Chapter 3
Classification and studies of reactions

<u>Introduction:</u>

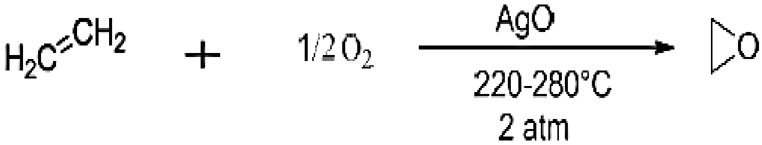
A chemical reaction is generally described by a chemical equation in which the reactants A and B undergo a chemical transformation and give rise to one or more products C and D and the experimental conditions on the arrow.

$$\underbrace{aA + Bb}_{\textbf{Reactants}} \xrightarrow{\textbf{Experimental conditions}} \underbrace{cC + dD}_{\textbf{Products}}$$

Substrate **Reactant**

The substrate (A), the organic compound that undergoes the transformation, and the reagent (B), often inorganic

Example :



The writing of a reaction equation does not provide information about the different steps involved in the transformation of reactants into products. There can be several elementary steps and a number of reactive intermediates formed during the reaction.

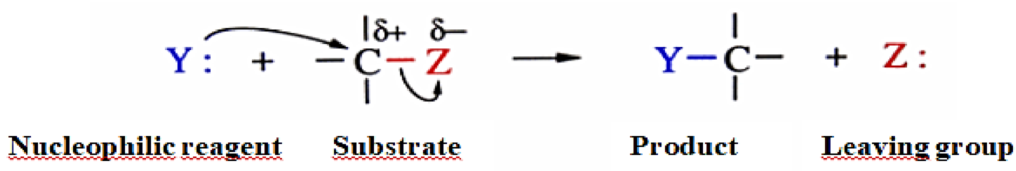
A chemical reaction can be considered under three essential aspects:

- **Electronic aspect**: Breaking and forming of bonds.
- **Geometric or steric aspect**: Change in molecular configurations.
- **Energetic and kinetic aspect**: variation in the energy of the molecules and speed of transformation of the chemical system.

<u>4.1. Classification of reactions:</u>

Organic chemistry reactions have been subdivided into four major categories. They are based on how substrates are transformed into products.

<u>4.1.1. Substitution reactions:</u> where one atom or group of atoms is replaced by another atom or group of atoms.



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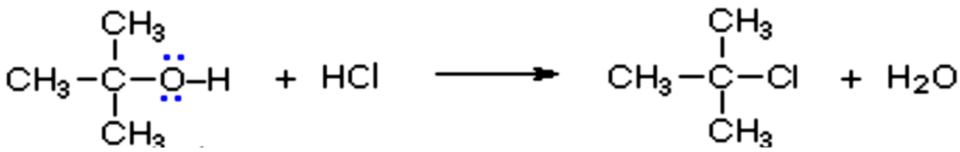
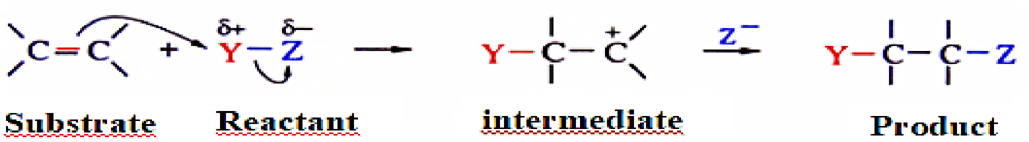


4.1.2. Addition reactions: generally on unsaturated molecules.



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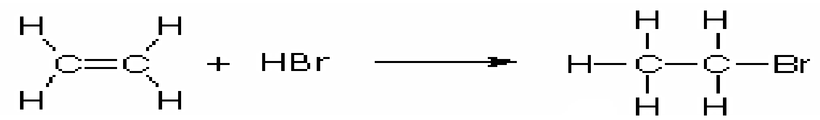
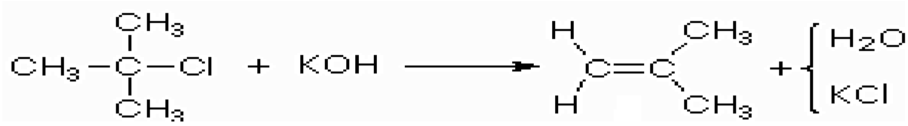
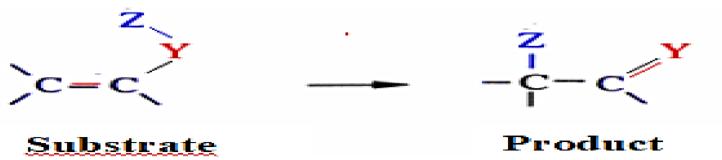


4.1.3. Elimination reaction: atoms are lost from a molecule and a multiple bond appears.

Example:



4.1.4. Transposition (or rearrangement) reactions: one or more atoms change position



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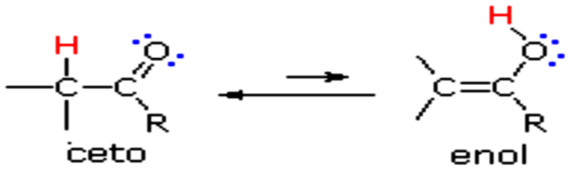
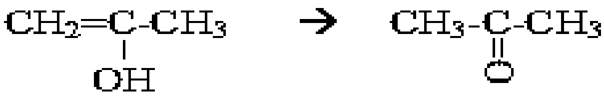




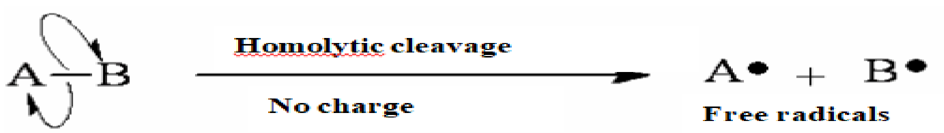
4.2. Electronic Aspect of Reactions:

4.2.1. Bond Breaking:

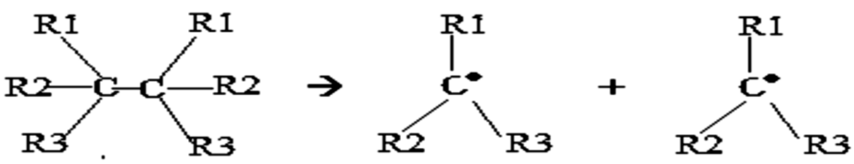
In the initial stage of a chemical reaction, there is typically a bond breaking with the formation of a reaction intermediate .

The breaking of a covalent bond can occur in two different ways:

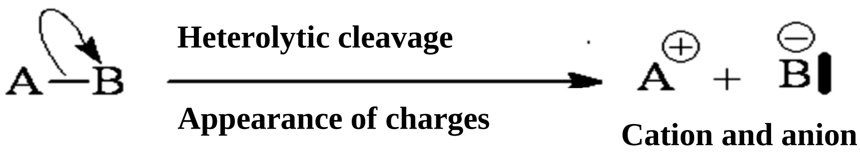
A. Homolytic cleavage: symmetrical cleavage of the covalent bond (formation of radicals). This cleavage is initiated, most often, by UV radiation.



Example :



B. Heterolytic cleavage: asymmetric cleavage of the covalent bond (passage through ionic intermediaries: cations and anions). Two oppositely charged ions are formed. If A^+ is C^+, the ion is a **carbocation** and if B^- is C^-, the ion is a **carbanion**.



4.2.2. Reaction intermediates:

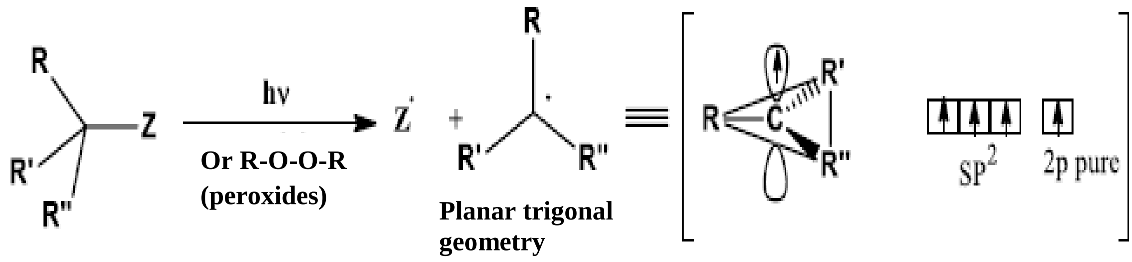
Reaction intermediates are chemical species that form between two elementary steps; they are very unstable and have a very short life.

These chemical species are completely consumed at the end of the reaction, so they do not appear in the stoichiometric equation.

4.2.2.1. Free radicals:

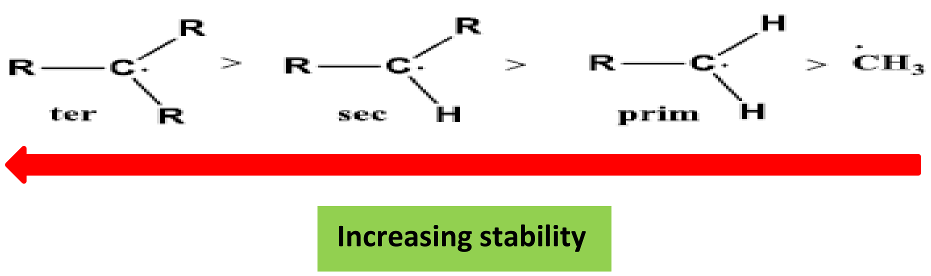
A. Formation

Result from thermal pathways in the presence of peroxides or through photochemical pathways.

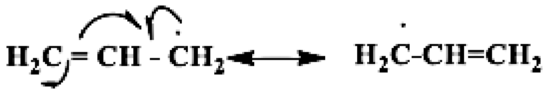


B. Stability

Their stability is similar to that of (C^+), the effects (+I, +M) can stabilize them by reducing their electronic deficit.



Allyl radical

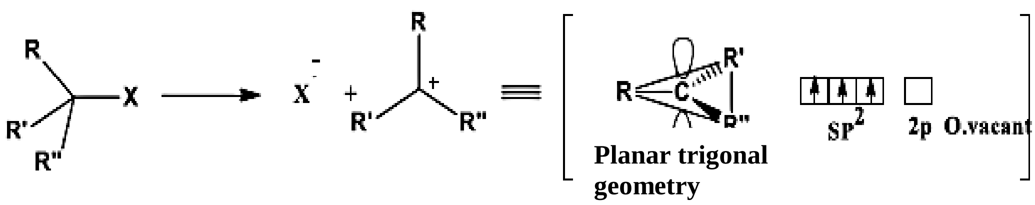


4.2.2.2. Carbocations: These are cations whose positive electronic charge is carried by a carbon atom.

A. Formation:

Carbocations can be formed by:

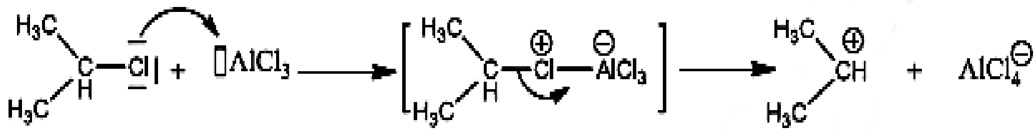
- **Solvolysis**



- **The addition of a proton to a double bond**

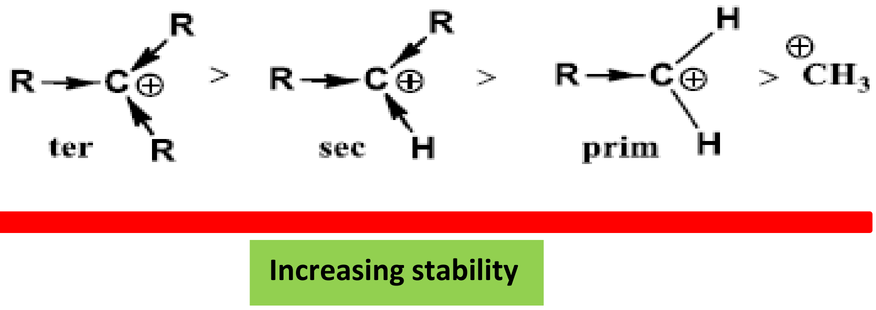
$$H_3C-CH=CH-C_6H_5 + H^{\oplus} \longrightarrow H_3C-CH_2-\overset{\oplus}{CH}-C_6H_5$$

- **Attack of a halogen by a Lewis acid:**

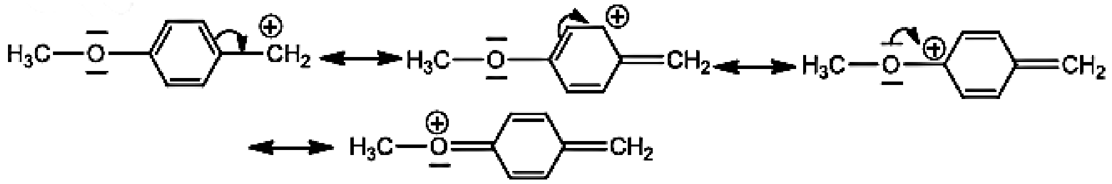


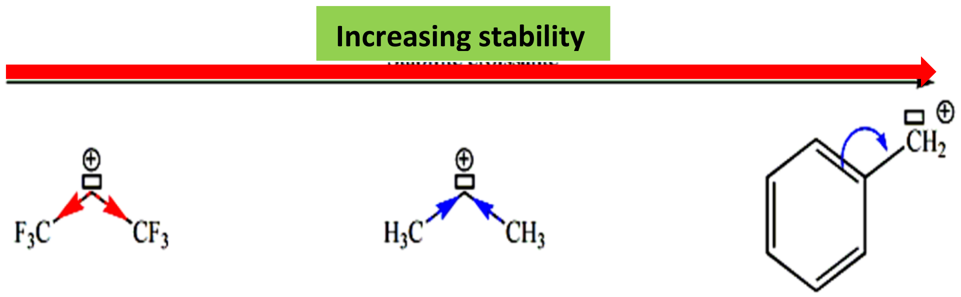
B. Stabillity:

Inductive or donor mesomeric effects (+I, +M) can stabilize them by reducing their electronic deficit.

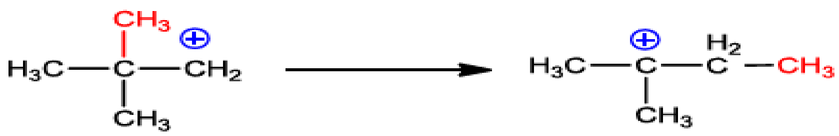


A carbocation stabilized by mesomerism is all the more stable as it has more mesomeric forms.



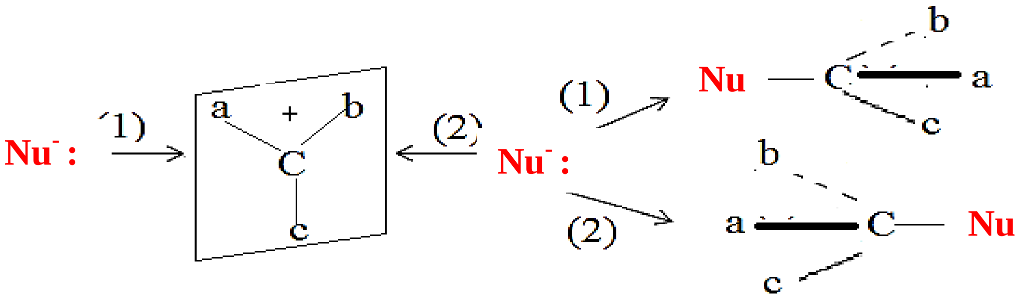


Some unstable carbocations evolve to a stable state by rearrangement of the molecule.



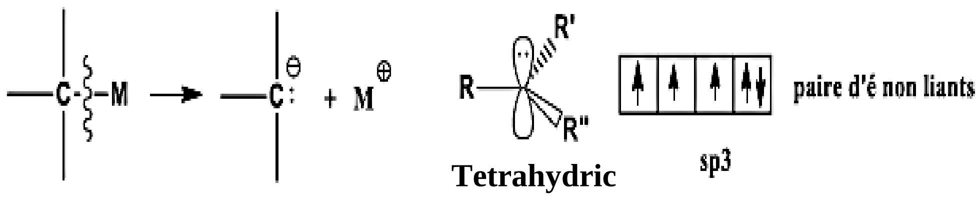
C. Reactivity:

Since the carbocation is electrophilic (positive charge), a nucleophile can attack it either from one side of the plane or the other, which can have an influence on the stereochemistry of the product obtained.



a ≠ b ≠ c ≠ Nu $\Longrightarrow$(A) and (B) form an enantiomeric pair and the mixture is **racemic**.

<u>4.2.2.3. Carbanions:</u> these are anions whose negative charge is carried by a carbon atom. They have a tetrahedral geometry and therefore sp3 hybridization.

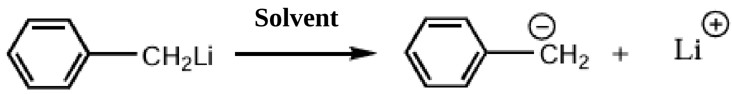


Tetrahydric geometry

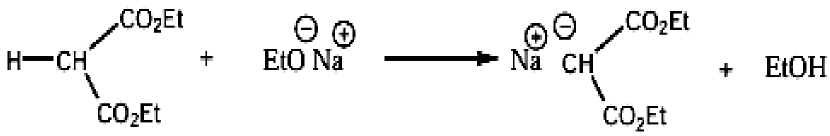
<u>A. Formation:</u>

Carbanions can be formed by:

- **Ionization of an organometallic**



- **By removal of a proton by a base**



- **From organometallic compounds**

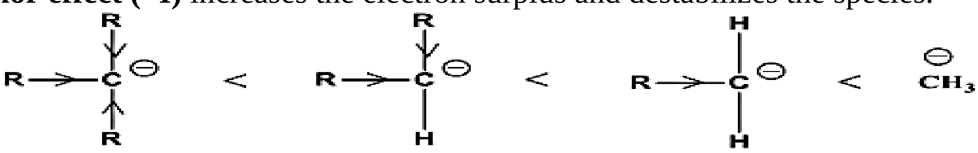
$$\mathbf{R{-}MgX \longrightarrow R:^{-} + MgX^{+}}$$

- **From an alkyne**

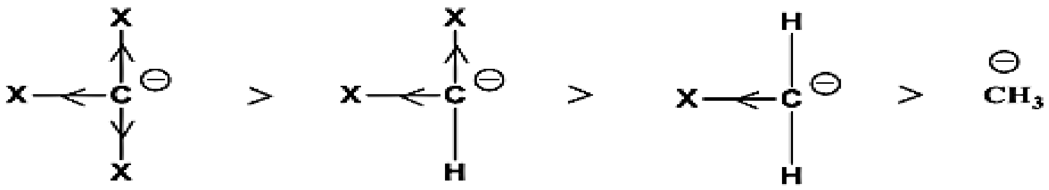
$$\mathbf{R{-}C{\equiv}C{-}H + NaNH_2 \longrightarrow R{-}C{\equiv}C:^{-}\,Na^{+} + NH_3}$$

<u>B. Stabillity:</u>

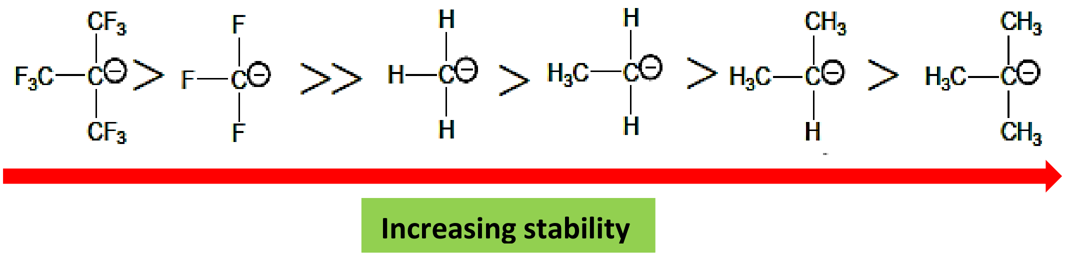
The donor effect (+I) increases the electron surplus and destabilizes the species.



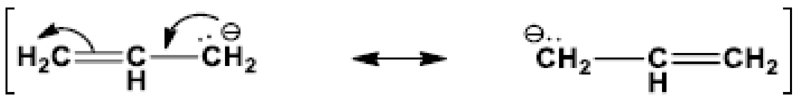
- **The attracting inductive effect (-I)** decreases reactivity ➞ stability increases.

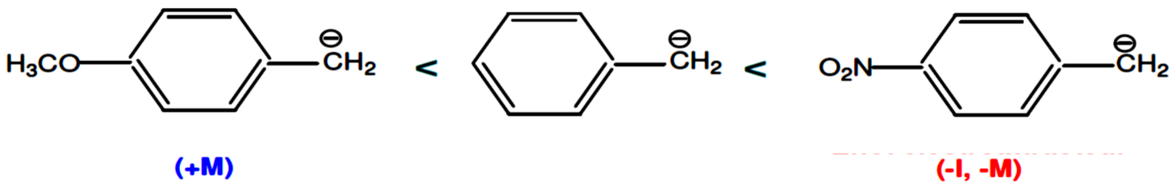


Example:



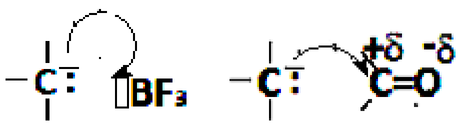
- **Mesomeric effect:** stabilizes the species





C. Reactivity:

Carbanions react at electron deficient sites, such as: carbocation, ketones and Lewis acids.



4.2.3. Electrophilic and Nucleophilic Reagents: Lewis Acids and Bases

4.2.3.1. Electrophilic reagents: these are reagents poor in electrons.

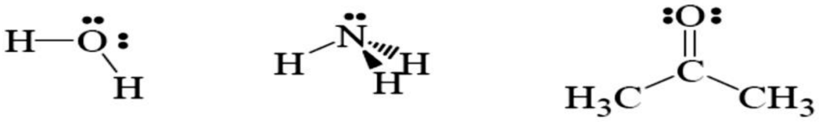
- They can be electrically neutral: molecules whose central atom has an electron deficiency: **BF_3, $AlCl_3$, $FeCl_3$**.
- They can be charged, in the form of cations

$-X^+$; $-{}^+NO_2$; $-C^+$

During a reaction, the electrophile (electron deficient) is attacked by an electron-rich center (nucleophile).

4.2.3.2. Nucleophilic reagents: These are reagents rich in electrons. Carbanions have a saturated and free atomic orbital and are called Lewis bases.

- They can be electrically neutral: molecules whose central atom has one (or more) free doublet(s)



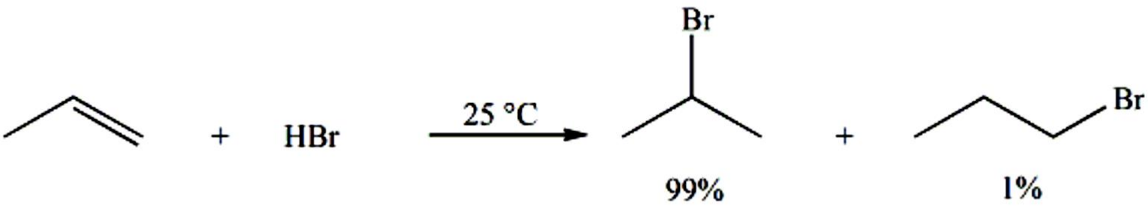
- They can be negatively charged (anions):

Anions are more nucleophilic than the corresponding neutral molecules.

4.3. Geometric or steric aspect (Reaction orientation or selectivity):
This aspect relates to the influence of configurations, conformations, or even just steric hindrances during the reaction.

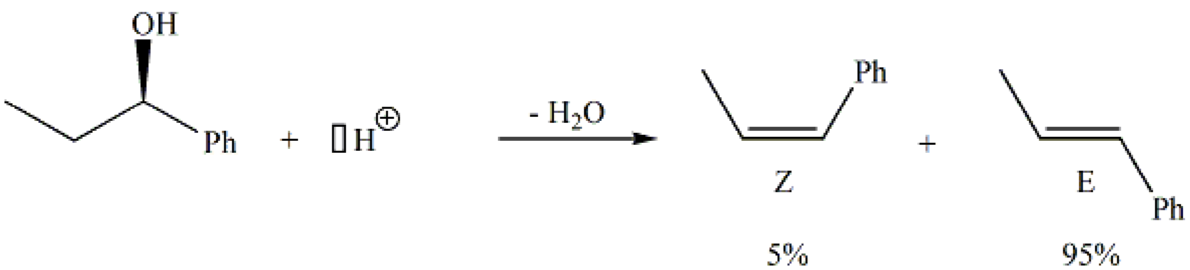
4.3.1. Regioselectivity:
A reaction is said to be regioselective if, when it can produce two or more constitutional isomers from a substrate with multiple potential reactive sites, it predominantly yields one of them.

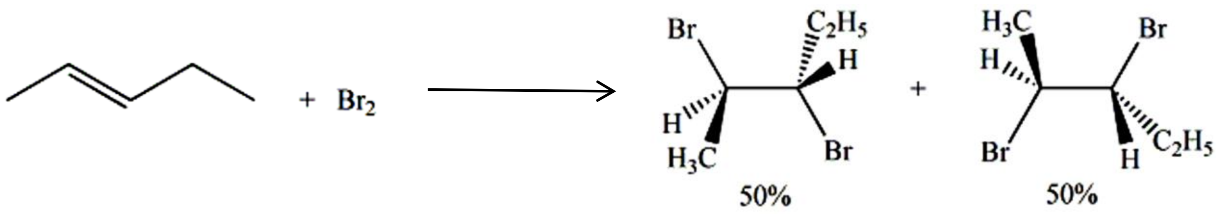
Example:



Stereoselectivity:
A reaction is said to be stereoselective if, when it could potentially produce several stereoisomeric products, it predominantly yields certain ones.

Example:





Solvents:

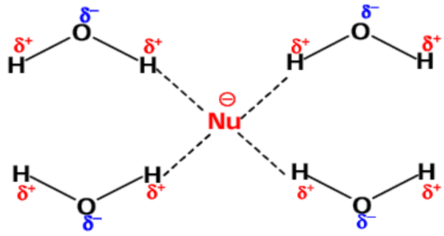
The role of the solvent is multiple in chemistry. It can be used first and foremost to dissolve the reagents involved in a chemical reaction and facilitate the encounter of reacting molecules.

There are 2 classes of solvents:

Non-polar solvents: These solvents are characterized by a zero dipole moment: Benzene (C_6H_6), toluene (C_6H_5-CH_3), carbon tetrachloride (CCl_4), hydrocarbons (hexane, cyclohexane)... Since they are uncharged, they do not solvate the ions in the reaction medium.

Polar solvents: they are divided into 2 groups:

- **Protic solvents:** they have at least one hydrogen atom bonded to a heteroatom (O, N, S...) as in water (H-O-H), alcohols (R-O-H). Due to the polarization of the bonds (H-O, H-N, H-S...), these mobile protons are capable of forming hydrogen bonds with molecules carrying lone pairs or negative charges.



- **Aprotic solvents:** they contain atoms with free pairs but do not have mobile hydrogen: the hydrogen atoms are exclusively linked to carbon atoms: