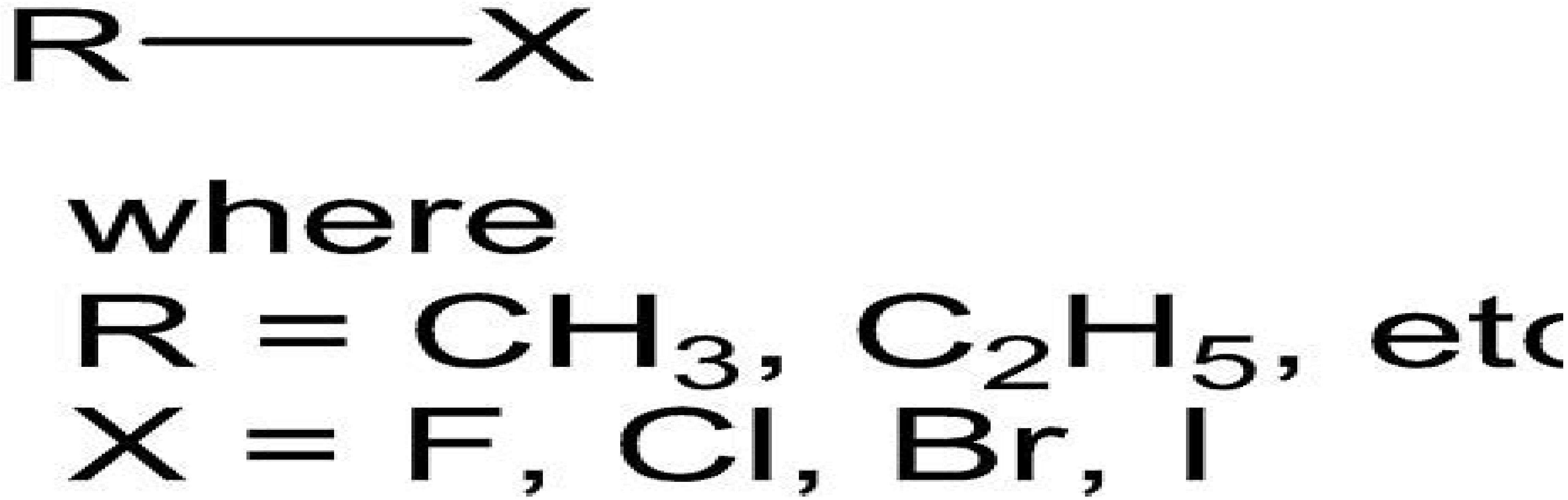
Alkyl Halides



$R—X$

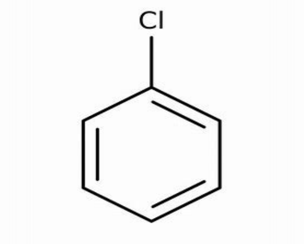
where

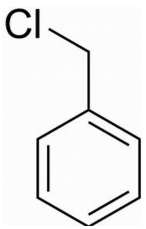
$R = CH_3, C_2H_5$, etc

$X = F, Cl, Br, I$

Organic halides

- **Aliphatic halogen derivatives**
  - Haloalkanes or Alkyl halides eg CH_3CH_2Cl
  - Haloalkenes or alkenyl halides $CH_2=CH-Cl$
  - Haloalkynes or alkynyl halides $CH\equiv C-Cl$
- **Halogen derivatives of aromatic hydrocarbons**
  - Nuclear substituted
    - Aryl halides
  - Side chain substituted
    - Aralkyl halides

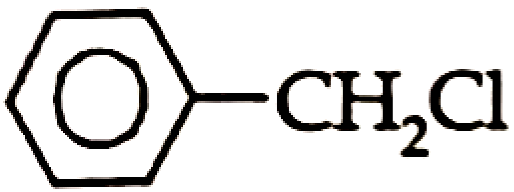




Darshan Kumar Assoc. Prof. GC Amb

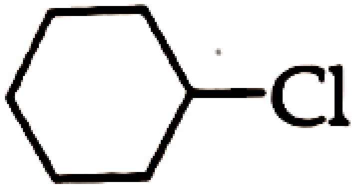
Alkyl halides

- Monohalogen derivatives of alkanes
- Also contain aralkyl halides



Benzyl chloride

(Phenyl chloromethane)



Cyclohexyl chloride

(Chlorocyclohexane)

CH_3Cl

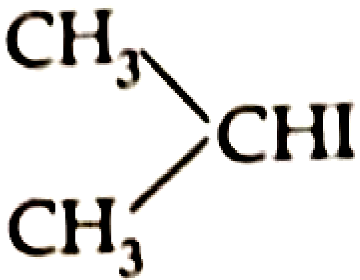
Methyl chloride

(Monochloromethane)

CH_3CH_2Br

Ethyl bromide

(Monobromoethane)



Isopropyl iodide

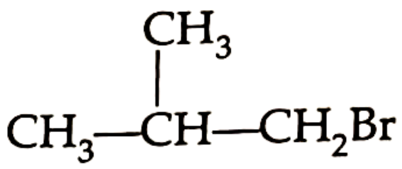
(2-Iodopropane)

Classification of Alkyl halides

❑ Primary alkyl halides

$CH_3-CH_2-CH_2I$

n-Propyl iodide
(1-Iodopropane)



$$CH_3-\overset{\overset{CH_3}{|}}{CH}-CH_2Br$$

Isobutyl bromide
(1-Bromo-2-methylpropane)

❑ Secondary alkyl halides

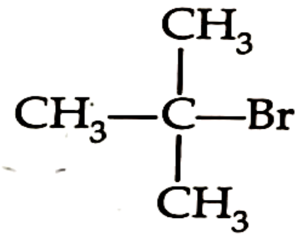
$CH_3-CHCl-CH_3$

Isopropyl chloride
(2-Chloropropane)

$CH_3-CH_2-CHBr-CH_3$

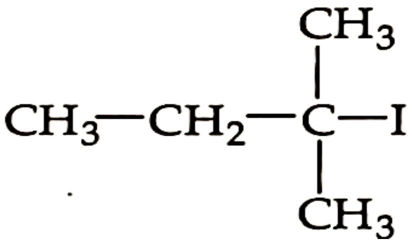
sec-Butyl bromide
(2-Bromobutane)

❑ Tertiary alkyl halides



$$CH_3-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-Br$$

tert- Butyl bromide
(2-Bromo-2-methylpropane)



$$CH_3-CH_2-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-I$$

tert-Pentyl iodide
(2-Iodo-2-methylbutane)

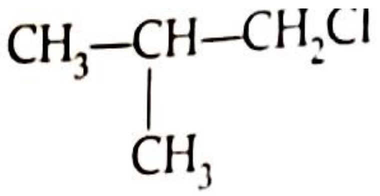
Structural Isomerism in alkyl halides

- **Chain Isomerism**
  - Isomers differ in the chain of carbon atoms
  - Compounds must contain 4 or more carbon atoms

$CH_3{-}CH_2{-}CH_2{-}CH_2Cl$

1-Chlorobutane

(*n*-Butyl chloride)



$$\begin{array}{l} CH_3{-}CH{-}CH_2Cl \\ \quad\quad\;\; | \\ \quad\quad CH_3 \end{array}$$

1-Chloro-2-methylpropane

(Isobutyl chloride)

- **Position isomerism**
  - Isomers differ in the position of halogen atom
  - Compound must contain 3 or more carbon atoms

$CH_3{-}CH_2{-}CH_2I$

1-Iodopropane

(*n*-Propyl iodide)

$CH_3{-}CHI{-}CH_3$

2-Iodopropane

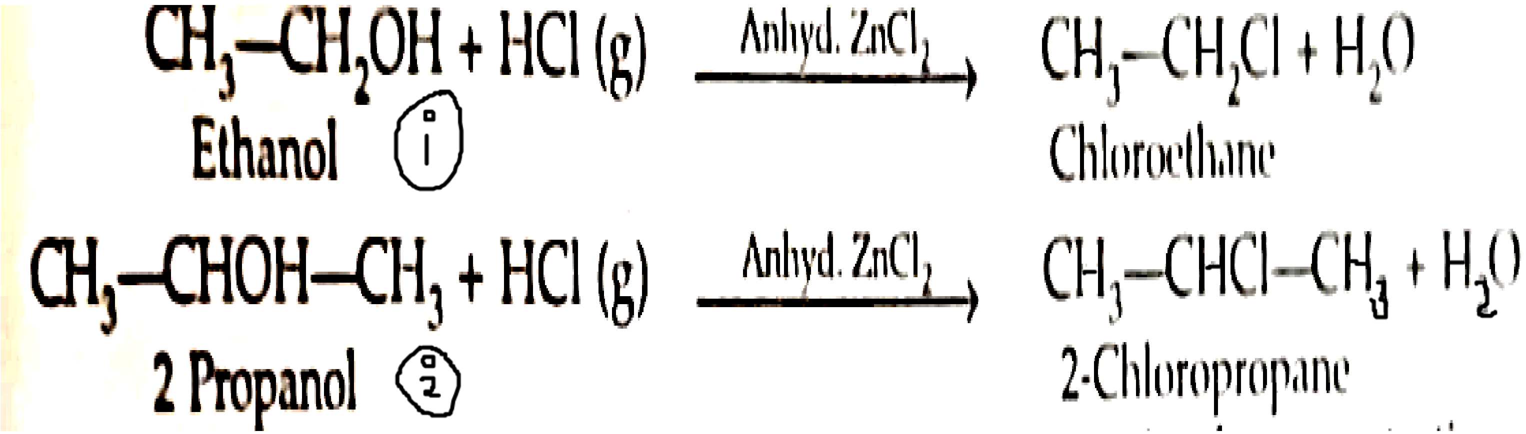
(Isopropyl iodide)

Methods of Preparation of alkyl halides

❑ From Alcohols

❖ By action of hydrogen halides

- ➢ ROH + HX → RX + H_2O
- ➢ Primary and secondary alkyl chlorides are prepared by action of HCl in the presence of Anhydrous $ZnCl_2$ on corresponding alcohol
- ➢ Process is known as Groove's Process
- ➢ Tertiary alkyl chlorides are prepared by action of Conc. HCl on corresponding alcohol(No $ZnCl_2$ required)

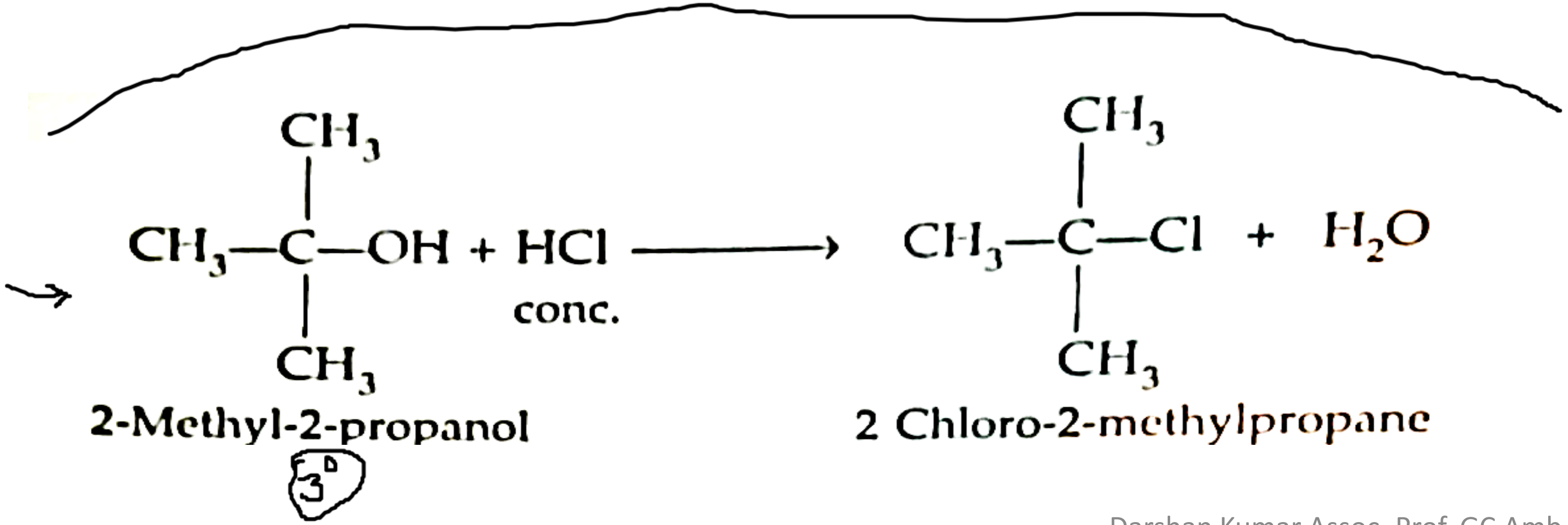


$$CH_3-CH_2OH + HCl\,(g) \xrightarrow{\text{Anhyd. } ZnCl_2} CH_3-CH_2Cl + H_2O$$

Ethanol ⓘ° Chloroethane

$$CH_3-CHOH-CH_3 + HCl\,(g) \xrightarrow{\text{Anhyd. } ZnCl_2} CH_3-CHCl-CH_3 + H_2O$$

2 Propanol 2° 2-Chloropropane



$$CH_3-\underset{CH_3}{\overset{CH_3}{\underset{|}{\overset{|}{C}}}}-OH + \underset{\text{conc.}}{HCl} \longrightarrow CH_3-\underset{CH_3}{\overset{CH_3}{\underset{|}{\overset{|}{C}}}}-Cl + H_2O$$

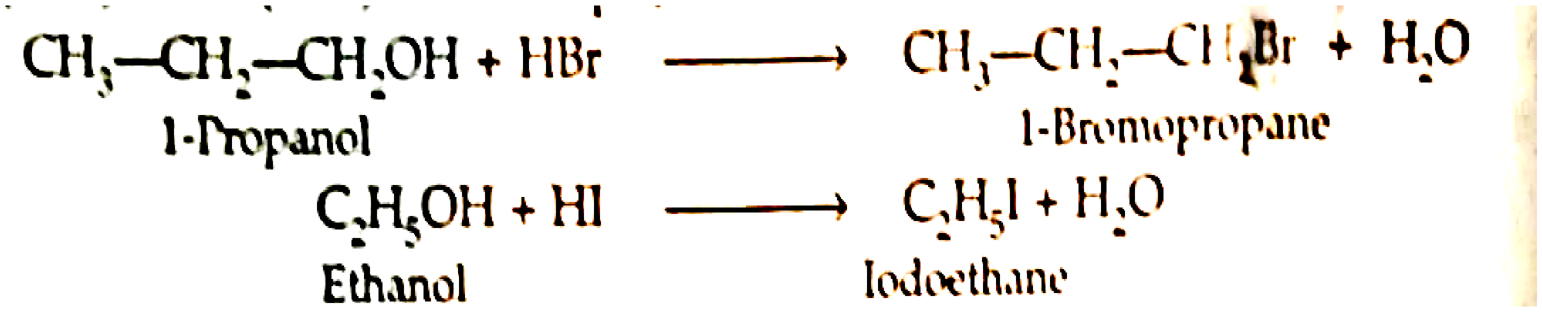
2-Methyl-2-propanol 2 Chloro-2-methylpropane

3°

Methods of Preparation of alkyl halides

☐ From Alcohols contd.

- ➢ Alkyl Bromides and iodides are prepared by action of HBr & HI on corresponding alcohol



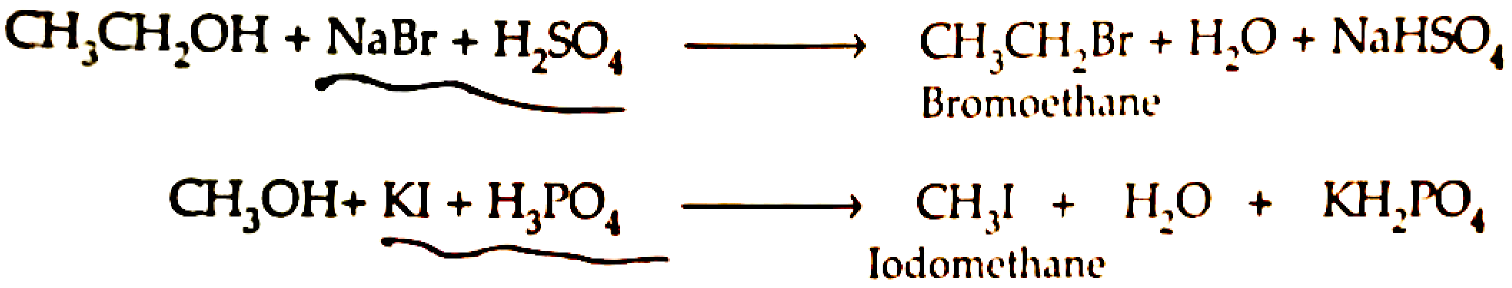
$CH_3—CH_2—CH_2OH + HBr \longrightarrow CH_3—CH_2—CH_2Br + H_2O$

1-Propanol 1-Bromopropane

$C_2H_5OH + HI \longrightarrow C_2H_5I + H_2O$

Ethanol Iodoethane

- ➢ HBr & HI can also be prepared in situ ie
- ✓ $NaBr + H_2SO_4 \rightarrow HBr + NaHSO_4$
- ✓ $KI + H_3PO_4 \rightarrow HI + KH_2PO_4$



$CH_3CH_2OH + \underline{NaBr + H_2SO_4} \longrightarrow CH_3CH_2Br + H_2O + NaHSO_4$

Bromoethane

$CH_3OH + \underline{KI + H_3PO_4} \longrightarrow CH_3I + H_2O + KH_2PO_4$

Iodomethane

☐ Order of reactivity of hydrogen halides

- ➢ HI > HBr > HCl

☐ Order of reactivity of alcohols

- ➢ Tertiary alcohols > Secondary alcohols > Primary alcohols

Methods of Preparation of alkyl halides

From Alcohols contd.

- **By action of phosphorus halides on corresponding alcohols**
- $3ROH + PX_3 \rightarrow 3RX + H_3PO_3$
- **Alkyl chlorides** by action of either PCl_3 or PCl_5
- **Alkyl bromides** and **alkyl iodides** are prepared by action of PBr_3 or PI_3
- PBr_3 and PI_3 are prepared in situ ie by action of red phosphorus on halogen
- ✓ $2P + 3I_2 \rightarrow 2PI_3$
- ✓ $2P + 3Br_2 \rightarrow 2PBr_3$

$$CH_3CH_2CH_2OH + PCl_5 \longrightarrow CH_3CH_2CH_2Cl + POCl_3 + HCl$$

1-Propanol → 1-Chloropropane

$$3CH_3\text{—}CHOH\text{—}CH_3 + PCl_3 \longrightarrow 3CH_3\text{—}CHCl\text{—}CH_3 + H_3PO_3$$

2-Propanol → 2-Chloropropane

$$3CH_3CH_2CH_2OH + PI_3 \longrightarrow 3CH_3CH_2CH_2I + H_3PO_3$$

1-Propanol → 1-Iodopropane

$$3CH_3CH_2OH + PBr_3 \longrightarrow 3CH_3CH_2Br + H_3PO_3$$

Ethanol → Bromoethane

From Alcohols contd.

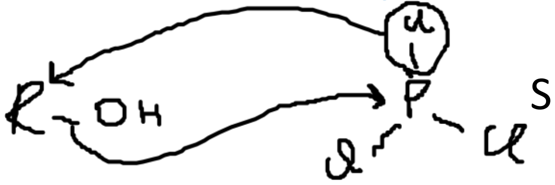
- **By action of thionyl chloride on corresponding alcohols**

$$CH_3CH_2OH + SOCl_2 \xrightarrow{\text{Pyridine}} CH_3CH_2Cl + SO_2 + HCl$$

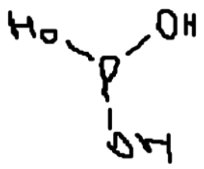
Ethanol → Chloroethane

Methods of Preparation of alkyl halides

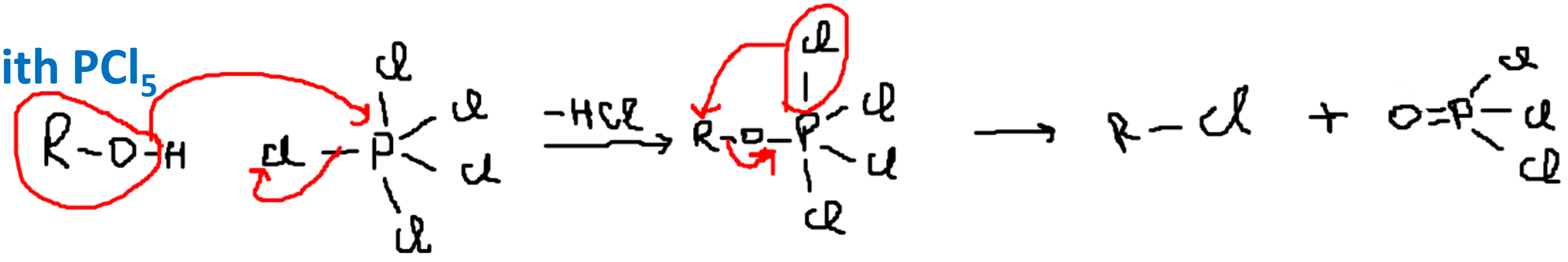
Mechanism with PCl_3



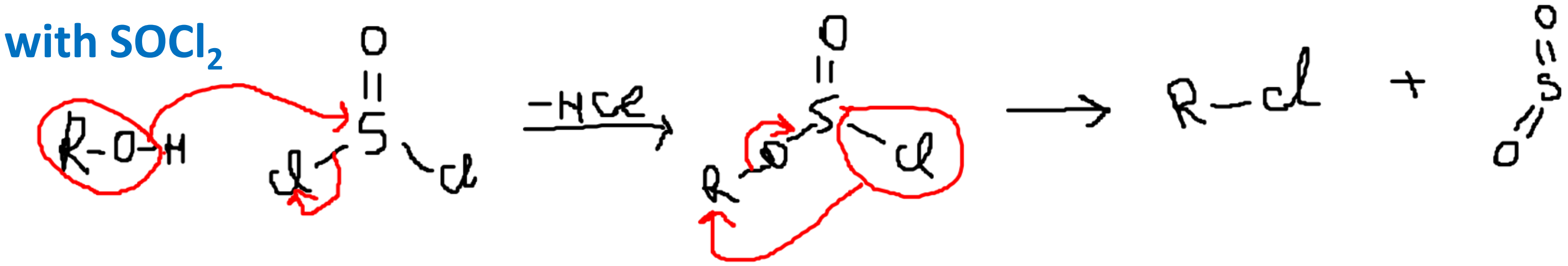
Similarly other two Cl atoms replace two other –OH gps & we get



Mechanism with PCl_5



Mechanism with $SOCl_2$



Methods of Preparation of alkyl halides

❑ **From Alkenes**

❖ **By addition of hydrogen halides**

➢ Addition is as per Markownikoff's rule

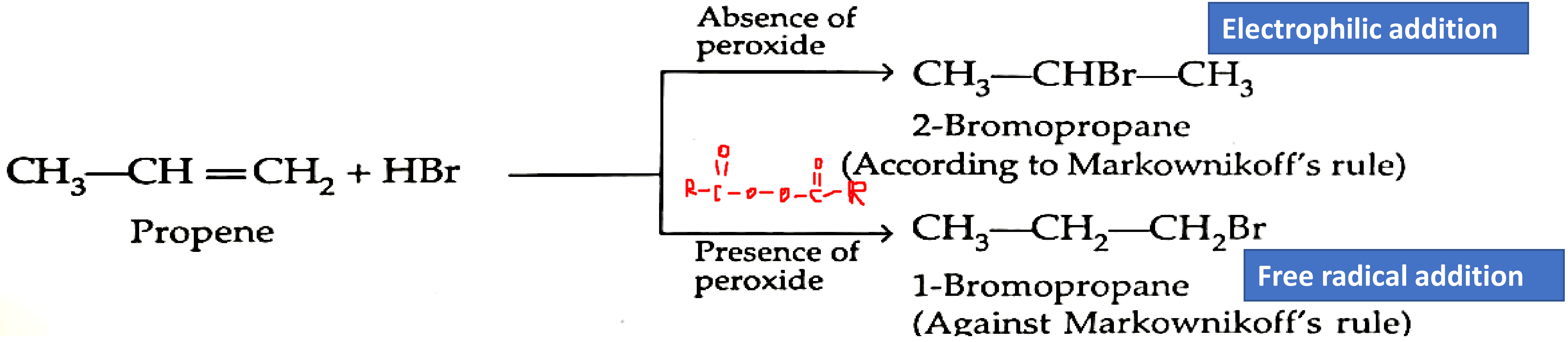
$$CH_2{=}CH_2 + \overset{+}{H}\overset{-}{I} \longrightarrow CH_3 \overset{\checkmark}{-} CH_2I$$

Ethene → Iodoethane

$$CH_3{-}CH{=}CH_2 + H\overset{-}{Cl} \longrightarrow CH_3{-}CHCl{-}CH_3$$

Propene → 2-Chloropropane

➢ **Peroxide effect or Kharasch's effect (Anti-Markownikoff's rule)**



$$CH_3{-}CH{=}CH_2 + HBr$$

Propene

Absence of peroxide → $CH_3{-}CHBr{-}CH_3$

2-Bromopropane

(According to Markownikoff's rule)

Electrophilic addition

$$R{-}\overset{O}{\overset{\|}{C}}{-}O{-}O{-}\overset{O}{\overset{\|}{C}}{-}R$$

Presence of peroxide → $CH_3{-}CH_2{-}CH_2Br$

1-Bromopropane

(Against Markownikoff's rule)

Free radical addition

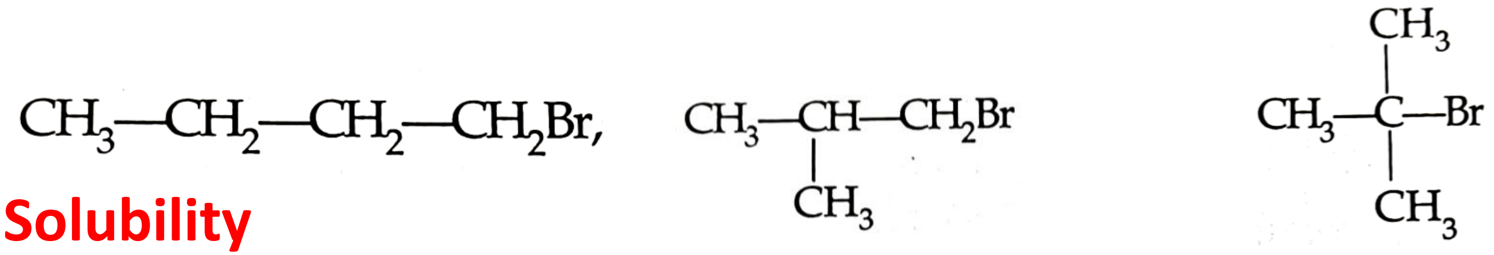
Darshan Kumar Assoc. Prof. GC Amb

Physical properties

Boiling points

- Alkyl halides have higher boiling points than corresponding alkanes

- For a given alkyl group
- R-I > R-Br > R-Cl
- For a given halogen atom
- $CH_3Br < CH_3CH_2Br < CH_3CH_2CH_2Br$
- As branching increases the B. Pt. decreases
- n- Butyl bromide(374.6 K) > iso Butyl bromide(364.7 K) > tert. Butyl bromide(346 K)



$CH_3-CH_2-CH_2-CH_2Br$, $CH_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_2Br$ $CH_3-\overset{\displaystyle CH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}-Br$

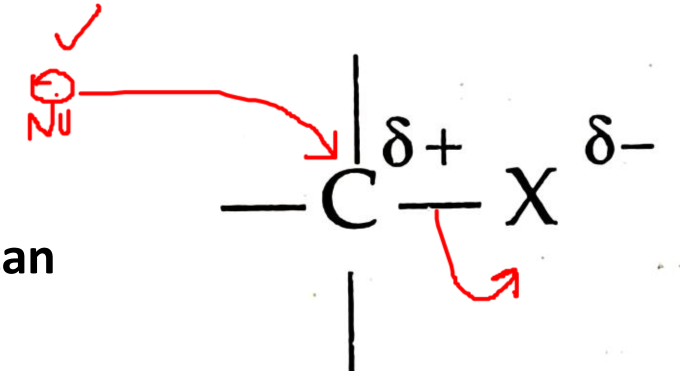
Solubility

- Insoluble in water

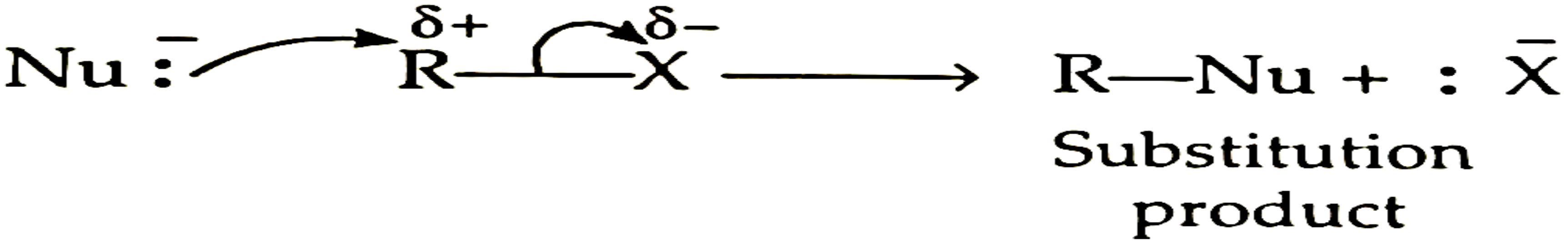
Density

- R-I > R-Br > R-Cl

Chemical properties



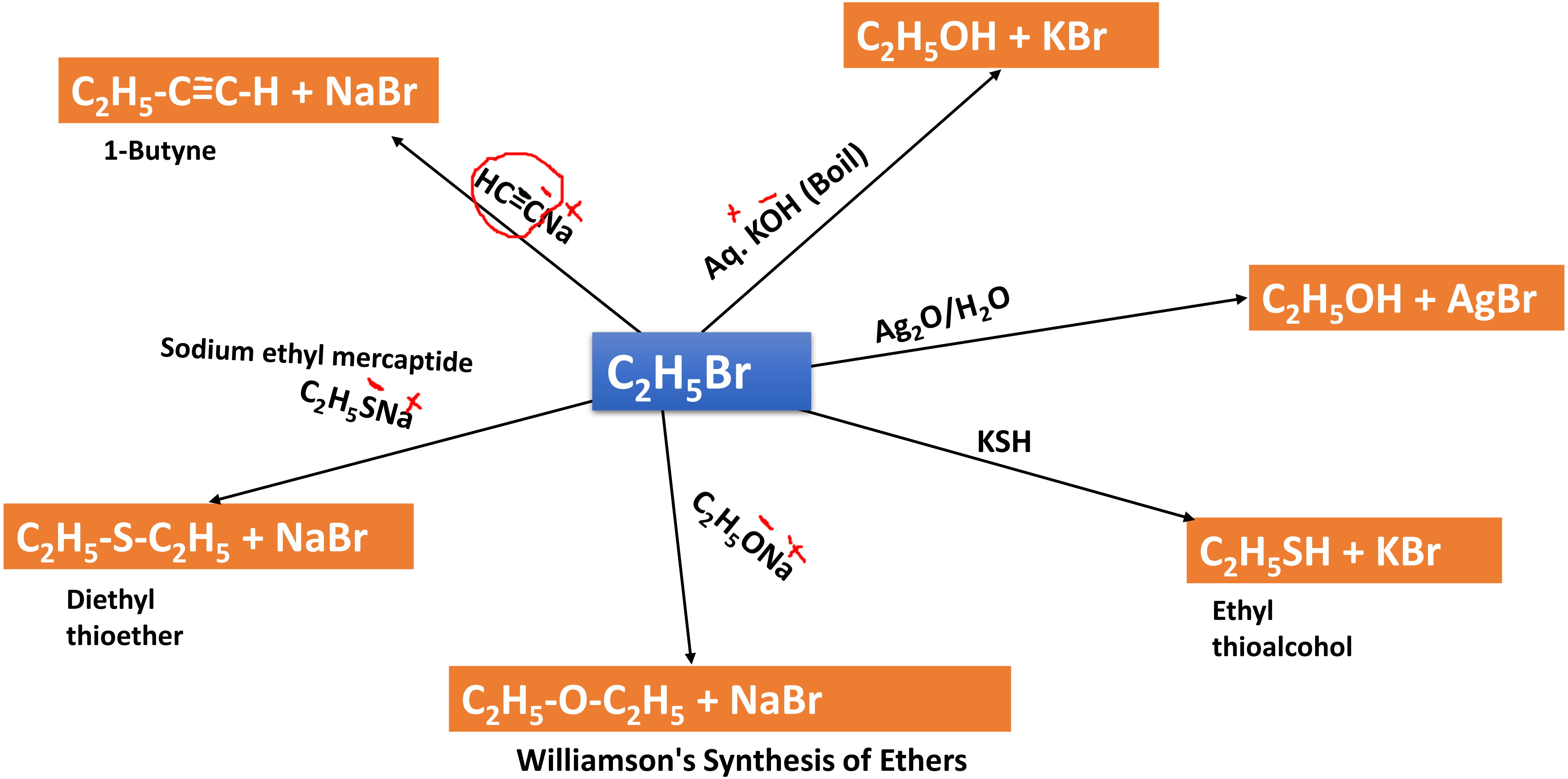
- ❑ Undergo Nucleophilic substitution reactions
- ❖ Most important synthetic reagents in organic chemistry
- ➢ C-X bond is polar
- ➢ Due to partial positive charge on Carbon atom, the nucleophile can attack it easily to replace halogen atom



- ❑ Order of reactivity wrt halogen atom
- ➢ R-I > R-Br > R-Cl > R-F

- ➢ It is because C-F bond is strongest due its smaller bond length

Nucleophilic substitution reactions



C_2H_5Br

$HC\equiv\overset{-}{C}Na^{+}$

$C_2H_5\text{-}C\equiv C\text{-}H + NaBr$

1-Butyne

Aq. $\overset{+}{K}\overset{-}{O}H$ (Boil)

$C_2H_5OH + KBr$

Ag_2O/H_2O

$C_2H_5OH + AgBr$

KSH

$C_2H_5SH + KBr$

Ethyl thioalcohol

$C_2H_5\overset{-}{O}Na^{+}$

$C_2H_5\text{-}O\text{-}C_2H_5 + NaBr$

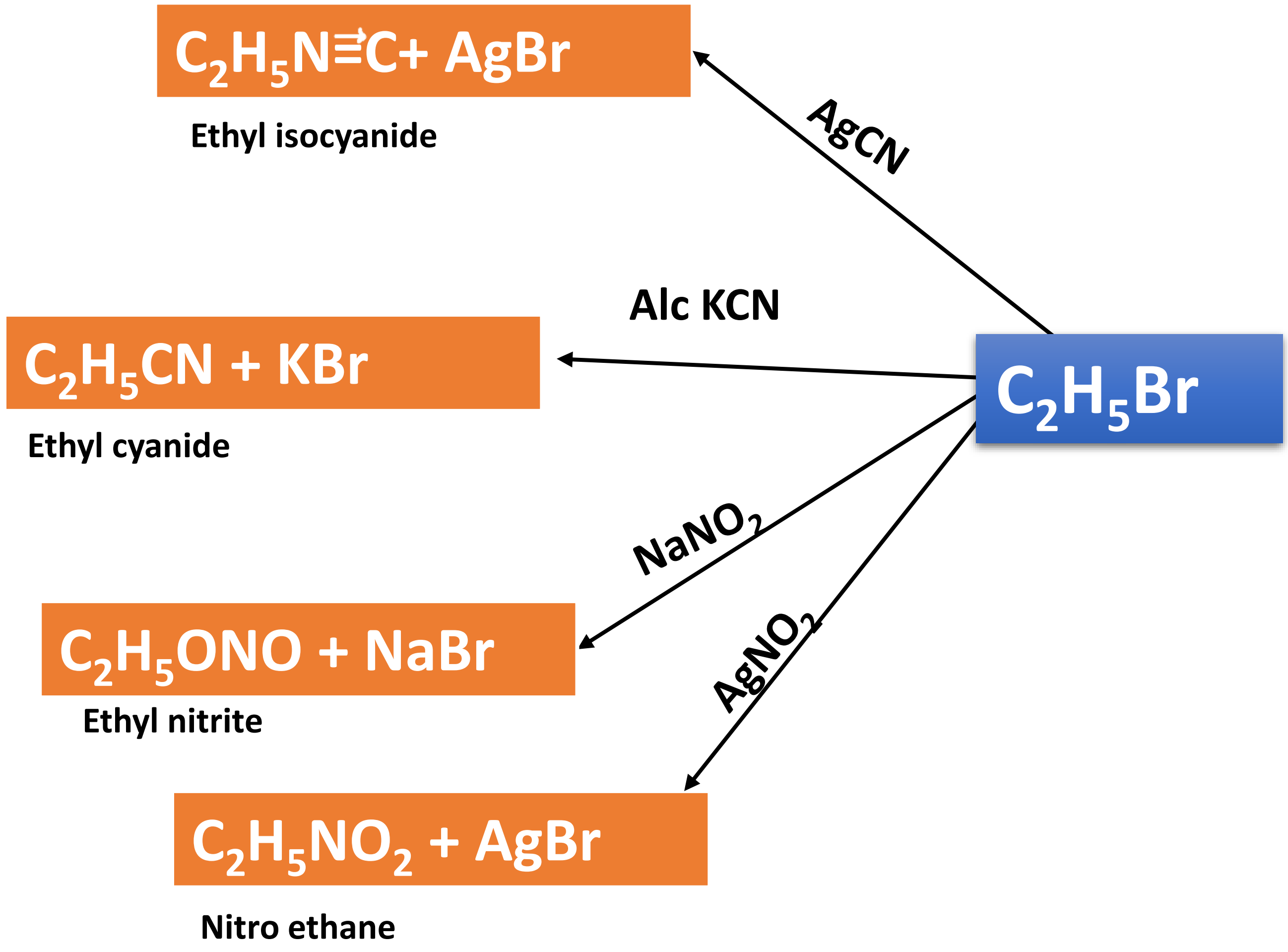
Williamson's Synthesis of Ethers

Sodium ethyl mercaptide $C_2H_5\overset{-}{S}Na^{+}$

$C_2H_5\text{-}S\text{-}C_2H_5 + NaBr$

Diethyl thioether

Nucleophilic substitution reactions



$C_2H_5N\equiv C$+ AgBr

Ethyl isocyanide

AgCN

Alc KCN

C_2H_5CN + KBr

Ethyl cyanide

C_2H_5Br

$NaNO_2$

$AgNO_2$

C_2H_5ONO + NaBr

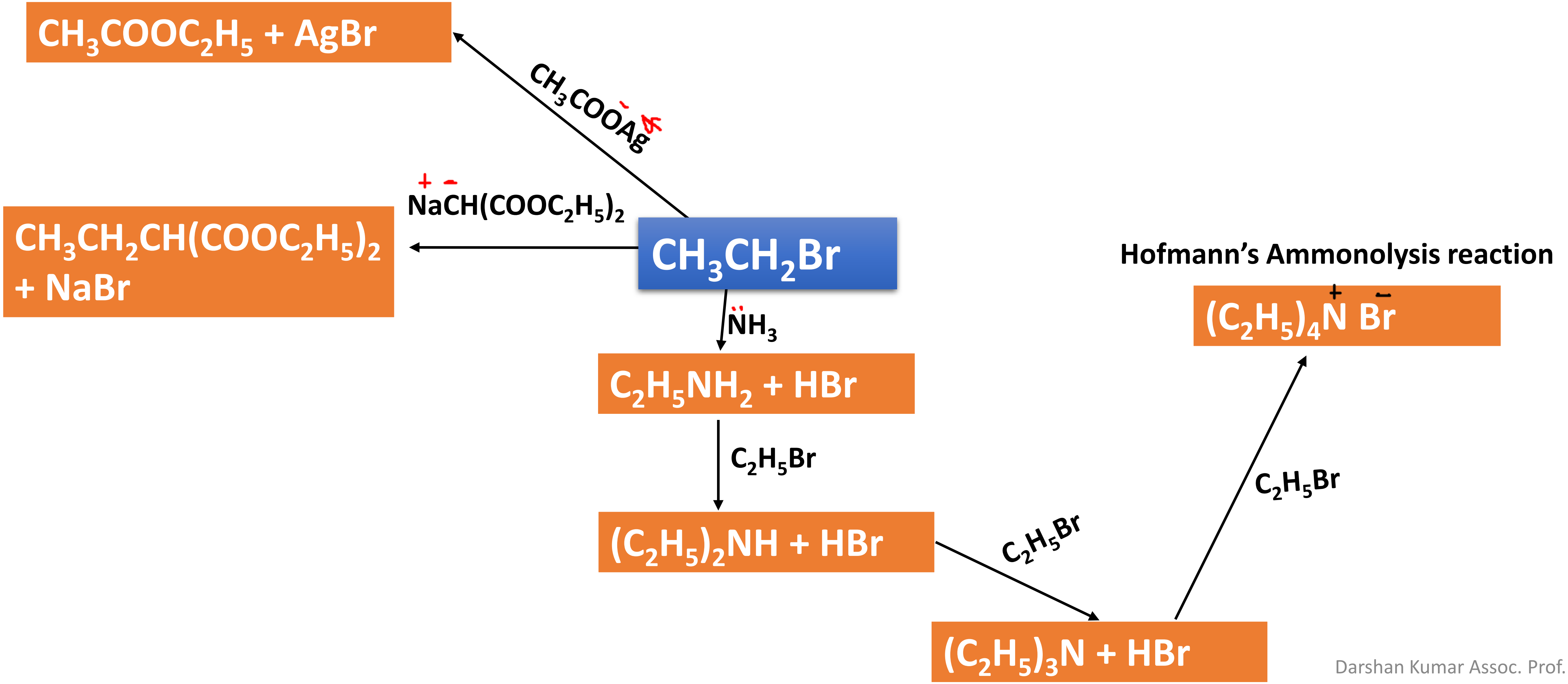
Ethyl nitrite

$C_2H_5NO_2$ + AgBr

Nitro ethane

- In Ag-O-$\ddot{N}$=O, Ag-O bond is covalent so attack takes place via the lone pair on nitrogen atom. In Na-O-N=O, Na–O bond is ionic so ionisation takes place and –vely charged oxygen attacks
- Similarly Ag-C bond in AgCN is covalent and attack takes place via lone pair present on Nitrogen atom

Nucleophilic substitution reactions



$CH_3COOC_2H_5$ + AgBr

$CH_3COO^-Ag^+$

$\overset{+}{Na}\overset{-}{C}H(COOC_2H_5)_2$

$CH_3CH_2CH(COOC_2H_5)_2$ + NaBr

CH_3CH_2Br

$\ddot{N}H_3$

$C_2H_5NH_2$ + HBr

C_2H_5Br

$(C_2H_5)_2NH$ + HBr

C_2H_5Br

$(C_2H_5)_3N$ + HBr

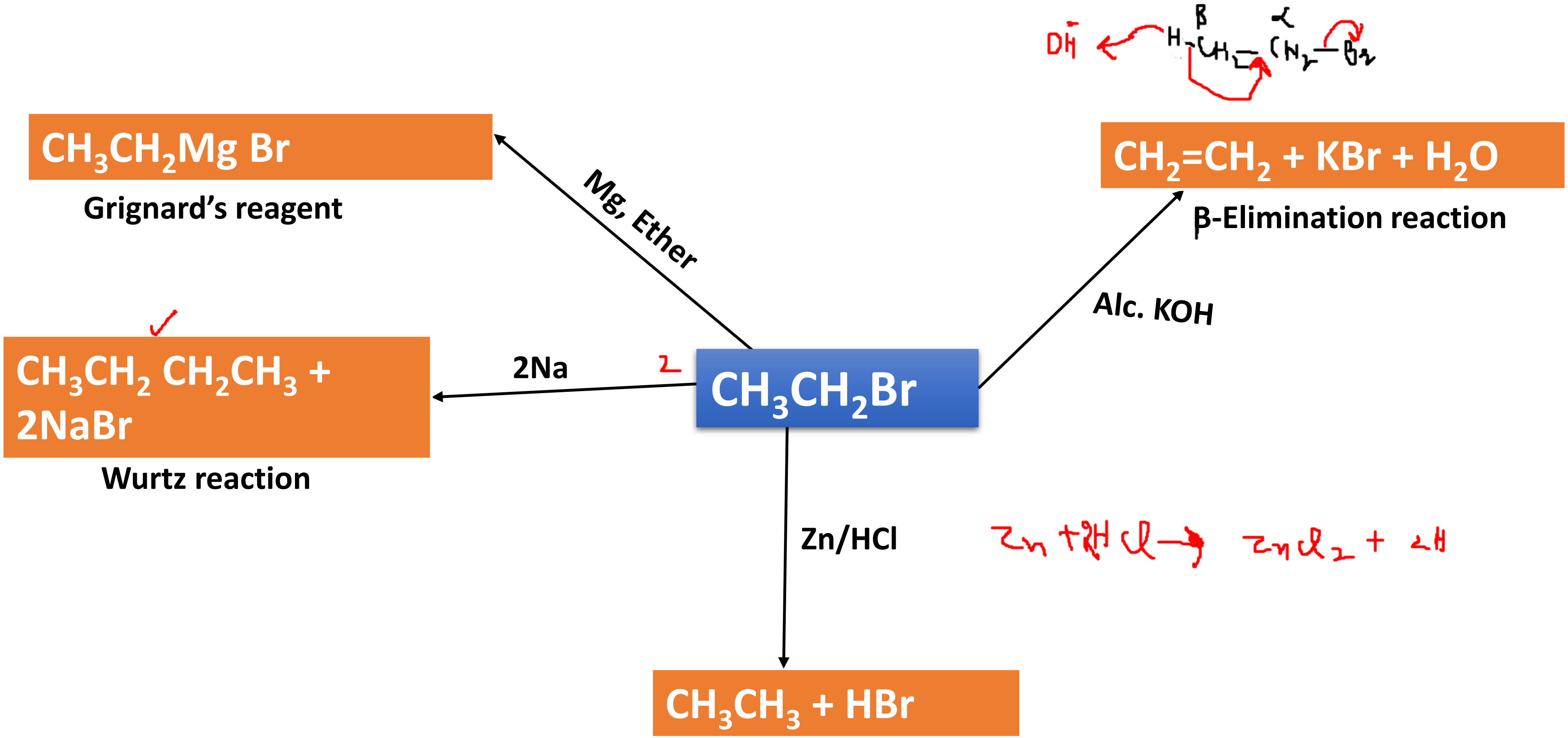
C_2H_5Br

Hofmann’s Ammonolysis reaction

$(C_2H_5)_4\overset{+}{N}\ \overset{-}{Br}$

Darshan Kumar Assoc. Prof. GC Amb

Some more reactions



$\overset{-}{OH}$ H–$\overset{\beta}{CH_2}$–$\overset{\alpha}{CH_2}$–Br

CH_3CH_2MgBr

Grignard's reagent

Mg, Ether

$CH_2{=}CH_2 + KBr + H_2O$

β-Elimination reaction

Alc. KOH

✓

$CH_3CH_2CH_2CH_3 + 2NaBr$

Wurtz reaction

2Na

2

CH_3CH_2Br

Zn/HCl

$Zn + 2HCl \rightarrow ZnCl_2 + 2H$

$CH_3CH_3 + HBr$

Darshan Kumar Assoc. Prof. GC Amb

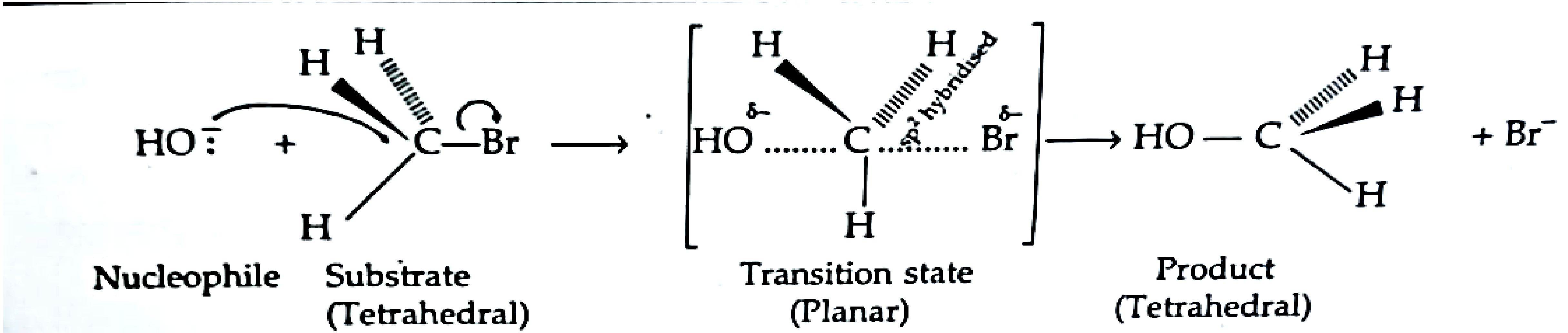
Types of Nucleophilic substitution reactions

❑ Bimolecular Nucleophilic substitution reactions ($S_N{}^2$ reactions)

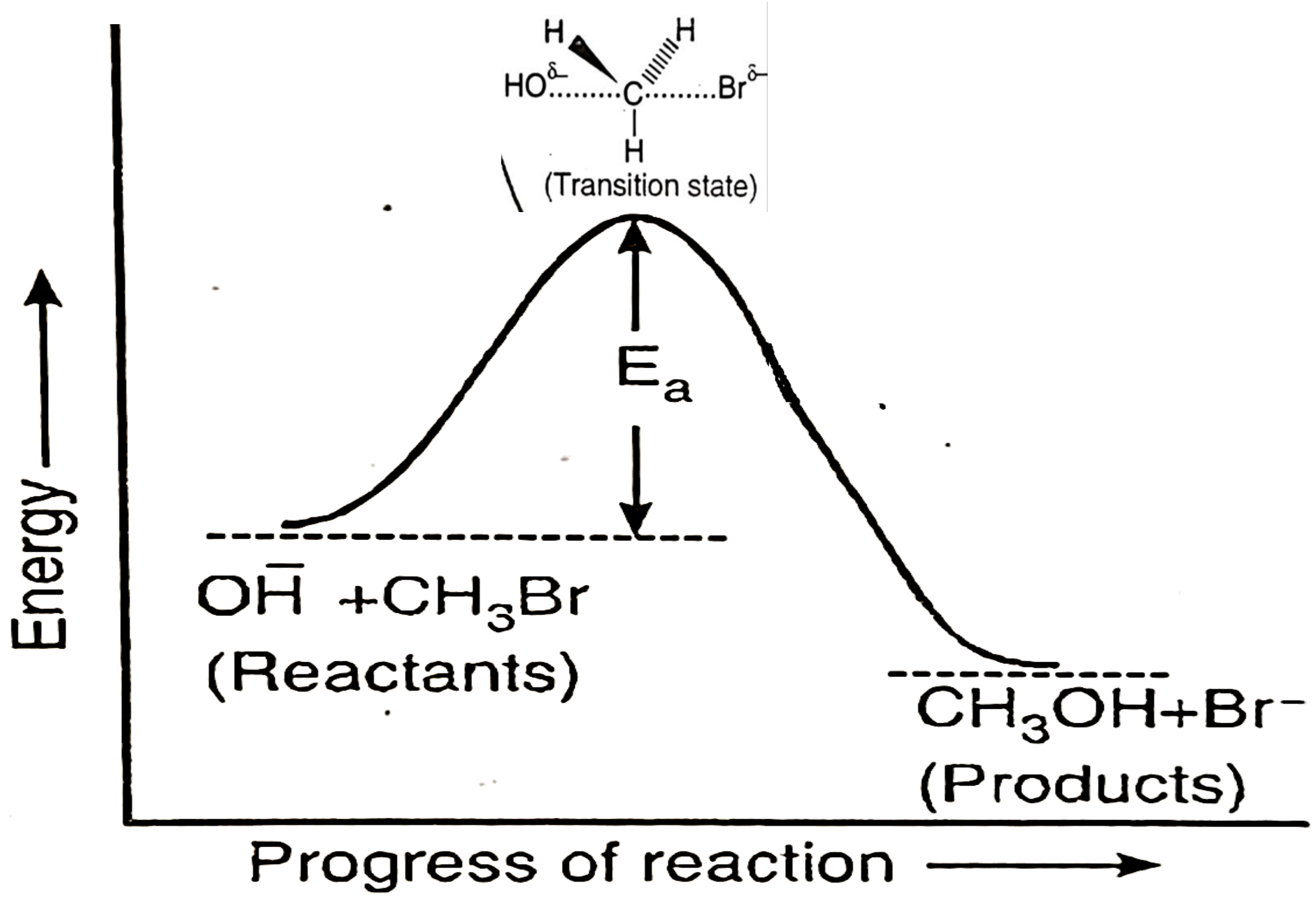
- ❖ When nucleophile is strong ie $\bar{O}R$, $\bar{O}H$, $C\bar{N}$
- ❖ Takes place by concerted one step process
- ❖ Rate of the reaction depends upon the conc. Of alkyl halide as well as conc. of nucleophile
- ❖ Order of reaction is 2

$$OH^- + R—X \longrightarrow R—OH + X^- \qquad r = k\,[RX]\,[OH^-]$$

- ❖ Attack of nucleophile takes place from opposite side of halogen atom



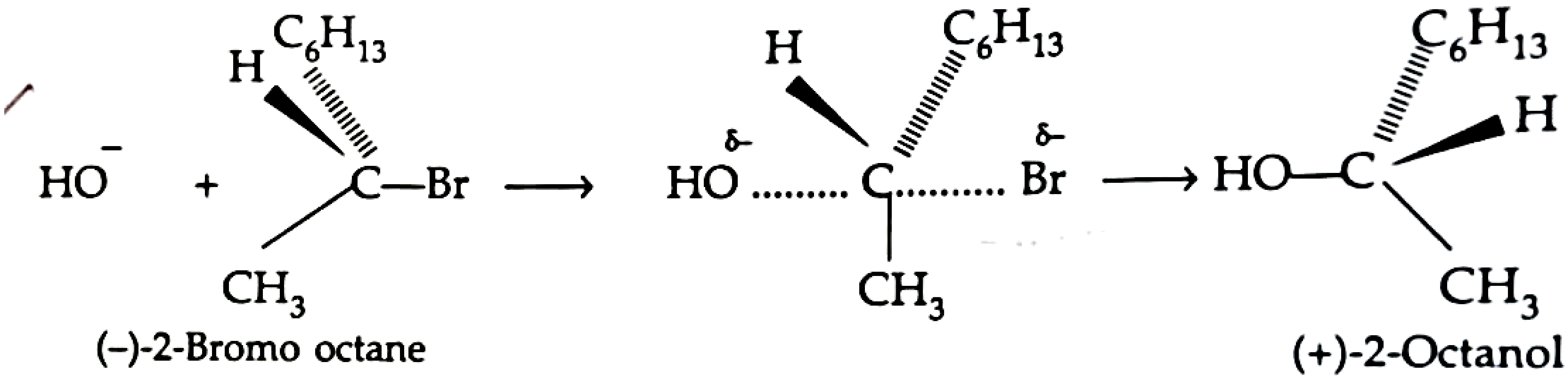
Energy profile diagram of S_N2 reactions



Darshan Kumar Assoc. Prof. GC Amb

Stereochemistry of S_N2 reactions

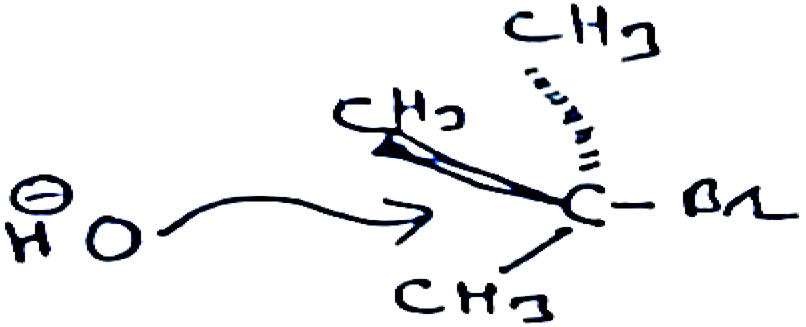
- ❑ **Take place with complete inversion of configuration**
- ❑ **Also known as Walden inversion**



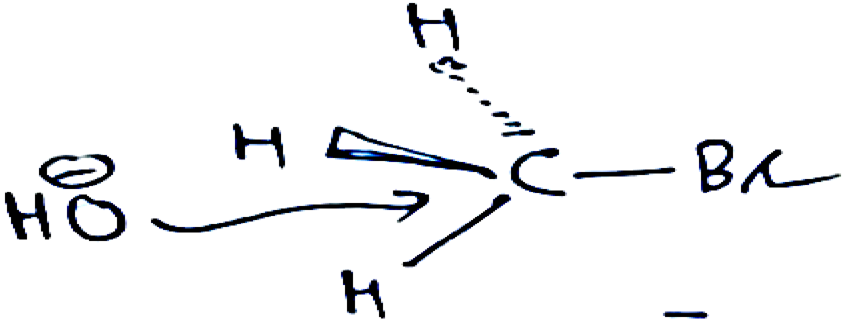
Factors affecting the occurrence and rates of S_N2 reactions

1. Nature of alkyl group in alkyl halides (Steric factors)

- If attack of nucleophile is sterically hindered, the reactivity of alkyl halide decreases
- Steric hinderance is maximum in 3^o halides
- Methyl halides > Primary alkyl halides > Secondary alkyl halides > Tertiary alkyl halides



Attack of $\bar{O}H$ ion difficult through Crowded $-CH_3$ groups.



Attack of $\bar{O}H$ ion easy

Factors affecting the occurrence and rates of $S_N{}^2$ reactions

2. Nature of halogen atom in alkyl halide (Nature of leaving group)

- Weaker is the basic nature of the leaving group, better would be its leaving tendency
- Order of increasing basic strength of halide ions is

$$:\ddot{\underset{..}{I}}:^{-} \;<\; :\ddot{\underset{..}{Br}}:^{-} \;<\; :\ddot{\underset{..}{Cl}}:^{-} \;<\; :\ddot{\underset{..}{F}}:^{-}$$

Low charge density
Makes halide ion a
weaker base

- So ease of elimination of leaving groups is as

$$:\ddot{\underset{..}{I}}:^{-} \;>\; :\ddot{\underset{..}{Br}}:^{-} \;>\; :\ddot{\underset{..}{Cl}}:^{-} \;>\; :\ddot{\underset{..}{F}}:^{-}$$

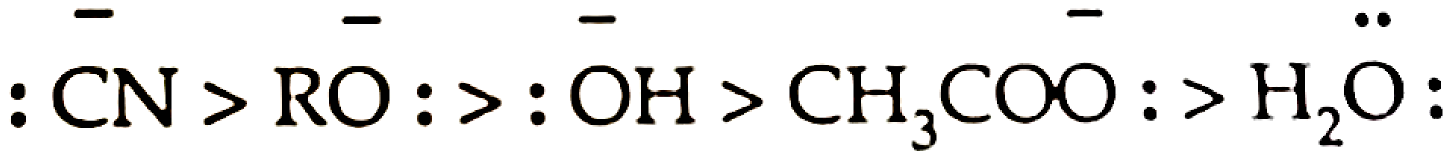
- R-I > R-Br > R-Cl > R-F

Reactivity decreases

Factors affecting the occurrence and rates of S_N2 reactions

3. Strength of nucleophile

- Stronger nucleophiles favour S_N2 mechanism
- Stronger is the nucleophile, greater is rate of S_N2 reaction



$$:\overset{-}{C}N > R\overset{-}{O}: > :\overset{-}{O}H > CH_3CO\overset{-}{O}: > H_2\ddot{O}:$$

4. Nature of solvent

- Transition state is less polar so less polar solvents favour S_N2 mechanism
- More polar solvents decrease rate of S_N2 reactions

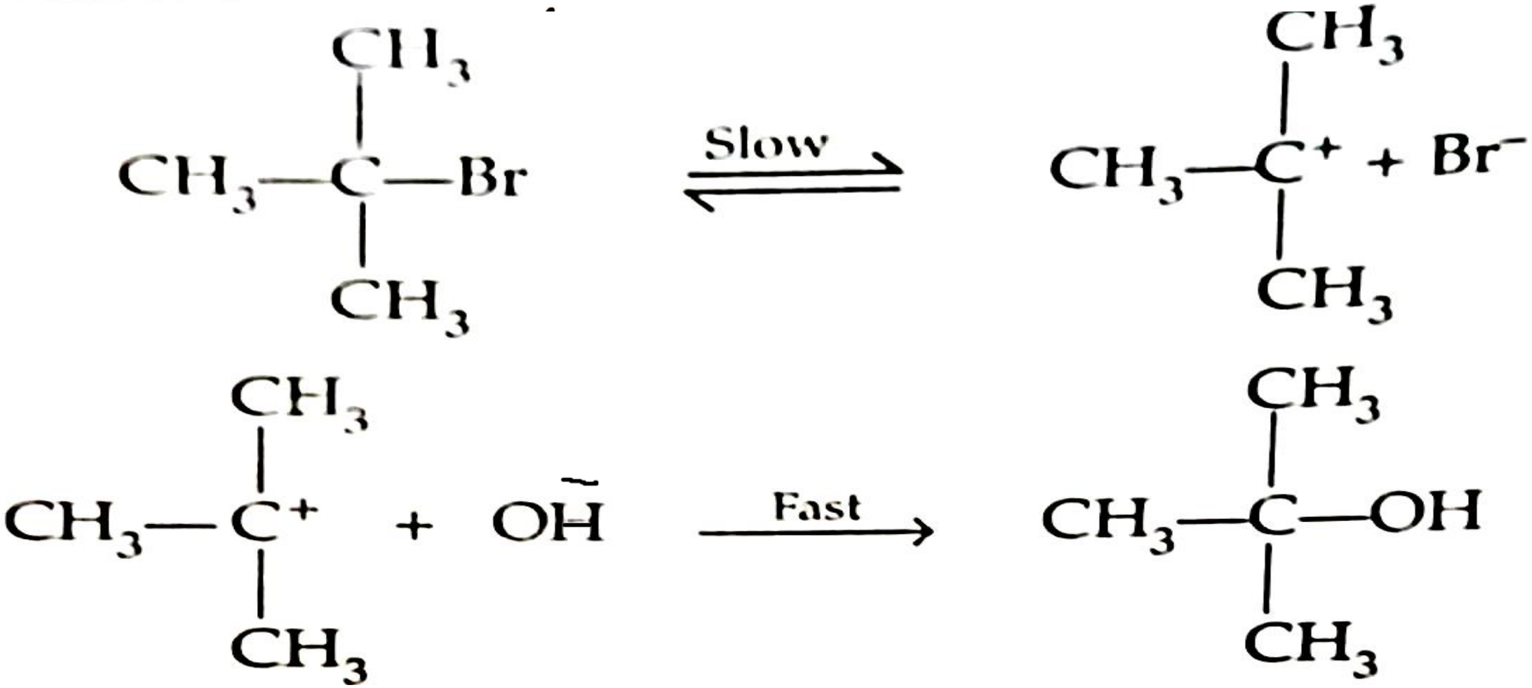
Unimolecular or Monomolecular Nucleophilic substitution (S_N1)

- **Two step mechanism**

$$R{-}X \xrightleftharpoons{\text{slow}} R^+ + X^-$$

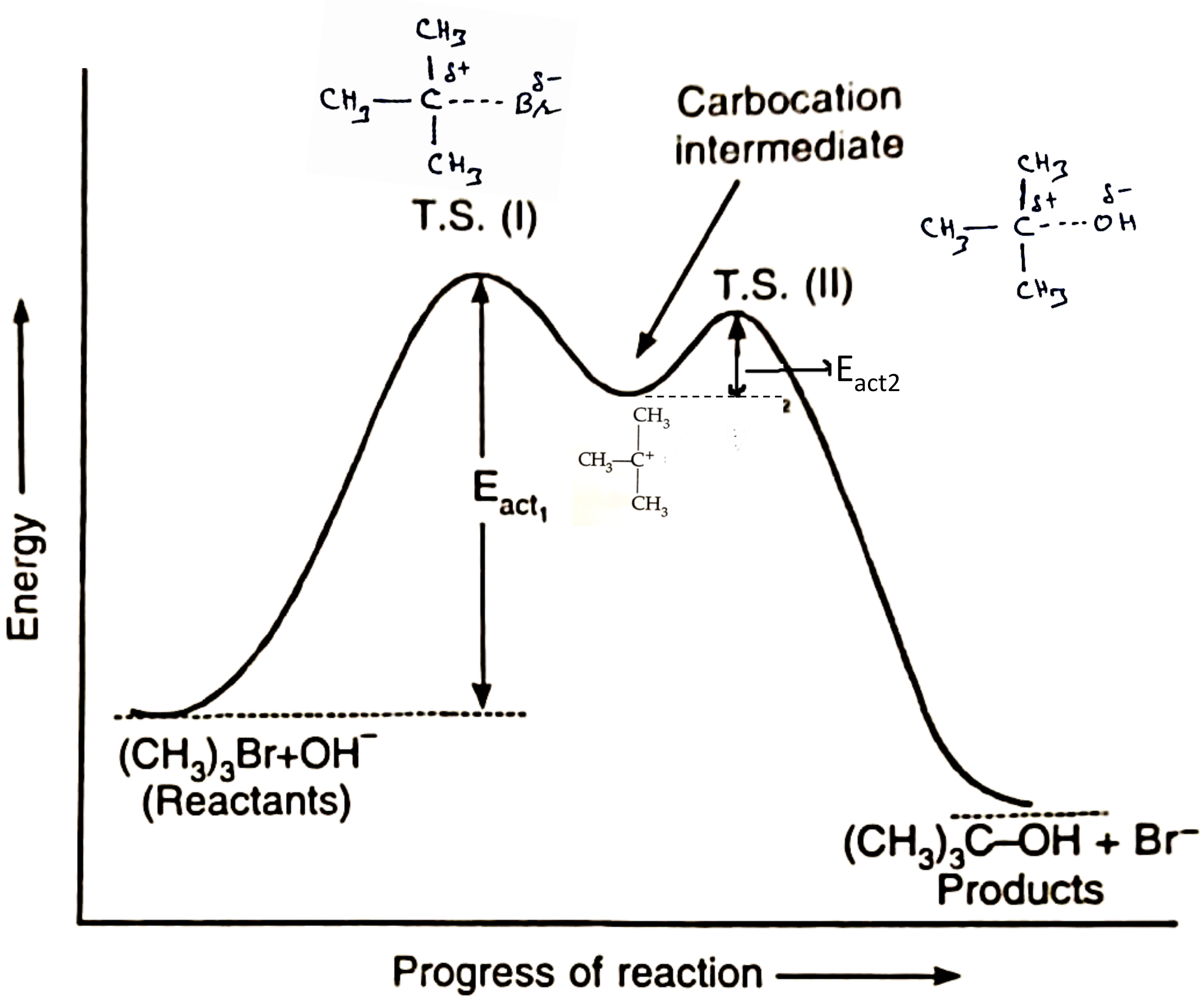
$$R^+ + OH^- \xrightarrow{\text{Fast}} R{-}OH$$

- **Rate depends upon the conc. Of alkyl halide only**
- **The order of reaction is one** $r = k\,[RX]$



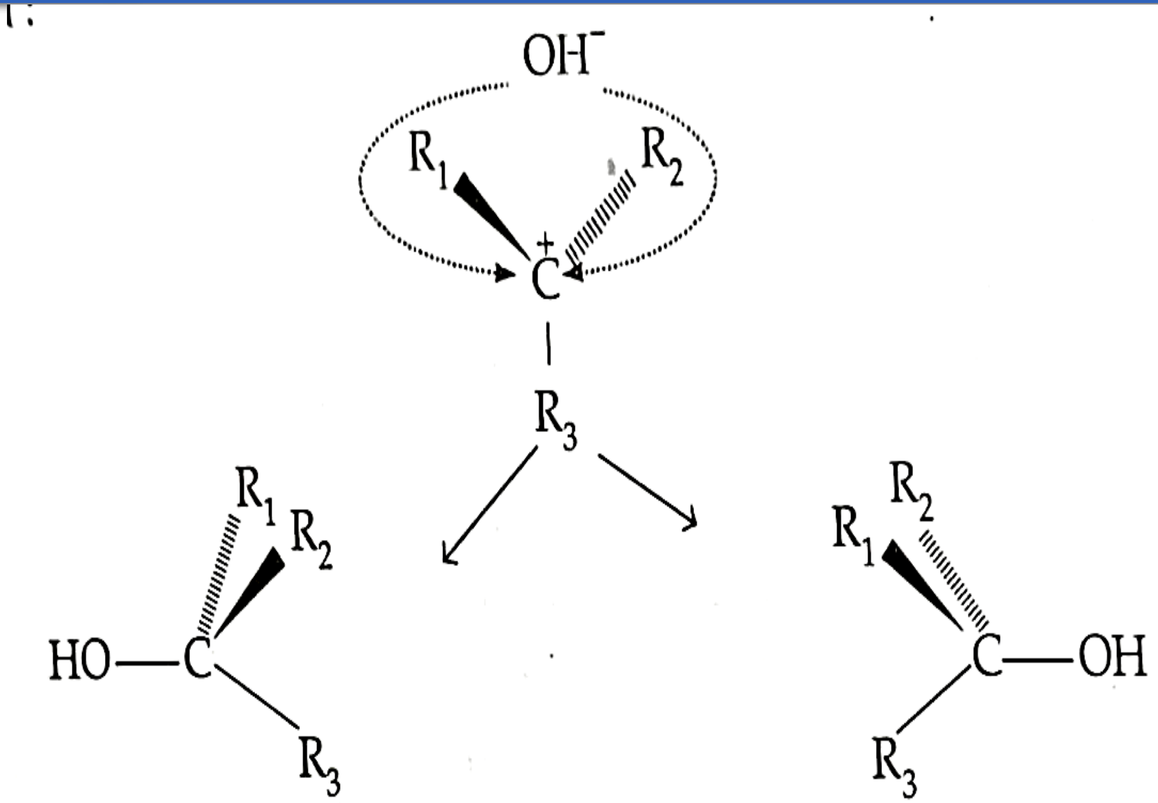
Energy profile diagram of S_N1 reaction

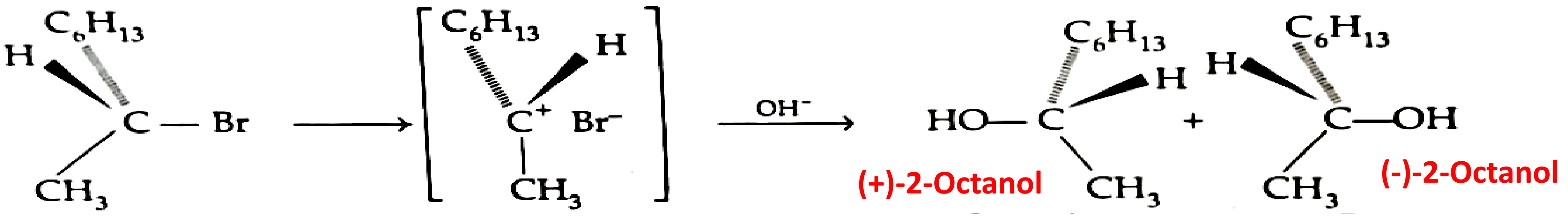
- ❑ **Two step mechanism so there are two transition states**



Stereochemistry of $S_N{}^1$ reaction

- **Reaction is accompanied by partial racemization (Racemic mixture is formed)**
- **It is because nucleophile can attack the planer carbocation from both the sides**
- **Racemization is not complete but partial**
- **It is because Bromide ion does not depart immediately so initially nucleophile attacks from the side opposite to bromine atom**
- **So one enantiomer will be more in concentration ie inversion dominates initially**





(+)-2-Octanol

(-)-2-Octanol

2-Bromooctane

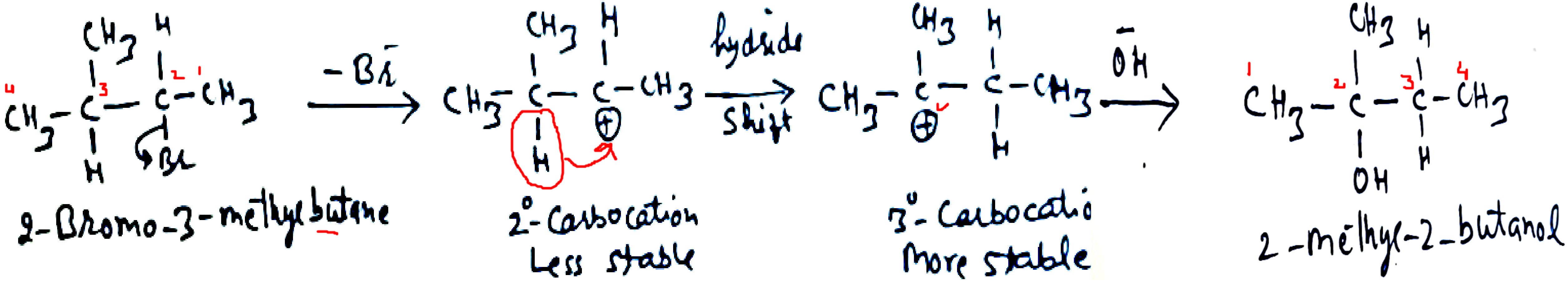
Inversion
dominates initially

Retention
Less favourable initially

Rearrangement in S_N^1 reactions

❑ S_N^1 reactions give rearranged products

- ➢ It is because of the formation of intermediate carbocation
- ➢ Less stable carbocation may change to more stable carbocation by Hydride or Methyl shift



Factors affecting the occurrence and rates of S_N1 reactions

1. Nature of alkyl group in alkyl halides (Electronic factors)

- **Since carbocation is formed in rate determining step, so relative stability of carbocation determines the rate of reaction.**

- **Tert. Alkyl halides from most stable tertiary carbocation so they are most reactive and follow S_N1 mechanism**

- **So order of reactivity towards S_N1 mechanism is**

Methyl halides < Primary alkyl halides < Secondary alkyl halides < Tertiary alkyl halides

Factors affecting the occurrence and rates of $S_N{}^1$ reactions

2. Nature of halogen atom in alkyl halide (Nature of leaving group)

- Weaker is the basic nature of the leaving group, better would be its leaving tendency
- Order of increasing basic strength of halide ions is

$$:I^- < :Br^- < :Cl^- < :F^-$$

- So ease of elimination of leaving groups is as

$$:I^- > :Br^- > :Cl^- > :F^-$$

- R-I > R-Br > R-Cl > R-F(Order of reactivity is same as in $S_N{}^2$ reactions)

Darshan Kumar Assoc. Prof. GC Amb

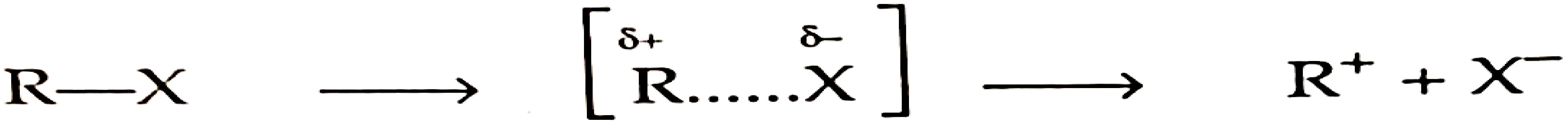
Factors affecting the occurrence and rates of S_N2 reactions

3. Strength of nucleophile

- Since attack of nucleophile is not involved in rate determining step so nature of nucleophile does not affect the rate of S_N1 reactions

4. Nature of solvent

- Carbocation formed is stabilised by solvation by the solvent
- Higher polarity of the solvent causes greater solvation of carbocation so alkyl halide can undergo ionisation easily
- Hence S_N1 reactions are favoured in polar solvents



$$R{-}X \longrightarrow \left[\overset{\delta+}{R}\cdots\cdots\overset{\delta-}{X}\right] \longrightarrow R^+ + X^-$$

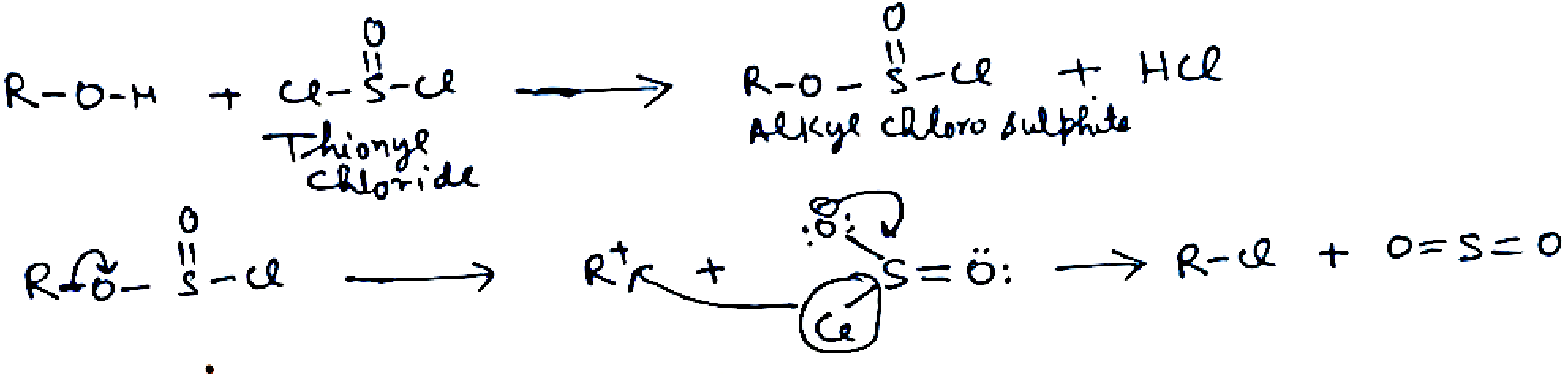
Transition state more polar than reactant and, therefore, strongly stabilised by solvation.

$S_N{}^i$ reactions(Internal nucleophilic substitution)

- Part of the leaving group gets detached and attack the substrate from the same side
- Follow 1st order Kinetics as in $S_N{}^1$ reactions

☐ Examples

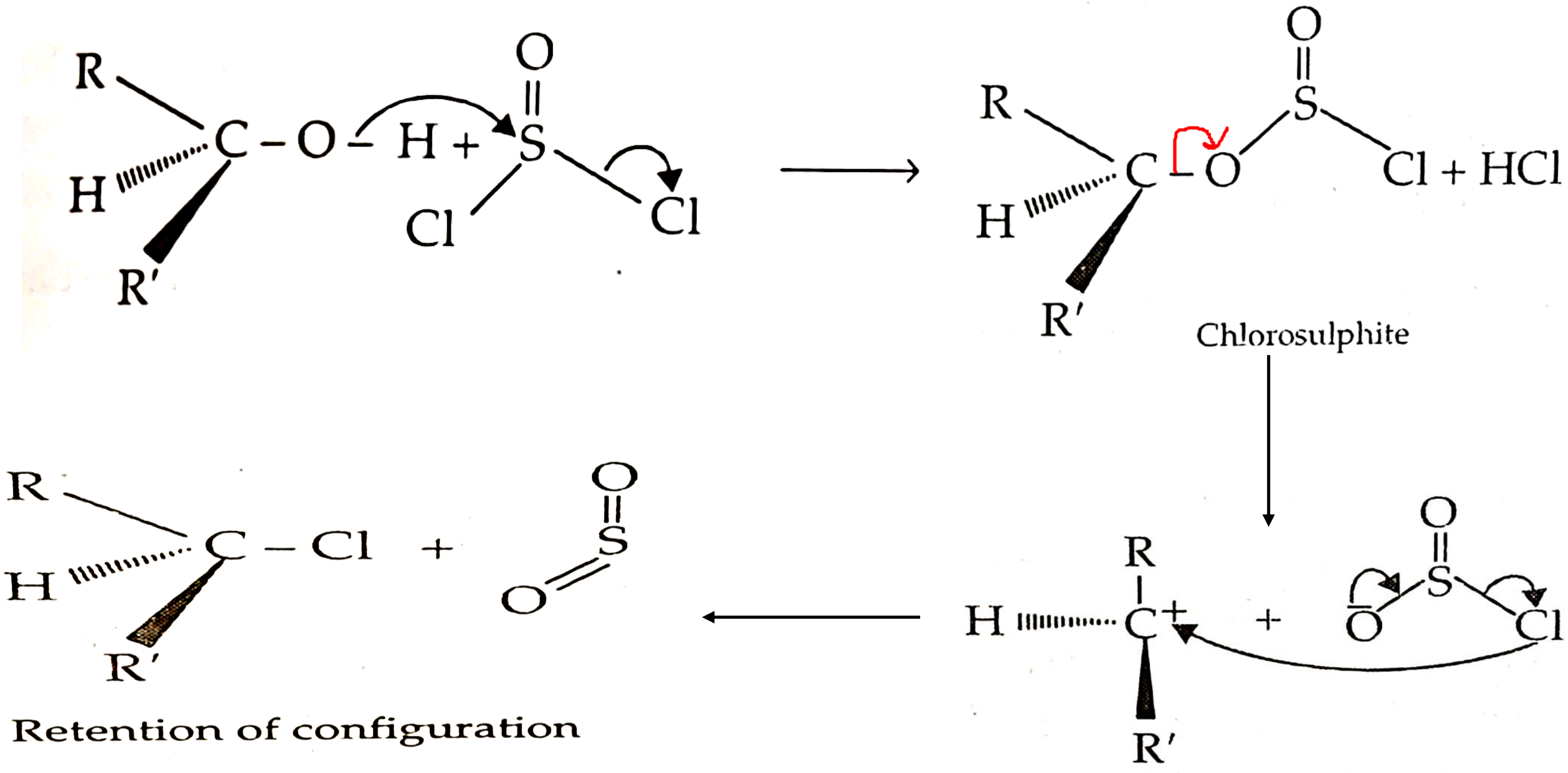
- Chlorination of alcohols with thionyl chloride
- $ROH + SOCl_2 \rightarrow R\text{-}Cl + SO_2 + HCl$
- The mechanism of this reaction is



S_N^i reactions(Internal nucleophilic substitution)

☐ stereochemistry

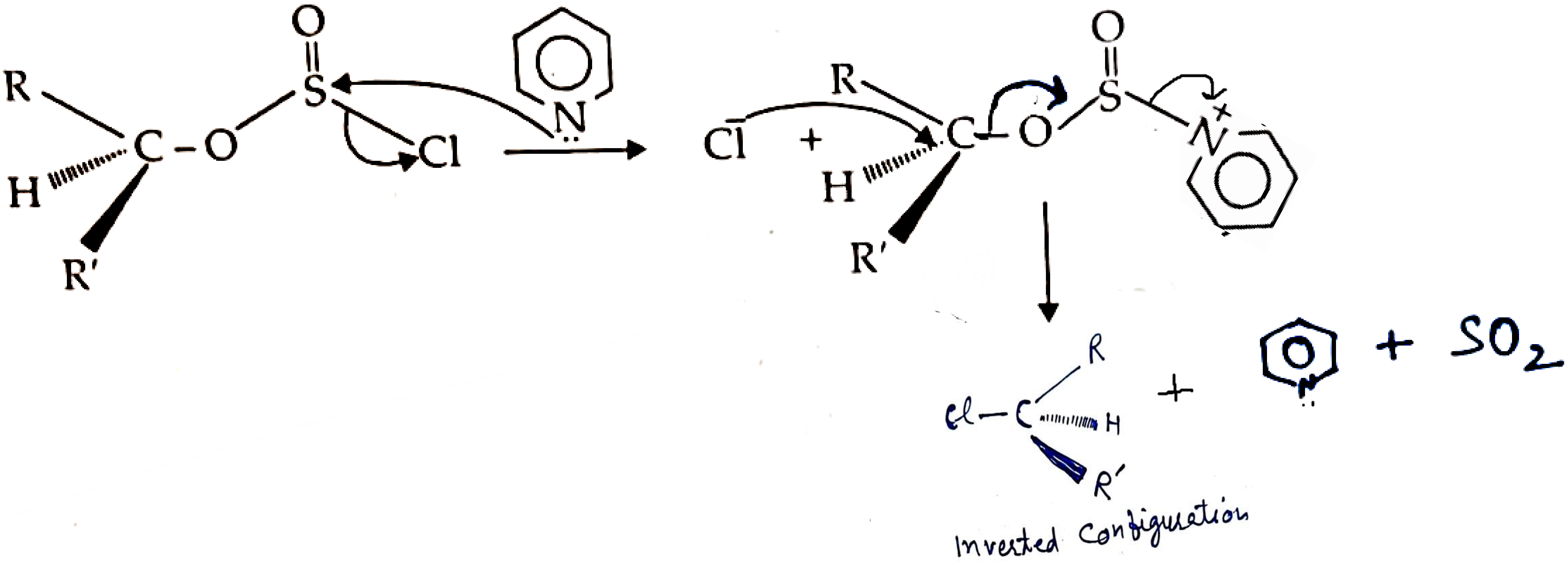
- Occur by retention of configuration as the detached group attacks from the same side



$S_N{}^i$ reactions(Internal nucleophilic substitution)

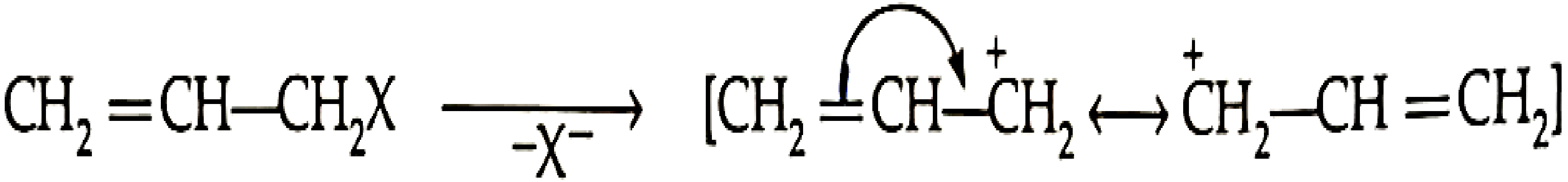
❑ Evidence for mechanism

- ➢ If we add pyridine to the reaction mixture, then there is inversion of configuration
- ➢ It is because pyridine attacks Alkyl chlorosulphite to make chloride ion free
- ➢ Chloride ion then attacks the alkyl group from back side



Relative reactivity of Allyl halides and Alkyl halides

- ☐ **Allyl halides are more reactive than alkyl halides towards nucleophilic substitution reactions**
- ➢ **It is because allyl carbocation is resonance stabilised**



$$CH_2=CH-CH_2X \xrightarrow[-X^-]{} [CH_2=CH-\overset{+}{C}H_2 \longleftrightarrow \overset{+}{C}H_2-CH=CH_2]$$

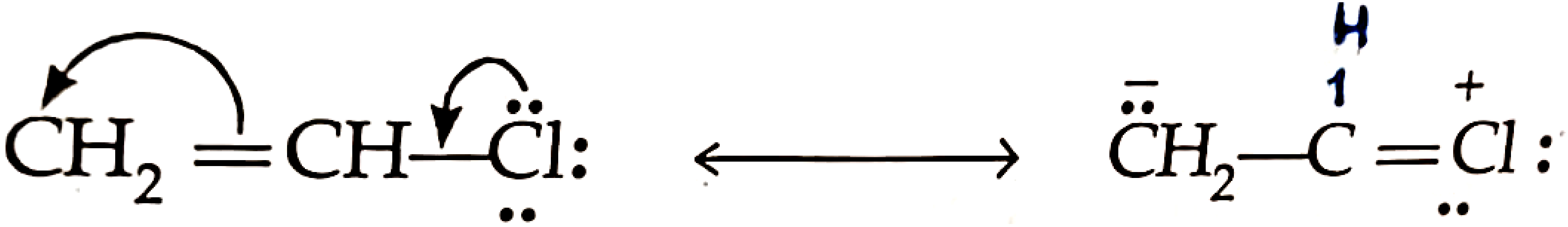
Allyl halide

Resonance stabilised allyl carbocation

$CH_3-CH_2-\overset{\oplus}{C}H_2$

Relative reactivity of Vinyl halides and Alkyl halides

- ❑ **Vinyl halides are less reactive than alkyl halides towards nucleophilic substitution reactions**
  - ➢ **It is because C-Cl bond acquires double bond character due to resonance and its cleavage becomes difficult**



$$CH_2{=}CH{-}\ddot{\underset{\cdot\cdot}{Cl}}{:} \longleftrightarrow \overset{-}{\ddot{C}}H_2{-}\overset{H}{\overset{|}{C}}{=}\overset{+}{\underset{\cdot\cdot}{Cl}}{:}$$

  - ➢ **Secondly, the carbon to which Cl is attached is SP^2 hybridised in case of vinyl halides. SP^2 hybridised carbon atom has greater electronegativity and it does not release the electron pair to Cl atom easily. Hence C-Cl bond cleavage becomes difficult**

$CH_2 = \underset{\uparrow}{C}H - Cl$

sp^2 hybridised Carbon.

Questions

1. Tabulate the differences between S_N2 & S_N1 reactions.
2. S_N1 reactions of alkyl halides are accompanied by partial racemization. Explain.
3. Discuss the effect of polarity of the solvent on S_N2 and S_N1 reactions.
4. Haloalkanes are polar in nature, still they are insoluble in water. Explain.
5. Vinyl chloride is less reactive than Ethyl chloride. Explain giving reasons.
6. How will you prepare the following
   - i. n-Propyl bromide from an alkene
   - ii. Ethyl chloride from an alcohol
7. How will you convert n-Propyl chloride into n-Propyl methyl ether?
8. Reaction of Ethyl bromide with Silver nitrite gives Nitroethane whereas its reaction with Sodium nitrite gives Ethyl nitrite. Explain.