POLYHALOGEN COMPOUNDS

Polyhalogen compounds are chemical compounds that contain more than one halogen atom in their molecular structure. These compounds typically consist of halogens from Group 17 of the periodic table, which includes fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At).

Polyhalogen compounds exhibit diverse chemical properties and are utilized in various fields, including organic synthesis, pharmaceuticals, materials science, and industrial processes. They are often synthesized through reactions involving halogenation, where halogen atoms are introduced into organic molecules.

Examples of polyhalogen compounds include:

Polyhalogen Derivatives

Trichloromethane (Chloroform), $CHCl_3$

1. Preparation

$$CH_4 + Cl_2 \xrightarrow{hv} CH_3Cl + HCl$$

Chloromethane

$$CH_3Cl + Cl_2 \xrightarrow{hv} CH_2Cl_2 + HCl$$

Dichloromethane

$$CH_2Cl_2 + Cl_2 \xrightarrow{hv} CHCl_3 + HCl$$

Trichloromethane

$$CHCl_3 + Cl_2 \xrightarrow{hv} CCl_4 + HCl$$

Tetrachloromethane

The mixture of CH_3Cl, CH_2Cl_2, $CHCl_3$ and CCl_4 can be separated by fractional distillation.

2. From chloral hydrate, Pure chloroform can prepare.

$$NaOH + CCl_3CHO \rightarrow HCOONa + CHCl_3$$

chloral

$$NaOH + CCl_3CH(OH)_2 \rightarrow HCOONa + CHCl_3 + H_2O$$

Chloral hydrate — sodium format — Chloroform

3. Laboratory Method

By reacting with a mixture of bleaching powder and water, one can obtain it from either ethanol or acetone.In case of ethanol, the reaction occurs as follows

$$CaOCl_2 + H_2O \rightarrow Ca(OH)_2 + Cl_2$$

$$CH_3CH_2OH + Cl_2 \xrightarrow{Oxidation} CH_3CHO + 2HCl$$

$$CH_3CHO + 3Cl_2 \xrightarrow{Chlorination} CCl_3CHO + 3HCl$$

Chloral

$$Ca(OH)_2 + 2CCl_3CHO \xrightarrow{Hydrolysis} 2CHCl_3 + (HCOO)_2Ca$$

Chloroform Calcium formate

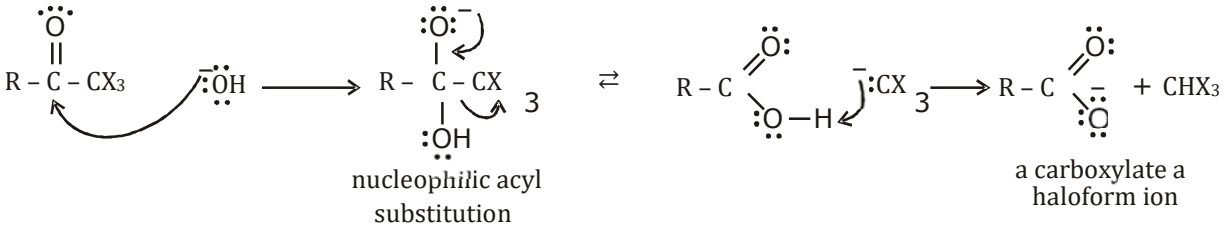
4. From carbon tetrachloride

$$CCl_4 + 2[H] \xrightarrow[Heat]{Fe/H_2O} CHCl_3 + HCl \text{ (partial reduction)}$$

5. Haloform reaction

$$R-\overset{\overset{O}{\|}}{C}-CH_3 + 3X_2 + 3OH^- \longrightarrow R-\overset{\overset{O}{\|}}{C}-CX_3 + 3X^- + 3H_2O$$

methyl ketone — methyl ketone — Tri halomethyl ketone



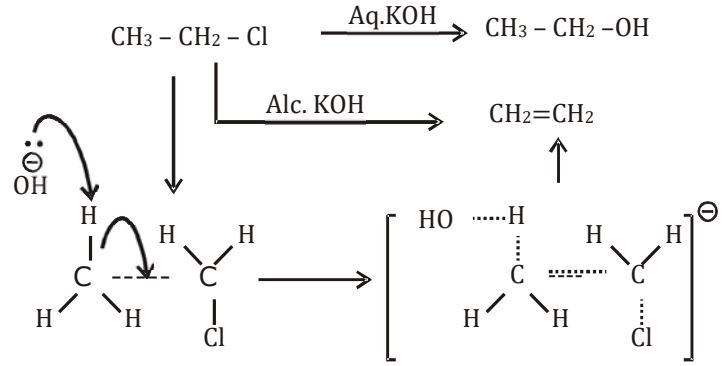
(Haloform)

Step 1: Attack of the nucleophile

Step 2: Elimination of the leaving group

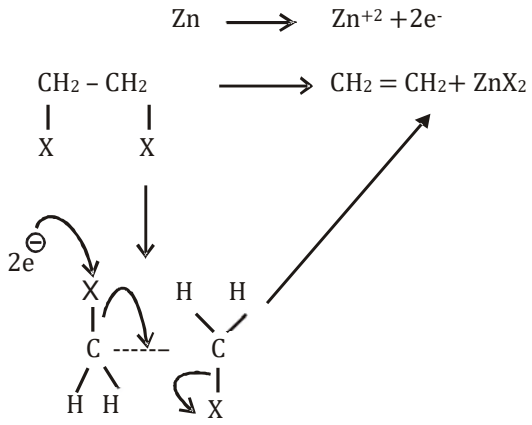
Step 3: Proton transfer

Dehyodro halegenation (–HX) E2



Anti-elimination

Dehalogenation: – ($-X_2$) E2



Anti-elimination

E_c or E_i (Intramolecular or cyclic elimination mechanism)

(1) Lg and Base present in same molecule

(2) It proceeds by cyclic transition state.

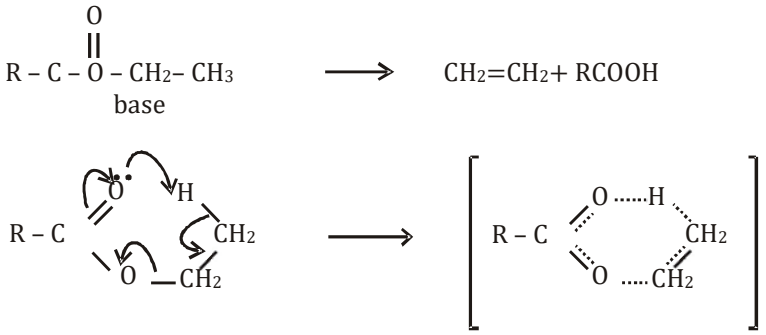
(3) Overall, it is syn ellimination.

(4) Hoffmann is major product as it is obtain by least hinberd site/cyclic transition state.

(5) No rearrangement.

Example of E_c/E_i

Pyrolysis of Ester



1. $CH_3-CH_2-CH_2-C(=O)-O-CD_2CH_3 \xrightarrow[E/E]{\Delta} CH_2=CD_2+CH_3CH_2COOD$

2. $CH_3-CH_2-CH_2-C(=O^{18})-O-CH_2-CH_2-CH_3 \xrightarrow[E_C/E_i]{\Delta} CH_3-CH=CH_2+CH_3CH_2-C(=O^{18})-OH$

Physical Properties of Chloroform

Chloroform is a colorless, dense liquid with a sweet and somewhat unpleasant odor and taste. It has a boiling point of 334º K and exhibits slight solubility in water. Being denser than water, chloroform can induce unconsciousness when its vapors are inhaled, making it suitable for use as an anesthetic agent in surgical procedures.

Chemical Properties of Chloroform

1. Action of sun light and air

$$2\,CHCl_3 + O_2 \xrightarrow{\text{SUN LIGHT}} \underset{\text{Phosgene}}{2COCl_2} + 2HCl$$

To maintain the high purity of chloroform for its anesthetic use, it is recommended to store it in opaque bottles (such as brown or blue) that block out active light radiation. Additionally, the bottles should be filled to the brim to exclude air. Furthermore, a small amount of ethanol (usually around 1%) is often added to chloroform bottles. This addition of ethanol helps to convert the toxic $COCl_2$ into non-poisonous diethyl carbonate.

$$\underset{\text{diethyl carbonate}}{COCl_2 + 2C_2H_5OH \rightarrow O=C(OC_2H_5)} + 2HCl$$

2. Hydrolysis

$$H-CCl_3 + (aq.)\ 3KOH \xrightarrow[-H_2O]{-3kcl} H-\underset{\underset{O}{\|}}{C}-O-H \xrightarrow[-H_2O]{+KOH} HCOOK$$

3. Reduction

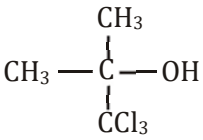
$$Zn + 2HCl \rightarrow ZnCl_2 + 2[H]$$
$$\underset{\text{Dichloromethane}}{CHCl_3 + 2[H] \rightarrow CH_2Cl_2} + HCl$$

(Methylene chloride)

$$CHCl_3 \xrightarrow{Zn + H_2O} CH_4 + 3HCl$$

4. Reaction with acetone

$$(CH_3)_2C = O + CHCl_3 \xrightarrow{KOH}$$



Chlroetone

Use: Chlroetone is used as hypnotic (a sleep inducing) drug.

5. Reaction with nitric acid

$$2CHCl_3 + HONO_2 \rightarrow CCl_3.NO_2 + H_2O$$

(chloropicrin)

Use: Chloropicrin is used as an insecticide and war gas.

6. Reaction with silver powder

$$2CHCl_3 + 6\,Ag \xrightarrow{Heat} CH \equiv CH + 6\,AgCl$$

(Acetylene)

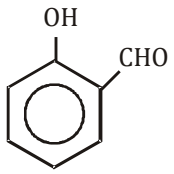
7. Chlorination

$$CHCl_3 + Cl_2 \xrightarrow{h\nu} CCl_4 + HCl$$

8. Reimer-Tiemann reaction

Phenol

$$+ CHCl_3 + 3NaOH \xrightarrow{333 - 343\ K}$$



Salicylaldehyde
(2-Hydroxybenzeldehyde)

$$+ \; 2NaCl + 2H_2O$$

Uses of Chloroform

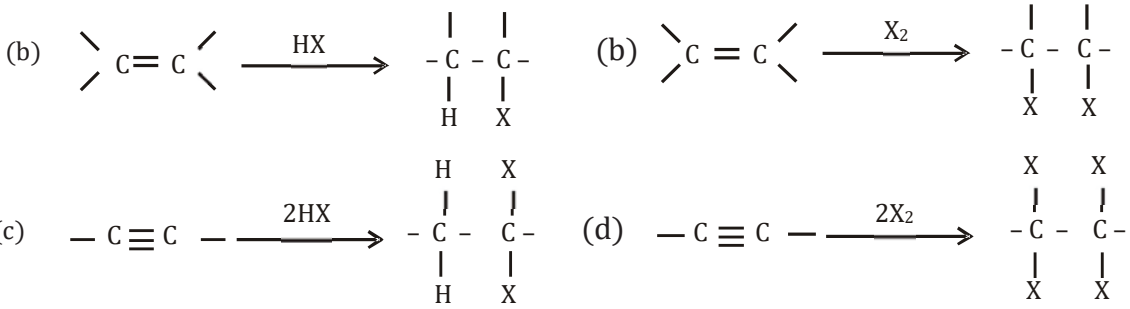
1. As solvent in oils and varnishes
2. As preservative for anatomical specimens
3. As laboratory reagent
4. As an anaesthetic

Preparation of Alkyl Halide

From alkane

$$R - H \xrightarrow[h\nu]{X_2} R - X + HX$$

From alkenes and alkynes (Detail in alkene and alkyne)



Formation of Alcohols & Preparation of Amines

From alcohol (Detail in the alcohol)

$$R-OH \xrightarrow{HX, PX_3, PX_5, SOX_2} R-X$$

From other halides

$$R-X + I^- \xrightarrow{\text{acetone}} R-I + X^-$$

$$R-Cl + KF \xrightarrow{18-\text{crown}} R-F$$

Finkelstein Reaction

1. $CH_3-CH_2-Cl \xrightarrow[\text{acetone}]{NaI} CH_3-CH_2-I$

   Nucleophility – in Polar Protic solvent $-F^{\ominus} < Cl^{\ominus} < Br^{\ominus} < I^{\ominus}$

   Polar Aprotic solvent – $F^{\ominus} > Cl^{\ominus} > Br^{\ominus} > I^{\ominus}$

   Covalent Nature:

   $$NaF < NaCl < NaBr < NaI$$

   Solubility in polar solvent ↓

   Acetone → Solubility in acetone is soluble

   $$NaF < NaCl < NaBr < NaI$$

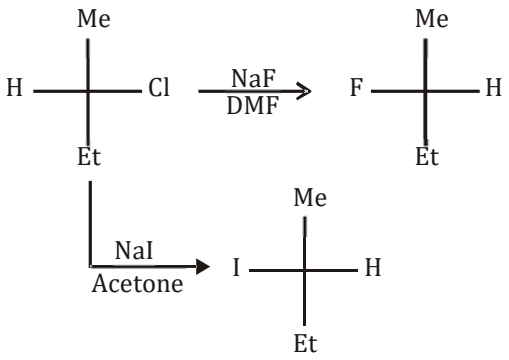
2. $C-C-Br \xrightarrow[\text{Acetone}]{NaBr} C-C-Br$

3. $C-C-Cl \xrightarrow[\text{Acetone}]{NaCl} C-C-Cl$

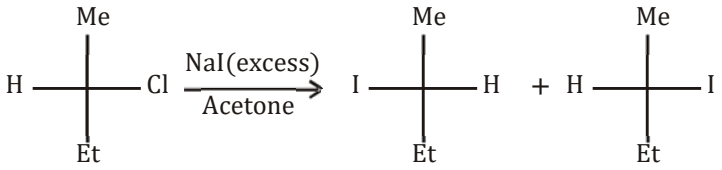
4. $C-C-Cl \xrightarrow[\text{Acetone}]{NaF} C-C-F$

5. $C-C-Cl$ or $\xrightarrow[DMF\ DMSO]{KF} C-C-F$ (swart reaction)

6.



7.

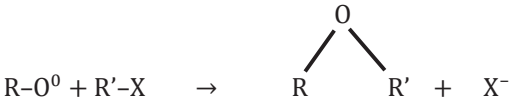


(racemisation)

Williamson's synthesis (preparation of ethers)

Williamson's synthesis, also referred to as the Williamson ether synthesis, is a chemical process utilized for the production of ethers. This method entails the interaction between an alkyl halide and a deprotonated alcohol, known as an alkoxide ion, resulting in the formation of an ether. The alkyl halide utilized in this synthesis can be an alkyl bromide, alkyl chloride, or alkyl iodide, while the alcohol counterpart can be either a primary or secondary alcohol.

The fundamental mechanism of this reaction involves:



Usually, this reaction occurs in the presence of a potent base like sodium or potassium hydroxide. These bases deprotonate the alcohol, leading to the formation of the alkoxide ion. Subsequently, the alkoxide ion serves as a nucleophile, attacking the electrophilic carbon atom in the alkyl halide. This process yields the desired ether product.

Named after its developer, Alexander William Williamson, the Williamson Ether Synthesis involves the use of deprotonated alcohol and an organohalide to produce an ether.

Alkyl Ethers

Ethers, commonly known as alkyl ethers, consist of one oxygen atom bonded with two alkyl groups. These alkyl groups can be identical or different, and they are connected to the oxygen atom through single bonds.

One of the primary applications of alkyl ethers in organic synthesis is in the formation of Grignard reagents and subsequent Grignard reactions. These reactions involve the addition of carbon-carbon bonds to the carbonyl group ($> C = O$) of aldehydes or ketones. Alkyl ethers' aprotic nature renders them excellent solvents for facilitating Grignard reactions.

Preparation of Ether Polymers

An ether is characterized by the presence of two alkyl groups bonded to an oxygen atom. Ethers find utility in various applications such as the production of soap, perfume, wax, and more. One specific type of ether surfactant, known as sodium laureth sulfate ($CH_3(CH_2)_{10}CH_2(OCH_2CH_2)_nOSO_3Na$), is commonly employed in soap formulations.

The manufacturing process of ether soap, exemplified by sodium laureth sulfate, involves several steps. It begins with the ethoxylation of dodecyl alcohol, followed by the conversion of the resultant product into a half ester of sulfuric acid. Finally, this compound is neutralized to produce the sodium salt form.

Uses of Ether

The synthesis of ethers, both in laboratory settings and industrially, predominantly relies on the Williamson ether synthesis method. This versatile approach allows for the preparation of both symmetrical and asymmetrical ethers.

In this process, the choice of reactants is determined based on factors such as reactivity and availability. Typically, two alcohols are employed in the Williamson reaction to produce ethers. One of the alcohols is converted into a suitable leaving group, often a Tosylate.

The alkylating agent is typically chosen to be primary, while the alkoxide can be primary, secondary, or tertiary. Alternatively, if not using a halide, a sulfonate ester is often created specifically for the purpose of the reaction to serve as the leaving group.

Preparation of Cyanides & Isocyanides

Preparation of cyanides and isocyanides involves different chemical methods depending on the desired product. Here are the typical methods used for their preparation:

Preparation of Cyanides

From Metal Cyanides

Cyanides can be prepared by reacting metal cyanides (such as potassium cyanide) with suitable metal halides or metal oxides.

For example: $KCN + AgCl \rightarrow AgCN + KCl$

From Alkyl Halides

Alkyl cyanides can be synthesized via nucleophilic substitution reactions of alkyl halides with cyanide ions (CN^-) using a strong base, such as potassium cyanide (KCN) or sodium cyanide (NaCN).

For instance: $CH_3CH_2Br+KCN\rightarrow CH_3CH_2CN+KBr$

From Nitriles

Cyanides can also be prepared by hydrolyzing nitriles, which are organic compounds containing the cyano functional group (-CN). Acidic or basic hydrolysis of nitriles leads to the formation of cyanides.

For example: $RCN+H_2O+HCl\rightarrow RCOOH+NH_4Cl$

$RCN+H_2O+NaOH\rightarrow RCOOH+NH_3$

Preparation of Isocyanides

From Primary Amines

Isocyanides, also known as isonitriles, can be prepared by reacting primary amines with chloroform in the presence of a strong base like potassium hydroxide (KOH). This reaction is known as the Carbylamine reaction.

For example: $CH_3NH_2 + CHCl_3 + KOH \rightarrow CH_3NC + KCl + H_2O$

Cyanide and isocyanide chemistry

Alkyl cyanides exhibit solubility in water, unlike alkyl isocyanides, due to their tendency to form hydrogen bonds with water molecules. However, as the molecular weight of alkyl cyanides increases,

their solubility in water decreases. Conversely, alkyl isocyanides (RNC) have lower water solubility because they lack a pair of electrons for hydrogen bonding. Additionally, the boiling temperatures of alkyl isocyanides are lower than those of their isomeric cyanides, which are toxic.

Applications of cyanides and isocyanides

During the Franco-Prussian War, cyanide was employed as a chemical warfare agent, highlighting its extreme toxicity to living organisms. Isocyanides find applications in various industries including painting, shipbuilding, fire-fighting, electrical wire protection, cement production, rubber manufacturing, and filament production.

In organic synthesis, isocyanides are favored due to their remarkable regioselectivity, chemo selectivity, stereoselectivity, and tolerance towards different functional groups. Cyanides are also utilized in organic processes as intermediates; for instance, when alkyl halides are converted to alkyl cyanides, a carbon atom is added to the chain. Acetonitrile (CH^3CN) and methyl carbylamine (CH^3NC) are examples of cyanides and isocyanides, respectively, illustrating their structural similarity despite being different functional groups.

Preparation of Ester

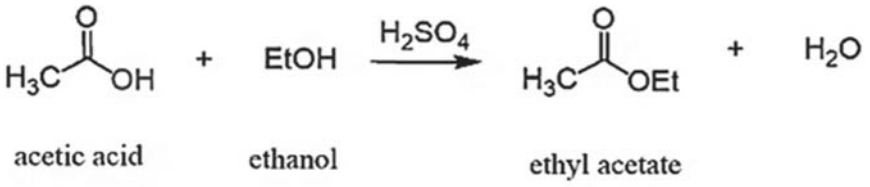
The synthesis of esters, also known as esterification, involves the reaction between an alcohol and a carboxylic acid. This process typically requires the presence of an acid catalyst, such as sulfuric acid or hydrochloric acid, to facilitate the reaction. The general equation for the esterification reaction is as follows:

Alcohol + Carboxylic Acid ⇌ Ester + Water

During the reaction, the hydroxyl (-OH) group of the carboxylic acid and the hydrogen atom of the alcohol's hydroxyl group (-OH) are eliminated, resulting in the formation of water. The remaining portions of the alcohol and carboxylic acid molecules combine to form the ester.

For example, the reaction between acetic acid and ethanol (commonly known as ethyl alcohol) yields ethyl acetate, a fruity-smelling ester commonly used in flavorings and fragrances:

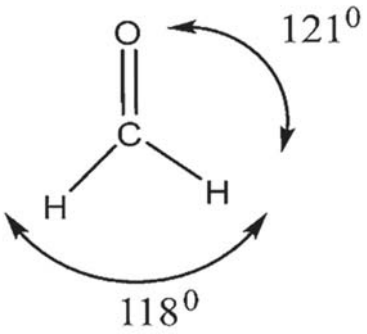
Acetic Acid + Ethanol → Ethyl Acetate + Water



This reaction is reversible, meaning that under certain conditions, esters can be hydrolyzed back into their original carboxylic acid and alcohol components.

Structure of Ester

The structure of esters is characterized by the presence of a carbonyl center, leading to bond angles of approximately 120° for the carbon-carbon-oxygen (C-C-O) and oxygen-carbon-oxygen (O-C-O) bonds. This structural arrangement allows for flexibility in the functional group due to the relatively low barrier to rotation around the carbon-oxygen-carbon (C-O-C) bonds. As a result of their flexibility and low polarity, esters exhibit distinct physical properties. They tend to be less rigid, with lower melting points, and more volatile, with lower boiling points, compared to their amide counterparts.



Structure of Ester

Physical Properties of Esters

Esters exhibit moderate polarity, falling between ethers and alcohols in terms of polarity strength. They are capable of participating in hydrogen bonding as acceptors, but unlike alcohols, they do not serve as hydrogen bond donors. This inability to donate hydrogen bonds means that esters do not self-associate. Consequently, they tend to be more volatile than carboxylic acids of similar relative molecular mass. Gas chromatography is commonly used to detect esters due to their volatility. In the IR spectra of esters, a distinct and intense sharp band is observed within the range of 1730 – 1750 cm^{-1}, which corresponds to the carbonyl stretch ($\nu C=O$). The precise position of this peak can vary depending on the specific functional groups attached to the carbonyl moiety.

Applications of Esters

- Esters with pleasant aromatic odors are commonly employed in the production of perfumes, essential oils, food flavorings, and cosmetics.
- They serve as organic solvents due to their ability to dissolve various organic compounds.
- Natural esters play a role in pheromones, which are chemical substances used for communication between organisms.
- Fats and oils found in nature are examples of esters, specifically fatty acid esters of glycerol.
- Nitrate esters like nitroglycerin are utilized as explosive materials.
- Polyesters can be processed into fibers for the manufacturing of textiles and clothing items.
- Esters are used in the production of surfactants, including soaps and detergents, which aid in the removal of dirt and grease.

Optical Activity

Optical activity, discovered by French physicist François Arago in 1811, refers to the phenomenon where certain substances rotate the plane of polarized light as it passes through them. This effect is particularly observed in crystals like quartz. When polarized light interacts with these substances, the plane of polarization of the emerging light is altered. This rotation of the plane of polarization is termed optical rotation or optical activity.

Optically Active Substances

Substances that exhibit optical activity are referred to as optically active substances. To measure optical activity, a polarimeter is commonly used. Polarimetry involves determining the rotation of plane-polarized light by an optically active substance. The setup of a polarimeter typically includes a light source, polarizer (such as a Nicol prism), and an analyzer.

Mechanism of Optical Activity

In a polarimeter, unpolarized light from a source is converted into plane-polarized light using a polarizer. This polarized light is then passed through the sample in a polarimeter tube. If the sample is optically active, the plane of polarization of the light gets rotated. This rotation is detected using an analyzer.

Types of Optically Active Substances

Dextrorotatory Substances

Dextrorotatory substances, also referred to as right-handed substances, are those optically active substances that rotate the plane of polarization of light towards the right or in a clockwise direction. When a substance causes the plane-polarized light to rotate to the right, it is termed as dextrorotatory.

Levorotatory Substances

Levorotatory substances, also known as left-handed substances, are the type of substances that rotate the plane of polarization of light towards the left or in a counterclockwise direction. When a substance causes the plane-polarized light to rotate to the left, it is termed as levorotatory.

Applications of Optical Activity

Optical rotation has various practical applications:

- Determination of the concentration of optically active substances in a solution.
- Measurement of sugar levels in urine for diagnosing conditions like diabetes.
- Monitoring of kinetic reactions over time.
- Analysis of molecular structure using optical rotatory dispersion curves.
- Evaluation of pharmaceutical products based on optical activity.

In summary, optical activity plays a significant role in chemical analysis, pharmaceuticals, and various scientific studies, providing valuable insights into the properties and behavior of optically active substances

R-S Configuration and Nomenclature

In an active molecule, there invariably exists a chiral center or chiral carbon. This chiral carbon is characterized by having four distinct groups attached to it. These groups are entirely different from one another.

The R and S configuration system plays a pivotal role in discerning enantiomers. Utilizing the R and S nomenclature, we allocate a numerical designation, following the CIP (Cahn-Ingold-Prelog) prioritizing rules, to each group or atom attached to the chiral carbon.

The CIP rules, derived from Cahn-Ingold-Prelog prioritization, dictate that substituents in the molecule are prioritized based on their atomic numbers. The substituent with the highest atomic number is assigned as 1, followed by 2, then 3, and finally 4.

This method is crucial in precisely defining the absolute configuration of chiral molecules.

Here's a breakdown of how it operates:

1. Assign Priorities

Determine the priority of the substituents attached to the chiral center based on the atomic number of the atoms directly bonded to the chiral center. The higher the atomic number, the higher the priority. If there's a tie, move outward from the chiral center until the tie is broken.

2. Orient the Molecule

Orient the molecule so that the lowest priority group (usually denoted as "4") is pointing away from you (into the page or away from your perspective).

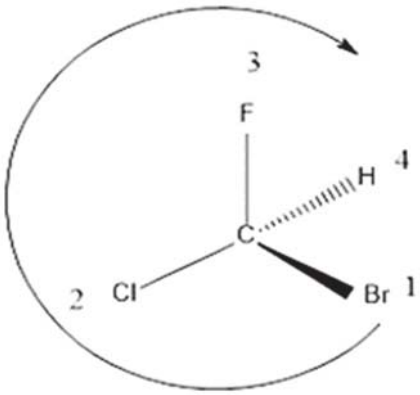
3. Follow the Sequence Rule

Trace a path from the highest priority (group "1") to the next highest priority (group "2") to the lowest priority (group "3"). If you need to go from "1" to "2" to "3" in a clockwise direction, it's designated as the "R" configuration. If the sequence is counterclockwise, it's designated as the "S" configuration.

- "R" stands for rectus, which is Latin for "right."
- "S" stands for sinister, which is Latin for "left."

This system provides a standardized way to describe the spatial arrangement of atoms or groups around a chiral center, irrespective of how the molecule is drawn.

For Example:



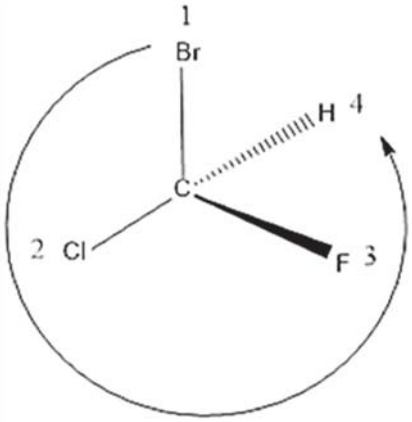
In this molecular structure, bromine (Br) possesses the highest atomic number among the substituents, and consequently, it is designated as the first priority group. Following Br, the subsequent priorities are assigned to chlorine (Cl), fluorine (F), and hydrogen (H).

Hydrogen is identified as the lowest priority group (LGP), denoted as such due to its lowest atomic number. The bond between hydrogen and the chiral carbon atom is depicted using dashed lines, indicating that this bond extends away from the observer. It is imperative that the LGP remains positioned away from the observer for consistent interpretation.

Having assigned priority groups, the next step involves tracing the directional arrangement of substituents from the highest priority group to the lowest. In adhering to this directionality within the structure, it becomes evident that the substituents align in a clockwise fashion.

Consequently, based on the clockwise arrangement of substituents, the molecule is identified as possessing an R configuration.

Consider now a hypothetical scenario where the structure exhibits an S configuration. In this instance, the arrangement of substituents would necessitate a counterclockwise orientation.



In this representation, we observe the same molecule, yet the spatial arrangement of its substituents differs. Following the assignment of priority groups, tracing the direction from the highest priority

group (HPG) to the lowest priority group (LGP) reveals a counterclockwise orientation, indicating an S configuration.

This system allows chemists to communicate the 3D structure of molecules accurately, which is essential for understanding their properties and behavior.

In terms of nomenclature, the R and S designations are used in the IUPAC (International Union of Pure and Applied Chemistry) naming system to specify the stereochemistry of chiral centers in organic molecules.