

Different Kinds of Chemical Reactions

Introduction

Organic chemistry is centered on the transformation of functional groups from one type to another. These molecular transformations are categorized into a few fundamental classes, providing a robust framework for predicting and understanding the vast majority of organic reactions. The classification primarily depends on the net structural change that occurs at the reaction center. Understanding these reaction types is crucial for synthesizing new compounds and predicting reaction outcomes.

Learning Objectives

By the end of this module, you will be able to:

- Identify and classify a chemical transformation as an addition, elimination, substitution, or rearrangement reaction.
- Differentiate between oxidation and reduction in the context of organic molecules.
- Predict the type of reaction based on the change in molecular bonding and saturation.

Key Concepts and Definitions

Term	Definition
Nucleophile	A species that donates an electron pair to form a new bond (nucleus-loving). Often negatively charged or has a lone pair.
Electrophile	A species that accepts an electron pair to form a new bond (electron-loving).

	Often positively charged or electron-deficient.
Leaving Group	An atom or group that dissociates from the substrate, taking the bonding electrons with it (e.g., halides, water). A good leaving group is a weak base.
Carbocation	A short-lived, unstable intermediate where a carbon atom carries a positive charge (usually sp^2 hybridized). Stability increases in the order $1^\circ < 2^\circ < 3^\circ$.
Oxidation	In organic chemistry, generally defined as increasing the number of bonds to oxygen or other heteroatoms (or decreasing bonds to hydrogen).
Reduction	In organic chemistry, generally defined as decreasing the number of bonds to oxygen or other heteroatoms (or increasing bonds to hydrogen).

Detailed Discussion

Addition Reactions

Additional reactions are characteristic of **unsaturated** compounds, such as alkenes, alkynes, and compounds containing **carbonyl groups** ($C=O$). These reactions involve the breaking of a π bond and the formation of new σ bonds.

- **Mechanism:** Two fragments (A and B) are added across a multiple bond (π bond).
- **Result:** The multiple bond is converted into a single bond, and the molecule becomes **more saturated**. The number of substituents on the reacting carbons increases.
- **Significance:** This is the primary method for adding functional groups to an alkene or alkyne backbone. The regioselectivity of these reactions often follows **Markovnikov's Rule** (the H atom adds to the carbon with more existing H atoms).

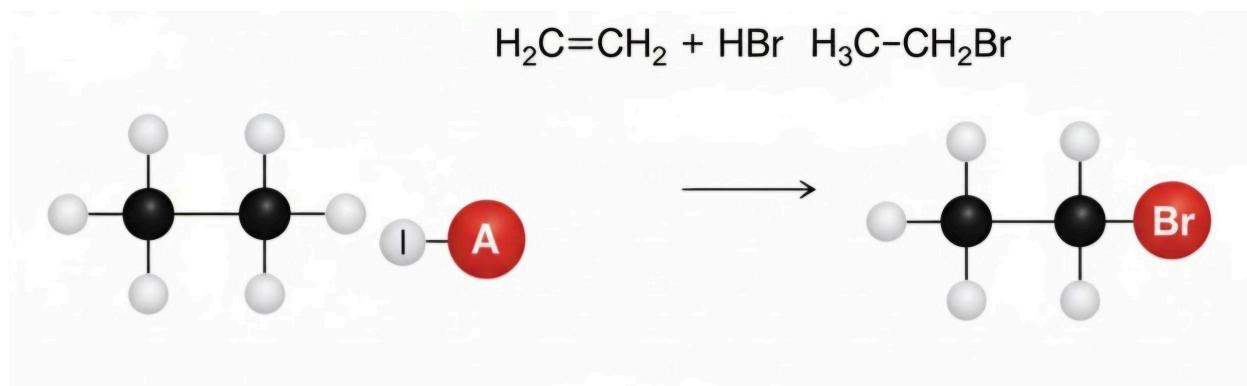
Example: The addition of HBr across a C = C double bond.

Common conditions and reagents include:

- Hydrogen gas (H_2) with metal catalysts such as Ni, Pt, or Pd

- Halogens (Br_2 , Cl_2)
- Hydrogen halides (HCl , HBr)
- Mild temperatures and absence of strong bases

Addition reactions typically increase molecular saturation.



Elimination Reactions

Elimination reactions are essentially the **reverse of addition reactions**. It involves the **removal of atoms or groups** from a molecule, resulting in the formation of a multiple bond.

- **Mechanism:** Two atoms or groups are removed (eliminated) from adjacent atoms, usually in the presence of a strong base or high heat. This creates a π bond.
- **Result:** A new multiple bond (π bond) is formed, increasing the degree of unsaturation in the molecule.⁷
- **Significance:** These are key methods for synthesizing alkenes. The major product often follows **Zaitsev's Rule** (or Saytseff's Rule), which states that the elimination proceeds in the direction that forms the most substituted, and therefore most stable, alkene product.

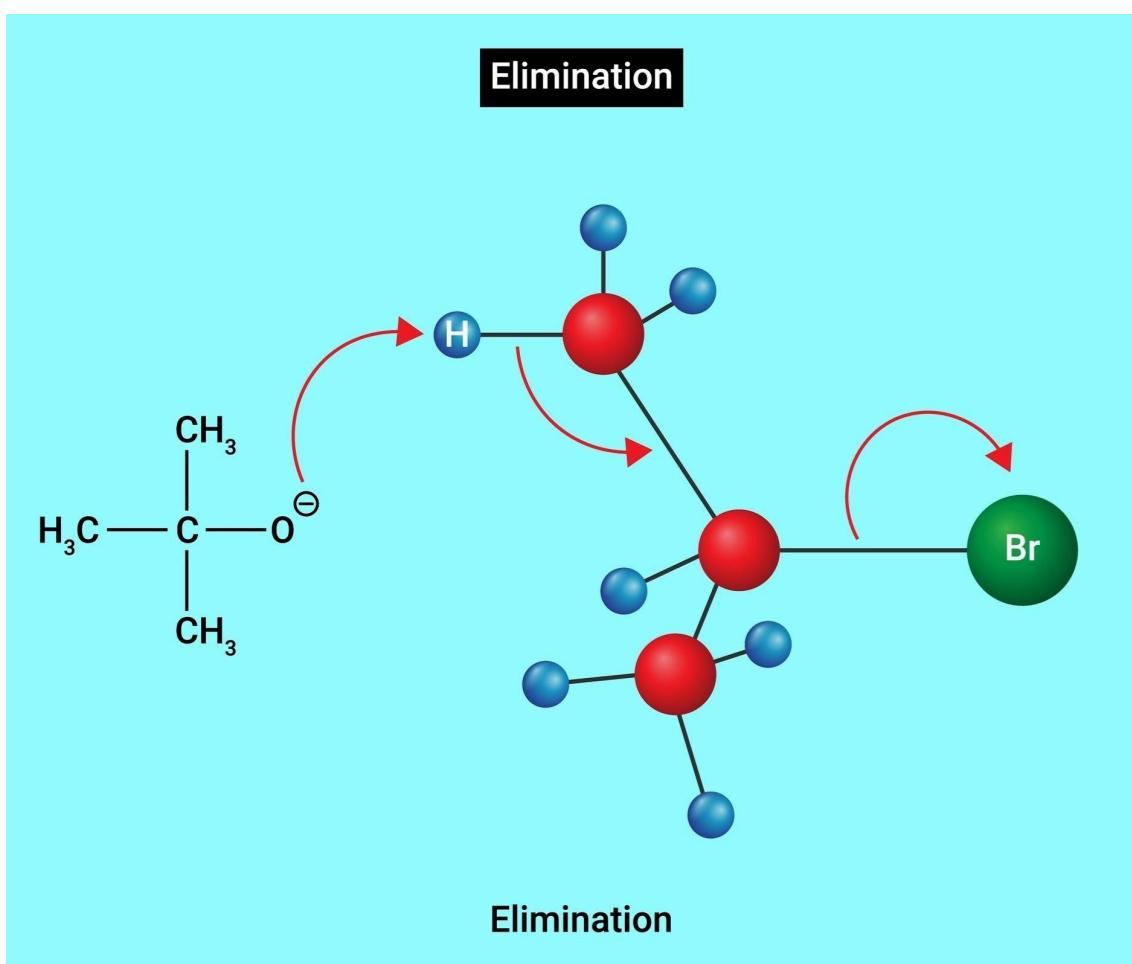
Example: The dehydrohalogenation of an alkyl halide using a strong base, where H and X are eliminated to form an alkene.

Common conditions and reagents include:

- Strong bases (e.g., KOH , NaOH)
- Alcoholic solvents

- High temperature
- Acid-catalyzed dehydration of alcohols

Elimination reactions commonly compete with substitution reactions.



Substitution Reactions

Substitution reactions are fundamental transformations where one functional group is replaced by another at a saturated carbon center.

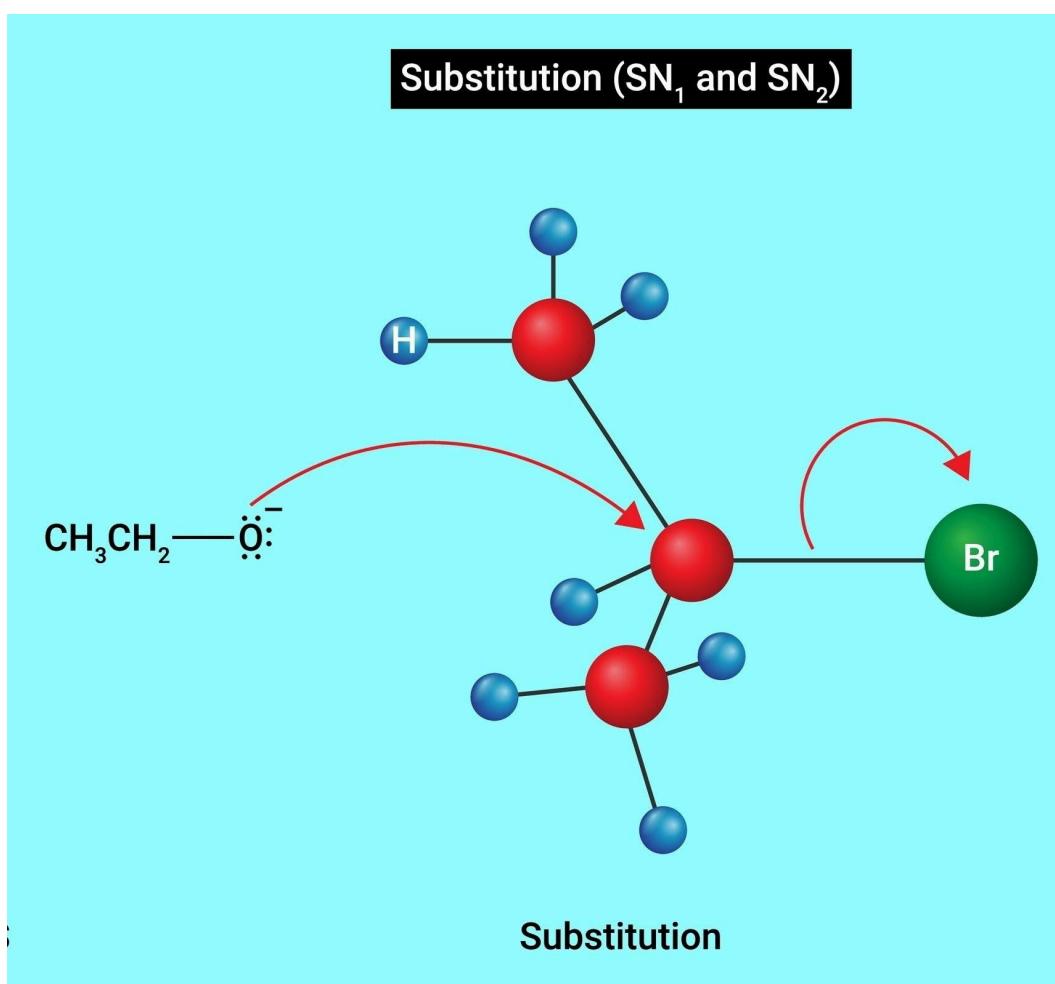
- **Mechanism:** An atom or group in the substrate (the **leaving group**, L) is displaced and replaced by another atom or group (the **nucleophile**, Nu). The carbon atom's hybridization remains sp^3 .
- **Result:** The degree of saturation of the molecule remains unchanged.
- **Classification:** These reactions are commonly classified by their mechanism as:

- **S_n2 (Substitution, Nucleophilic, Bimolecular):** A one-step process where the nucleophile attacks simultaneously as the leaving group departs. Inversion of configuration occurs.
- **S_n1 (Substitution, Nucleophilic, Unimolecular):** A two-step process involving the formation of a **carbocation intermediate**, followed by nucleophilic attack. This often leads to a racemic mixture.

Example: The reaction of an alkyl halide with hydroxide ion, replacing the halogen with a hydroxyl OH group to form an alcohol.

Common conditions and reagents include:

- Polar protic or aprotic solvents
- Strong or weak nucleophiles
- Moderate temperature
- Haloalkanes as common substrates



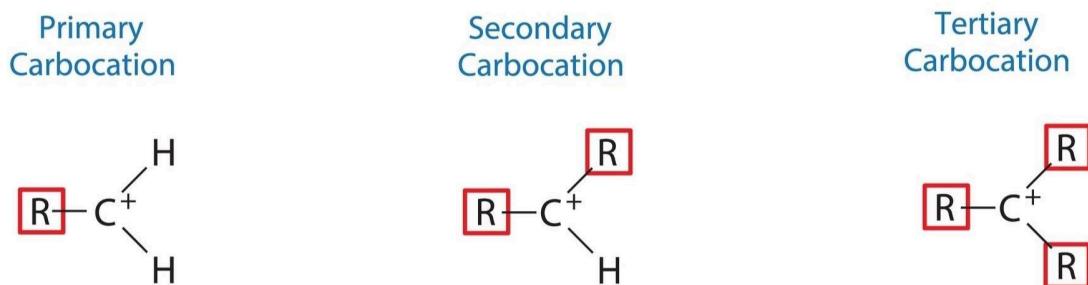
Substitution reactions are typical in saturated compounds such as alkanes and haloalkanes.

Rearrangement Reactions

Rearrangement reactions involve the migration of an atom or group from one atom to another **within the same molecule**.

- **Mechanism:** These reactions typically occur when an unstable intermediate (like a **carbocation**) is formed. A H atom (hydride shift) or an alkyl group (alkyl shift) migrates from an adjacent carbon to the positively charged carbon.
- **Result:** The migration leads to the formation of a **more stable intermediate** (e.g., $2^\circ \rightarrow 3^\circ$ carbocation), ultimately resulting in a product that is a constitutional isomer of the initially expected product.
- **Significance:** Rearrangements must always be considered whenever a reaction proceeds through a carbocation intermediate.

Example: A 1,2-hydride shift where a hydrogen atom moves from C_2 to C_1 to change a secondary carbocation into a more stable tertiary carbocation.



Common features include:

- Formation of carbocation intermediates
- Acidic conditions
- Migration of alkyl groups or hydride ions

These reactions occur to form **more stable intermediates**.

Oxidations and Reductions (Redox)

In organic chemistry, redox reactions are defined by tracking the relative number of bonds an atom (usually carbon) has to **hydrogen** and to more **electronegative atoms** (O, N, X)

Process	Bond Change	Functional Group Transformation
Oxidation	Increase in C–O (or C–N, C–X) bonds; Decrease in C–H bonds.	Primary Alcohol → Aldehyde → Carboxylic Acid
Reduction	Decrease in C–O (or C–N, C–X) bonds; Increase in C–H bonds.	Ketone → Secondary Alcohol
Reagents	Oxidizing agents (like CrO_3 , KMnO_4 , O_3) are used to introduce oxygen atoms or remove hydrogen.	Reducing agents (like LiAlH_4 , NaBH_4 , H_2 with a catalyst) are used to introduce hydrogen atoms or remove oxygen.

The progressive oxidation of a carbon atom typically proceeds from the least oxidized to the most oxidized state:

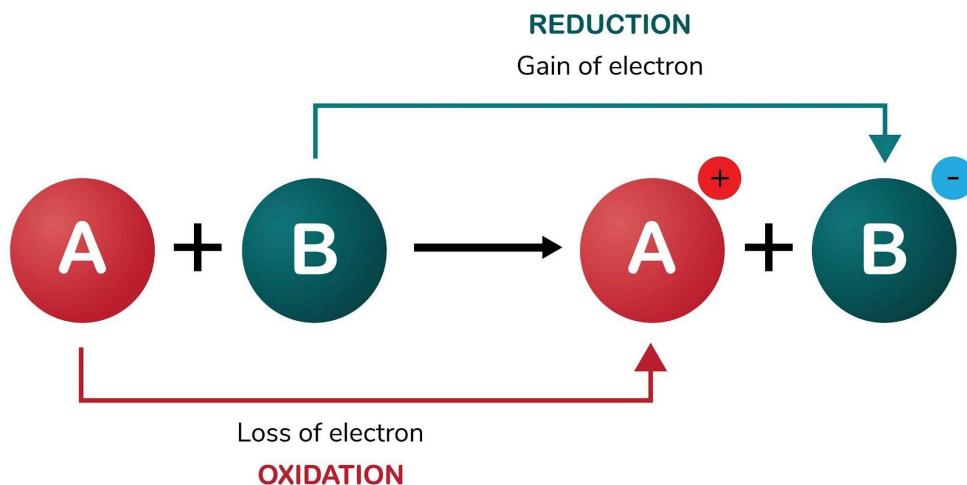
Alkane → Alcohol → Aldehyde/Ketone → Carboxylic Acid → Carbon Dioxide

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Redox Reaction

Redox or oxidation-reduction reaction

The chemical reaction of electron transferring between two species



Oxidation and Reduction – Common Reagents

Common oxidizing agents:

- Potassium permanganate (KMnO_4)
- Potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$)
- Chromic acid

Common reducing agents:

- Hydrogen gas (H_2)
- Zinc (Zn)
- Sodium borohydride (NaBH_4)

Understanding Oxidation and Reduction: Oxidation and reduction reactions always occur simultaneously and involve the transfer of electrons.

Oxidation may involve:

- Loss of electrons
- Gain of oxygen
- Loss of hydrogen

Reduction may involve:

- Gain of electrons
- Loss of oxygen
- Gain of hydrogen

In organic chemistry, oxidation and reduction are often identified by observing changes in functional groups rather than direct electron transfer.

How to Quickly Identify Reaction Types

Observation in Reaction	Reaction Type
Atoms are added to a molecule	Addition
Atoms or small molecules are removed	Elimination
One group replaces another	Substitution
Structure changes but formula remains the same	Rearrangement
Oxidation number changes	Oxidation–Reduction

Applications of Chemical Reactions

Addition Reactions: Hydrogenation of vegetable oils to produce margarine.

- **Elimination Reactions:** Production of alkenes in the petrochemical industry.
- **Substitution Reactions:** Manufacture of pharmaceuticals and polymers.

- **Rearrangement Reactions:** Synthesis of complex organic compounds.
- **Oxidation-Reduction Reactions:** Rusting of iron, combustion of fuels, and biological respiration.

These applications show how chemical reactions are fundamental to both industry and daily life.

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