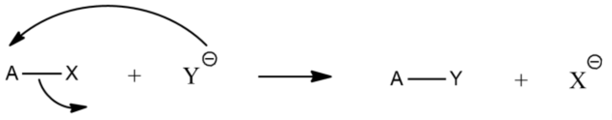
General Treatment of Reaction Mechanism I (02 Lectures)

Reaction Type: Organic reactions are of four types, *viz.*,

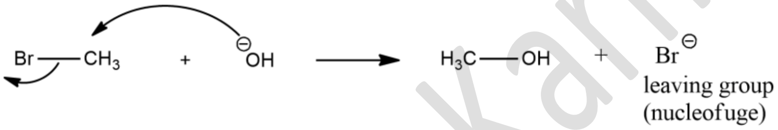
1) Substitution
2) Addition
3) Elimination
4) Rearrangement

1) Substitution reaction: When an atom or group of atoms of a substrate molecule is replaced by some other atom or group of atoms from the reagent, the reaction is known as substitution. Depending on the mechanism, it can be classified as follows:

- Nucleophilic substitution: Here the atom or group of atoms from the reagent attacks the substrate as a nucleophile. Example -

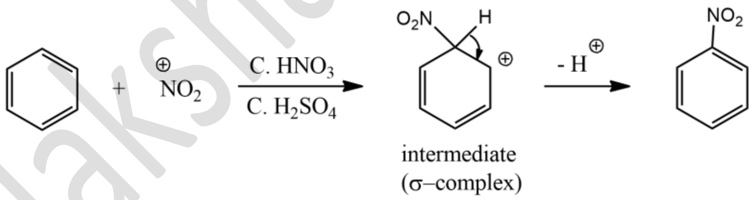


S_N2 reaction (bimolecular nucleophilic substitution)



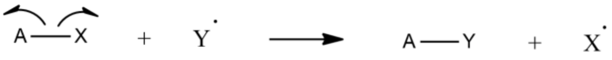
- Electrophilic substitution: Here the substrate attacks an electrophile from the reagent with subsequent removal of an electrofuge. This is found in case of electrophilic aromatic substitution (S_EAr). Example -

S_EAr (electrophilic aromatic substitution)



Both nucleophilic and electrophilic substitutions belong to heterolytic substitution as they involve heterolysis of covalent bonds forming ionic species.

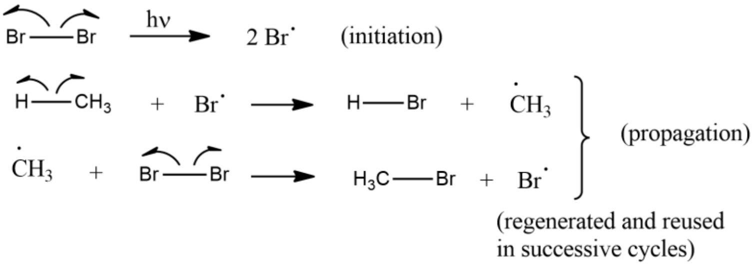
- Radical substitution: Here substitution of atom or group of atoms from the substrate occurs in the form of a free radical, formed by homolysis of covalent bond. Halogenation of alkanes is an example of radical substitution. Example -



Bromination of methane:

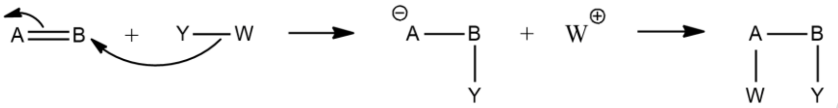
$$CH_4 + Br_2 \longrightarrow CH_3Br + HBr$$

Mechanism:

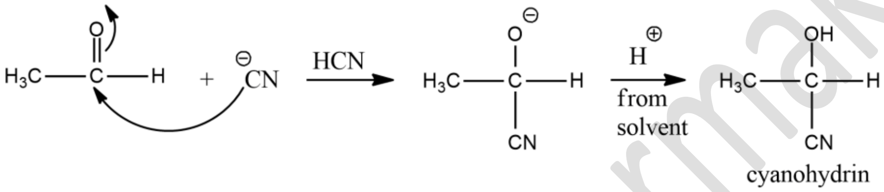


2) Addition reaction: When substrate and reagent combine together to form a single molecule as the product, no atom/group is replaced or eliminated from the substrate, the reaction is called addition. This is the characteristic reaction of compounds having unsaturated linkages, e.g., C=C, C=O, C≡C etc. Depending on the mechanism, it can be classified as follows:

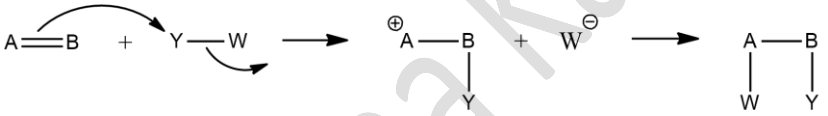
- Nucleophilic addition: Here the addition of the reagent (called addendum) across the π-bond is initiated by nucleophilic attack. This happens to be the case of addition to carbonyl compounds in which the C=O π-bond is polar in nature (due to difference in electronegativity of carbon and oxygen), and hence it is attacked by a nucleophile. Example -



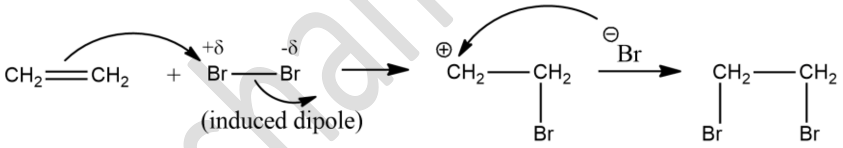
Nucleophilic addition to carbonyl: Formation of cyanohydrin



- Electrophilic addition: In this case the reagent is added across the π-bond as an electrophile. Bromination of alkene belongs to this category. Example -

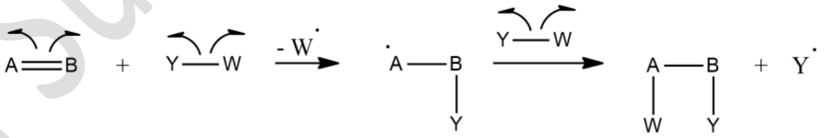


Electrophilic addition: Bromination of ethyene

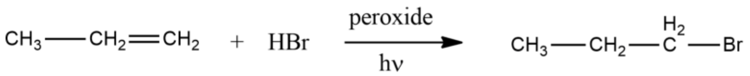


Both nucleophilic and electrophilic additions belong to heterolytic addition as they involve heterolysis of covalent bonds resulting in the formation of ionic species.

- Radical addition: Here, both the substrate (the π-bond) as well as the reagent undergo homolytic fission to produce free radical species prior to the addition. Example -

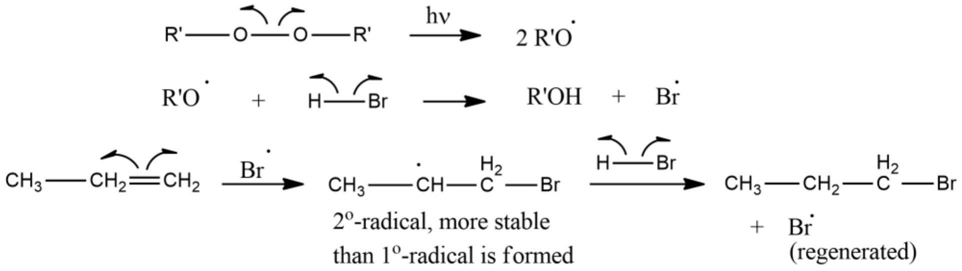


Addition of HBr to alkene in presence of peroxide: Peroxide effect r Kharasch effect

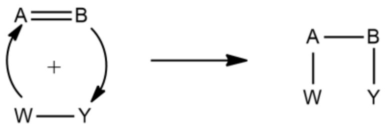


$$CH_3{-}CH_2{=}CH_2 + HBr \xrightarrow[h\nu]{peroxide} CH_3{-}CH_2{-}\overset{H_2}{C}{-}Br$$

Mechanism:

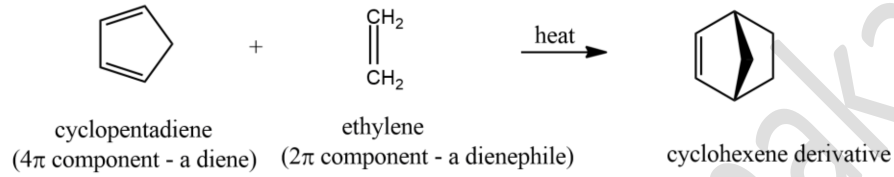


- Pericyclic addition: No ions or radicals are involved in this mechanism, the whole of the reagent is added across the unsaturated linkage with simultaneous bond breaking and bond making. The overall process is concerted and takes place by movement of certain number of electrons along a cycle among the substrate and the reagent. Example -



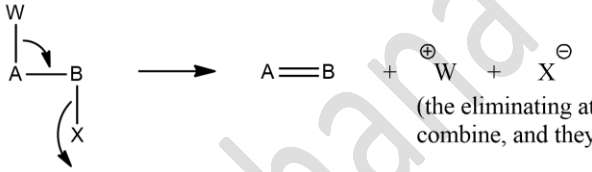
(here, W - Y bond breaks when B is making a bond with Y)

Cycloaddition reaction: Diels-Alder reaction



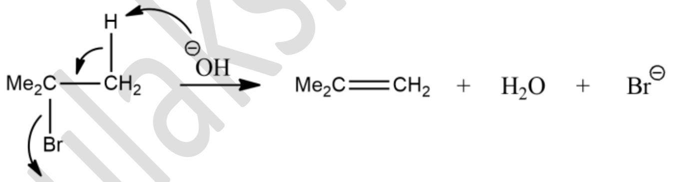
3) Elimination reaction: When one or two small molecules are removed from the substrate to form unsaturated molecule or ring compound as the product, the reaction is known as elimination reaction. Thus, it is the reverse of addition reaction. Following are the types of elimination reactions:

- β-elimination or 1,2-elimknation: The eliminating atoms or groups are initially bonded to two adjacent carbon atoms, *viz.*, C1 and C2. This is the most commonly observed elimination reaction which produces unsaturated molecules like alkenes.

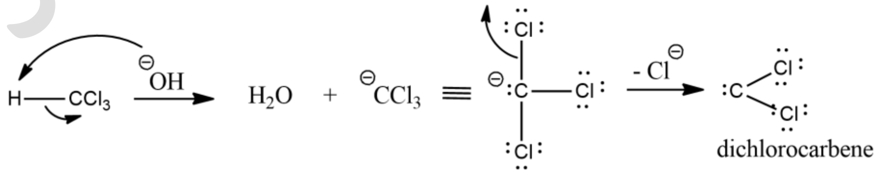


(the eliminating atoms/groups may or may not combine, and they may or may not leave together)

E2 reaction (Elimination bimolecular)

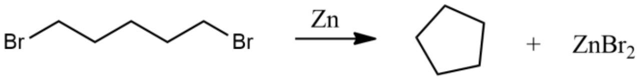


- α-elimination or 1,1-elimination: This is not so common. Here the eliminating atoms or groups are originally attached to the same carbon atom.

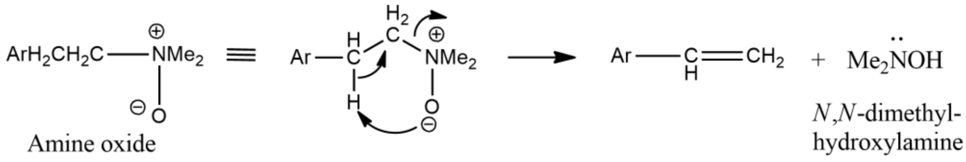


Both β-elimination and α-elimination involves ionic mechanism, i.e., heterolytic bond fissions occur.

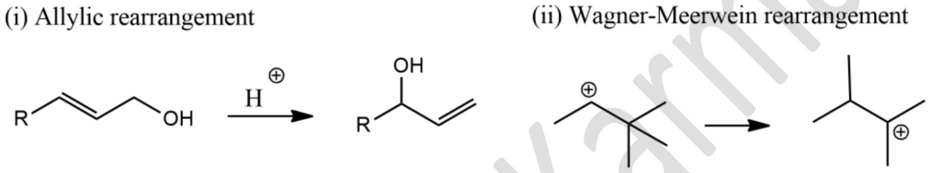
- Dehalogenation of alkyl dihalide with zinc: In this case elimination of atoms or groups occurs from two non-adjacent carbons forming a cyclic product.



- Pericyclic elimination: In this case, elimination of two atoms/groups takes place following a pericyclic mechanism, i.e., involving a concerted one-step process through movement of electrons along a cycle. COPE elimination is one such example.

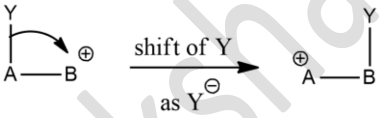


(4) Rearrangement reaction: When substrate molecule undergoes reorganisation of atom or group within the molecule such that bond connectivity changes to form a new molecule having the same molecular formula as that of the substrate, the reaction is called rearrangement. This occurs due to migration or shifting of an atom or group from one position to the new position within the molecule. Intramolecular rearrangements are those where such shifting takes place within the same molecule, but migration to another molecule of the same substrate is known as Intermolecular rearrangement. Example -

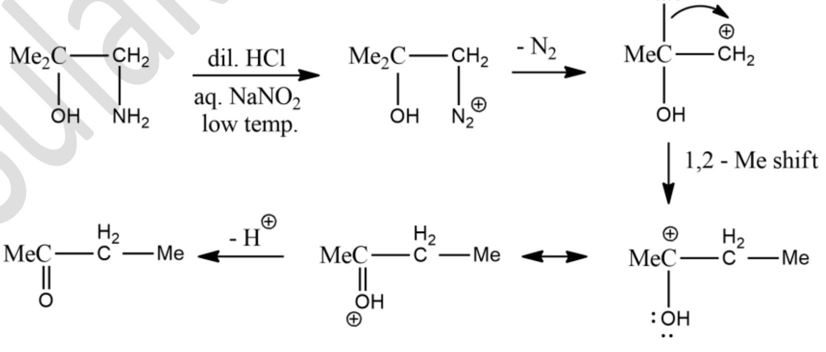


Depending on the number of electron(s) carried by the migrating groups rearrangement is of the following types:

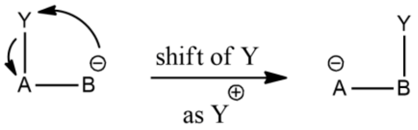
- Nucleophilic rearrangement: Here the atom/group migrates with a pair of electrons, i.e., as a nucleophile, to the adjacent electron deficient atom. This is the most common type of rearrangements. Example -



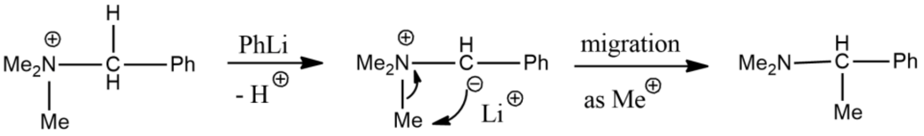
Pinacol-pinacolone type rearrangement



- Electrophilic rearrangement: Here the atom/group migrates without any electron, i.e., as an electrophile, to the adjacent electron rich atom. Example -

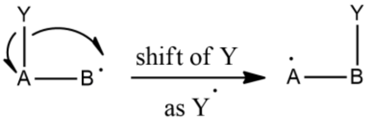


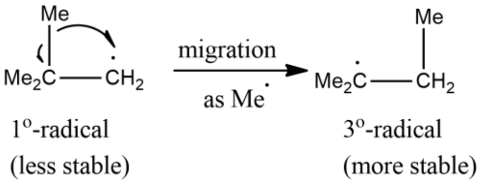
Stevens rearrangement



Both nucleophilic and electrophilic rearrangements follow ionic mechanism as they involve heterolytic bond fissdions.

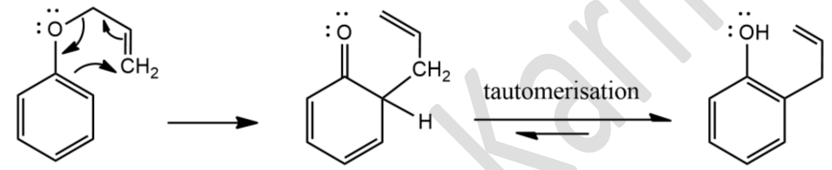
- Radical rearrangement: Here the atom/group migrates with one electron, i.e., as a free radical, to the adjacent radical centre. This is a homolytic process. Example –





All the above rearrangements are 1,2-rearrangemnents as they involve migration of atom or group to the adjacent position.

- Pericyclic rearrangement: Here rearrangement occurs via pericyclic mechanism, i.e., simultaneous breaking and formation of bonds via a cyclic (5 or 6-membered) T.S. with no involvement of any ionic or radical intermediates. There are many examples of this kind, of which Claisen rearrangement is depicted below. This belongs to [3,3]-sigmatropic shift, an important class of pericyclic reactions.



Allyl phenyl ether

o-allylphenol

Reagents are of two types, viz.,

1. **Electrophiles** ('*electro*' means electron, '*phile*' means to like): These are reagents that accept electron pair. They may be ***positively charged*** like H^+, NO_2^+, Br^+, NO^+, R^+, $H_2C{=}NR_2^+$ etc. or may be ***neutral electron deficient molecules*** like $AlCl_3$, BF_3, $TiCl_4$ etc. In each of the latter examples there is a central atom which is short of octet electronic configuration. Hence, they can accept electrons from an electron rich species called nucleophiles.
2. **Nucleophiles** ('*nucleo*' means nucleus, '*phile*' means to like): These are reagents that bring with them electron pairs. They may be ***negatively charged*** like HO^-, NH_2^-, CN^-, R^-, OR^-, $(CO_2Et)_2CH^-$ etc. or may be ***neutral electron rich molecules*** like H_2O, NH_3, R_3N, PH_3, NH_2OH, C=C, C=O etc. In each of the latter examples there is one or more lone pair of electrons on atom which can be donated to electron deficient species called electrophiles.

Leaving groups are of two types, viz.,

1. **Electrofuge**: Leaving group that comes out from the substrate molecule without the bonding electron pair is called an electrofuge. Example - H^+ in S_EAr reaction.
2. **Nucleofuge**: Leaving group that takes away the bonding electron pair from the substrate molecule is called a nucleofuge. Example – Br^- in S_N2 reaction.

References

1. Advanced Organic Chemistry by Jerry March
2. A Guidebook to Mechanism in Organic Chemistry by Peter Sykes
3. Organic Chemistry by Morrison and Boyd