to these structures, it has been proposed that the composition of Grignard reagents in ether may be represented by the following equilibria.



- The crystalline Grignard reagents have been isolated by evaporation of their etheral solution.
- The structure of Grignard reagent is determined by X-Ray diffraction technique.
- This study shows that these compounds exist as $RMgX.2Et_2O$ but for convenience we use the formula R-Mg-X.

→ Reactions of Organomagnesium compounds (Grignard reagent):→

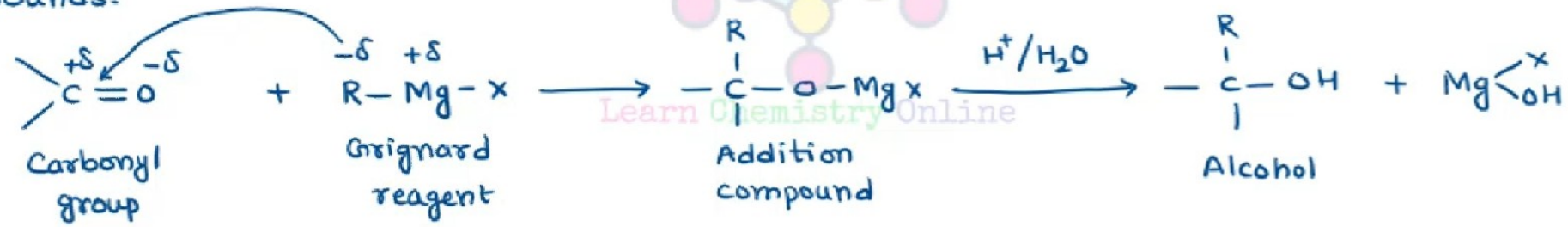
- Due to large difference in electronegativity of carbon (2.5) and magnesium (1.2), the C–Mg bond is highly polar as shown-



Due to greator electron density around the carbon atom of the alkyl group in Grignard reagent behave as carbanion or a nucleophile and hence, the main reactions of these reagents are either nucleophilic addition or nucleophilic substitution reactions.

(i) Nucleophilic Addition reactions:-

- Grignard reagent combines with compound containing double bond to form addition compounds.



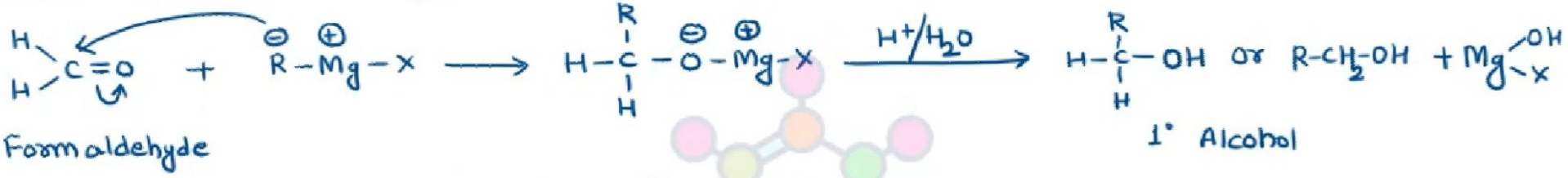
(ii) Nucleophilic substitution reactions:-

- Due to carbanion character of alkyl group, Grignard reagent attacks as nucleophile on postively charged centers having an acidic hydrogen or halogen attached to them.

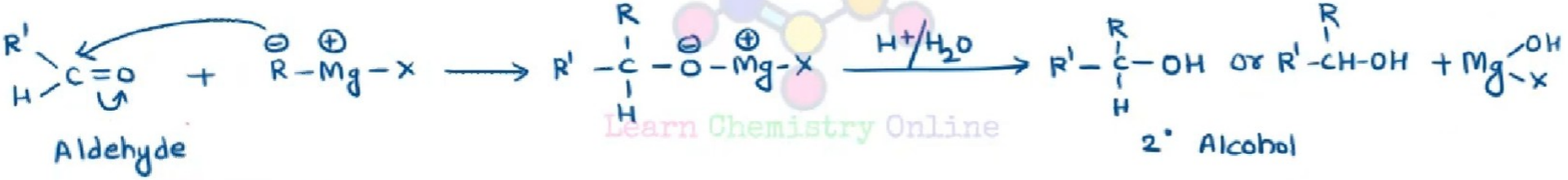
→ Synthetic applications of organomagnesium compounds (Grignard reagents):-

1. Synthesis of alcohols and ketones. (Nucleophilic addition):-

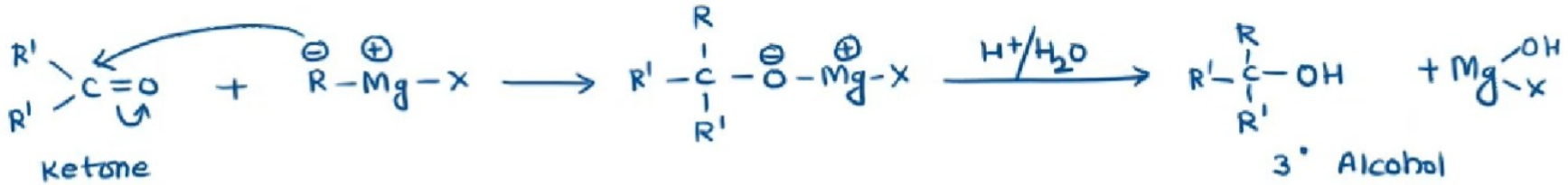
(a) Reaction with formaldehyde



(b) Reaction with aldehyde other than formaldehyde:-

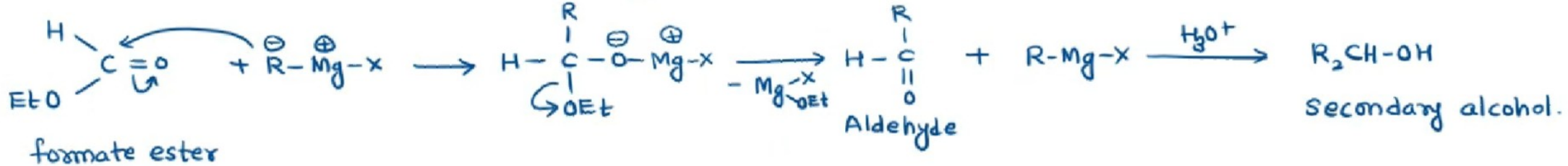


(c) Reaction with ketone



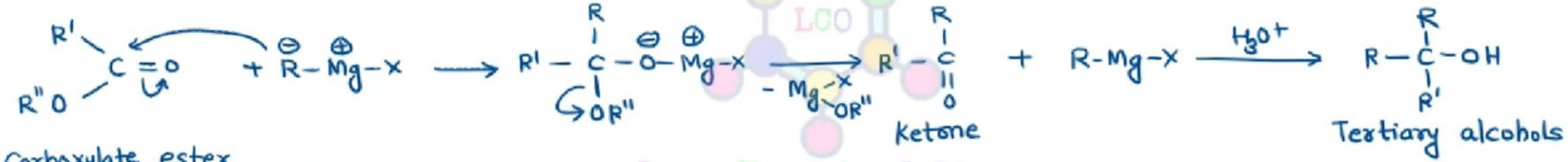
(d) Reaction with ester:-

- Reaction of formate ester with Grignard reagents (1:2):-



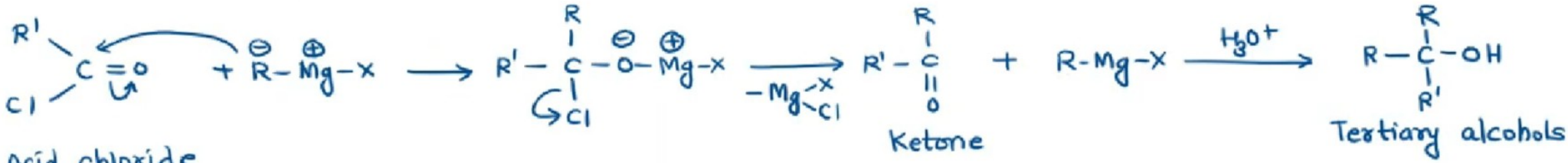
formate ester

- Reaction of formate ester with Grignard reagents (1:1) gives aldehyde.
- Reaction of carboxylate ester with Grignard reagents (1:2) gives tertiary alcohol.



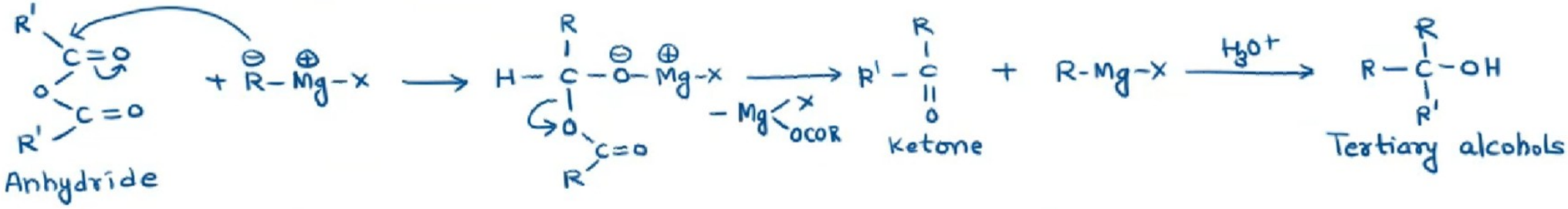
Carboxylate ester

(e) Reaction with acid chlorides:-

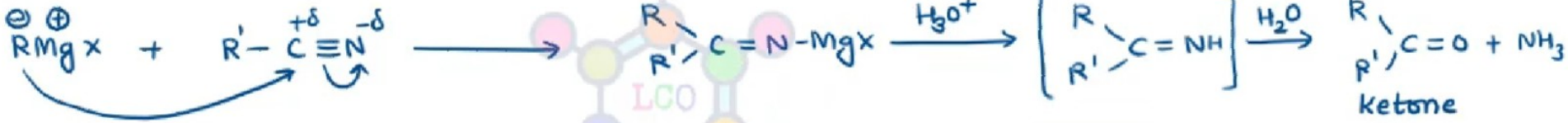


Acid chloride

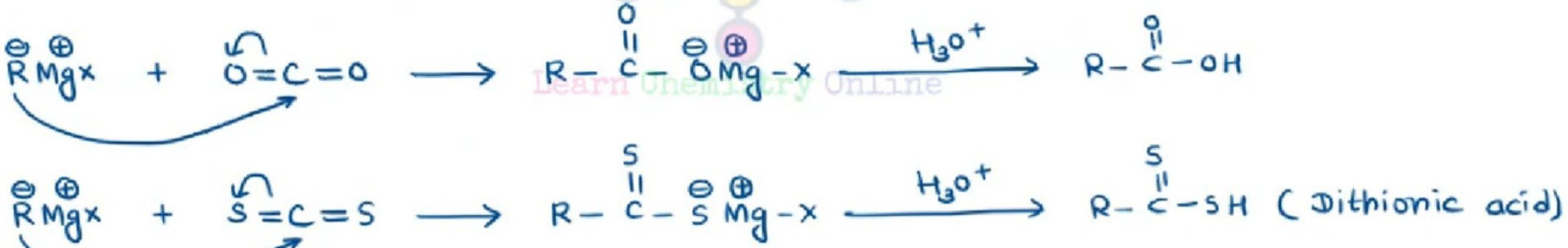
(f) Reaction with acid anhydrides:-



2. Nucleophilic addition to nitriles:-



3. Reaction with CO_2 and CS_2:-



4. Reaction with oxygen, sulphur and halogen:-

$$8\,RMgX + S_8 \longrightarrow 8\,RSMgX \xrightarrow{H_3O^+} 8\,RSH \quad (\text{Thio alcohol})$$

$$RMgX + X_2' \longrightarrow RX' + Mg\langle^{X}_{X'}$$

5. Nucleophilic displacement :-

$$R\text{-}\overset{\ominus}{M}\overset{\oplus}{g}\text{-}X + R'\text{-}X \longrightarrow \underset{\text{hydrocarbon}}{R\text{-}R'} + MgX_2$$

6. Reaction with epoxide :-

$$\overset{\ominus}{R}\overset{\oplus}{M}gX + CH_2\text{-}CH_2 \longrightarrow R\text{-}CH_2\text{-}CH_2\text{-}O\overset{\ominus}{M}\overset{\oplus}{g}X \xrightarrow{H_3O^+} R\text{-}CH_2\text{-}CH_2\text{-}OH + Mg\langle^{OH}_{X}$$

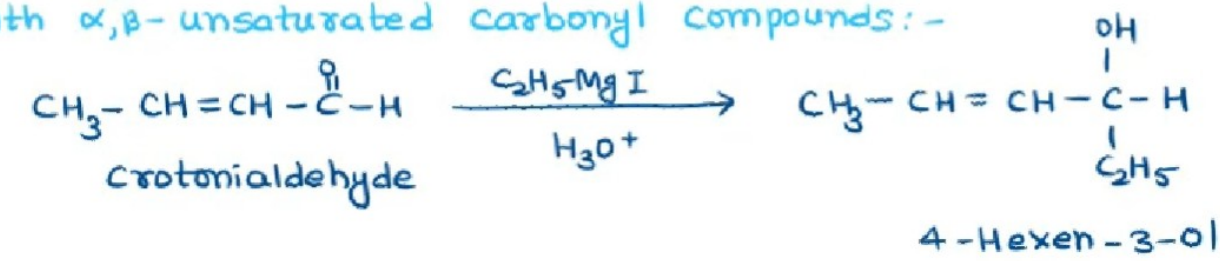
7. Reaction with compounds containing active hydrogen (acidic hydrogen):-

$$RMgX + H_2O \longrightarrow R\text{-}H + Mg\langle^{OH}_{X}$$

Grignard reagent containing strong Carbon base

-This reaction is used for conversion of an alkyl halide into a hydrocarbon.

8. Reaction with α,β- unsaturated carbonyl compounds :-



Crotonialdehyde

4-Hexen-3-ol

→ Limitations in the uses of Grignard synthesis :-

- These reagents are highly sensitive to moisture, oxygen and CO_2. Due to this problem the handling of Grignard reagent becomes difficult.
- Presence of bulky groups near the functional group hinder the approach of the reagent.
- Nitro compounds can not be used in Grignard synthesis since they oxidize these reagents.
- These reagents cannot be prepared from alkyl halides containing functional groups with which they are react.

→ Organozinc compounds :-

- Organozinc compounds (R_2Zn) are used as reagent in organic synthesis.

→ Formation:-

1. From alkyl haides:-

$$RI + Zn \text{ fillings} \longrightarrow RZnI$$

Alkylzinc iodide

$$2RZnI \xrightarrow[\text{distillation}]{CO_2} R_2Zn + ZnI_2 \text{ (disproportionation reaction)}$$

- In a less hazardous procedure, high boiling ether is used as solvent and zinc-copper alloy is used in place of metallic zinc

2. From organoaluminium compounds :-

$$2\,R_3Al + ZnCl_2 \longrightarrow R_2Zn + 2R_2AlCl$$

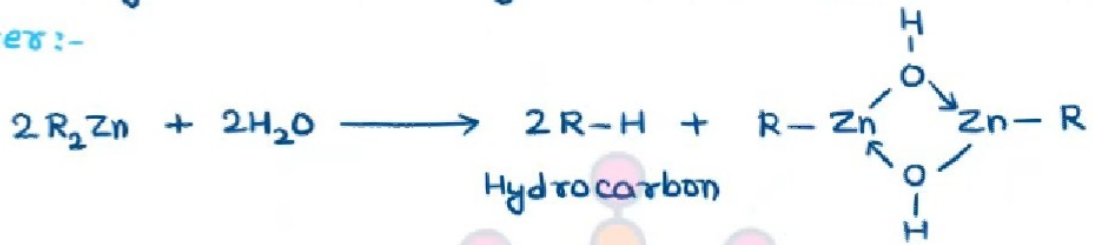
→ Physical properties:-

- Organozinc compounds have linear geometry because zinc atom is sp hybridised.
- These compounds can exist in higer coordination if combines with electron-donor molecules.
- Non-polar
- low m.p an b.p.
- Soluble in organic solvents.
- The lower zinc compounds are highly inflammable in air, therefore prepared and used under CO_2 atomsphere.

→ Chemical reactions:-

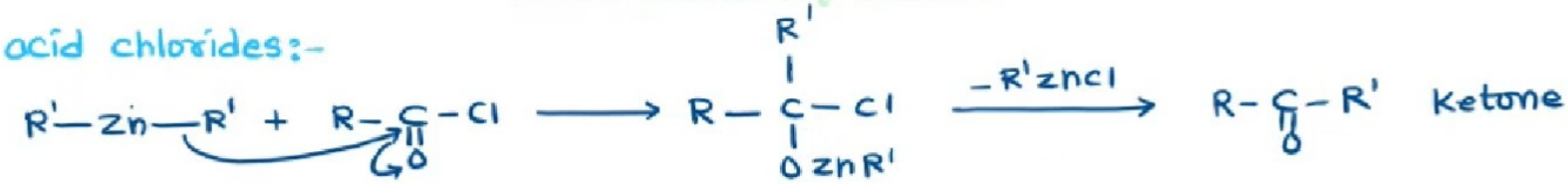
- Organozinc compounds show similar reactions to those of the Grignard reagent but reactivity of organozinc compounds is less than Grignard reagents. For example, they do not react with CO_2 and and only slowly react with cyanides, ketones and esters.

1. Reaction with water:-



2. Reaction with alkyl halides:-

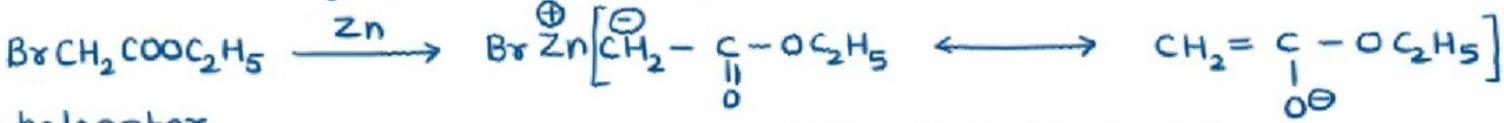
3. Reaction with acid chlorides:-



- The reaction of dialkylzinc derivatives with esters, cyanides etc. is extremely slow and hence, they have practically no synthetic importance.

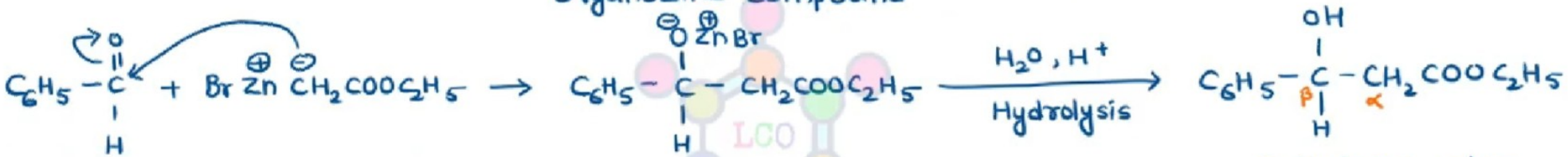
4. Reformatsky reaction : Formation of β-hydroxyesters :-

- If an aldehyde or ketone is added to a solution of an α-haloester in presence of zinc, a nucleophilic addition reaction is takes place giving a β-hydroxy ester. This reaction is known as Reformatsky reaction.



α-haloester

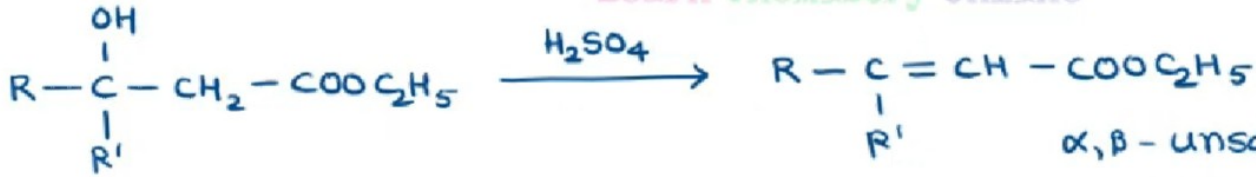
Organozinc compound



Benzaldehyde

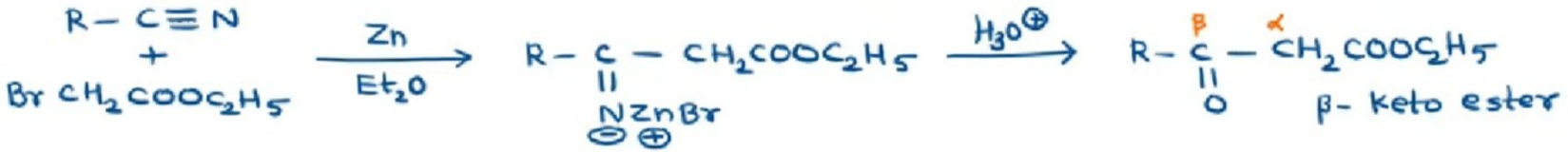
β-Hydroxy ester

- Dehydration of β-hydroxy ester gives α,β-unsaturated esters.



α,β-unsaturated esters.

- The Reformatsky reaction is also known to occur with nitriles to give β-keto ester.



β-keto ester

→ Iodomethylene zinc iodide :→

- An important organozinc compound is iodomethylenezinc iodide, ICH_2ZnI.
- It reacts with olefins to form cyclopropane derivatives.

→ Organolithium compounds:→

- Organolithium compounds are the most important reagents for organic synthesis.
- These reagents are more reactive than Grignard reagents.
- They possess a polar-covalent carbon-lithium bond and are represented by the general formula R-Li where R may be an alkyl or aryl group.

→ Formation:-

1. From alkyl or aryl haide:-

$$R-X + 2Li \xrightarrow[\text{Argon}]{N_2 \text{ or}} R-Li + LiX$$

$$Ar-X + 2Li \xrightarrow[\text{"}]{\text{"}} Ar-Li + LiX$$

2. By halogen-metal exchange reaction:-

$$R-X + R'-Li \longrightarrow R'-X + R-Li$$

3. Direct metallation:-

→ Physical properties:→

- Organolithium compounds are either liquids or low-melting solids which are readily soluble in non-polar hydrocarbon solvents.

→ Chemical reactions:→

- Because of strong bond polarisation and small size of lithium, alkyllithium compounds exist as polymeric aggregates of two or more molecules in solution as well as in gas phase.

1. Reaction with acidic substances:-

- Like Grignard reagents, alkyllithium compounds show basic nature and react with acidic substances.

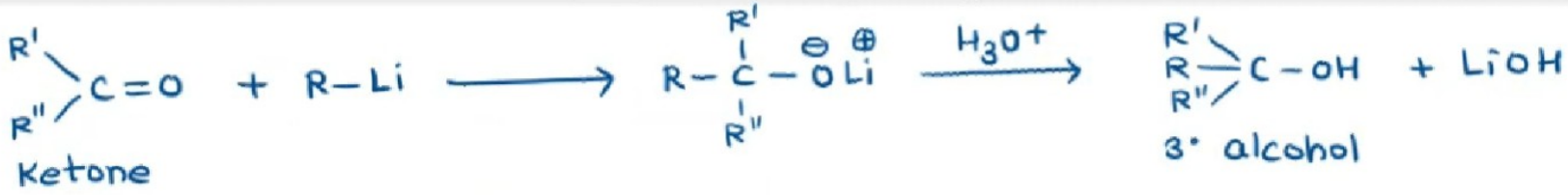
$$R^{-\delta}-Li^{+\delta} + H^{+\delta}-A^{-\delta} \longrightarrow R-H + LiA$$

2. Reaction with carbonyl compounds:-

- Like Grignard reagents, alkyllithium compounds react with carbonyl compounds to form alcohols.

$$\underset{\text{Formaldehyde}}{H_2C=O} + R-Li \longrightarrow R-CH(H)-O^{\ominus}Li^{\oplus} \xrightarrow{H_3O^+} \underset{1^\circ \text{ alcohol}}{R-CH_2-OH} + LiOH$$

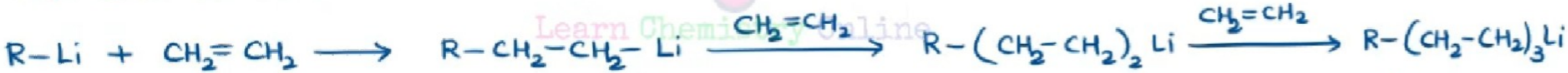
$$\underset{\text{Aldehyde}}{R'HC=O} + R-Li \longrightarrow R-CH(R')-O^{\ominus}Li^{\oplus} \xrightarrow{H_3O^+} \underset{2^\circ \text{ alcohol}}{R'RCH-OH} + LiOH$$



- The alkyllithiums have an advantage over Grignard reagents.
- Grignard reagents fail to give tertiary alcohols when react with highly hindered ketones while alkyllithiums easily react with highly hindered ketone to give tertiary alcohols.
- Thus these compouds are less affected by steric hinderance than Grignard reagents.

3. Reaction with CO_2:-

4. Reaction with alkenes:-



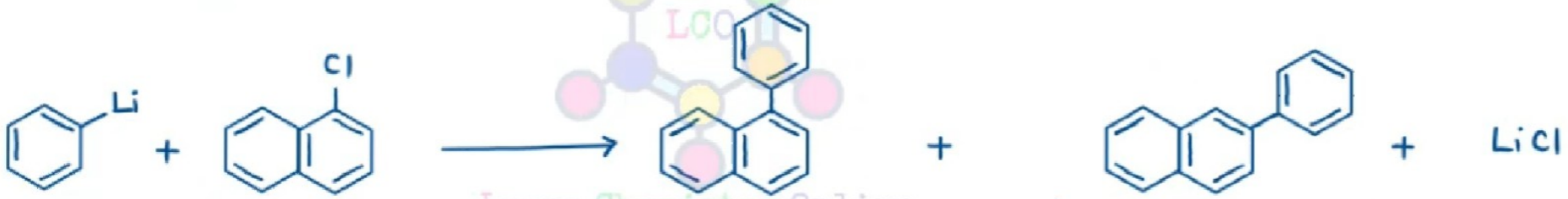
5. Metal-halogen exchange: Electrophilic substitution:-

6. Nucleophilic substitution:-

- Alkyllithium compounds can be used in substitution reactions of alkyl halides.
- Grignard reagents do not this substitution reaction.
- The mechanism is quite similar to mechanism of Wurtz reaction. (S_N2 mechanism).

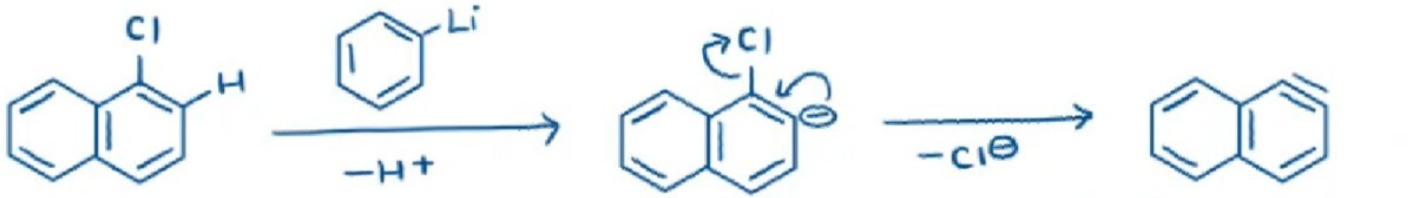
$$R-Li + R'-X \longrightarrow \underset{\text{Hydrocarbon}}{R-R'} + LiX$$

Example:- Reaction of Phenyllithium with 1-chloronaphthalene gives a product containing both 1-phenylnaphthalene and 2-phenylnaphthalene.

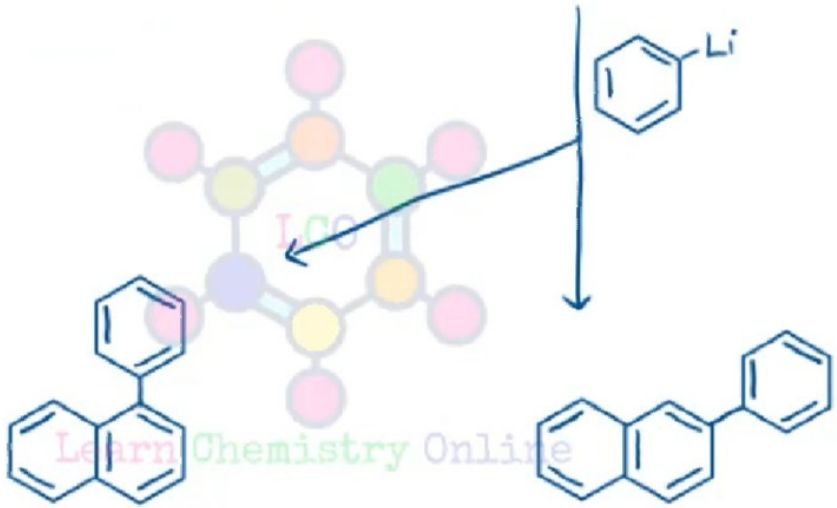


1(α)-phenylnaphthalene 2(β)-Phenylnaphthalene.

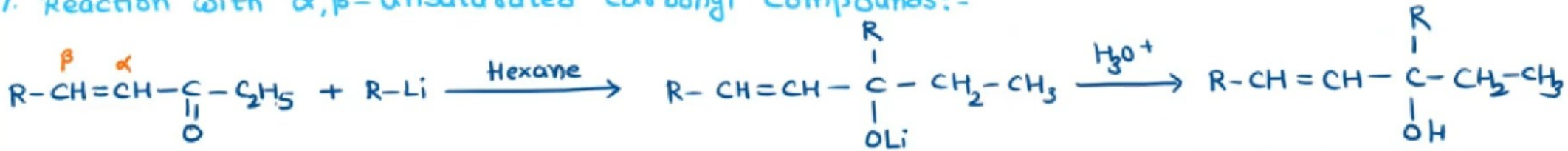
- The above reaction does not takes place through normal aromatic substitution reaction. It rather takes place via an elimination-addition mechanism involving naphthyne.



1 - Naphthyne



7. Reaction with α,β- unsaturated carbonyl compounds:-



unsaturated alcohol