

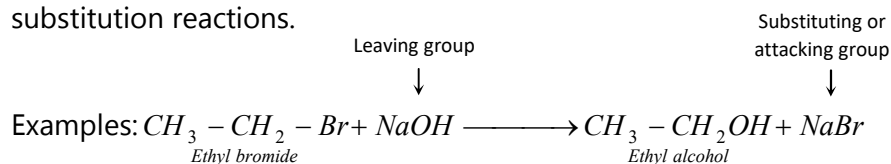
Types of organic reactions.

It is convenient to classify the numerous reactions of the various classes of organic compound into four types,

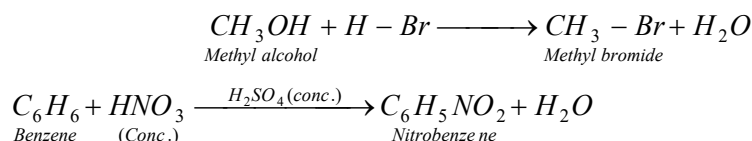
- Substitution reactions,
- Addition reaction,
- Elimination reactions,
- Rearranged reactions,

Substitution reactions

Replacement of an atom or group of the substrate by any other atom or group is known as substitution reactions.

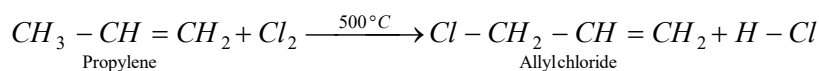


(Bromine atom is replaced by hydroxyl group)

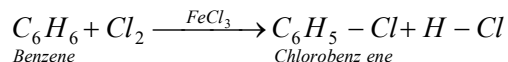


(Hydroxyl group is replaced by bromine group)

(Hydrogen is replaced by NO_2 group)



(Hydrogen is replaced by chlorine)



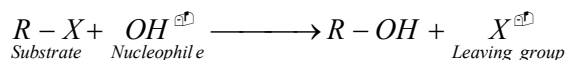
(Hydrogen is replaced by chlorine)

Types of substitution reactions: On the basis of the nature of attacking species substitution reactions are classified into following three categories:

- (1) Nucleophilic substitution reactions
- (2) Electrophilic substitution reactions,
- (3) Free radical substitution reactions

(1) Nucleophilic substitution reactions

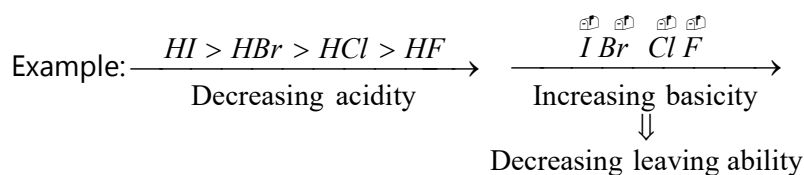
(i) Many substitution reactions, especially at the saturated carbon atom in aliphatic compounds such as alkyl halides, are brought about by nucleophilic reagents or nucleophiles.



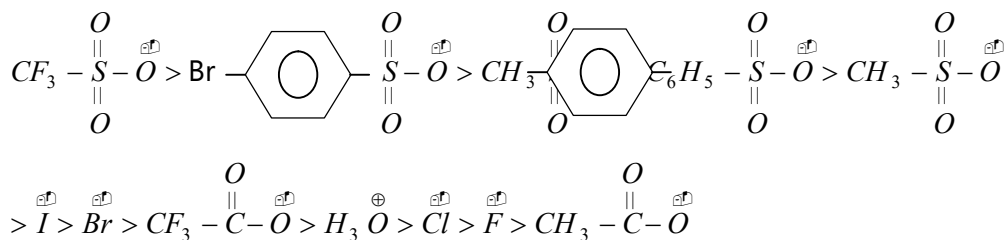
Such substitution reactions are called nucleophilic substitution reactions, i.e., S_N reactions (S stands for substitution and N for nucleophile).

(ii) The weaker the basicity of a group of the substrate, the better is its leaving ability.

$$\text{Leaving power of the group} \propto \frac{1}{\text{Basicity of the group}}$$



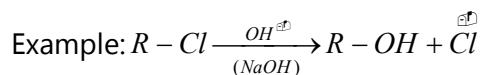
(iii) The leaving power of some nucleophilic groups are given below in decreasing order,



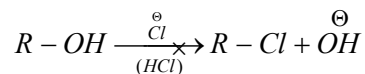
(iv) In these reactions leaving group of the substrate is replaced by another nucleophile. If reagent is neutral than leaving group is replaced by negative part of the reagent. Negative part of the reagent is always nucleophilic in character.



(v) In S_N reactions basicity of leaving group should be less than the basicity of incoming nucleophilic group. Thus strongly basic nucleophilic group replaces weakly basic nucleophilic group of the substrate.



Basicity of OH^{\ominus} is more than Cl^{\ominus} hence OH^{\ominus} replaces Cl^{\ominus} as Cl^{\ominus}



Basicity of $\overset{\ominus}{Cl}$ is less than $\overset{\ominus}{OH}$ hence $\overset{\ominus}{Cl}$ will not replace OH as $\overset{\ominus}{OH}$.

(vi) Unlike aliphatic compounds having nucleophilic group as leaving group, aromatic compounds having same group bonded directly with aromatic ring do not undergo nucleophilic substitution reaction under ordinary conditions.

The reason for this unusual reactivity is the presence of lone pair or π bond on key atom of the functional group. Another factor for the low reactivity is nucleophilic character of aromatic ring.

(vii) The S_N reactions are divided into two classes, S_{N^2} and S_{N^1} reactions.

Distinction between S_{N^2} and S_{N^1} reactions

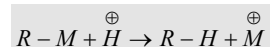
Factors	S_{N^2} Reactions	S_{N^1} Reactions
Number of steps	One: $R : L + : Nu^{\ominus} \rightarrow R : Nu + : L^{\ominus}$	Two: (i) $R : L \xrightarrow{\text{Slow}} R^+ + : L^{\ominus}$ (ii) $R^+ + : Nu^- \xrightarrow{\text{Fast}} R : Nu$
Reaction rate and order	Second order: Rate \propto [Substrate] [Nucleophile] or Rate = $K_2[RL][: Nu^{\ominus}]$	First order: Rate \propto [Substrate] or Rate = $K_1[RL]$
Molecularity	Bimolecular	Unimolecular
TS of slow step	$\overset{\delta^-}{: Nu} \cdots C \cdots \overset{\delta^-}{L}$	$: Nu \cdots \overset{\delta^+}{C} \cdots \overset{\delta^-}{L} \cdots Nu :$
Reacting nucleophile	The nucleophile attacks the carbon of the substrate exclusively from the back side.	The nucleophile can attack the carbon of the substrate both on the back and front sides although the back side attack predominates.
Stereochemistry	Complete inversion of configuration takes place.	Inversion and retention takes place.
Reactivity order of alkyl halides	Methyl > 1° > 2° > 3° halides. (I > Br > Cl > F)	3° > 2° > 1° > methyl halides. (I > Br > Cl > F)
Rearrangement	No rearrange product is form (except for allylic).	Rearrange products can be formed.
Nature of nucleophiles	Favored by strong and high concentration of nucleophiles.	Favored by mild and low concentration of nucleosides.
Polarity	Favored by solvents of low polarity.	Favored by solvents of high polarity.

Reaction rate determining factor	By steric hindrance.	By electronic factor (stability of R^{\oplus}).
Catalysis	Not catalyzed by any catalyst (phase transfer).	Catalyzed by Lewis and Bronsted acids, e.g., Ag^{\oplus} , $AlCl_3$, $ZnCl_2$ and strong HA.

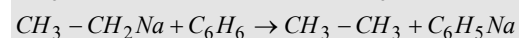
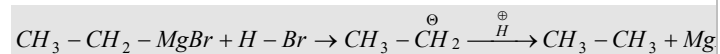
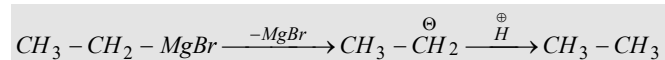
(2) **Electrophilic substitutions reactions:** Electrophilic substitution involves the attack by an electrophile. It is represented as S_E (S stands for substitution and E stands for electrophile). If the order of reaction is 1, it is written as S_{E1} (unimolecular) and if the order is 2, it is S_{E2} (Bimolecular).

S_E^1 Reaction mechanism : Electrophilic substitution in aliphatic compounds (S_N^1) are very rare; some of the important examples are:

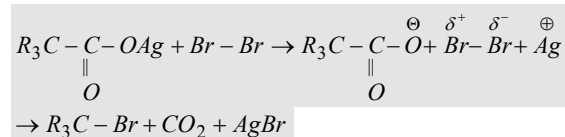
(i) Replacement of the metal atom in an organometallic compound by hydrogen :



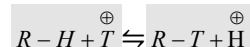
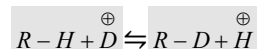
e.g.,



(ii) Decarboxylation of silver salt of carboxylic acid by means of bromine:



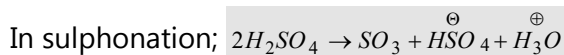
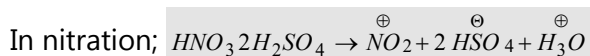
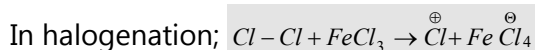
(iii) Isotopic exchange of hydrogen for deuterium or tritium:



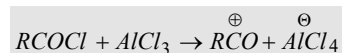
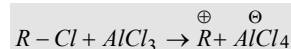
S_E^2 Reaction mechanism: Electrophilic substitution (S_E^2) is very common in benzene nucleus (aromatic compounds) in which π -electrons are highly delocalized and an electrophile can attack this region of high electron density.

In all electrophilic aromatic substitution reactions, it involves:

Step 1. The formation of an electrophile, E^{\oplus} , i.e.,



In Friedel-crafts reaction;



Step 2. The electrophile attacks the aromatic ring to form carbonium ion (or arenium ion) which is stabilized by resonance.

Step 3. Carbonium ion loses the proton to

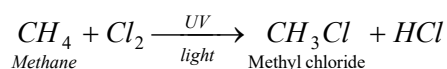
form substitution product.

The bromination of benzene in the presence of $FeBr_3$ is an example of electrophilic substitution.

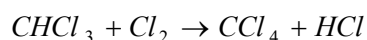
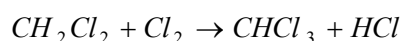
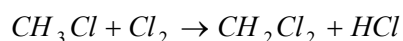
Similarly, Nitration, sulphonation and Friedel-Crafts reaction.....etc., in benzene nucleus are the other examples of electrophilic substitution.

3) **Free radical substitution reactions:** Free radical substitution reactions involve the attack by a free radical. These reactions occur by a free radical mechanism which involves: Initiation, Propagation and Termination steps. Examples,

(i) **Chlorination of methane:** The chlorination of methane in the presence of ultraviolet light is an example of free radical substitution (HOMOLYSIS).

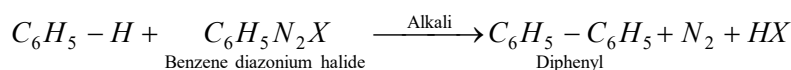


The reaction does not stop with the formation of methyl chloride (CH_3Cl) but the remaining hydrogen atoms are replaced one by one with chlorine atoms to give rise to a chain reaction.

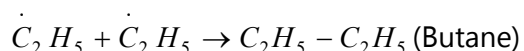
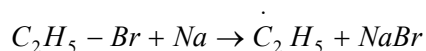
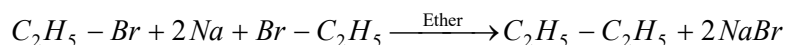


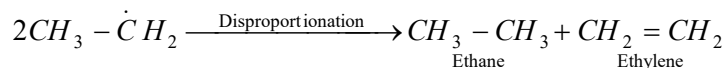
Reactivity of the halogens for free radical substitution is in the order: $F_2 > Cl_2 > Br_2 > I_2$

(ii) **Arylation of aromatic compounds** (Gomberg reaction): The reaction of benzene diazonium halide with benzene gives diphenyl by a free radical substitution reaction.

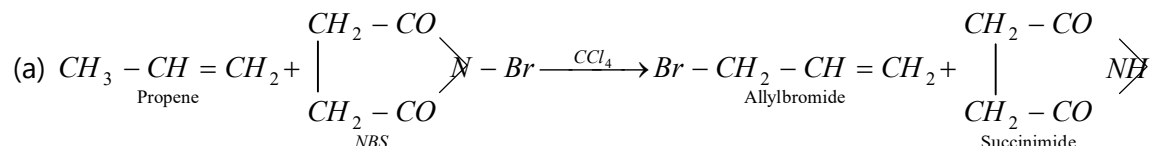


(iii) **Wurtz reaction:** Ethyl bromide on treatment with metallic sodium forms butane, ethane and ethylene by involving free radical mechanism.





(iv) **Allylic bromination by NBS** (N-Bromosuccinimide): NBS is a selective brominating agent and it normally brominates the ethylenic compounds in the allylic ($\text{CH}_2 = \text{CH} - \text{CH}_2 -$) position. This type of reaction involving substitution at the alpha carbon atom with respect to the double bond is termed Allylic substitution. It is also used for benzylic bromination. Some examples are:



Note: Halogenation of alkanes occurs by a free radical mechanism and is catalyzed by radical initiators like $(\text{C}_6\text{H}_5\text{COO})_2$, $\text{Pb}(\text{CH}_3)_4$, $\text{Pb}(\text{C}_2\text{H}_5)_4$ etc.

Addition reactions

These reactions are given by those compounds which have at least one π bond,

i.e., ($> \text{C} = \text{C} <$, $-\text{C} \equiv \text{C}-$, $-\overset{\text{O}}{\parallel}{\text{C}}-$, $\text{C} \equiv \text{N}$). In this reaction there is loss of one π bond and gain of two σ bonds. Thus product of the reaction is generally more stable than the reactant. The reaction is a spontaneous reaction.

Types of addition reactions: Addition reactions can be classified into three categories on the basis of the nature of initiating species.

- (1) Electrophilic additions (2) Nucleophilic additions and (3) Free radical additions

(1) Electrophilic addition reactions

- (i) This reaction is mainly given by alkenes and alkynes.
- (ii) Electrophilic addition reactions of alkenes and alkynes are generally two step reactions.
- (iii) Alkenes and alkynes give electrophilic addition with those reagents which on dissociation gives electrophile as well as nucleophile.
- (iv) If the reagent is a weak acid then electrophilic addition is catalyzed by strong acids (Generally H_2SO_4).
- (v) Unsymmetrical alkenes and alkynes give addition reactions with unsymmetrical reagents according to

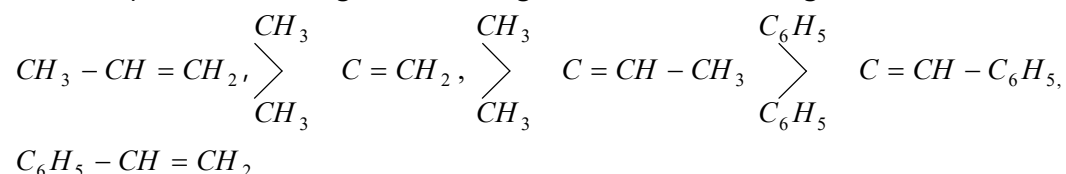
Markownikoff's rule.

The negative part of the reagent adds on that doubly bonded carbon of the alkene which has least number of hydrogen (s).

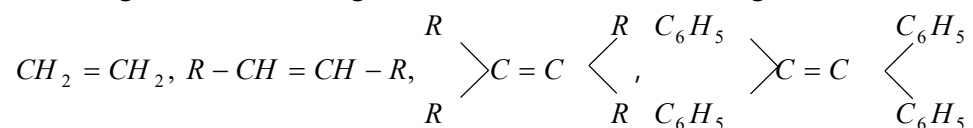
This rule can be used only in those alkenes which fulfil the following conditions:

- (a) Alkene should be unsymmetrical.
- (b) Substituent/substituents present on doubly bonded carbon/(s) should only be +I group.
- (c) If phenyl group is present on doubly bonded carbon, then both doubly bonded carbons should be substituted by phenyl groups.

For example, the following alkenes will give addition according to the Markownikoff's rule.

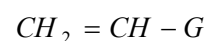


Following alkenes will not give addition reaction according to Markownikoff's rule.

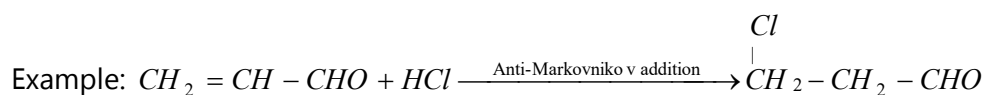
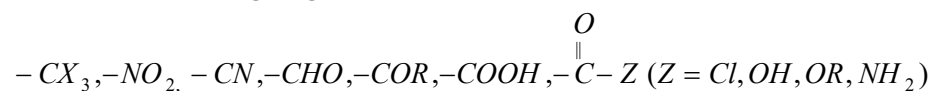


(vi) Unsymmetrical alkenes having the following general structure give addition according to anti

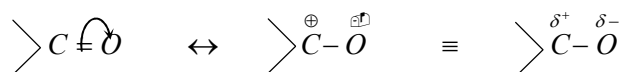
Markownikoff's rule.



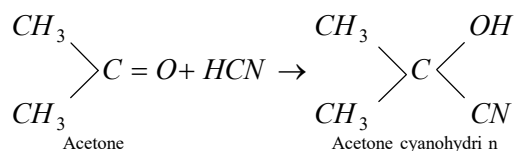
Where G is a strong -I group such as



(2) **Nucleophilic addition reactions:** When the addition reaction occurs on account of the initial attack of nucleophile, the reaction is said to be a nucleophilic addition reaction. Due to presence of strongly electronegative oxygen atom, the π -electrons of the carbon-oxygen double bond in carbonyl group ($C=O$) get shifted towards the oxygen atom and thereby such bond is highly polarized. This makes carbon atom of the carbonyl group electron deficient.

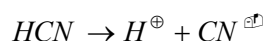


Example: The addition of HCN to acetone is an example of nucleophilic addition.

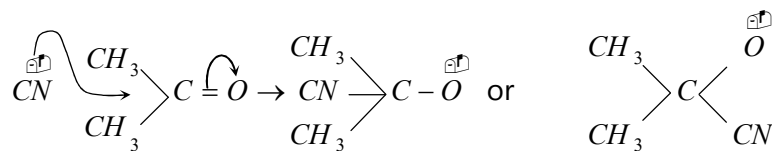


The mechanism of the reaction involves the following steps:

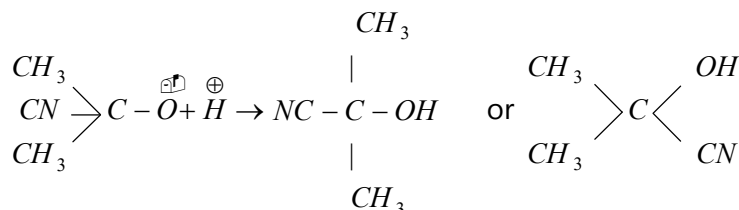
Step 1. HCN gives a proton (H^+) and nucleophile, a cyanide ion (CN^-).



Step 2. The nucleophile (CN^-) attacks the positively charged carbon as to form an anion [H^+ does not attack the negatively charged oxygen as anion is more stable than cation].

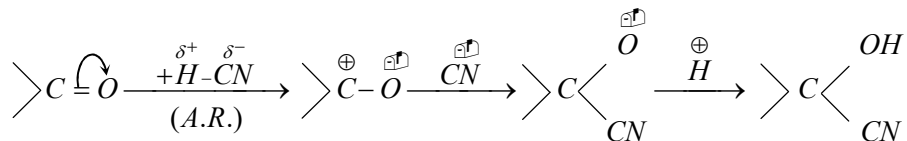


Step 3. The proton (H^+) combines with anion to form the addition product.

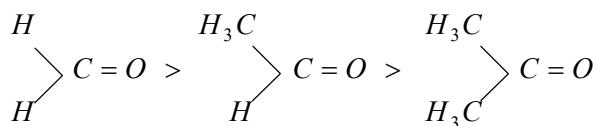


In $\text{>C}=\text{O}$ compounds, the addition of liquid HCN gives cyanohydrin and the addendum

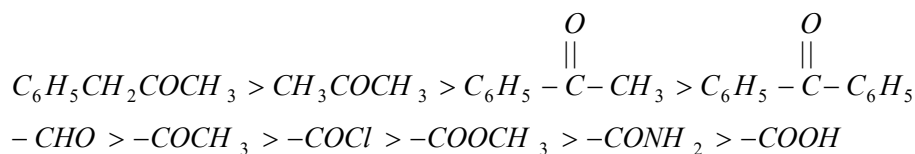
is CN^- ion (addition is catalyzed by bases or salts of weak acids and retarded by acids or unaffected by neutral compounds) and not HCN directly.



Nucleophilic addition (A_N) reactions on carbonyl compounds will be in order:

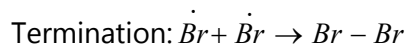
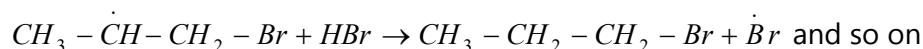
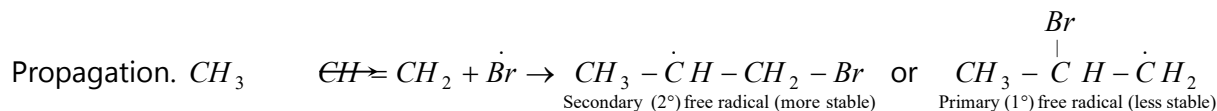
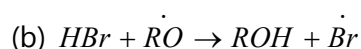
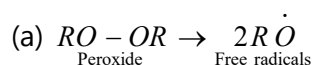


Note: Decreasing order of nucleophilic addition in some species.

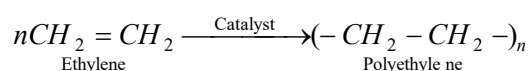


(3) **Free radical addition reactions:** Those reactions which involve the initial attack by a free radical are known as free radical reactions. Addition of hydrogen bromide to alkenes (say, propylene) in the presence of peroxide (radical initiator) follows free radical mechanism. Free radical reactions generally take place in non-polar solvents such as CCl_4 , high temperature, in presence of light or a free radical producing substance like O_2 and peroxides. The essential steps of the reactions are as follows.

Initiation (Formation of free radical)



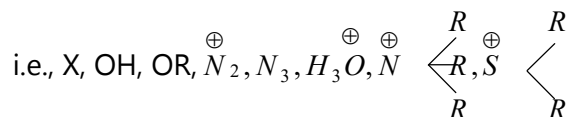
Polymerization of ethylene to polyethylene and vinyl monomers to polyvinyl polymers are free radical addition reactions.



Elimination reactions

Elimination reactions are formally the reverse of addition reactions and consist in removing the two groups (Generally, one being a proton) from one or two carbon atoms of a molecule to form an unsaturated linkage or center.

Elimination reaction is given by those compounds which have a nucleophilic group as leaving group,

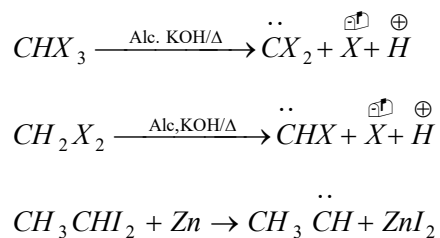


Elimination reactions are generally endothermic and take place on heating.

Elimination reactions are classified into two general types,

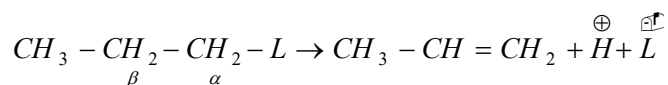
- (I) α - elimination reactions or 1, 1-elimination reactions.
- (II) β - elimination reaction or 1, 2-elimination reactions.

(I) **α - elimination reactions or 1, 1-elimination reactions:** A reaction in which both the groups or atoms are removed from the same carbon of the molecule is called α - elimination reaction. This reaction is mainly given by gem dihalides and gem trihalides having at least one α -hydrogen.



Product of the reaction is halocarbenes or dihalocarbenes. Carbenes are key intermediates in a wide variety of chemical and photochemical reactions.

(II) **β - elimination reactions or 1, 2-elimination reactions:** Consider the following reactions,



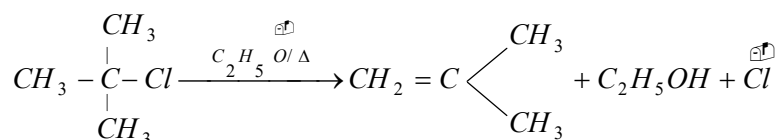
A reaction in which functional group (i.e., leaving group) is removed from α - carbon and other group (Generally hydrogen atom) from the β - carbon is called β - elimination reaction. In this

reaction there is loss of two σ bonds and gain of one π bond. Product of the reaction is generally less stable than the reactant.

(1) **Types of β - elimination reactions:** In analogy with substitution reactions, β - elimination reactions are divided into three types:

(i) E_1 (Elimination unimolecular) reaction, (ii) E_2 (Elimination bimolecular) reaction and (iii) E_{1cb} (Elimination unimolecular conjugate base) reaction

(i) **E_1 (Elimination unimolecular) reaction:** Consider the following reaction,



(a) Reaction velocity depends only on the concentration of the substrate; thus reaction is unimolecular reaction.

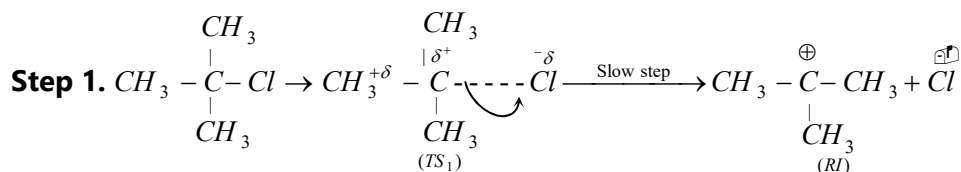
Rate \propto [Substrate]

(b) Product formation takes place by formation of carbocation as reaction intermediate (RI).

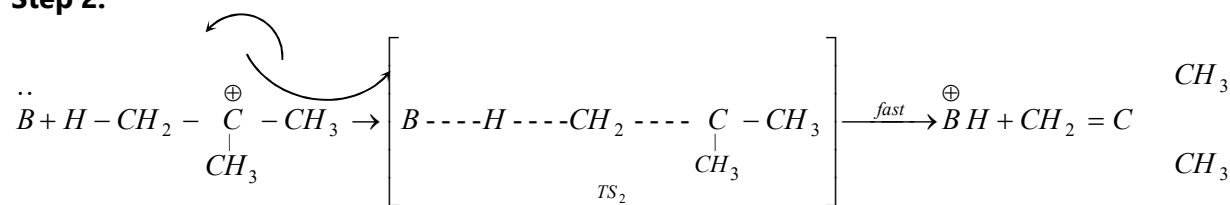
(c) Since reaction intermediate is carbocation, rearrangement is possible in E_1 reaction.

(d) Reaction is carried out in the presence of polar protic solvent.

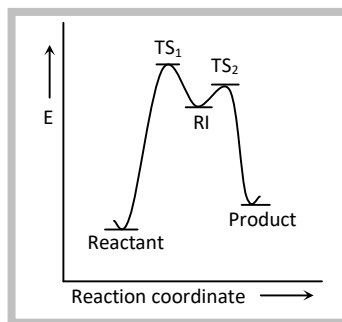
(e) The E_1 reaction occurs in two steps,



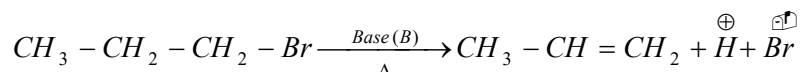
Step 2.



(f) Energy profile diagram for E_1 reaction is,



(ii) **E₂(Elimination bimolecular)reaction:** Consider the following reaction,



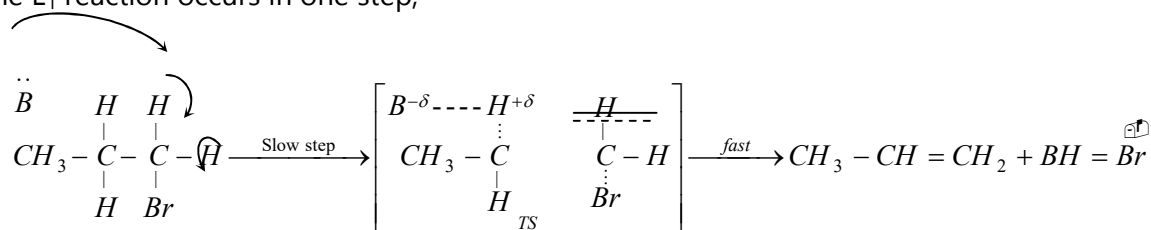
(a) Reaction velocity depends only on the concentration of the substrate and the base used; thus reaction is bimolecular reaction. Rate \propto [Substrate] [Base]

(b) Since the reaction is a bimolecular reaction, the product formation will take place by formation of transition state (TS).

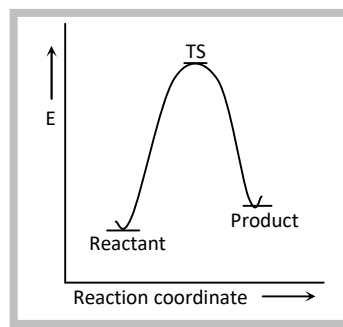
(c) Rearrangement is not take place in E₂ reaction but in case of allylic compound rearrangement is possible.

(d) Reaction is carried out in the presence of polar aprotic solvent.

(e) The E₁ reaction occurs in one step,



(f) Energy profile diagram for E₂ reaction is,



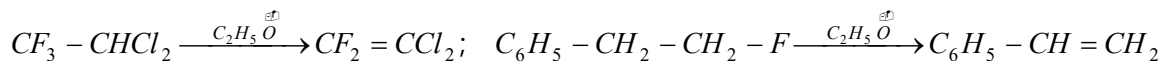
(iii) **E_{1cb}(Elimination unimolecular conjugate base) reaction**

(a) E_{1cb} mechanism is limited to substrates with substituents which can stabilize the carbanion as reaction intermediate.

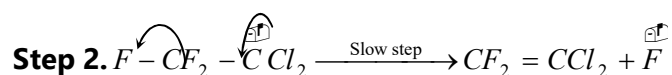
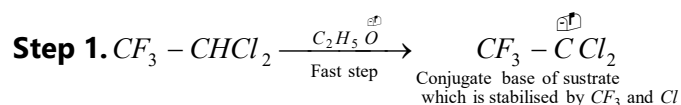
Thus β- carbon should contain strong -I group, e.g., $-\overset{O}{\parallel}C-$, $-NO_2$, $-C \equiv N$ or other carbanion stabilizing group.

(b) This reaction is given by those compounds, which have poor leaving group, otherwise carbanion will not be formed.

(c) β - hydrogen should be highly acidic so that it can easily be removed as proton to give carbanion.

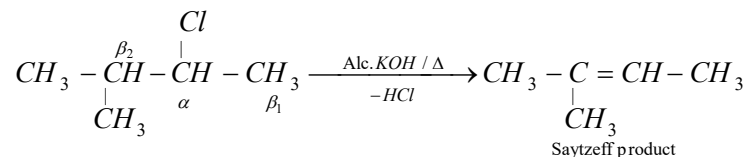


(d) The E_{1cb} reaction occurs in two step,

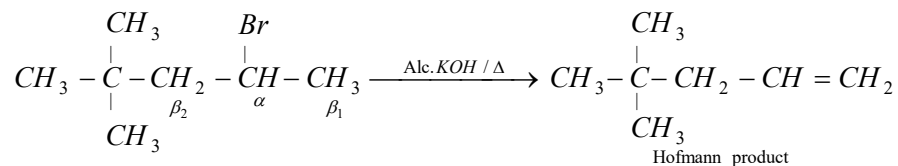


(2) **Orientation in β - elimination reactions:** If substrate is unsymmetrical, then this will give more than one product. Major product of the reaction can be known by two empirical rules.

(i) **Saytzeff rule:** According to this rule, major product is the most substituted alkene i.e., major product is obtained by elimination of H^+ from that β - carbon which has the least number of hydrogen. Product of the reaction in this case is known as Saytzeff product.



(ii) **Hofmann rule:** According to this rule, major product is always least substituted alkene i.e., major product is formed from β - carbon which has maximum number of hydrogen. Product of the reaction in this case is known as Hofmann product.



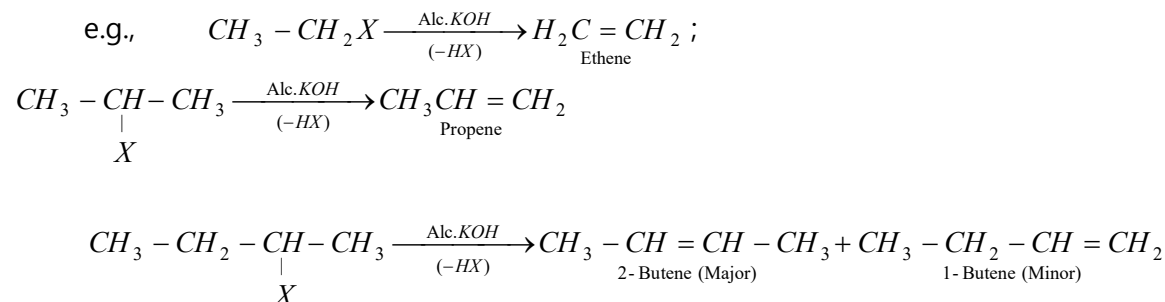
Note: In E_1 reactions, product formation always takes place by Saytzeff rule.

In E_{1cb} reactions, product formation always takes place by Hofmann rule.

In E_2 reactions, product formation takes place by Saytzeff as well as Hofmann rule. In almost all E_2 reactions product formation take place by Saytzeff rule.

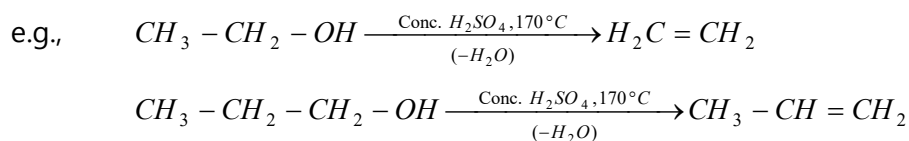
(3) Examples of β - elimination reactions

(i) **Dehydrohalogenation** is removal of HX from alkyl halides with alcoholic KOH or KNH_2 or OK - ter-Bu (Potassium tertiary butoxide) and an example of α - β elimination,



(ii) **Dehydration** of alcohol is another example of elimination reaction. When acids like conc. H_2SO_4 or H_3PO_4 are used as dehydrating agents, the mechanism is E_1 . The proton given by acid is taken up by alcohol.

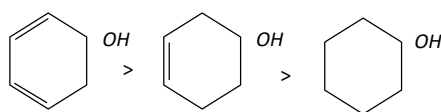
Dehydration is removal of H_2O from alcohols,



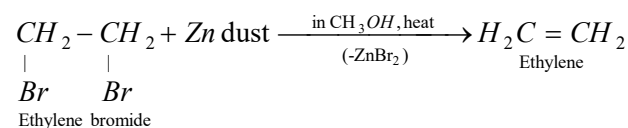
Note: Dehydration of alcohols is in the order: Tertiary > Secondary > Primary
(3°) (2°) (1°)

2° and 3° alcohol by E_1 process and 1° alcohol by E_2 process. Alcohols leading to conjugated alkenes are more easily dehydrated than the alcohols leading to non-conjugated alkenes. $\text{CH}_2 = \text{CH} - \underset{\text{OH}}{\text{CH}} - \text{CH}_3$ is

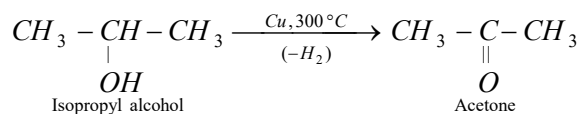
easily dehydrated than $\text{CH}_3 - \text{CH}_2 - \underset{\text{OH}}{\text{CH}} - \text{CH}_3$ and so



(iii) **Dehalogenation:** It is removal of halogens, e.g.



(iv) **Dehydrogenation:** It is removal of hydrogen, e.g.,



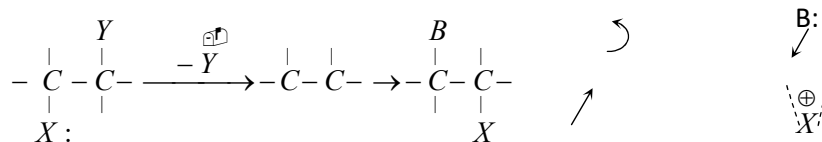
Rearrangement reactions

The reactions, which involve the migration of an atom or group from one site to another within the molecule (nothing is added from outside and nothing is eliminated) resulting in a new molecular structure, are known as rearrangement reactions. The new compound is actually the structural isomer of the original one.

It is convenient to divide rearrangement reactions into following types:

(1) **Rearrangement or migration to electron deficient atoms** (Nucleophilic rearrangement):

Those rearrangement reactions in which migrating group is nucleophilic and thus migrates to electron deficient center which may be carbon, nitrogen and oxygen.



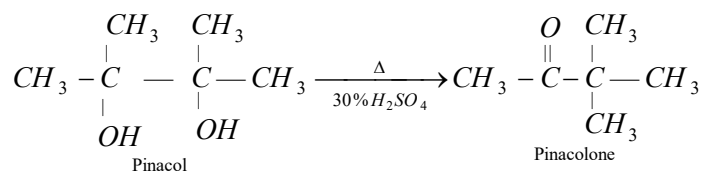
Bridged or

Non-classical carbocation

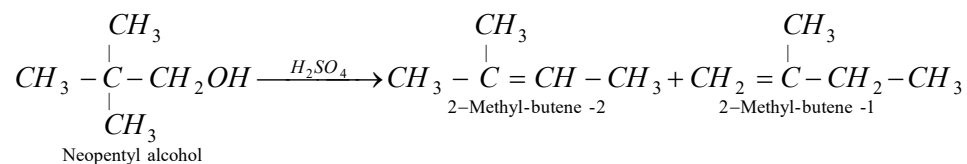
X = Nucleophilic species, Y = Electronegative group, B = another nucleophile.

Examples:

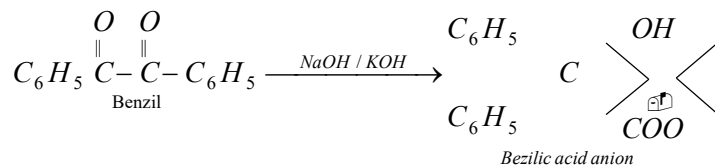
(i) **Pinacol – pinacolone rearrangement**



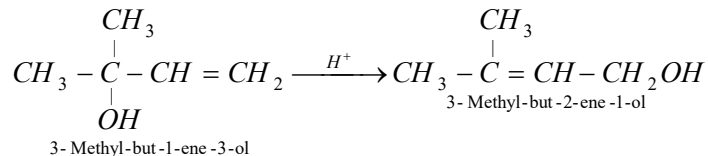
(ii) **Wagner – Meerwein rearrangement**



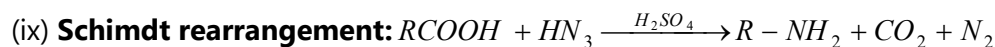
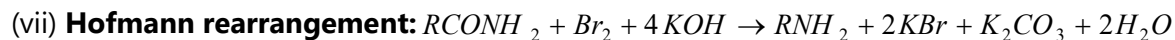
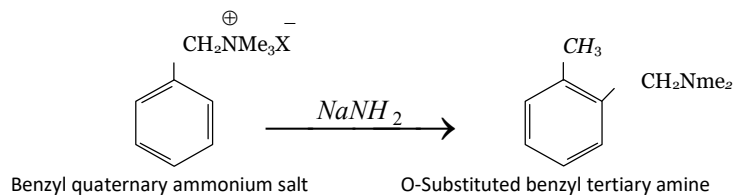
(iii) **Benzilic acid rearrangement**



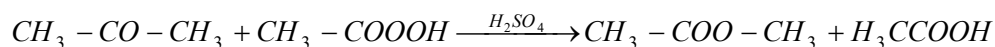
(v) **Allylic rearrangement**



(vi) **Sommelet – Hauser rearrangement**



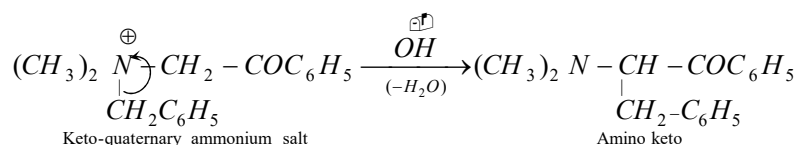
(x) **Baeyer Villiger reaction:**



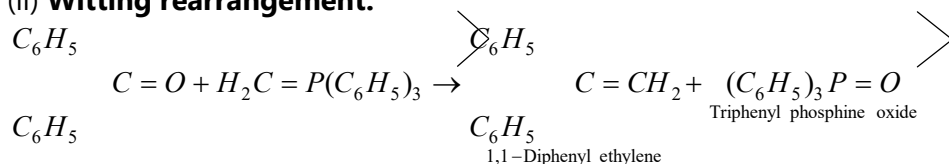
(2) **Rearrangement or migration to electron rich atoms** (Electrophilic rearrangement): Those rearrangement reactions in which migrating group is electrophile and thus migrates to electron rich center.

Examples:

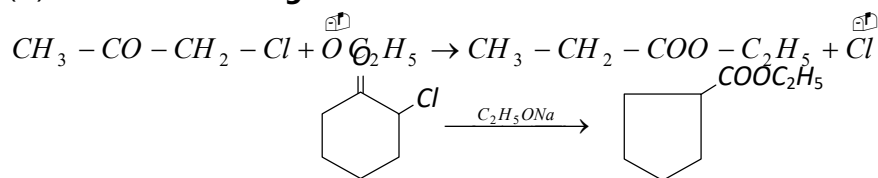
(i) **Stevens rearrangement:**



(ii) **Witting rearrangement:**

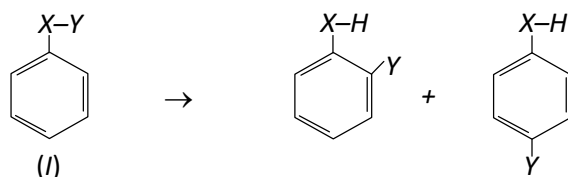


(iii) **Favorskii rearrangement:**



(3) **Rearrangement or migration to free radical species** (Free radical rearrangement): Those rearrangement reactions in which the migrating group moves to a free radical center. Free radical rearrangements are comparatively rare.

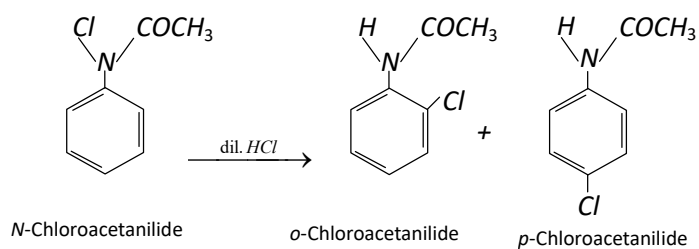
(4) **Aromatic rearrangement:** Those rearrangement reactions in which the migrating group moves to aromatic nucleus. Aromatic compounds of the type (I) undergo rearrangements in the manner mentioned below,



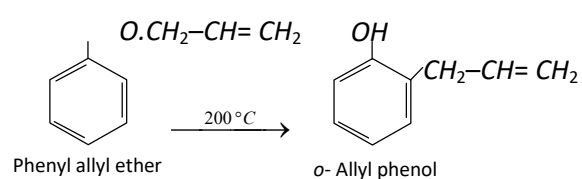
The element X from which group Y migrates may be nitrogen or oxygen.

Examples:

(i) **Orton rearrangement**



(ii) **Claisen rearrangement**



(iii) **Fries rearrangement**

