

Organic Reactions

Introduction :

In a chemical reaction, the reactant molecule undergoing attack is known as the substrate and the attacking species is the reagents.



The steps of an organic reaction showing the breaking and forming of new bonds of carbon atoms in the substrate resulting in the formation of the final products through transitory intermediates (reaction intermediates), are often termed to as its Mechanism.



Generally, the attacking reagents carry either a positive or a negative charge. The positively charged reagents attack the parts of high electron density in the substrate molecule while the negatively charged reagents will attack the parts of low electron density in the substrate molecule.

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Electronic Effect :

1. Inductive effect
2. Mesomeric effect
3. Electromeric effect

1. Inductive Effect :

In case of a covalent bond between atoms having similar electronegativity, the electron pair of the bond occupies a central position between the two nuclei of the concerned atoms. viz.



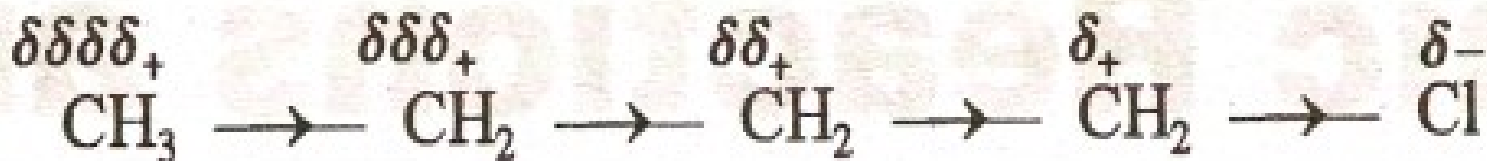
Such a covalent bond is known as non-polar bond, on the other hand, in case of a covalent bond between the two dissimilar atoms, electrons are displaced towards the more electronegative atom. This introduces a certain degree of polarity in the bond.

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The more electronegative atom gets a small -ve charge (δ) while less electronegative atom gets a small + (δ).

The inductive effect (I effect) may be defined as the permanent displacement of electrons forming a covalent bond towards the more electronegative element or group.

Atoms or groups which lose electrons toward a carbon atom are said to have a + I effect. Those atoms or groups which attract electrons away from a carbon atom are said to have a - I effect. The inductive effect is always transmitted along a chain of carbon atoms e.g.,

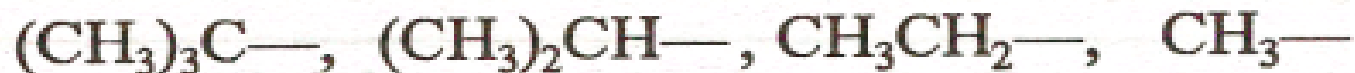


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(i) - I effect groups (Electron-attracting)



(ii) + I effect groups (Electron-releasing)



The inductive effect results in a permanent state of the molecule and can be observed practically in the form of dipole moments. The effect does not depend upon the presence of a reagent.

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(i) + M effect groups

-Cl, -Br, -I, -NH₂, -NR₂, -OH, -OCH₃

(ii) -M effect groups



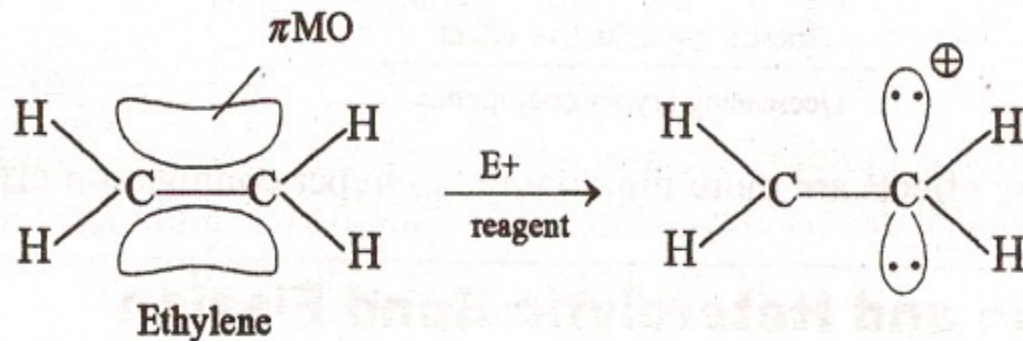
This effect does not depend upon the presence of reagent. It is a permanent effect and always operates in the non reacting molecule.

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3. Electromeric effect :

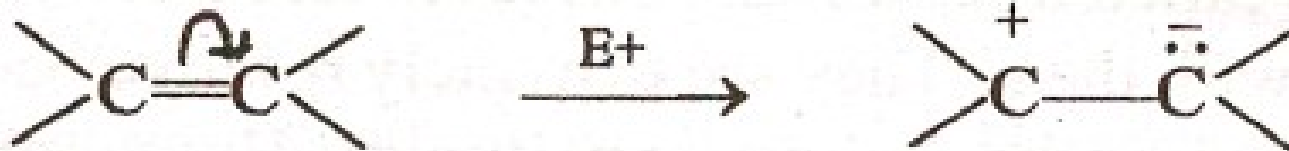
It is a temporary effect. It takes place only in the presence of a reagent. It also involves π electrons, like mesomeric effects ..

When a multiple bond is attacked by an electrophile (E^+) the π electrons which form the π bond are completely transferred to one atom or the other. It is represented as:



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This gives rise a negative charge to the carbon atom to which π -electron-pair shifts, while the other atom acquires a positive charge.

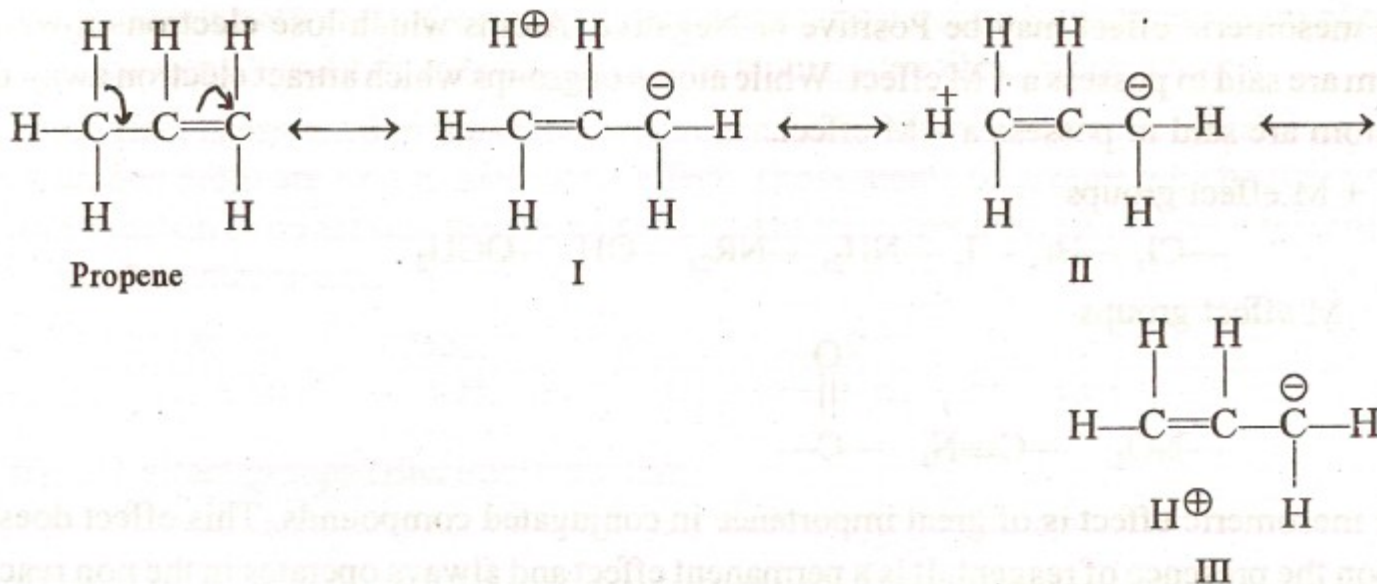


Thus, the electromeric effect (E effect) may be defined as the polarity developed in a multiple bonded compound as it is attacked by a reagent.

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Hyperconjugation : It involves the delocalization of σ electrons through the overlapping of p-orbitals of a double bond with σ -orbital of the adjacent single bond. As it involves the delocalisation of σ and π bond orbitals; thus it is known as σ - π conjugation. This type of electron release due to the presence of the system

H-C-C=C is known as hyperconjugation.



Organic Reactions

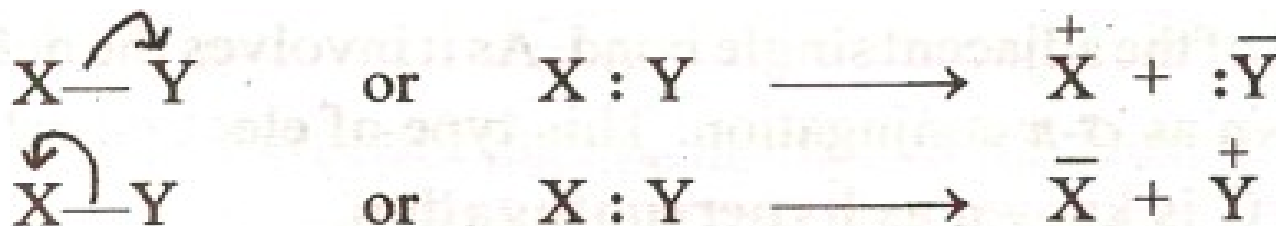
Homolytic and Heterolytic Bond Fission : In Homolytic fission each of the atom acquires one of the bonding electrons shared between them.



The products $X\cdot$ and $Y\cdot$ are called free radicals. These are electrically neutral species and have one unpaired electron associated with them. They are extremely reactive because of the tendency of this odd electron to become paired at the earliest opportunity. Homolytic reactions are usually initiated by heat, light or organic peroxides. Homolytic fission is the most common mode of fission in the vapour state.

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In Heterolytic fission, one of the atoms acquires both of the bonding electrons on breaking of the bond



Heterolytic fission occurs most readily with polar compounds in polar solvents. The products of heterolytic fission are ions.

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Types of Reagents :

The attacking reagents are classified into two main groups.

- (i) Electrophile or Electrophilic reagents
- (ii) Nucleophile or Nucleophilic reagents

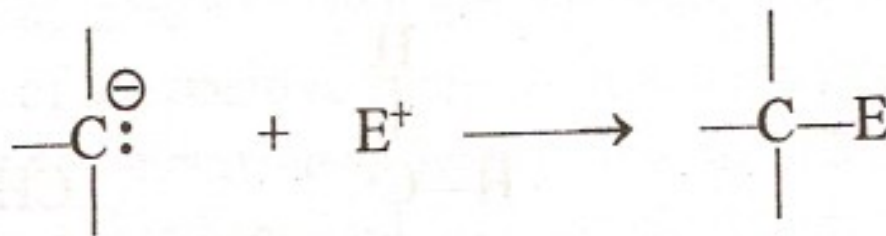
(i) Electrophiles or Electrophilic Reagents

A reagent which can accept an electron pair in a reaction is called an electrophile or an electrophilic species, having electron-deficient atom or centre. Electrophiles may be positive ions (including carbonium ions) or neutral molecules with electron deficient centres.

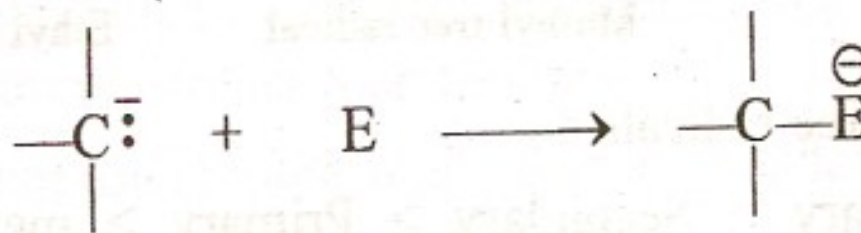
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Example :

H^+ , Cl^+ , Br^+ , I^+ , NO_2^+ , NH_4^+ , R_3C^+ , RN_2^+ , $^+SO_3H$, $AlCl_3$, BF_3



**Electrophile
(+ve charged)**



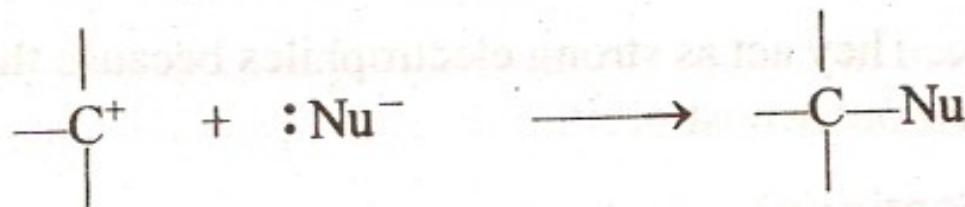
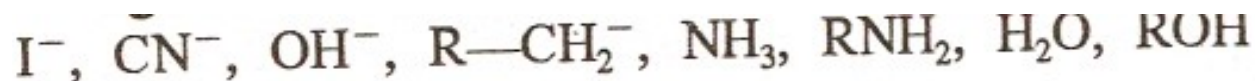
**Electrophile
(neutral)**

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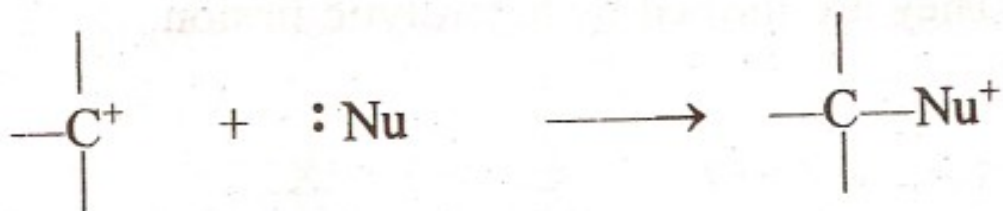
(ii) Nucleophiles :

A reagent which can donate an electron pair in a reaction is called a nucleophile. They may be negative ions (including carbanions) or neutral molecules with free electron pairs.

Example :



Nucleophile
(-ve charged)



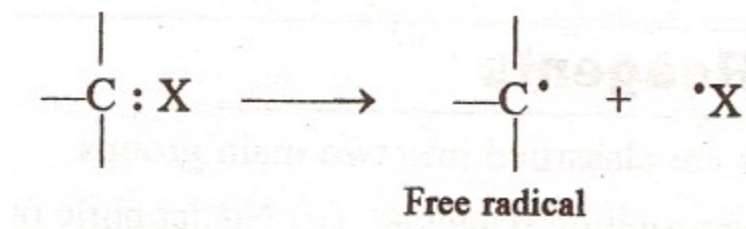
Nucleophile
(neutral)

Organic Reactions

Reaction Intermediates:

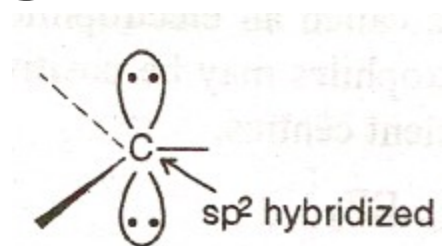
1. Free radicals :

These are formed by homolytic fission. It may be defined as any species which is having an odd or unpaired electron is called free-radical.



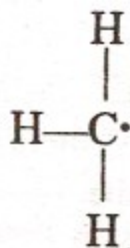
Here X and carbon atom have similar electronegativities. In a carbon free radical, the carbon atom uses Sp^2 hybrid orbital to form three σ -bonds .

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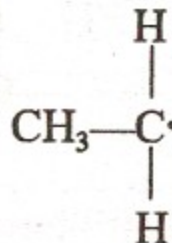


A half filled p-orbital extends above and below the plane of σ -bonds. Carbon free radicals are very reactive due to tendency of odd unpaired electron to become paired at the earliest opportunity. They are named after the parent alkyl group.

Example:



Methyl free radical



Ethyl free radical

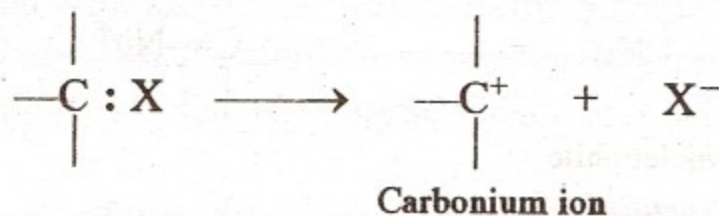
Order of stabilities of carbon free radicals:

Benzyl > Allyl > tertiary > Secondary > Primary > methyl > Vinyl

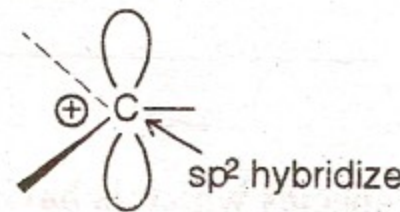
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2. Carbonium ions (or Carbocations) :

Carbonium ions are positively charged species containing a carbon atom having only six electrons in three sigma bonds. They are formed by heterolytic fission.

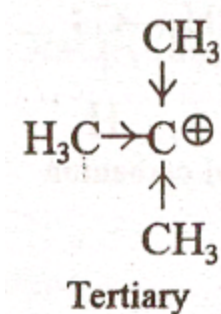
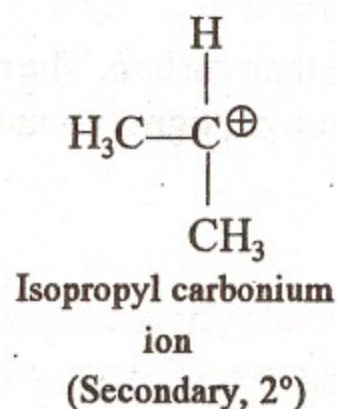
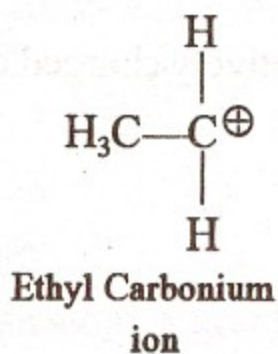
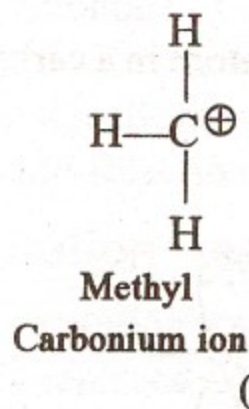


where X is more electronegative than carbon atom. The positively charged carbon atom in a carbonium ion uses sp^2 hybrid orbitals to form three σ -bonds.

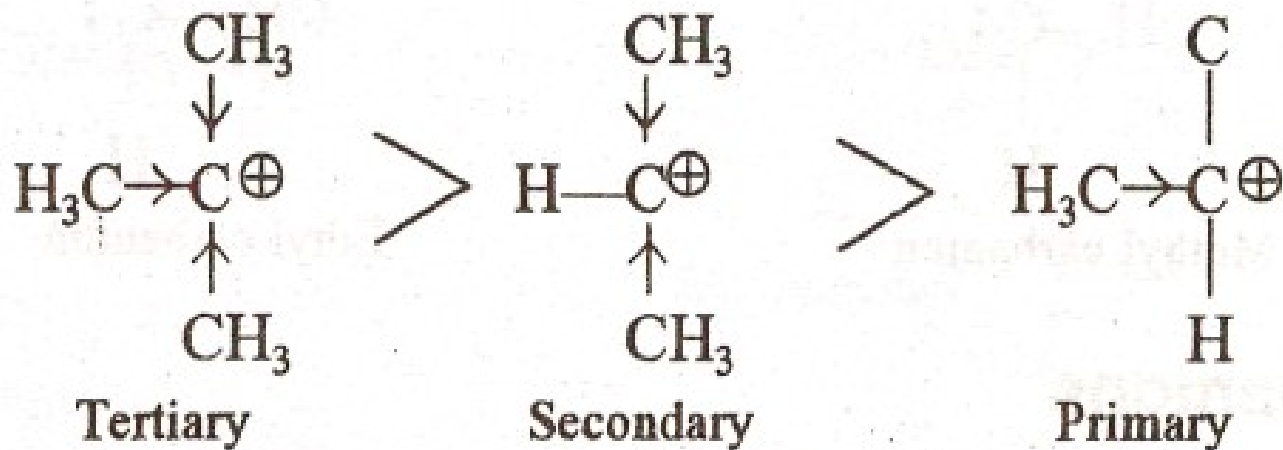


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A vacant p-orbital extends above and below the plane of the σ -bonds. The carbon atom becomes electron-deficient by vacant p-orbital and ready to combine with any substance (nucleophile) which can donate a pair of electrons. The carbonium ions are named after the parent alkyl group and simply adding the words carbonium ion. On the basis of nature of carbon atom, carbonium ions are classified as primary, secondary or tertiary. (e.g.),

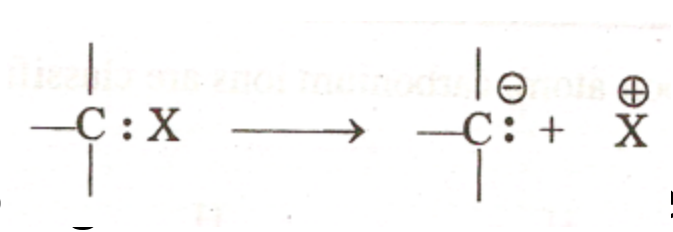


Organic Reactions



Organic Reactions

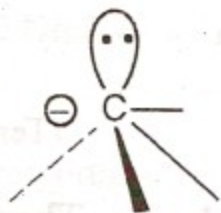
Carbanions : Carbanions are negatively charged species containing a carbon atom with three bonds and an unshared pair of electrons. They are formed by heterolytic fission.



where X is less electro

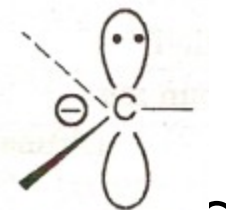
negatively

charged carbon atom in a carbanion uses Sp^3 hybrid orbitals to form three sigma bonds.



Negatively

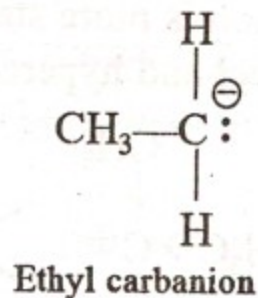
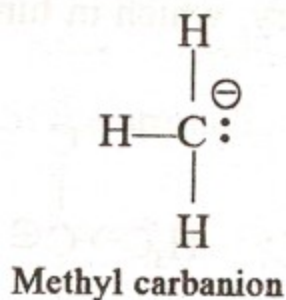
is sp^3 hybridized



is sp^2 hybridized

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When bonded to hydrogens or alkyl groups and if it is bonded to an unsaturated group, uses Sp^2 hybrid orbitals to form the three σ -bonds. Thus, a carbanion is ready to combine with any substance (electrophile) which can accept a pair of electrons. The carbanions are also named after the parent alkyl group.



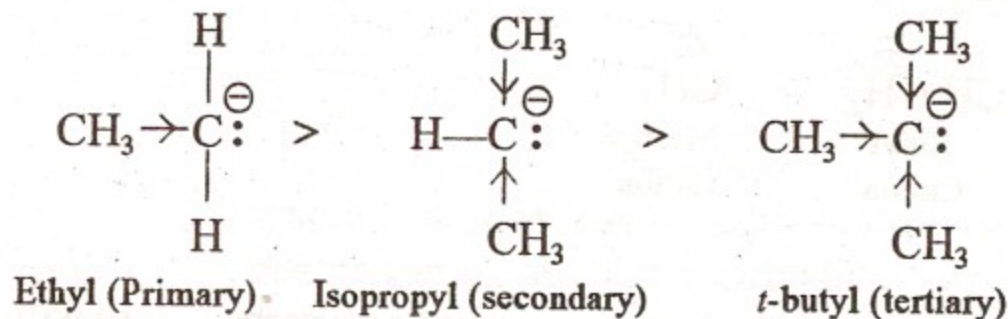
Organic Reactions

Stability of Carbanions :

The stability of carbanion is also influenced by resonance and inductive effect. The relative order of stability of some carbanions is as follow :

Phenyl > Cyclopropyl > Methyl > Ethyl > n-Propyl > Isopropyl > Isobutyl > Cyclobutyl etc.

A primary carbanion is more stable than a secondary, which in turn is more stable than a tertiary because of + I effect of alkyl group.



Organic Reactions

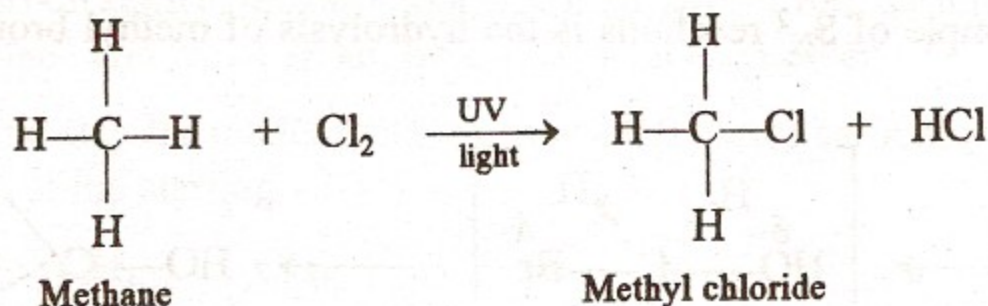
Electron releasing groups (+ I Groups) like $-\text{CH}_3$, $-\text{C}_2\text{H}_5$ make the carbanions less stable while electron attracting groups (-I Groups) like $-\text{NO}_2$, $-\text{Br}$ will stabilize carbanion by partial removal of the negative charge on the carbon.

Organic Reactions

Types of Organic Reactions :The reactions of organic compounds can be classified into following types :

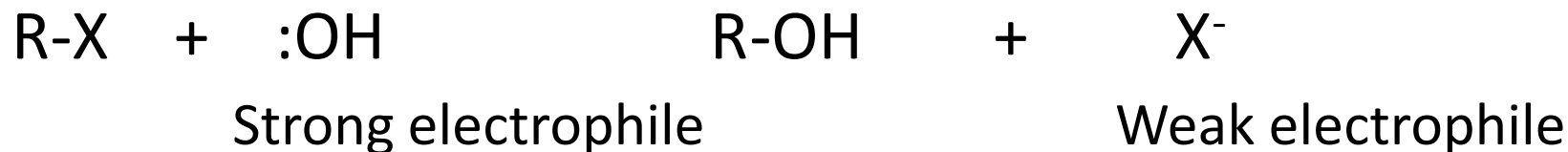
1. Substitution Reactions
2. Addition Reactions
3. Elimination Reactions

1. Substitution Reactions In substitution reactions, an atom or group of atom directly attached to a carbon in the substrate molecule is replaced by another atom or group of atoms. These reactions may be initiated by a nucleophile, electrophile, or free radical, *e.g.*, chlorination of methane :

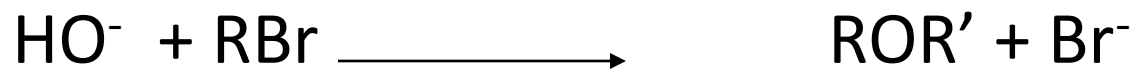


Types of Substitution Reactions

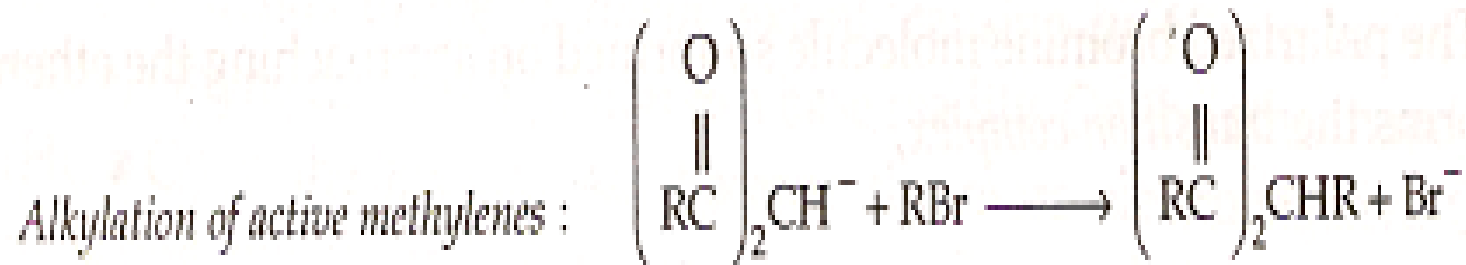
1) Nucleophilic Substitution Reactions: It involves displacement reaction brought about by stronger nucleophile (e rich species), thereby displacing a weaker nucleophile from the molecule for example



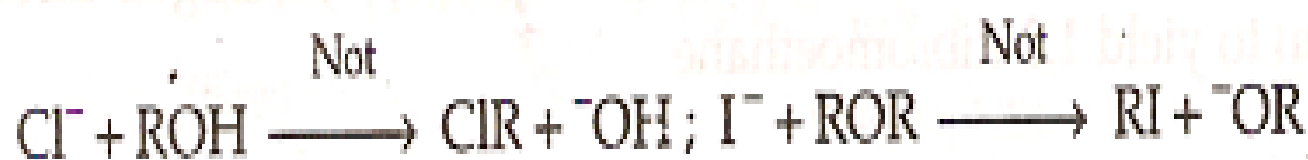
Nucleophilic substitution proceeds only if a weak base is displaced by strong base



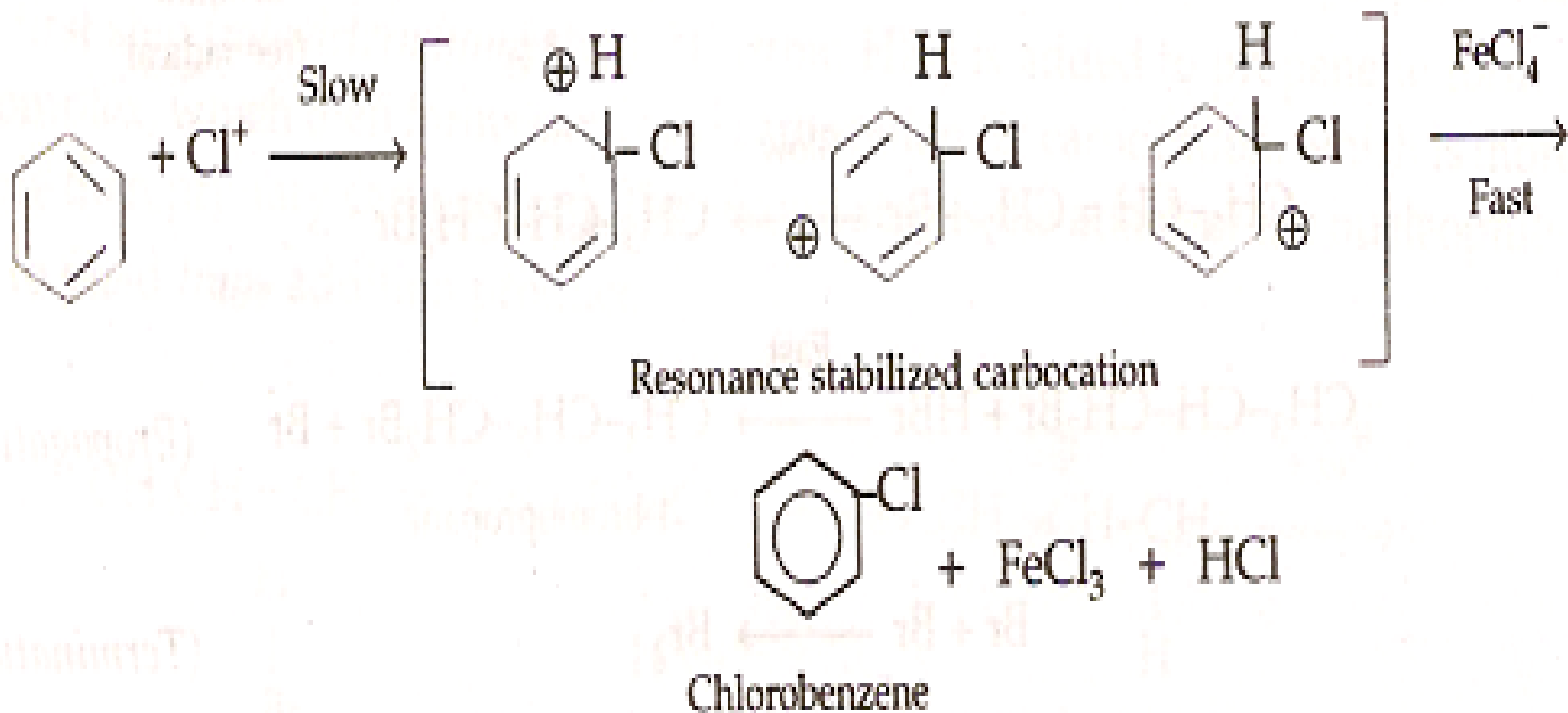
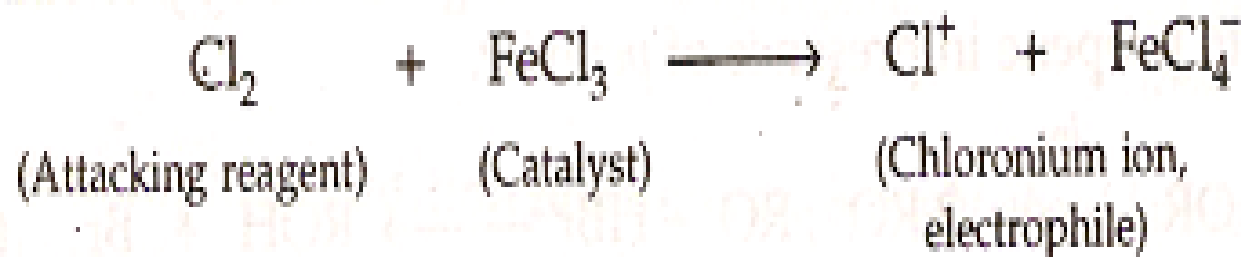
Hydrolysis of alkyl halide



On the other hand, the following reaction will *not* occur, because *the leaving group is not enough basic* to be displaced by the nucleophile employed. In fact, each of these reactions proceeds in exactly the *reverse* direction, because the equilibrium favours the left side of the reaction.



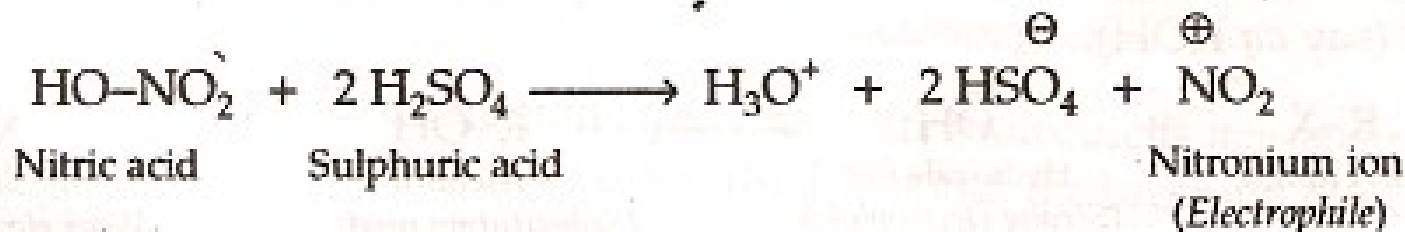
(ii) **Electrophilic substitution reaction** is a substitution reaction of a hydrogen atom on the benzene ring brought about by an electrophile (an electron-deficient species). For example, halogenation of arenes.



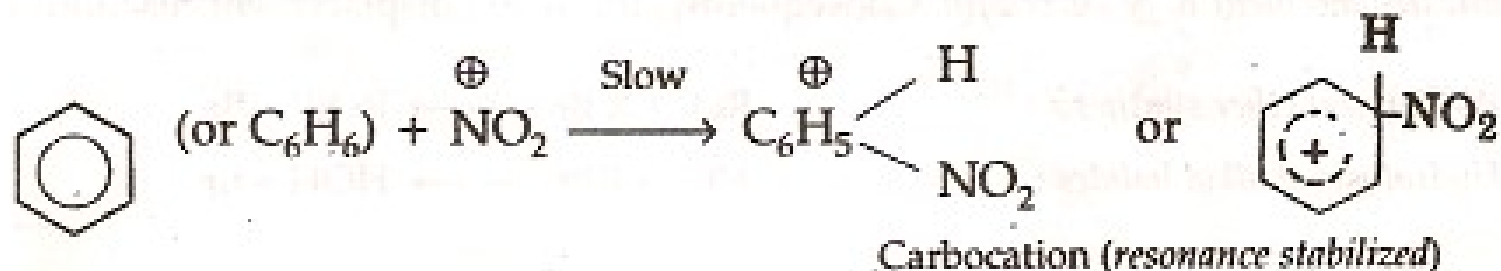
Other examples of electrophilic substitution reactions are :

(1) *Nitration of benzene with conc. HNO₃ and conc. H₂SO₄ to yield nitrobenzene.* The commonly accepted mechanism involves :

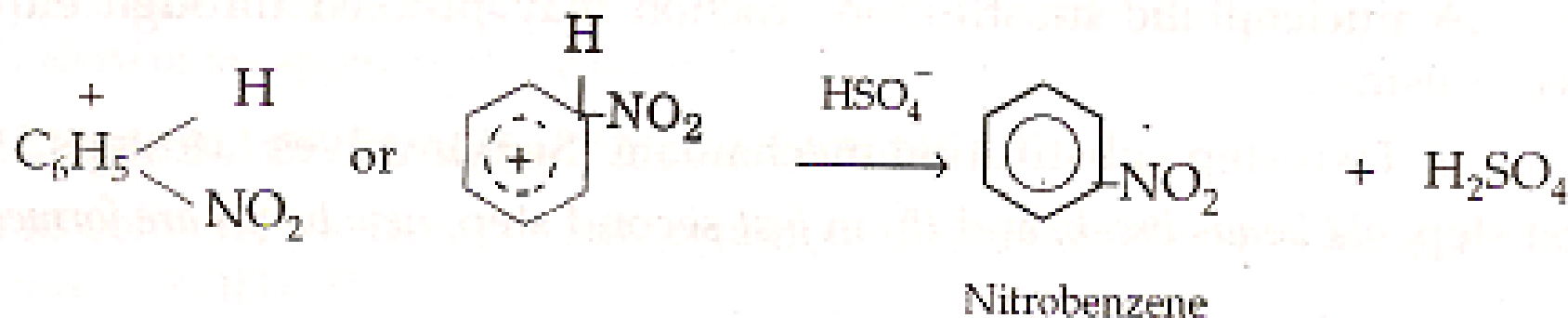
Step I : Formation of *electrophile* (nitronium ion) from HNO₃ by strong acid, H₂SO₄.



Step II : Benzene (a *nucleophile*, i.e. an electron-rich molecule) is attacked by nitronium ion forming a *carbocation*, which is *stabilized by resonance*.

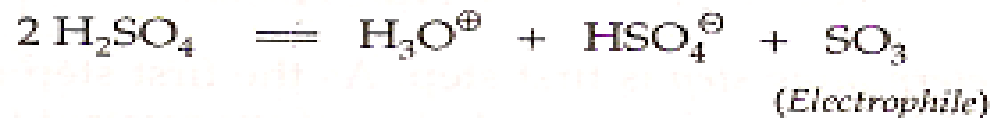


Step III : The carbocation then *loses a proton* to yield nitrobenzene.

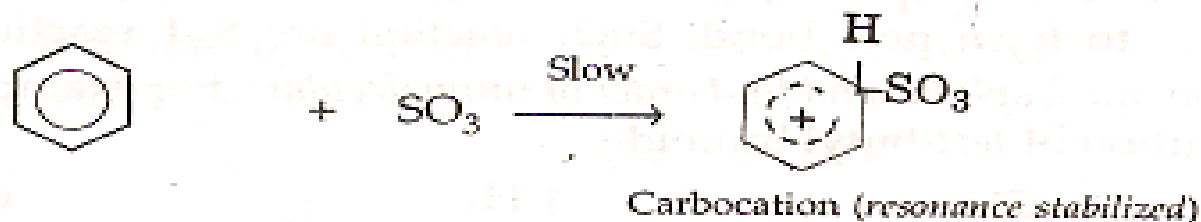


(2) *Sulphonation of benzene by conc. H_2SO_4 to yield benzene sulphonic acid.*
The commonly accepted mechanism involves :

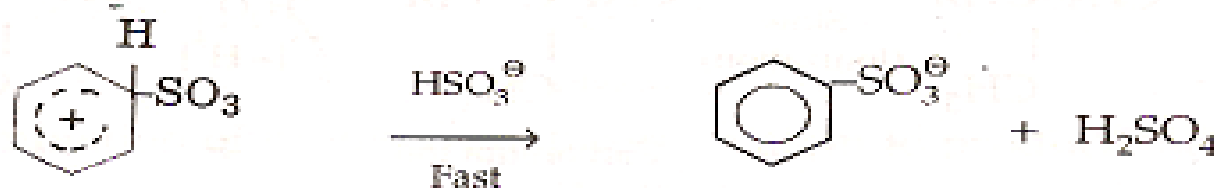
Step I : Formation of *electrophile* (SO_3).



Step II : Benzene (a *nucleophile*, i.e., an electron-rich molecule) is attacked by SO_3 forming a *carbocation*, which is *resonance stabilized*.



Step III : The carbocation then *loses a proton* to form the *anion* of benzene sulphonic acid.



Step IV : The anion of benzenesulphonic acid *takes a proton* to yield benzenesulphonic acid.



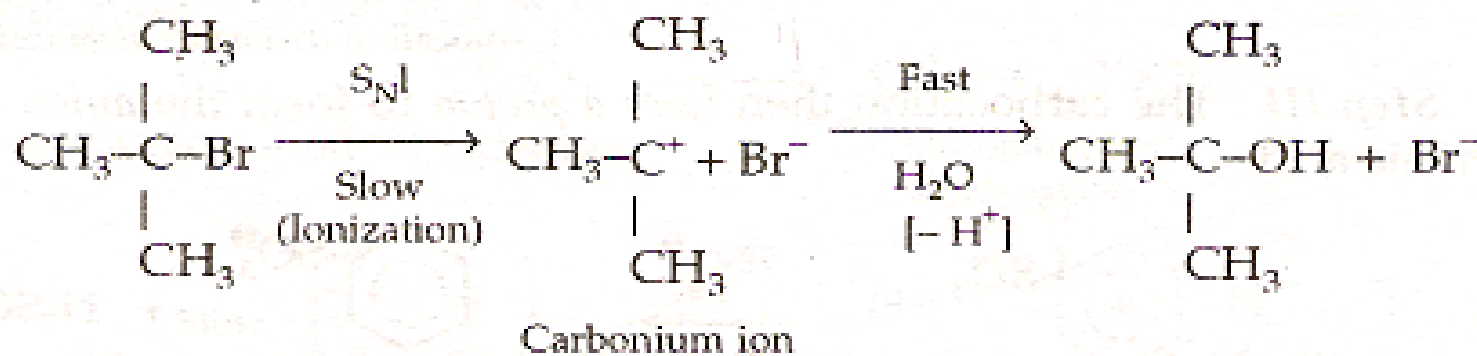
MECHANISM OF NUCLEOPHILIC SUBSTITUTION REACTION

A nucleophilic substitution reaction may proceed through either of *two* mechanisms :

(i) **Two-step substitution mechanism (S_N1)** involves *two* steps : (a) In *slow* first step, *old bonds break*, and (b) in *fast* second step, *new bonds are formed*. Thus :



The *rate-determining step* is first step. As the first step does not involve the attacking nucleophile and *molar concentration of one reactant (A-X) is only changed*, so the overall reaction is of *first order*, because the time taken by the reaction depends mainly on step 1. No sooner A^+ is generated, it is attacked by the nucleophile $\bar{\text{Nu}}:$ to form new bond. Such reaction are S_N1 reaction (which means *substitution, nucleophilic, and first order or unimolecular*). For example, the nucleophilic substitution of *tert*-butyl bromide.



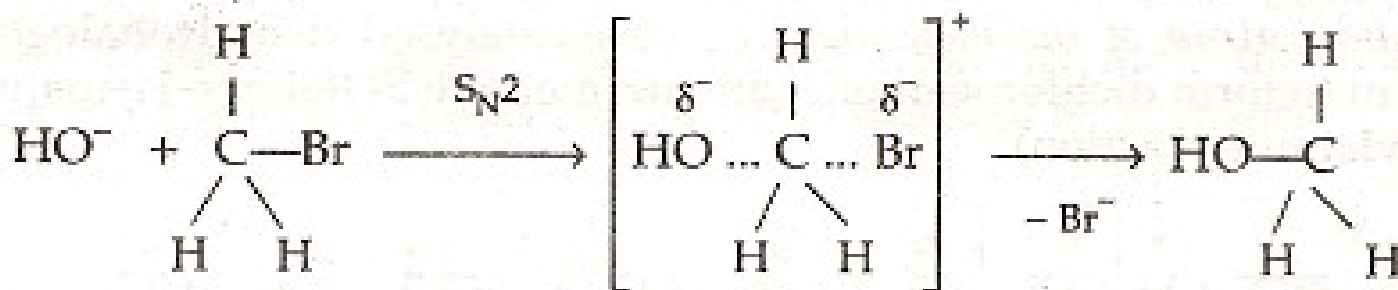
(ii) One-step substitution mechanism (S_N2) involves simultaneous bond-breaking and bond-making. Thus :



In this, attacking nucleophile $\bar{\text{Nu}}:$ attacks at carbon in substrate $\text{A}-\text{X}$, forming a *high energy transition state* in which : (a) the bond Nu-carbon is in the process of forming, and (b) bond X-carbon is in process of breaking with simultaneous secession of the leaving group, $\bar{\text{X}}$:

In this one step reaction, the *molar concentrations of two reactants (viz., $\bar{\text{Nu}}:$ and $\text{A}-\text{X}$) are changed* and hence, the reaction is of *2nd order* (or bimolecular) and hence, called S_N2 reaction (meaning *substitution, nucleophilic, and second order*).

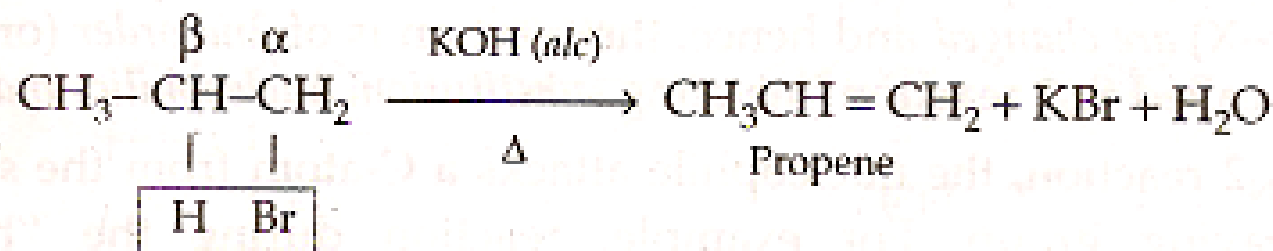
In S_N2 reaction, the nucleophile attacks a C-atom from the *side opposite* to that of leaving group. For example, reaction during the "hydrolysis of bromomethane" by aqueous alkali can be depicted as :



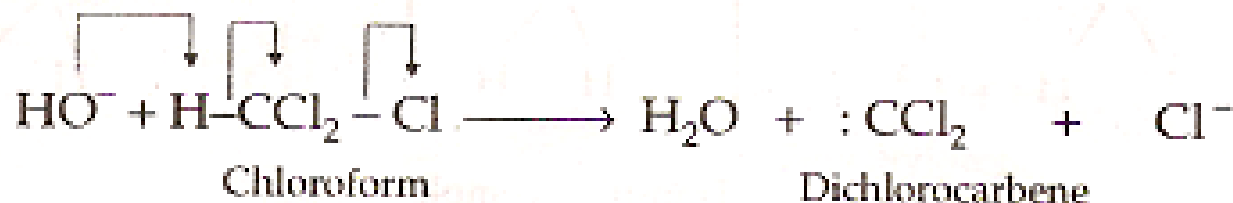
Transition complex

TYPES OF ELIMINATION REACTION

(a) β -elimination reaction involves the loss of two atoms or groups from the adjacent carbon atoms of the molecule, e.g., base-catalysed dehydrohalogenation of propyl bromide.



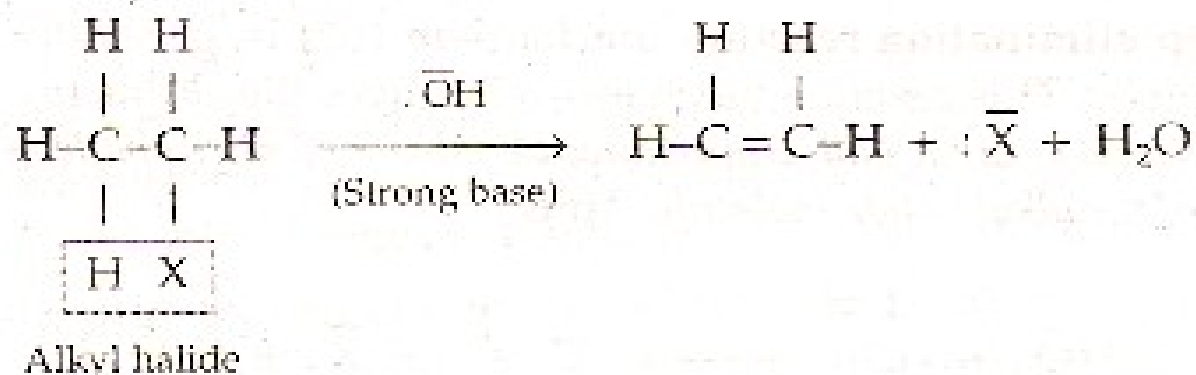
(b) α -elimination reaction involves the loss of two atoms or groups from the same carbon atom of the molecule, e.g., base-catalysed dehydrohalogenation of chloroform to form dichlorocarbene (an intermediate in Reimer-Tiemann reaction and carbylamine reaction).



Note : The distinction between S_N2 and S_N1 reactions is not as clear cut. In pure S_N2 reaction, the nucleophilic attack is *exactly simultaneous* with the departure of the leaving group. On the other hand, in pure S_N1 reaction, the leaving group leaves *before* the nucleophile even puts in an appearance. In intermediate cases (as for a secondary halide), the leaving group leaves only slightly *ahead* of the approach of the nucleophile.

MECHANISM OF ELIMINATION REACTION

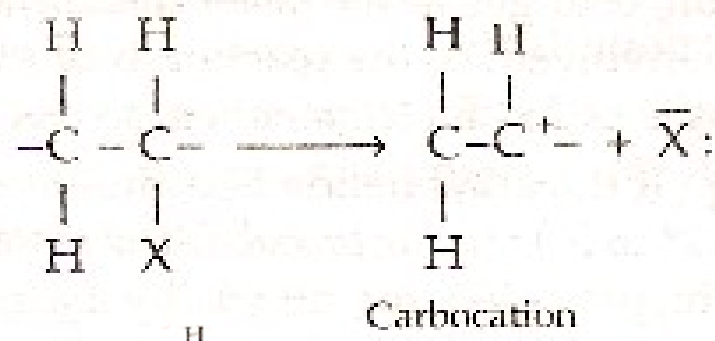
Let us consider the dehydrohalogenation of alkyl halide by heating in presence of alcohol (ROH). Thus :



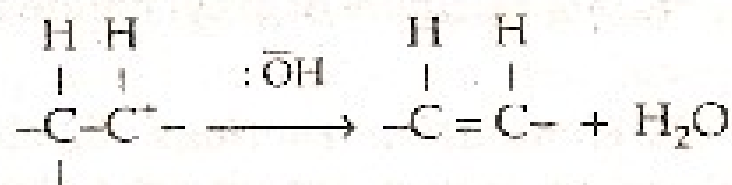
Depending on the *nature of alkyl halides and other conditions*, the elimination reaction may proceed through *two* different mechanisms :

Two-steps elimination reaction mechanism (E1) involves :

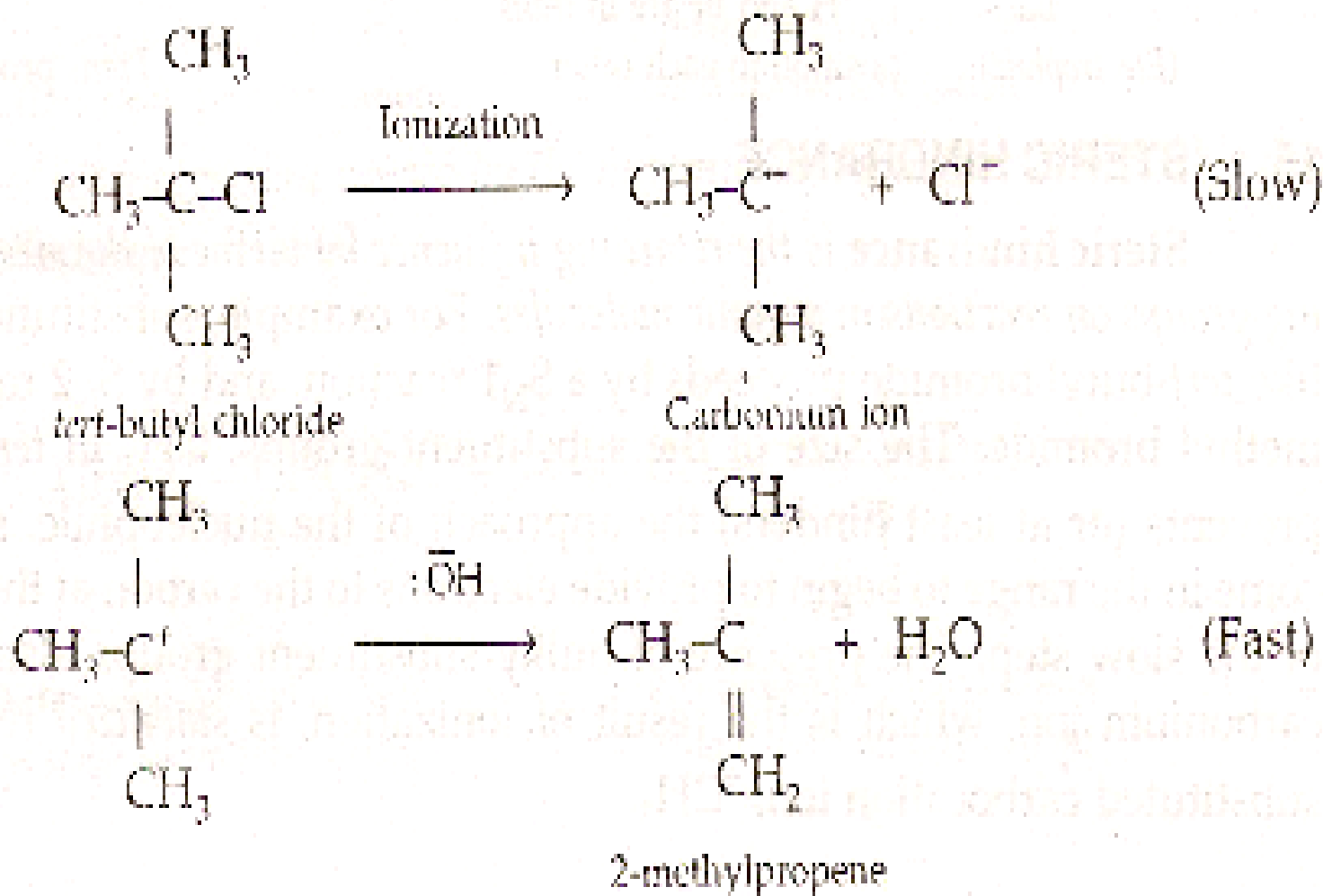
Step 1 : Heterolytic fission to yield carbocation.



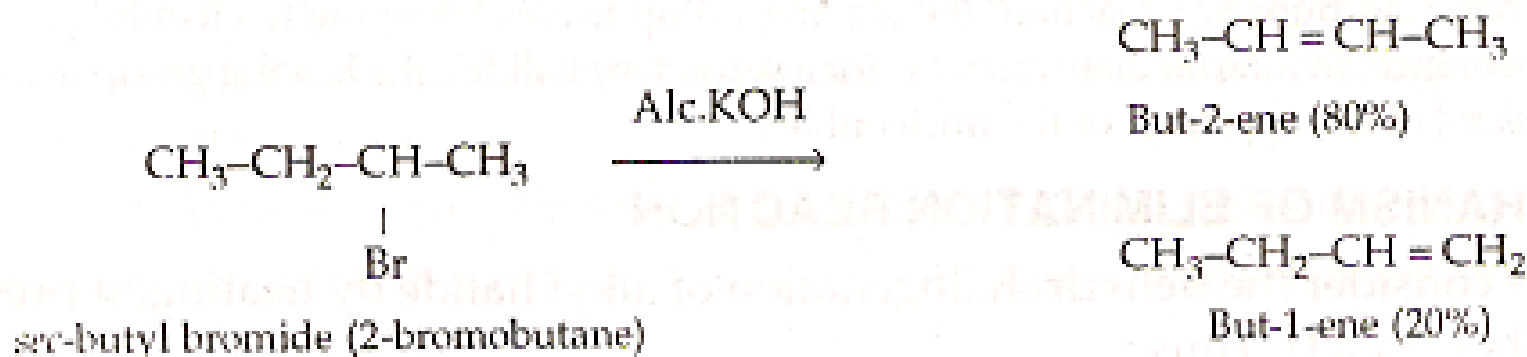
Step 2 : Elimination of proton from β -carbon atom to produce the alkene.



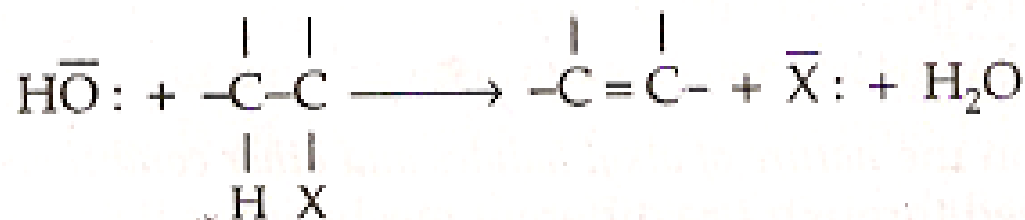
The first step is slow step and it determines the rate. Since this step involves the change in molar concentration of alkyl halide only, so the reaction is of first order or unimolecular. Hence, such a mechanism is termed E1 (elimination, first order). For example, the formation of 2-methylpropene (isobutylene) from *tert*-butyl chloride on heating with alcoholic KOH can be explained follows :



Note : Sometimes *more than one alkene* is formed. In such a case, the *main product* is the *maximum substituted alkene (Saytzeff's rule)*. For example :



One-step elimination reaction mechanism (E2) is, generally, followed by *primary alkyl halides*. This reaction mechanism involves the *abstraction of a proton* by base from the β -carbon atom and *simultaneous* release of nucleophile ($(: X)$) from the α -carbon atom of the alkyl halide molecule. Thus :

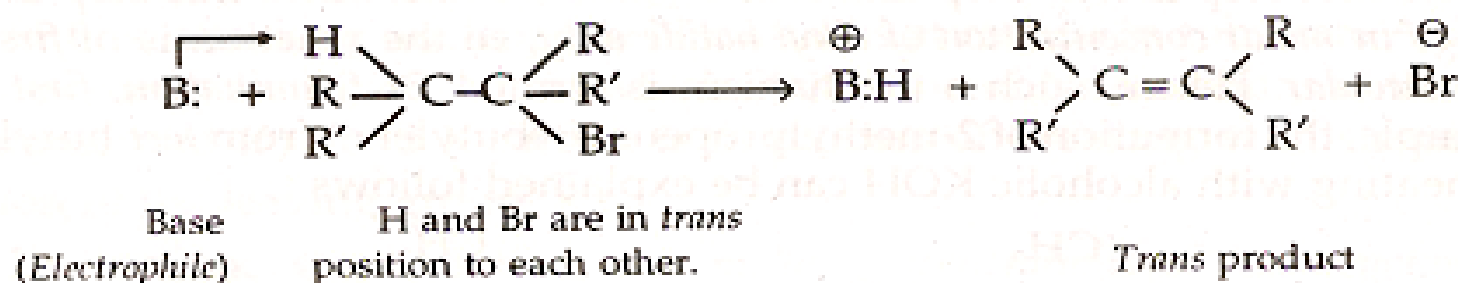


Nucleophile
(from base)

Since in this reaction, changes in the *molar concentration* of two reactants (*viz.* alkyl halide and base) are involved, so the reaction is of *second order* or *bimolecular*. Hence, such a mechanism is called **E2** (*elimination, second order*).

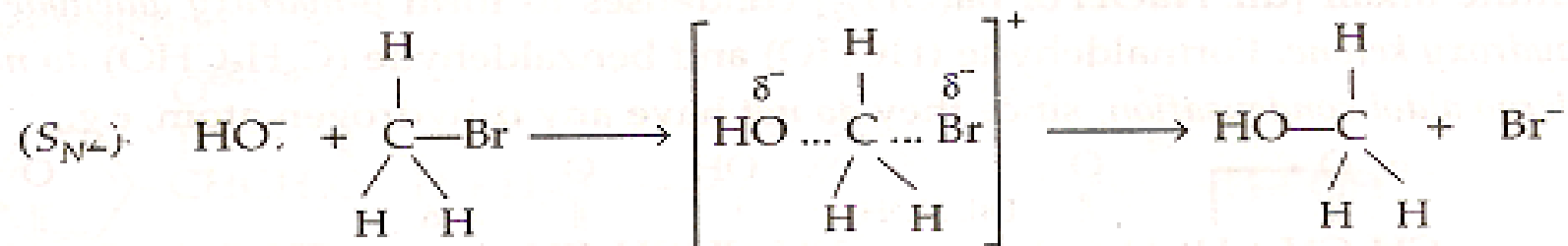
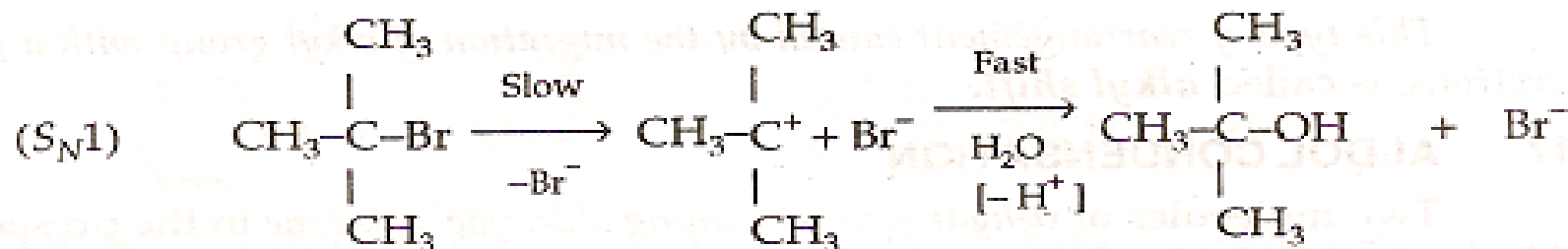
Effect of branching : If the alkyl halide becomes *more and more branched* (i.e., on proceeding from 1° to 2° to 3°): (i) the probability is more favourable, since greater number of hydrogens are provided for attack by base (electrophile); (ii) the transition state becomes more stable, and (iii) the energy of activation (E_a) is lowered. As a result of above facts, the *order of reactivity* of alkyl halide in dehydrohalogenation is : $3^\circ > 2^\circ > 1^\circ$.

Stereospecificity in E2 elimination reactions : E2 elimination reactions proceed *more readily*, if the atoms or groups, which are to be eliminated, are located at *trans positions to each other*.



STERIC HINDRANCE

Steric hindrance is the retarding influence by virtue of the size of the neighbouring groups on reactions in organic molecules. For example, substitution in a substrate like *tert*-butyl bromide proceeds by a S_N1 reaction, and by S_N2 reaction in case of methyl bromide. The size of the substituent groups, CH_3 in *tert*-butyl bromide prevents (or at least hinders) the approach of the nucleophile, so that it cannot come in the range to begin to provide electrons to the carbon at the transition state of the slow step. The presence of bulky substituent groups also means that the carbonium ion, which is the result of ionization, is *stabilized* relative to an unsubstituted carbocation ion, $^+\text{CH}_3$.

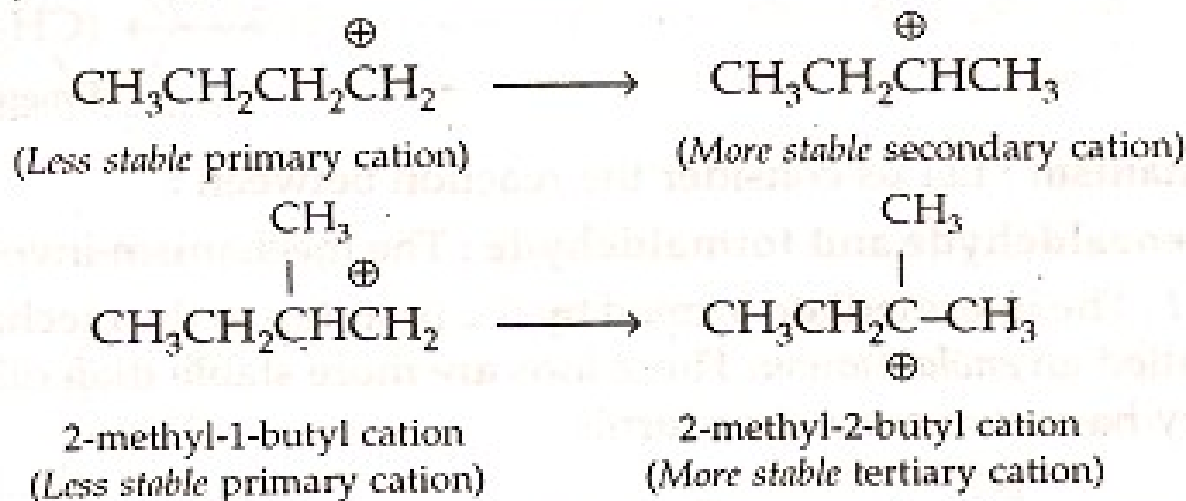


Whenever a reaction has two possible courses, that course is chosen which has the *lowest-energy barrier*, since such a reaction proceeds more rapidly. A *primary* halide (e.g., CH_3Br) would require a *great deal of energy* to undergo unimolecular ionization to the primary carbonium ion ($^+\text{CH}_3$), because a primary carbonium ion is *very energetic*. On the other hand, the energy required for a bimolecular displacement reaction on a primary carbon atom is relatively small, so the S_N2 displacement reaction is favoured in primary halide.

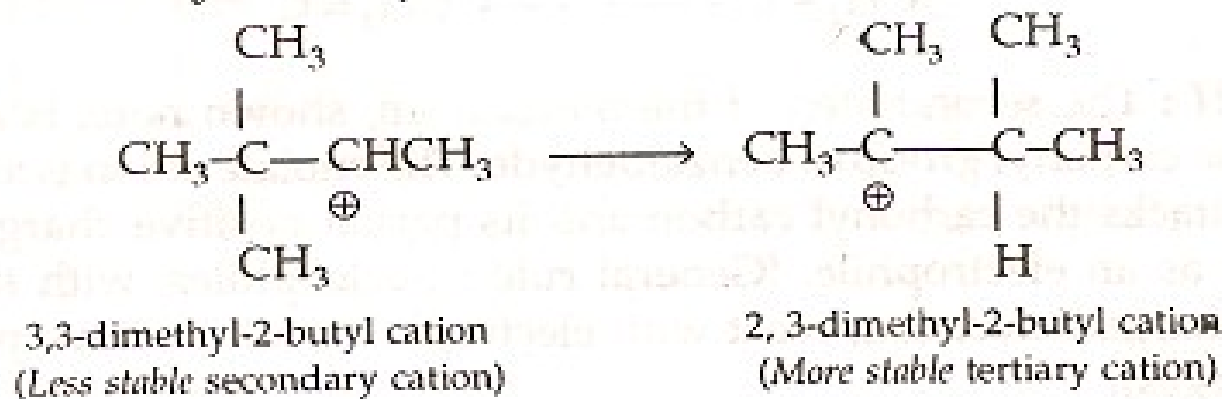
A *tertiary* halide, on the other hand, can *ionize relatively easily*, because the tertiary carbonium ion is considerably *more stable* than a primary carbonium ion. Consequently, the bimolecular nucleophilic substitution (S_N2) reaction is relatively difficult, because of the *steric effect* to the approach of the nucleophile, which *raises the energy of the bimolecular reaction*. Accordingly, for a tertiary halide, the unimolecular S_N1 reaction is favoured.

HYDRIDE AND ALKYL SHIFT

Since a tertiary carbocation is *more stable* than secondary carbocation, which is more stable than primary carbocation, so in organic reactions, *rearrangement of carbocation takes place producing more stable carbocation*. For example, the rearrangement :



*This type of rearrangement caused by the migration of hydrogen atom with a pair of electrons, is called **hydride shift**.*



*This type of rearrangement caused by the migration of alkyl group with a pair of electrons, is called **alkyl shift**.*