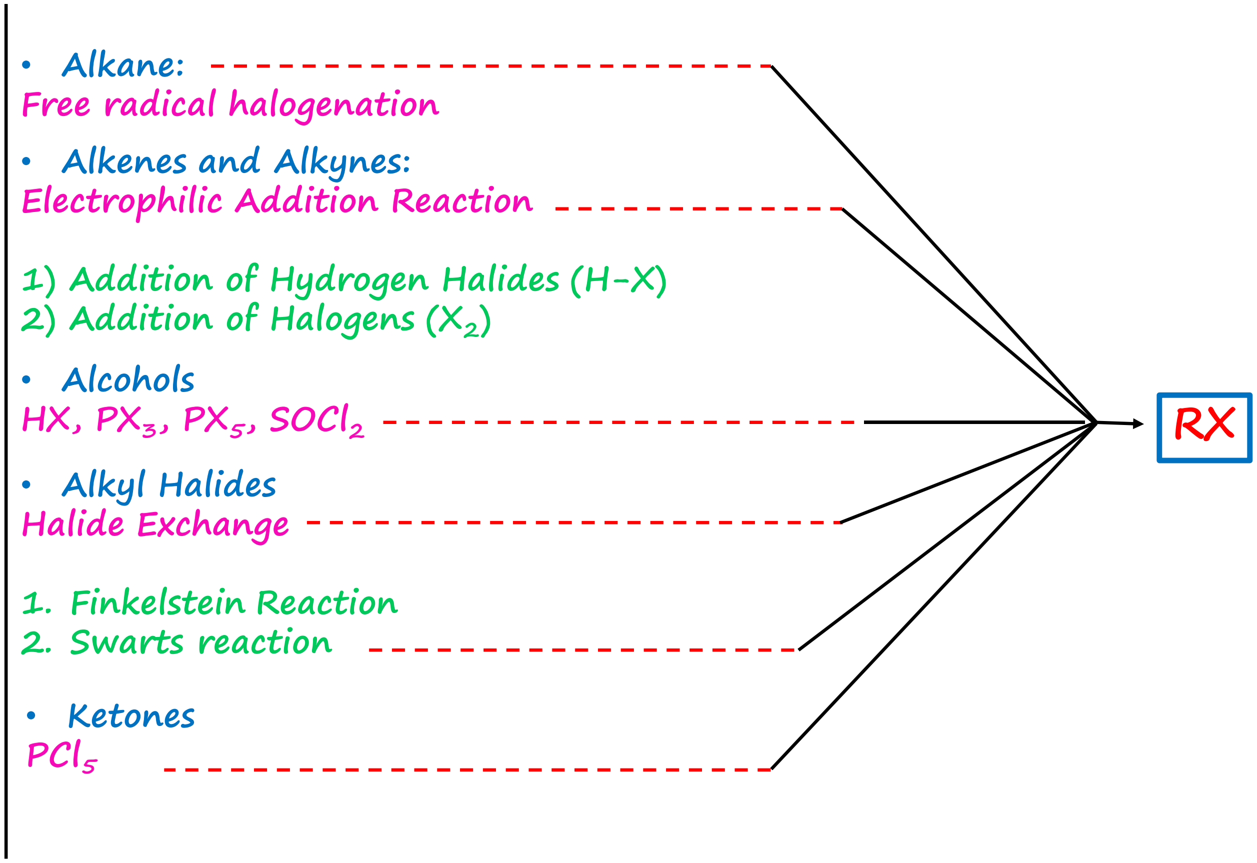
Haloalkanes

Haloalkanes or Alkyl halides are a group of chemical compounds that are derived from alkanes containing one or more halogen groups i.e. –F, Cl, Br, or I. For example, methane (CH_4) is an alkane. When one hydrogen atom of methane is replaced by a halogen, e.g. Cl, methyl chloride, i.e. CH_3Cl is formed. CH_3Cl is a haloalkane.

Preparation of Alkyl Halides

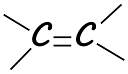


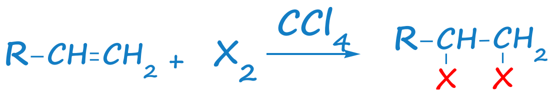
Preparation of alkyl halides from haloalkanes

$$R{-}H \xrightarrow[h\nu \text{ or heat}]{Cl_2} R{-}Cl + HCl$$

N.B: As the reaction proceeds through a free radical pathway, it is not possible to stop the reaction to monohalogenation stage. Subsequently, this reaction gives a mixture of mono, di and trihalides.

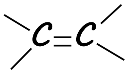
Preparation of alkyl halides from alkenes

- Electrophilic addition of halogens to 



$$R\text{-}CH{=}CH_2 + X_2 \xrightarrow{CCl_4} R\text{-}\underset{X}{CH}\text{-}\underset{X}{CH_2}$$

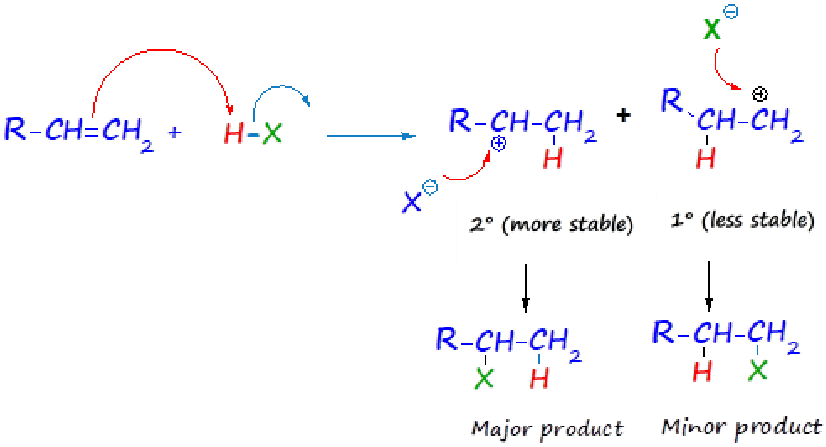
X = $-Cl$, $-Br$

- Electrophilic addition of hydrogen halides to 

$$R\text{-}CH{=}CH_2 + H\text{-}X \longrightarrow R\text{-}\underset{X}{CH}\text{-}\underset{H}{CH_2}$$

N.B: The outcome of HX addition to unsymmetrical alkenes is governed by Markovnikov's rule. The rule states that when a protic acid HX or other polar reagent is added to an asymmetric alkene, the acid hydrogen (H) or electropositive part gets attached to the carbon with more hydrogen substituents, and the halide (X) group or electronegative part gets attached to the carbon with more alkyl substituents i.e. fewer hydrogen atoms.

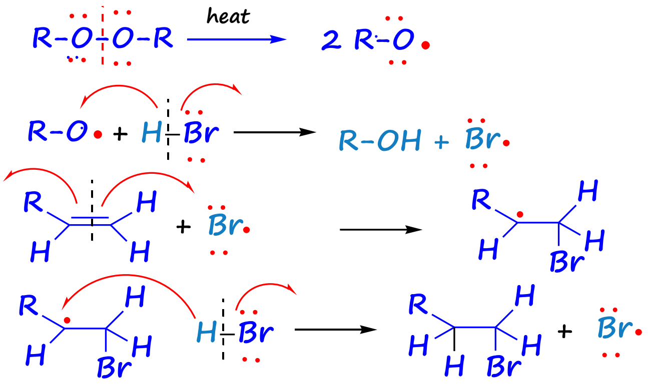
The chemical basis for Markovnikov's Rule is the formation of the most stable carbocation during the electrophilic addition process. The addition of the hydrogen ion to one carbon atom in the alkene creates a positive charge on the other carbon, forming a carbocation intermediate. More stable the carbocation intermediate, lower is the activation energy barrier required to reach the transition state of the reaction. So, in any electrophilic addition reaction, the product that is formed through the more stable carbocation intermediate will dominate.



Secondary carbocation is more stable than the primary carbocation. Therefore, secondary carbocation intermediate gives rise to the major product.

Anti-Markovnikov's rule. Anti Markovnikov's addition is an exception of the Markovnikov's rule. As compared to MK addition, which follows ionic mechanism and proceeds through a carbocation intermediate, anti-MK addition, also known as the Kharash effect follows a free radical pathway. This reaction is observed with HBr and not HCl and occurs in presence of organic peroxides.

Anti MK reaction proceeds through the following steps:



- Step I: Free radical is generated through homolytic cleavage of peroxide compound.
- Step II: The generated free radical attacks on hydrogen halide to form halide radical through homolysis.
- Step III: The generated halide radical attacks on alkene molecule to form alkyl radical through homolysis.
- Step IV: The generated alkyl radical attacks on HBr to form the anti Markovnikov's product through homolytic cleavage of the hydrogen halide bond.

Preparation of alkyl halides through halogen exchange method.

- Finkelstein Reaction.

$$R-Br + Na-I \xrightarrow{acetone} R-I + NaBr$$

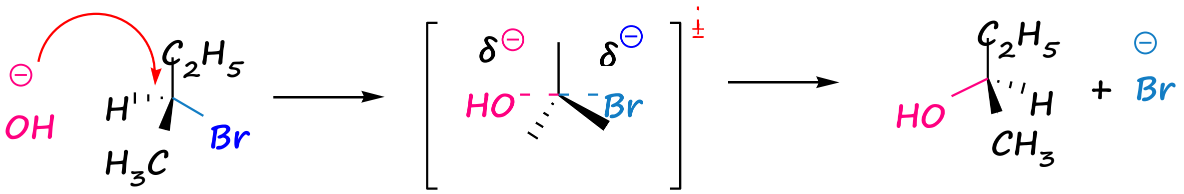
$$R-Cl + Na-I \xrightarrow{acetone} R-I + NaCl$$

Finkelstein reaction involves single-step S_N2 reaction with stereochemistry inversion.

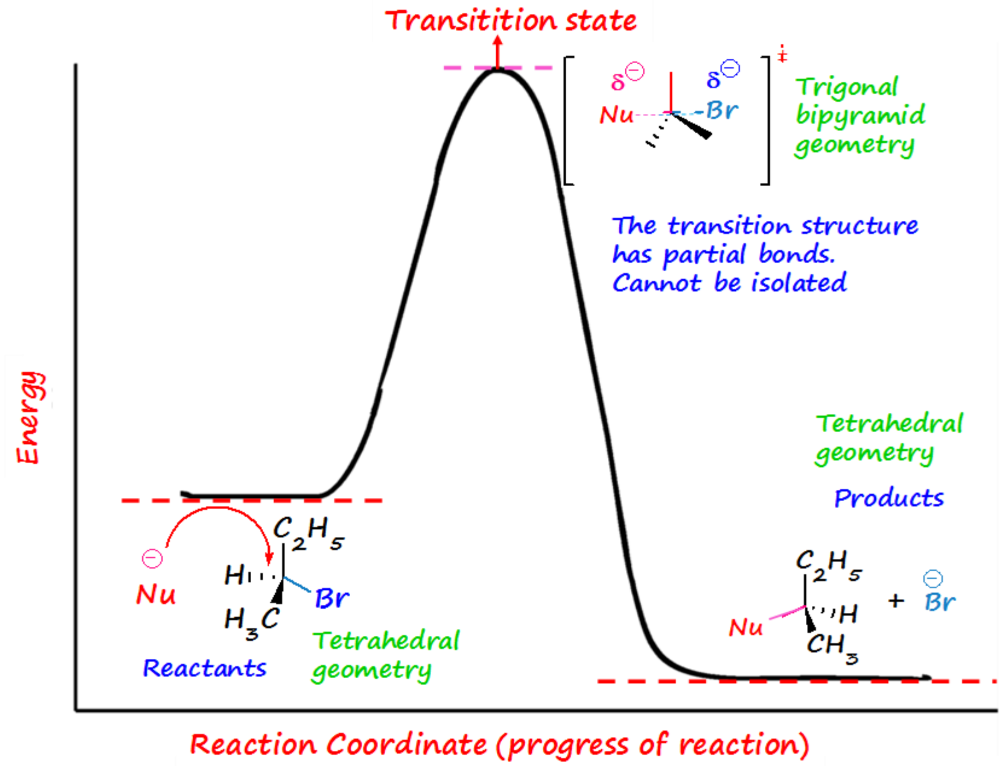
Notes on S_N2 reaction mechanism:

The term "S_N2" is the abbreviated form of substitution, nucleophilic bimolecular. A nucleophile is a species that tends to donate electrons or react at electron-poor sites such as protons. The word nucleophile is derived from "nucleus" and the Greek word "philos" which means for love. The word electrophile is derived from "electron" + "philos" – a species that has affinity for electrons and will accept electron pair from an electron-rich species. Hence a nucleophile is likely to donate electron pair to an electrophile.

Mechanism of S_N2 reaction



Transition state



Reaction Energy Diagram for S_N2 reaction

Salient features of S_{N_2} reaction

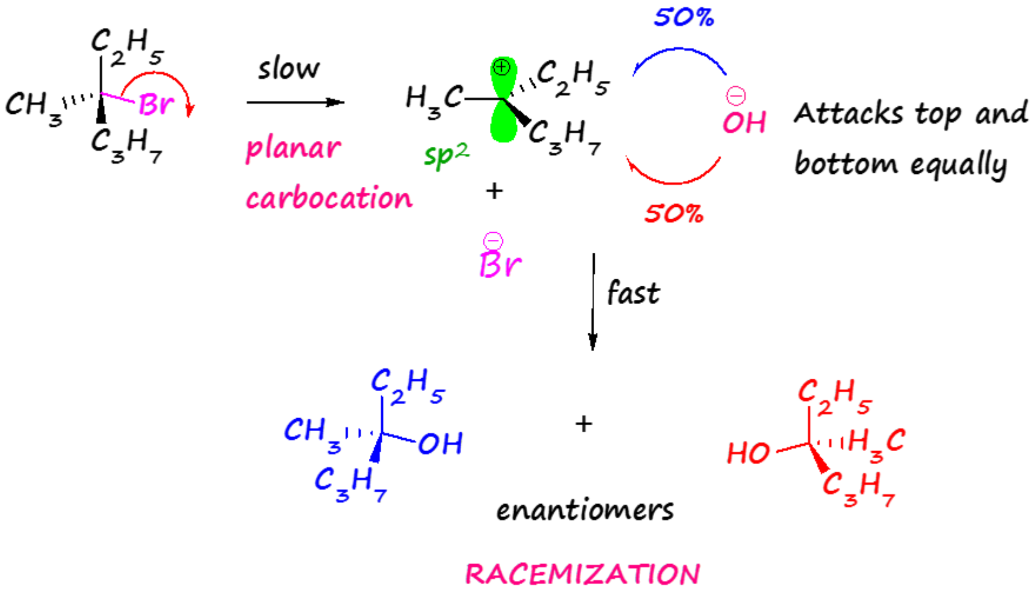
- Single step reaction
- Bimolecular reaction. (Molecularity of an elementary reaction is the number of reactant molecules involved in a reaction). Rate = $k[RX][Nu^-]$. The rate of S_N2 reaction depends on the concentration of the nucleophile.
- Concerted, synchronous pathway. No intermediate is formed. The reaction goes through a transition state.
- The nucleophile attacks from the back side.
- No rearrangement is observed.
- Order of reactivity of alkyl halides: CH_3X > 1°(primary) > 2° (secondary) > 3° (tertiary). The reactivity order can be attributed to the steric hindrance to back side attack of the nucleophile.
- Inversion of configuration is observed. S_N2 reactions are stereospecific.
- Favored by polar aprotic solvents such as acetone, dimethyl formamide etc.

As Finkelstein reaction follows S_N2 pathway, the success of this reaction depends on nucleophilicity of the incoming halide, nature of the leaving group, carbon halogen bond and alkyl halide reactivity.

Notes on S_N1 reaction mechanism:

The term “S_N1 ” is the abbreviated form of substitution, nucleophilic unimolecular. For an S_N1 reaction, Rate = k [RX]. The nucleophile does not participate in the rate determining step i.e. the slow step of the reaction. Hence rate of SN_1 reaction is independent of the concentration of the nucleophile.

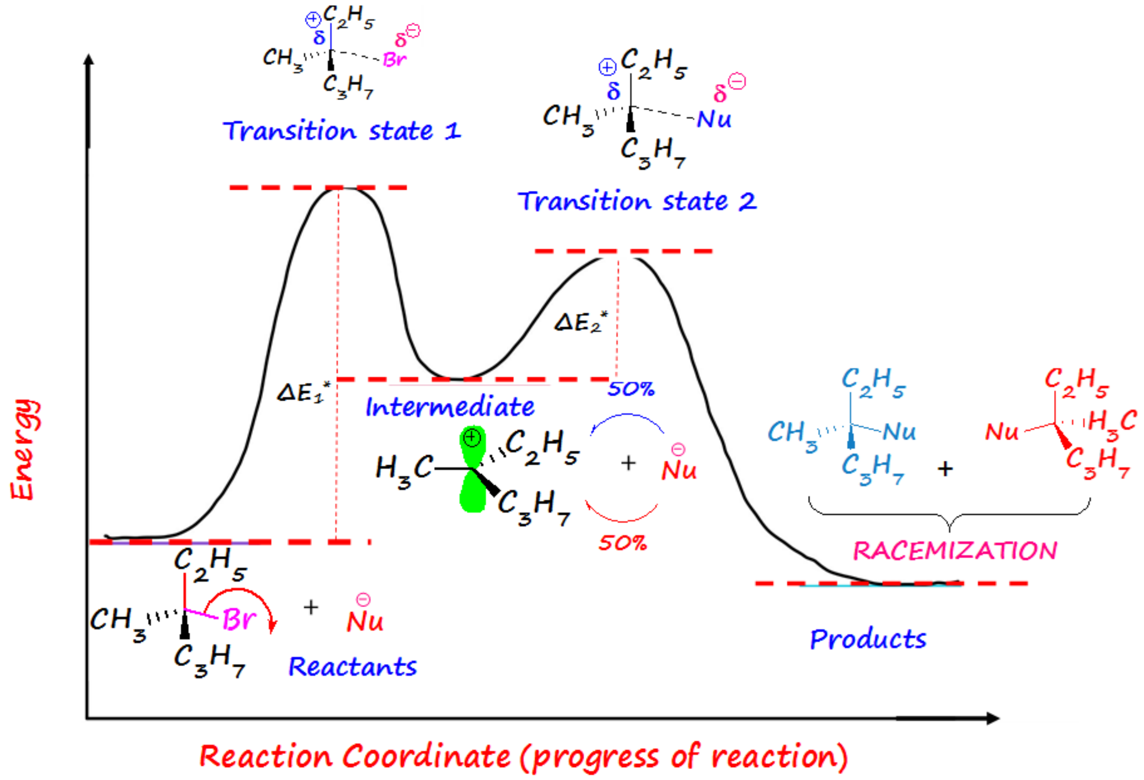
Mechanism of S_N1 reaction



Salient features of S_{N_1} reaction

- Two step reaction. The first step, which is the rate determining step of the reaction, involves the formation of a carbocation intermediate and its rearrangement to a more stable carbocation (if applicable). The second step involves the attack of the nucleophile to the carbocation intermediate.
- Unimolecular reaction.
- Stepwise mechanism. A carbocation intermediate is formed. More stable the carbocation, faster the reaction state.
- The carbocation intermediate has planar geometry. Hence, the nucleophile can attack from both sides leading to a pair of enantiomers.
- Order of reactivity of alkyl halides: 3°(tertiary) > 2° (secondary) > 1° (primary). Any contributing factor such as inductive effect or resonance, that leads to the stabilization of the carbocation intermediate will lower the activation energy barrier, and thus, lead to faster reaction. This is in accordance with Hammond's

postulate, which states that the transition state of a reaction resembles either the reactants or the products, to whichever it is closer in energy.



Reaction Energy Diagram for S_N1 reaction

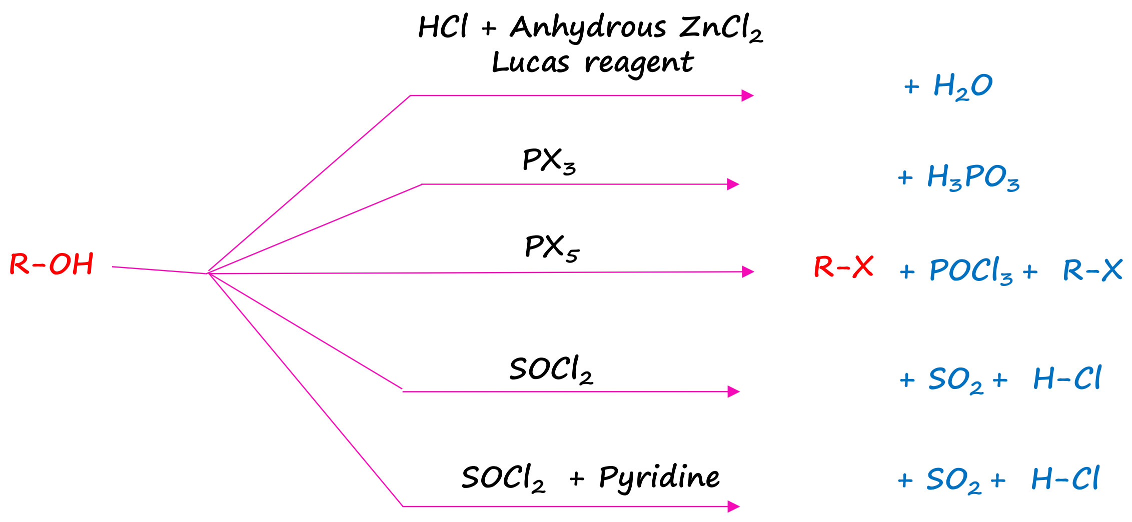
- Racemization is observed as the planar carbocation is attacked by nucleophile from both the sides equally to form d and l isomers in equal proportion.
- Favored by polar protic solvents such as methanol, water etc.

- Swarts Reaction.

  – Preparation of alkyl fluorides from alkyl chlorides or bromides

$$\begin{array}{c} R\text{–}I \\ R\text{–}Br \\ R\text{–}Cl \end{array} + AgF \xrightarrow[\text{Polar protic}]{\text{DMSO}} R\text{–}F + \begin{array}{c} AgI \\ AgBr \\ AgCl \end{array}$$

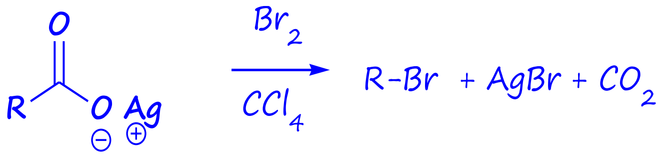
Preparation of alkyl halides from alcohols



N.B: A base, e.g., pyridine, is used in the preparation of alkyl halides from alcohol (Darzen's process) to remove the hydrogen chloride byproduct, and to catalyze the reaction. When the reaction is carried out with pyridine, the reaction follows a normal S_N2 pathway and the resultant product is formed with inversion of configuration. When the reaction is carried out under milder condition without pyridine, the reaction follows an S_Ni (substitution nucleophilic internal) pathway and the resultant alkyl halide is formed with retention of configuration.

Preparation of alkyl halides from silver salts of carboxyl acids

- Hunsdiecker Reaction – The silver (I) salts of carboxylic acids react with halogens to give unstable intermediates which readily decarboxylate thermally to yield alkyl halides.



- The reaction is believed to involve homolysis of the C-C bond and a radical chain mechanism.