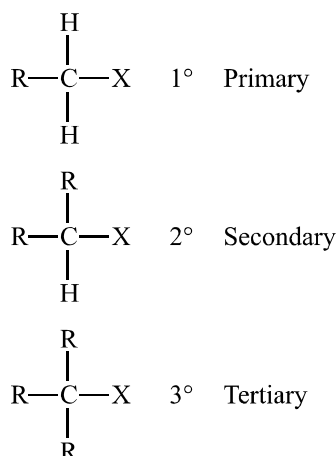


# ALKYL HALIDE

## 1. INTRODUCTION

The **alkyl halides** or **haloalkanes** are a group of chemical compounds, derived from alkanes containing one or more halogens. They are used commonly as flame retardants, fire extinguishers, refrigerants, propellants, solvents and pharmaceuticals. The alkyl halides are classified broadly into three categories based on type of carbon atom to which the halogen atom is attached.



X may be F, Cl, Br or I.

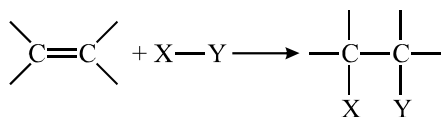
## 2. REACTIONS IN ORGANIC CHEMISTRY

There are various types of reactions possible in organic compounds depending on reaction conditions and attacking reagent. Reactions in organic chemistry are classified into three categories :

### 2.1 Addition Reaction

This reaction involves addition of groups to a  $\pi$  bond.

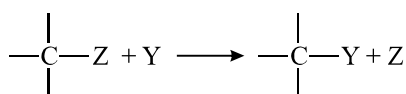
#### Example - 1



### 2.2 Substitution Reaction

This reaction involves the replacement of an atom or a group of atoms by another atom or group of atoms.

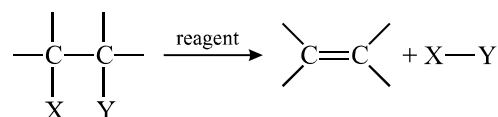
#### Example - 2



### 2.3 Elimination Reaction

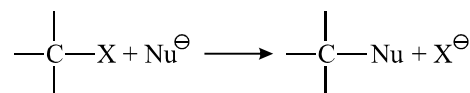
This reaction involves the loss of atoms or groups of atoms to form an unsaturated compound.

#### Example - 3



## 3. NUCLEOPHILIC SUBSTITUTIONS REACTIONS

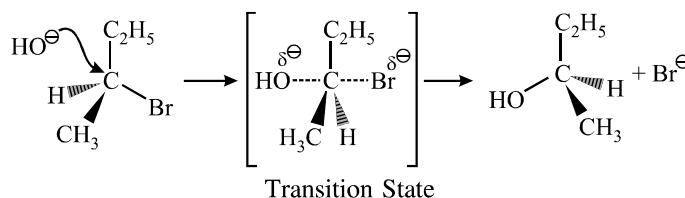
#### Example - 4



The replacement of halogen atom (leaving group) by the attacking nucleophile is called nucleophilic substitution reaction at  $\text{sp}^3$  carbon. This reaction was studied in great detail and two extreme mechanisms have been outlined to explain the course of the reaction.

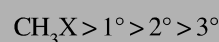
### 3.1 Substitution Nucleophilic Bimolecular – $\text{S}_\text{N}2$

#### Example - 5



#### Key Features of $\text{S}_\text{N}2$ Mechanism

1. Single step reaction.
2. Rate =  $k[\text{RX}][\text{Nu}]$
3. No intermediate is formed. Reaction goes through a transition state.
4. Rearrangement is not observed.
5. Inversion of configuration is observed.
6. Order of reactivity of alkyl halides :



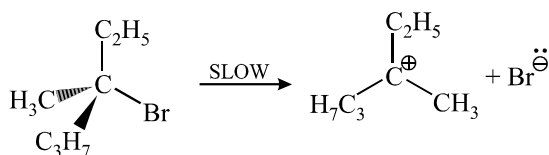
This can be attributed to the steric hinderance to back side attack of nucleophile.

7. Favoured by aprotic solvents.

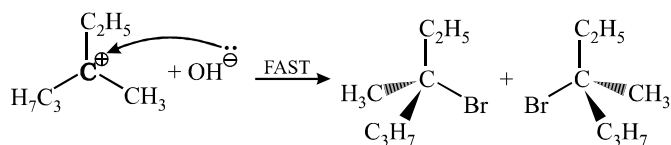
3.2 Substitution Nucleophilic Unimolecular – S<sub>N</sub>1

## Example - 6

Step 1 :

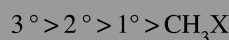


Step 2 :


*Note...*

 Key Features of S<sub>N</sub>1 Mechanism

- Two step reaction. First step is the formation (and rearrangement) of carbocation while second step is the attack of nucleophile on the carbocation.
- Rate =  $k[\text{RX}]$
- Carbocation is formed.
- Rearrangement is commonly observed.
- Racemic mixture is obtained.
- Order of reactivity of alkyl halides :

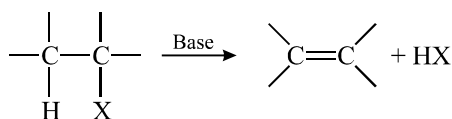


This can be attributed to the stability of the carbocation that is formed.

- Favoured by protic solvents.

## 4. ELIMINATION REACTIONS

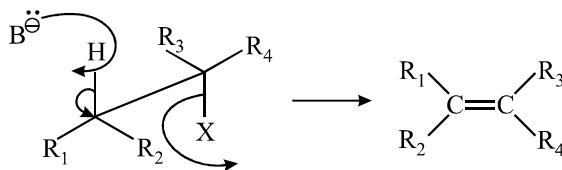
## Example - 7



The removal of halogen from the carbon to which it is attached along with the removal of hydrogen from adjacent carbon is called  $\alpha$ ,  $\beta$ -elimination or simply elimination. Three mechanisms have been outlined for elimination reactions.

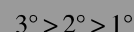
## 4.1 Elimination Bimolecular – E2

## Example - 8


*Note...*

## Key Features of E2 Mechanism

- Single step reaction.
- Rate =  $k[\text{RX}][\text{Base}]$
- No intermediate is formed. Reaction goes through a transition state.
- Rearrangement is not observed.
- Observed in presence of strong bases.
- Order of reactivity of alkyl halides :



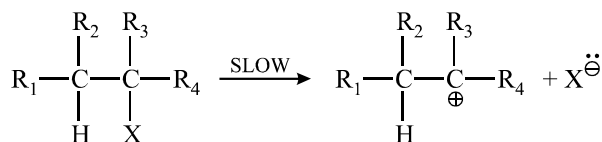
This can be attributed to the stability of alkene formed.

- Favoured by aprotic solvents.

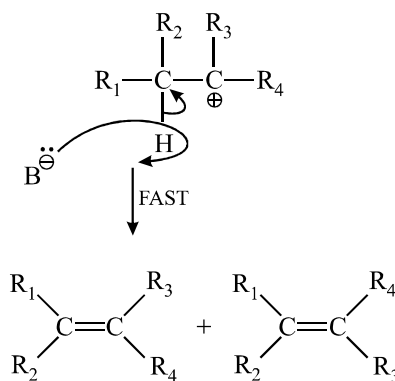
## 4.2 Elimination Unimolecular – E1

## Example - 9

Step 1 :



Step 2 :

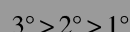


## ALKYL HALIDE

*Note..*

### Key Features of E1 Mechanism

- Two step reaction. First step is the formation of carbocation while second step is the loss of proton by a base.
- Rate =  $k[\text{RX}]$
- Carbocation is formed.
- Rearrangement is commonly observed.
- Observed in presence of weak bases.
- Order of reactivity of alkyl halides :



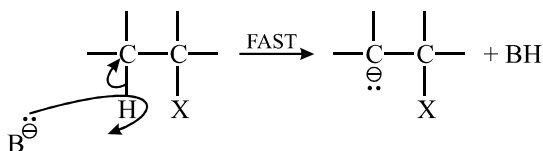
This can be attributed to the stability of carbocation as well as the stability of alkene formed.

- Favoured by protic solvents.

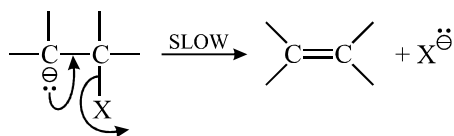
### 4.3 Elimination Unimolecular via Conjugate Base – E1cB

#### Example - 10

Step 1 :



Step 2 :



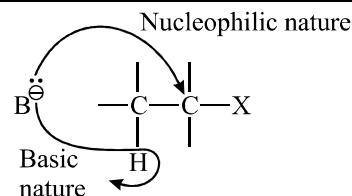
*Note..*

### Key Features of E1cB Mechanism

- Two step reaction. First step is the formation of carbanion and second step is the loss of leaving group.
- Rate =  $k[\text{RX}][\text{Base}]$
- Carbanion is formed.
- Occurs when poor leaving group is present.

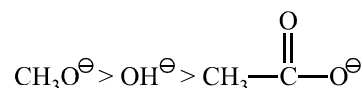
## 5. SUBSTITUTION AND ELIMINATION

Any species that acts as a base can also act as a nucleophile. To understand how elimination and substitution compete with each other, we compare the nucleophilic behaviour with the basic behaviour.

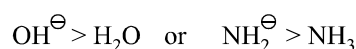


### 5.1 Nucleophilicity vs Basicity

- (a) Nucleophilicity & basicity will be parallel if the comparing nucleophile have same attacking atom e.g.

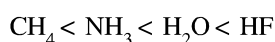


- (b) Negatively charged nucleophiles are stronger than neutral nucleophiles. e.g.

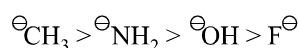


- (c) Electrons on larger atoms are less tightly bound by the nucleus and are more polarisable and more readily available to carbon & will be better nucleophile. But they will be weaker base as their bond with smaller H-atom will be weaker & their conjugate acids will be more reactive. If the attacking atoms are of same size, the stronger bases are better nucleophile. (In a period basicity of anions decreases) e.g.

**Acidic Strength :**



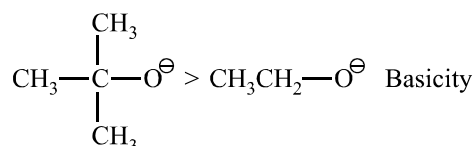
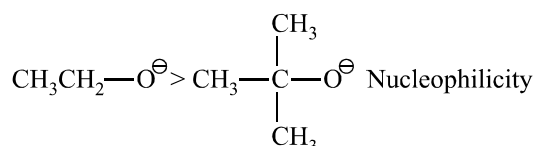
**Basic Strength and Nucleophilicity :**



- (d) If the attacking atoms are different in size, the nucleophilicity depends on the solvents. However, in gaseous phase nucleophilicity parallels basicity.
- (e) Nucleophilicity is inversely proportional to stability of anion.

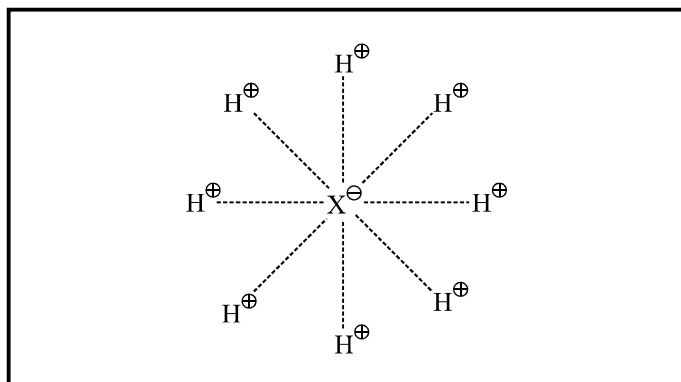
$\text{R—}\overset{\text{O}}{\parallel}\text{C—O}^\ominus$  is a weaker nucleophile as it is resonance stabilized.

- (f) Steric factor limits nucleophilicity

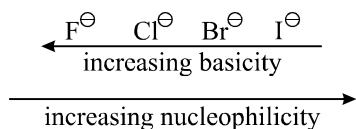


(g) A strong base can be made a good leaving agent e.g. Oxygen containing group like  $\text{OH}^\ominus$  can be made a weak base in acidic medium by protonation & become a better leaving agent  $-\text{OH}_2^\oplus$ .

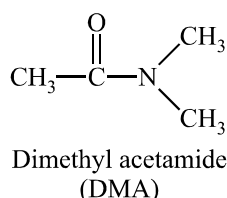
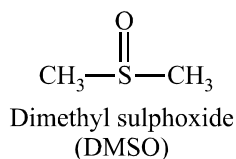
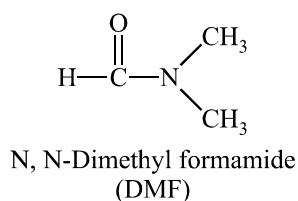
(h) **Protic solvent** : These solvents have a hydrogen atom attached to an atom of a strongly electronegative element (e.g. oxygen). Molecules of protic solvent can, therefore form hydrogen bonds to nucleophiles as :



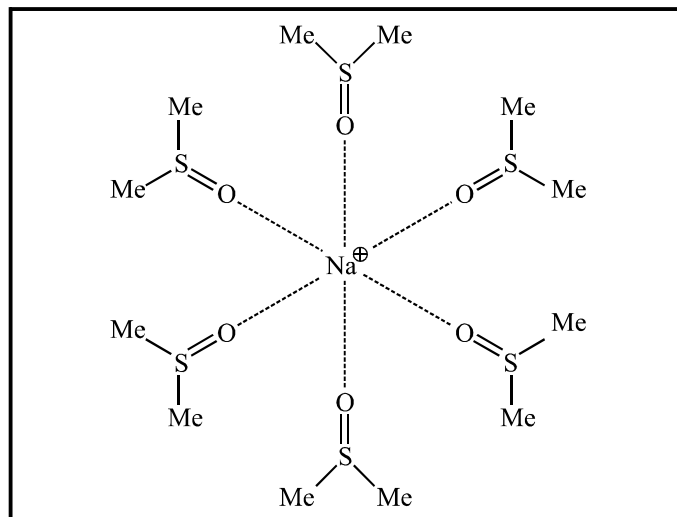
A small nucleophile which is having high charge density than the larger nucleophile is strongly solvated and this solvation hinders the direct approach to the nucleophilic centre. Hence the smaller nucleophile doesn't act as a good nucleophile as the larger one. Hence in protic solvent nucleophilicity is reverse of basicity.



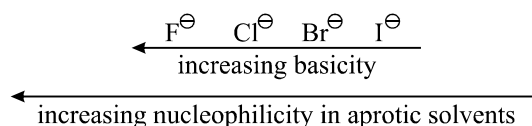
(i) **Aprotic solvents** : These are the polar solvents that don't have H atom, capable of forming H-bonds e.g.



These solvents dissolve ionic compounds and solvate the cations.



Now the naked anions are highly reactive as nucleophile and now nucleophilicity follows the basicity e.g.



## 5.2 Saytzeff vs. Hofmann Rule

When alkene is formed by elimination of alkyl halides, the orientation of the double bond formed is governed by two rules.

### 5.2.1 Saytzeff's Rule/Zaitsev Rule

This rule suggests the formation of more stable alkene and therefore more substituted double bond. Reactions following this rule are said to be **thermodynamically controlled**.

### 5.2.2 Hofmann Rule

This rule suggests the formation of less stable alkene and therefore less substituted double bond. In such cases, the more acidic  $\beta$ -hydrogen is abstracted to produce alkene. Such reactions are said to be **kinetically controlled**.

## 5.3 Effect of Temperature

High temperature favours elimination while low temperature favours substitution reaction.

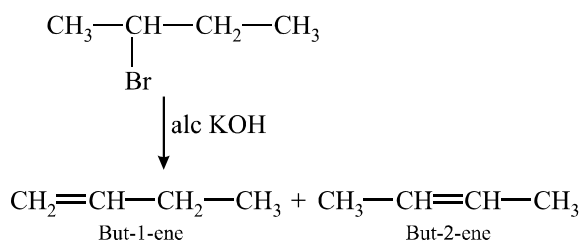
## 6. STEREOCHEMISTRY

### 6.1 Regioselectivity

It is the preference of one direction of chemical bond making or breaking over all other possible directions.

## ALKYL HALIDE

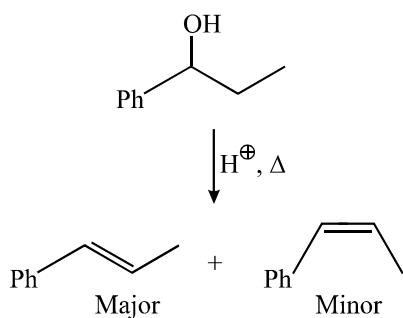
### Example - 11



### 6.2 Stereoselectivity

Stereoselective reactions give one predominant product because the reaction pathway has a choice. Either the pathway of lower activation energy (kinetic control) is preferred or the more stable product (thermodynamic control).

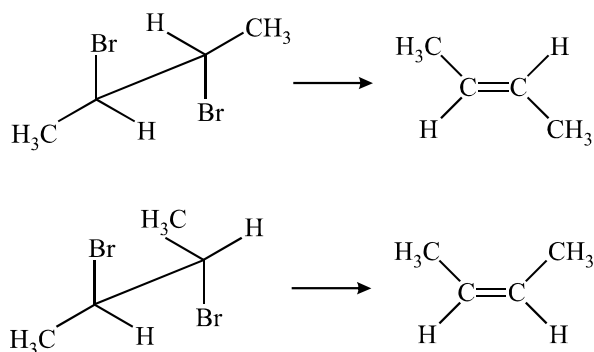
### Example - 12



### 6.3 Stereospecificity

Stereospecific reactions lead to the production of a single isomer as a direct result of the mechanism of the reaction and the stereochemistry of the starting material. There is no choice. The reaction gives a different diastereomer of the product from each stereoisomer of the starting material.

### Example - 13

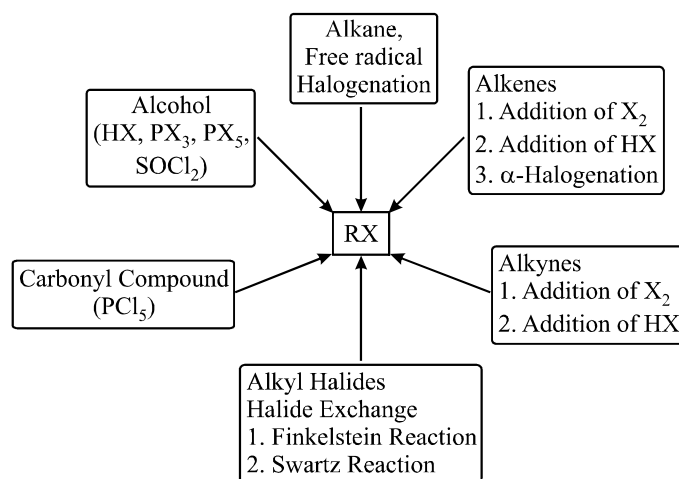


### 6.4 Chemoselectivity

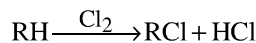
When there are two or more functional groups in a molecule, a given reagent may react preferentially with one rather than the other. Such reactions are called chemoselective.

## 7. ALKYL HALIDES

### 7.1 Preparation of Alkyl Halides

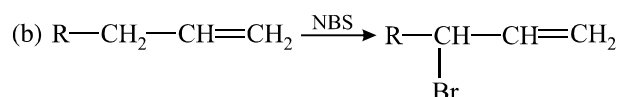
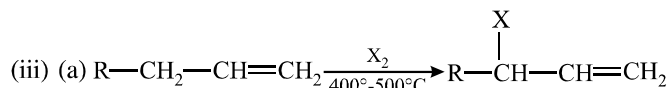
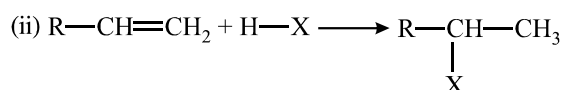
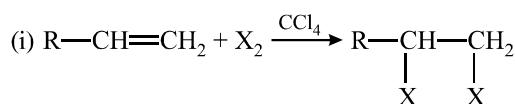


#### 1. Alkanes

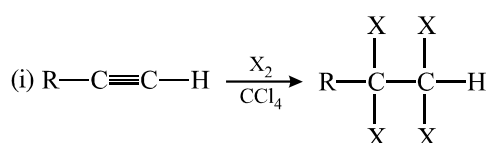


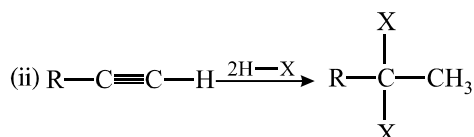
This method gives a mixture of mono, di & trihalides.

#### 2. Alkenes



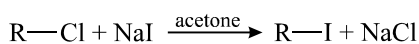
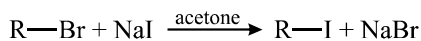
#### 3. Alkynes



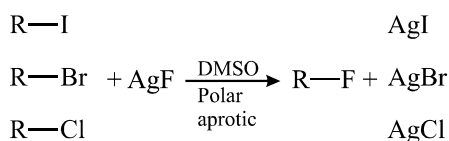


#### 4. Alkyl Halides

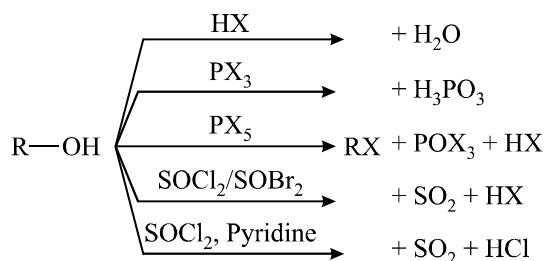
##### (i) Finkelstein Reaction



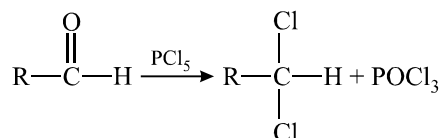
##### (ii) Swartz Reaction



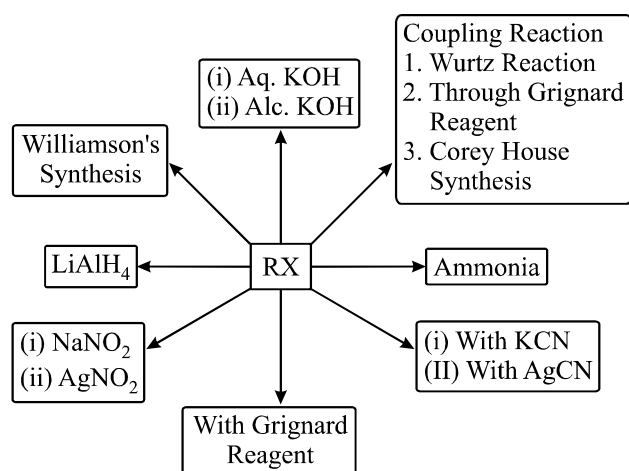
#### 5. Alcohol



#### 6. Carbonyl Compound

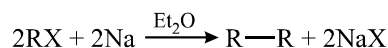


### 7.2 Reactions of Alkyl Halide

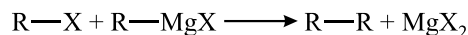


#### 1. Coupling Reaction

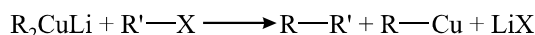
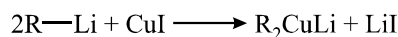
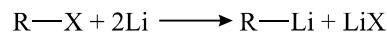
##### (a) Wurtz Reaction



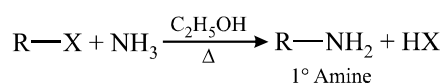
##### (b) Grignard Reagent



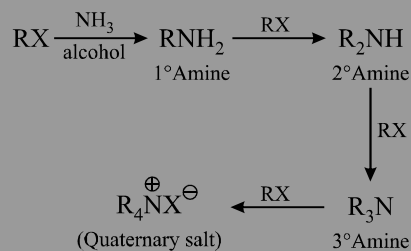
##### (c) Corey-House Synthesis



#### 2. Ammonia

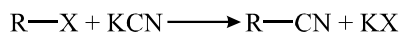


*Note...* If alkyl halide is in excess, then 2° and 3° amines and even quaternary salts are also formed.

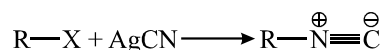


This reaction is called Hofmann ammonolysis of alkyl halides.

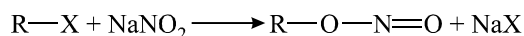
#### 3. KCN



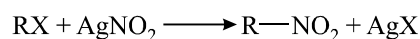
#### 4. AgCN



#### 5. NaNO<sub>2</sub>



#### 6. AgNO<sub>2</sub>



#### 7. LiAlH<sub>4</sub>



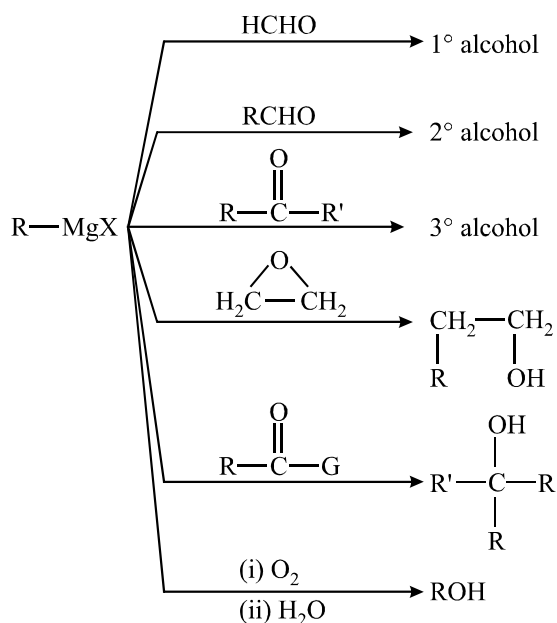
#### 8. Williamson's Synthesis



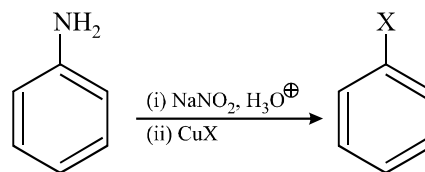
#### 9. Aq. KOH & Alc. KOH



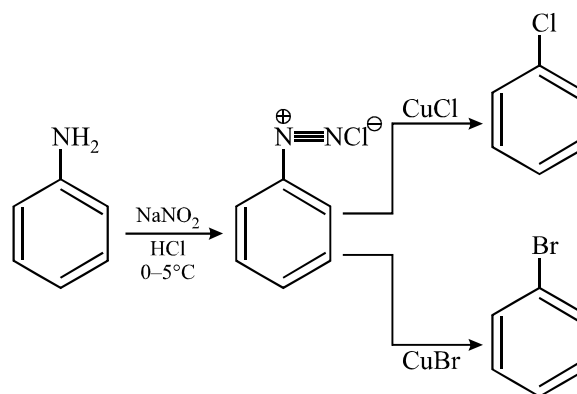
## 10. Reactions of R-MgX



## (b) Sandmeyer Reaction

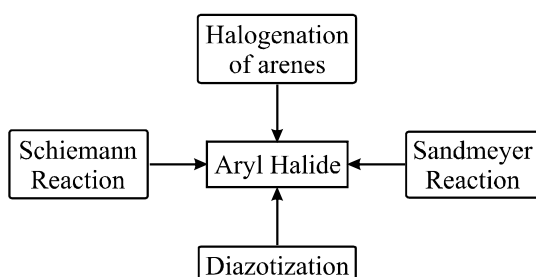


## (c) Diazotization

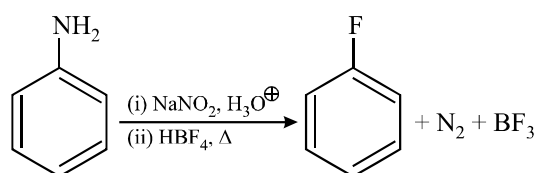


## 8. ARYL HALIDE/HALOARENES

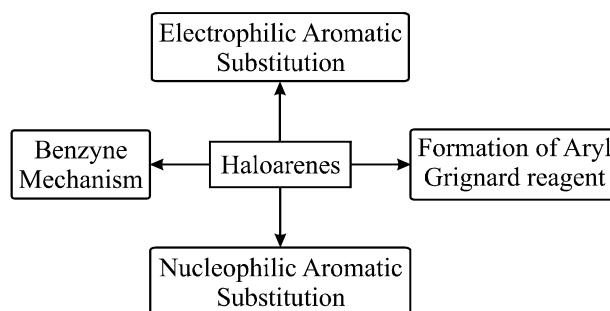
## 8.1 Preparation of Aryl Halide/Haloarenes



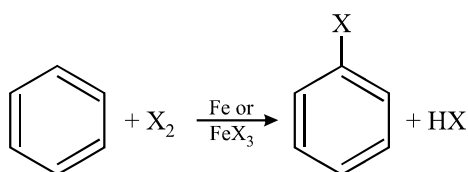
## (d) Schiemann Reaction



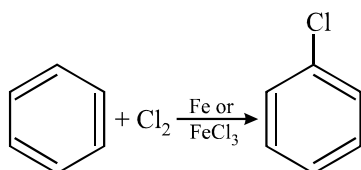
## 8.2 Reactions of Aryl Halide/Haloarenes



## (a) Halogenation of Arenes

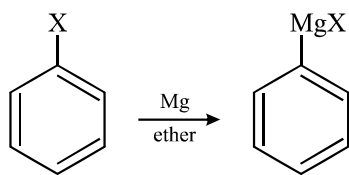


## Example - 14



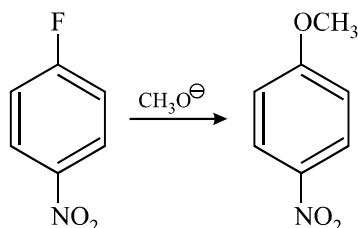
- (a) Electrophilic Aromatic Substitution Reaction : Halogens are weakly deactivating and ortho/para directing.

(b) Formation of Aryl Grignard Reagent :



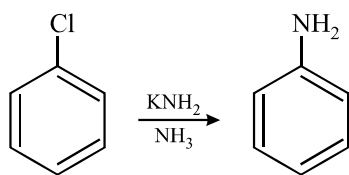
Reactivity order :  $\text{Ar-I} > \text{Ar-Br} > \text{Ar-Cl} > \text{Ar-F}$

(c)  $\text{S}_{\text{N}}\text{Ar}$  – Aromatic Nucleophilic Substitution Reaction



(d) Benzyne Mechanism (Elimination Addition Mechanism)

Strong bases such as Na, K and amide react readily with aryl halides.



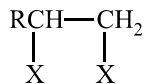
## 9. REACTIONS OF SPECIAL ALKYL HALIDES

### 9.1 Di-Halides



Alkylidene Dihalides or

Geminal Dihalides

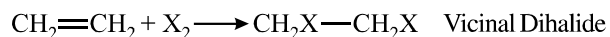


Alkylene Dihalides or

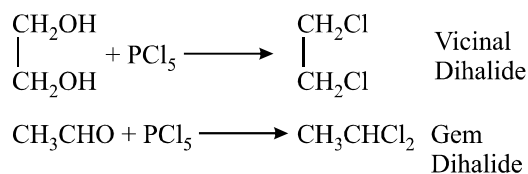
Vicinal (1, 2) Dihalides

### 9.1.1 Preparation

(a) Alkenes and Alkynes Halogenation of Alkenes & Alkynes

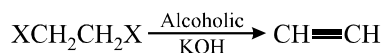


(b)  $\text{PCl}_5$  with Diols & Carbonyl Compounds

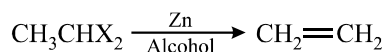
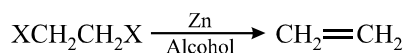


### 9.1.2 Properties

(a) Alcoholic KOH : (Dehydrohalogenation)

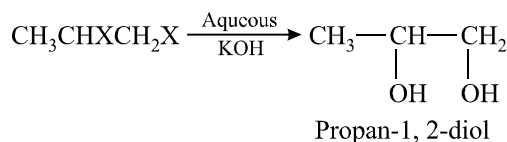
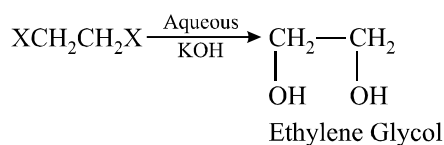


(b) Zinc Dust : (Dehalogenation)

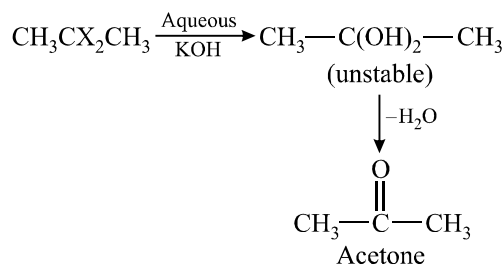
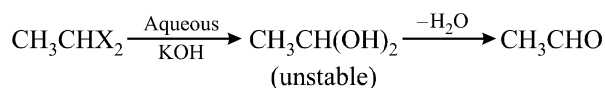


(c) Action of aq. KOH : (Alkaline Hydrolysis)

(i) Vicinal Dihalides



(ii) Gem Dihalides





## ALKYL HALIDE



The above reaction is used to distinguish between gem and vicinal dihalides.

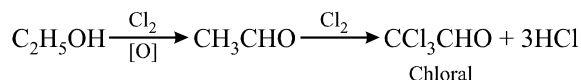
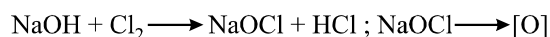
### 9.2 TRI-HALIDES & TETRA-HALIDES

$\text{CHCl}_3$ Chloroform (liquid)	$\text{CHBr}_3$ Bromoform (liquid)
$\text{CHI}_3$ Iodoform (yellow solid)	$\text{CCl}_4$ Carbon Tetrachloride (liquid)

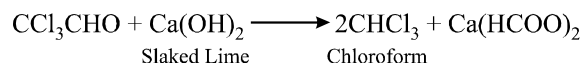
#### 9.2.1 CHLOROFORM : $\text{CHCl}_3$

##### (A) Preparation

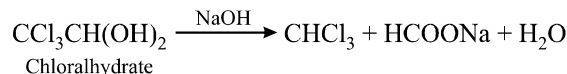
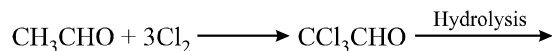
(i) **Ethyl Alcohol** : (using  $\text{NaOH}/\text{Cl}_2$  or  $\text{CaOCl}_2$ )



**$\text{Ca}(\text{OH})_2$**

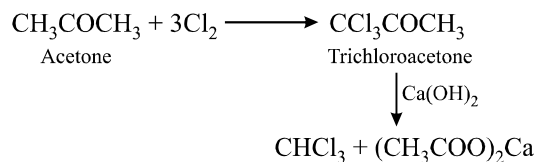


**$\text{NaOH}$**

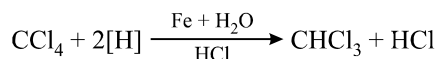


Pure form of chloroform is prepared from chloral by treating it with  $\text{NaOH}$ .

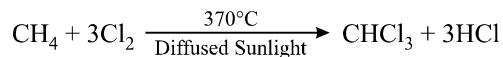
##### (ii) Methyl Ketones



##### (iii) Carbon Tetrachloride



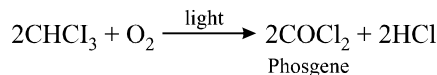
##### (iv) Chlorination of Methane at $370^\circ\text{C}$



##### (B) Reactions

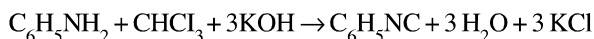
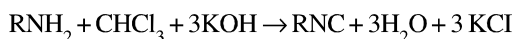
###### (i) Oxidation

Chloroform in presence of light and air ( $\text{O}_2$ ) forms a highly poisonous gas, Phosgene.



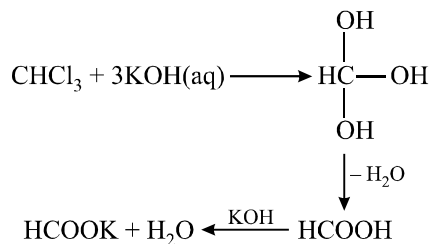
1% ethanol is added and then chloroform is stored in brown bottles, filled upto brim to stop the above decomposition.

###### (ii) Carbylamine Reaction

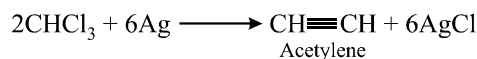


Isocyanides (carbylamines) have a very disagreeable smell, so the above reaction is used as a test of chloroform and test of  $1^\circ$  (aliphatic and aromatic) amines.

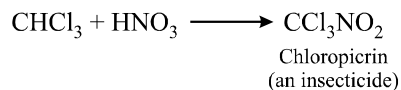
###### (iii) Hydrolysis



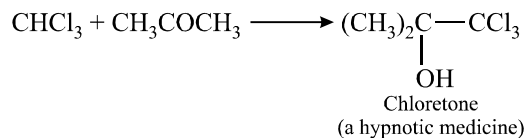
##### (iv) Formation of Acetylene



##### (v) Formation of Chloropicrin

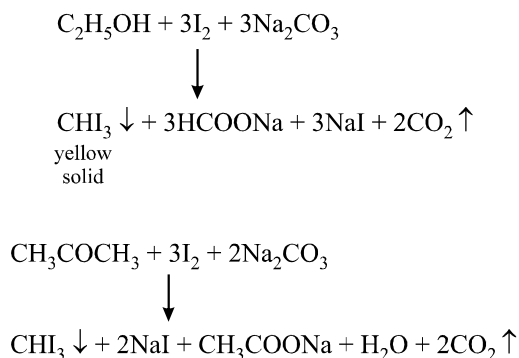


##### (vi) Formation of Chloretone



9.2.2 IODOFORM :  $\text{CHI}_3$ 

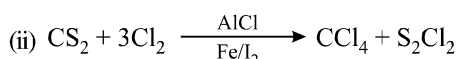
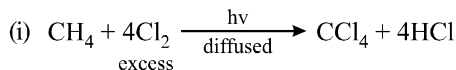
## (A) Preparation :



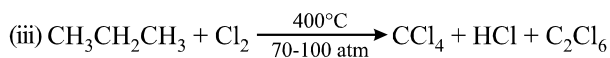
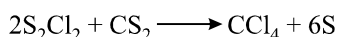
*Note...* This reaction is known as Iodoform reaction or **Iodoform test**. Since the iodoform is a yellow colored solid, so the iodoform reaction is used to test ethyl alcohol, acetaldehyde, sec. alcohols of  $\text{R}(\text{CH}_3)\text{CHOH}$  (methyl alkyl carbinol) and methyl ketones ( $\text{RCOCH}_3$ ), because all these form iodoform. The side product of the iodoform reaction, sodium carboxylate is acidified to produce carboxylic acid ( $\text{RCOOH}$ ).

 9.2.3 CARBON TETRACHLORIDE :  $\text{CCl}_4$ 

## (A) Preparation :



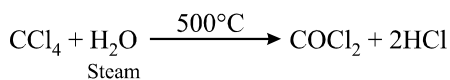
$\text{S}_2\text{Cl}_2$  is separated by fractional distillation. It is then treated with more  $\text{CS}_2$  to give  $\text{CCl}_4$ . C washed with  $\text{NaOH}$  and distilled to obtain pure  $\text{CCl}_4$ .



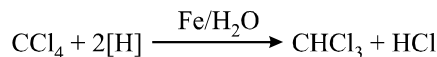
*Note...*  $\text{CCl}_4$  is a colourless and poisonous liquid which is insoluble in  $\text{H}_2\text{O}$ . It is a good solvent for grease and oils.  $\text{CCl}_4$  is used in fire extinguisher for electric fires as Pyrene. It is also an insecticide for hookworms.

## (B) Reactions :

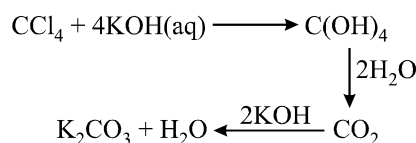
## (i) Oxidation



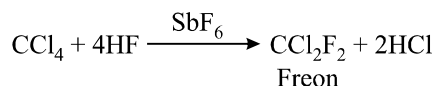
## (ii) Reduction



## (iii) Hydrolysis

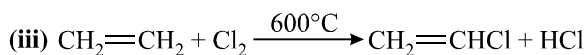
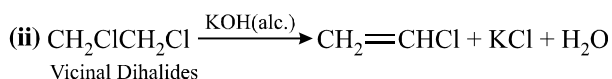
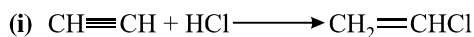


## (iv) Action of HF


 9.2.4 VINYL CHLORIDE :  $\text{CH}_2 = \text{CHCl}$ 

Vinyl group  $\text{CH}_2 = \text{CH} -$

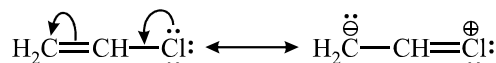
## (A) Preparation



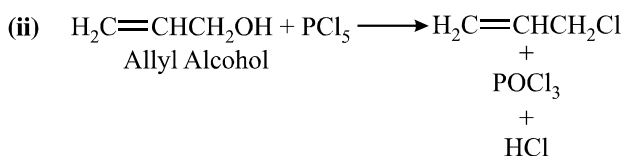
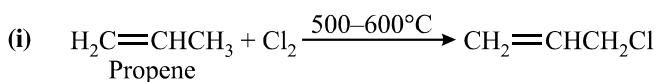
## (B) Reaction



Halogen atom in vinyl chloride is quite stable and does not respond to nucleophilic substitution reactions easily. It is due to resonance stabilisation of vinyl chloride.


 9.2.5 ALLYL CHLORIDE :  $\text{H}_2\text{C} = \text{CHCH}_2\text{Cl}$ 

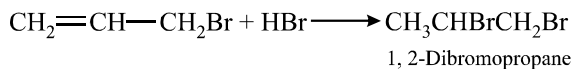
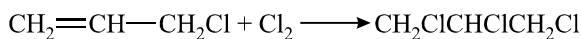
## (A) Preparation



## ALKYL HALIDE

### (B) Reactions

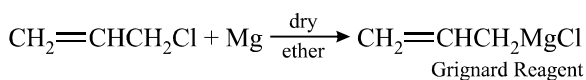
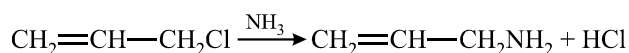
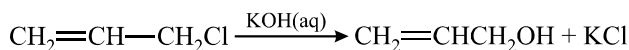
#### (i) Addition Reactions



The addition follows Markonikov's rule. However in presence of peroxides, 1, 3-dibromopropane is formed.

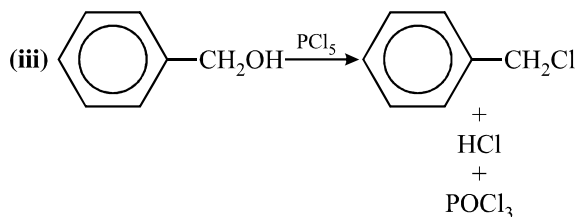
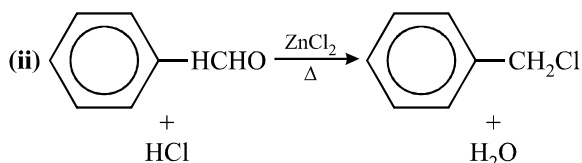
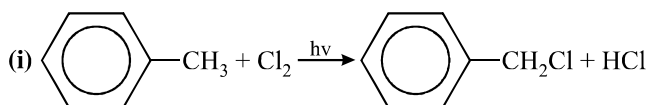
#### (ii) Nucleophilic Substitution Reactions

Since in allyl chloride, there is no resonance (unlike in vinyl chloride), nucleophilic substitution reactions take place with ease.



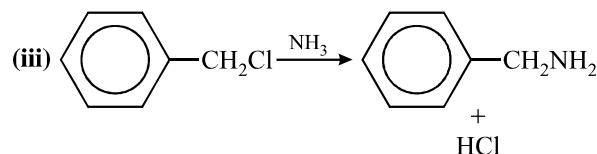
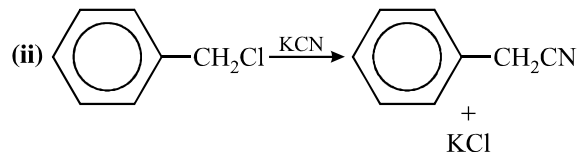
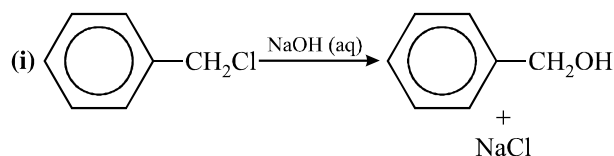
### 9.2.6 Benzyl Chloride : $\text{C}_6\text{H}_5\text{CH}_2\text{Cl}$ : $\text{PhCH}_2\text{Cl}$

#### (A) Preparation

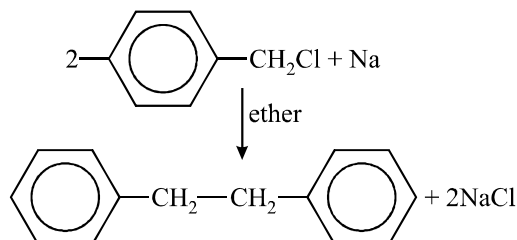


### (B) Reactions

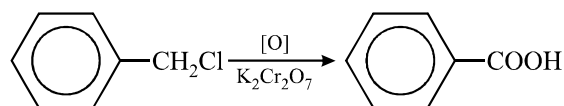
The main reactions are like those of Alkyl Halides (since there is no resonance in benzyl chloride and intermediate benzyl carbonium ion is stable supporting  $\text{S}_{\text{N}}1$  substitution). Nucleophilic substitution reactions occur with ease unlike in case of aryl halides (due to resonance in aryl halides).



#### (iv) Wurtz Reaction

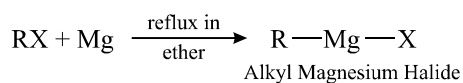


#### (v) Oxidation



## 10. CHEMISTRY OF GRIGNARD REAGENT : $\text{R-Mg-X}$

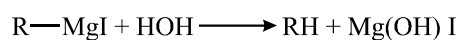
### 10.1 Preparation

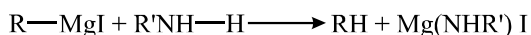
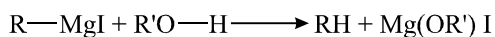


**Note...** In Grignard reagent, we can have phenyl or alkenyl or alkynyl or aromatic group instead of R. All the reactions will remain same.

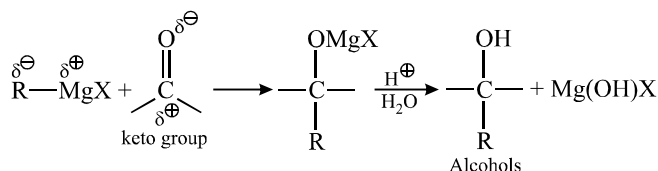
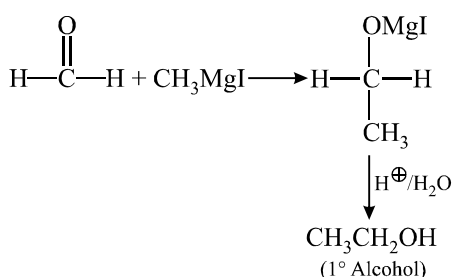
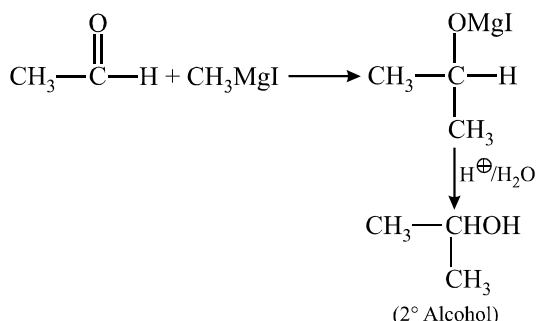
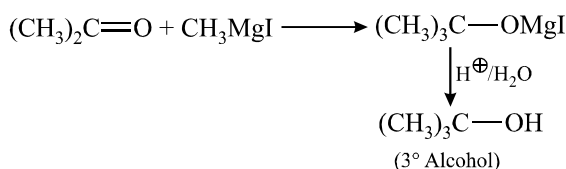
### 10.2 Reactions

(A) Grignard reagent as a base reacts with compounds containing active H to give alkanes.

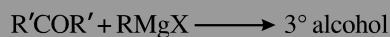
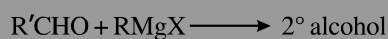
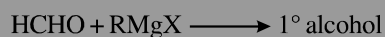
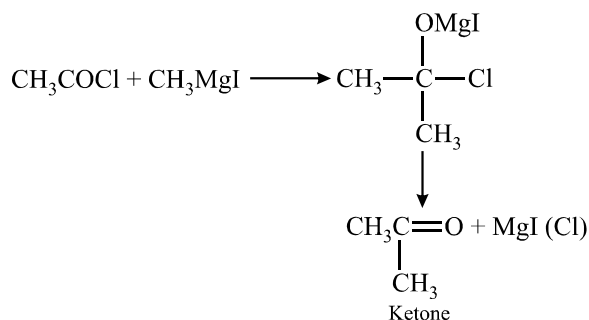




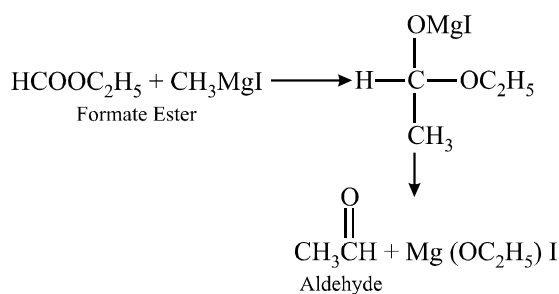
- (B) Grignard reagent acts as a strong nucleophile and shows nucleophilic additions to give various products. Alkyl group being electron rich (carbanion) acts as nucleophile in Grignard Reagent.


**Example - 15**

**Example - 16**

**Example - 17**


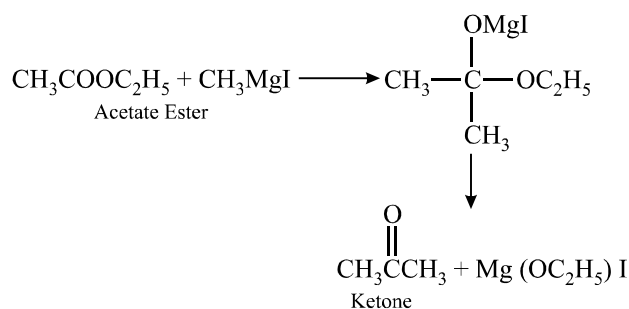
*Note...*


**(C) Acid Chloride**
**Example - 18**


Ketones (acetone) formed further reacts with Grignard reagent to form 3° alcohols (tert. butyl alcohol). However, with 1 : 1 mole ratio of acid halide and Grignard Reagent, one can prepare ketones.

**(D) Esters**
**Example - 19**


The aldehydes react further with  $CH_3MgI$  to give 2° alcohol, if present in excess. But 1 : 1 mole ratio of reactants will certainly give aldehydes.

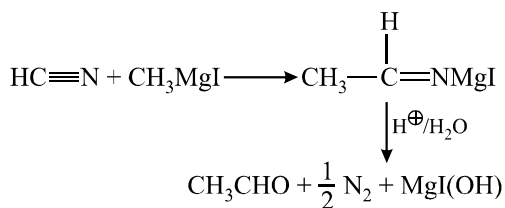
**Example - 20**


The ketones react further with  $CH_3MgI$  to give 3° alcohol, if present in excess. But 1 : 1 mole ratio of reactants will certainly give ketones.

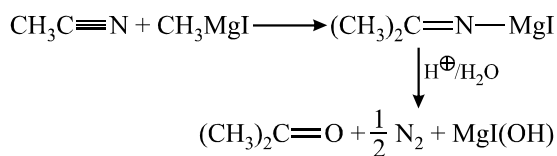
## ALKYL HALIDE

### (E) Cyanides

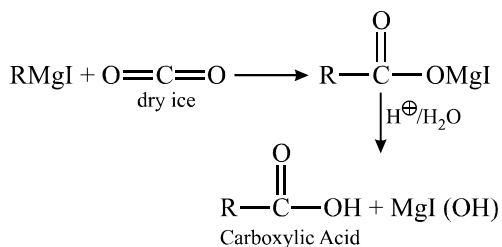
#### Example - 21



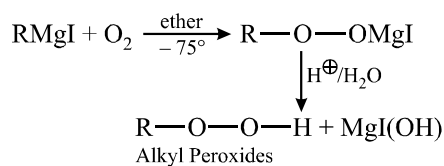
#### Example - 22



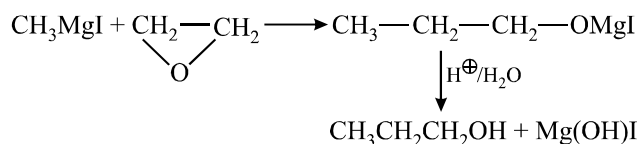
### (F) CO<sub>2</sub>



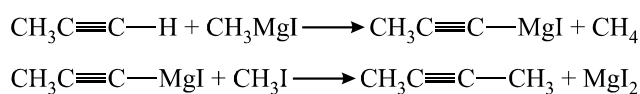
### (G) Oxygen



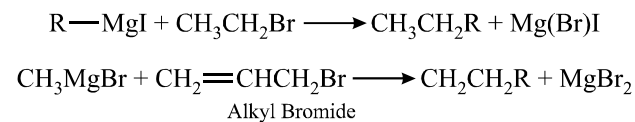
### (H) Ethylene Oxide (Oxiranes)



### (I) Alkynes



### (J) Alkyl Halides



### (K) Inorganic Halides

