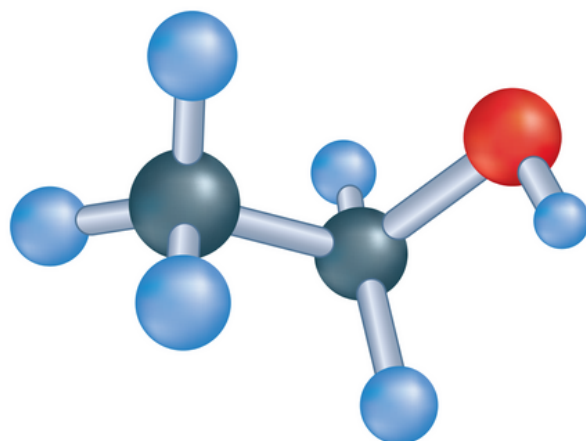


CHAPTER 8

SUBSTITUTED HYDROCARBONS



CHAPTER SUMMARY

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SECTION 1:

ALKYL HALIDES AND ARYL HALIDES

SECTION 2:

ALCOHOLS, ETHERS, AND AMINES

SECTION 3:

CARBONYL COMPOUNDS

SECTION 4:

OTHER REACTIONS OF ORGANIC COMPOUNDS



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8.1 – Alkyl Halides and Aryl Halides

Functional Groups

In **hydrocarbons**, carbon atoms are linked only to other carbon atoms or hydrogen atoms. Carbon can also form covalent bonds with other elements close to it on the periodic table. These elements include nitrogen (N), oxygen (O), phosphorus (P), sulfur (S), and halogens (F, Cl, Br, and I).

A **functional group** is an atom or a group of atoms that give an organic molecule its chemical properties. In most organic compounds, the functional groups are the **most reactive** part of the molecule. These functional groups determine how a compound will react during a chemical reaction.

Table 1 Organic Compounds and Their Functional Groups		
Compound Type	General Formula	Functional Group
Halocarbon	$R-X$ (X = F, Cl, Br, I)	Halogen
Alcohol	$R-OH$	Hydroxyl
Ether	$R-O-R'$	Ether
Amine	$R-NH_2$	Amino
Aldehyde	$\begin{array}{c} O \\ \\ * - C - H \end{array}$	Carbonyl
Ketone	$\begin{array}{c} O \\ \\ R - C - R' \end{array}$	Carbonyl
Carboxylic acid	$\begin{array}{c} O \\ \\ * - C - OH \end{array}$	Carboxyl
Ester	$\begin{array}{c} O \\ \\ * - C - O - R \end{array}$	Ester
Amide	$\begin{array}{c} O & H \\ & \\ * - C - N - R \end{array}$	Amide

The symbols (**R**) and (**R'**) represent carbon chains or rings bonded to the functional group. An(*) represents a hydrogen atom, carbon chain, or carbon ring.

By learning the properties associated with a given functional group, you can predict the properties of organic compounds for which you know the structure, even if you have never studied them.

Keep in mind that **double** and **triple** bonds between two carbon atoms affect the chemical properties of an organic compound and are considered **functional groups** even though only carbon and hydrogen atoms are involved.

8.1 – Alkyl Halides and Aryl Halides

Organic Compounds Containing Halogens

A **substituted hydrocarbon** is an organic compound that forms when a functional group replaces one or more hydrogen atoms in a hydrocarbon.

The most simple functional groups can be thought of as **substituent groups** attached to a hydrocarbon. Recall that a substituent group is a side branch attached to a parent chain. The elements in **group 17** of the periodic table—fluorine, chlorine, bromine, and iodine—are the **halogens**.

Halocarbon – is any organic compound that contains a halogen substituent.

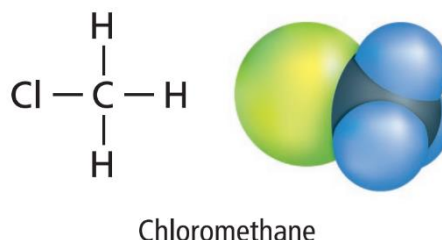
We can represent halocarbons with the general formula: **RX**

- **R** represents a hydrocarbon chain or a hydrocarbon ring.
- **X** represents the halogen functional group.

Alkyl halide – is an organic compound containing a halogen atom covalently bonded to an aliphatic carbon atom.

If you replace any of the hydrogen atoms in an alkane with a halogen atom, you form an **alkyl halide**.

Chloromethane is an alkyl halide that is used in the manufacturing process for silicone products, such as window and door sealants.



Alkyl halides are widely used as **refrigerants**. **Hydrofluorocarbons (HFCs)** replaced **chlorofluorocarbons (CFCs)** as coolant after scientists discovered that CFCs had a negative effect on our **ozone layer**. (HFCs) contain only hydrogen and fluorine atoms bonded to carbon. One of the more common **HFCs** is **1,1,2-trifluoroethane**, also called **R134a**.

Aryl halide – an organic compound containing a halogen atom bonded to a benzene ring or other **aromatic group**. The structural formula for an aryl halide is created by first drawing the aromatic structure and then replacing its hydrogen atoms with the halogen atoms specified.

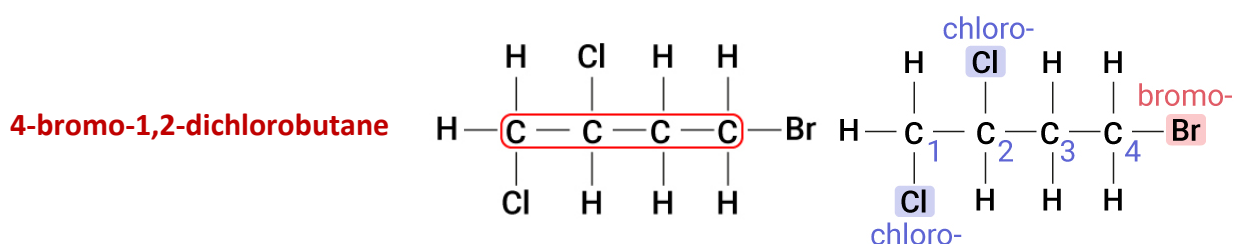
Naming Halocarbons

We can consider a **functional group** as a **substituent group** attached to a hydrocarbon. We follow the **IUPAC** rules based on the parent alkane chain present to name halocarbons.

8.1 – Alkyl Halides and Aryl Halides

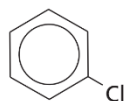
- **Step 1:** Identify and name the parent chain.
- **Step 2:** Identify and list the substituents in alphabetical order.
- **Step 3:** Use number prefixes to indicate the number of times a halogen appears.
- **Step 4:** Number the carbon atoms in the parent chain.
- **Step 5:** Write the alkyl halide's full name.

We use prefixes to identify the halogens bonded to the parent chain. To name the substituents, change the *-ine* in the halogen name to *-o*. The prefix for fluorine is **fluoro-**, chlorine is **chloro-**, bromine is **bromo-**, and iodine is **iodo-**.



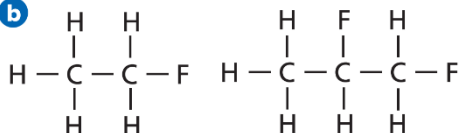
Similarly, the benzene ring in an aryl halide is numbered to give each substituent the **lowest position** number possible.

a



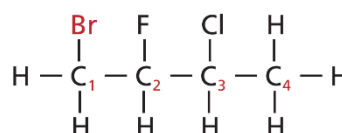
Chlorobenzene

b



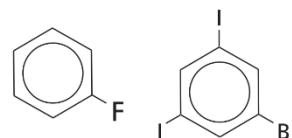
Fluoroethane and 1,2-Difluoropropane

c



1-Bromo-3-chloro-2-fluorobutane

d



Fluorobenzene and 1-Bromo-3,5-diiodobenzene

Table 2 A Comparison of Alkyl Halides and Their Parent Alkanes

Structure	Name	Boiling Point (°C)	Density (g/mL) in Liquid State
CH ₄	methane	−162	0.423 at −162°C (boiling point)
CH ₃ Cl	chloromethane	−24	0.911 at 25°C (under pressure)
CH ₃ CH ₂ CH ₂ CH ₂ CH ₃	pentane	36	0.626
CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ F	1-fluoropentane	62.8	0.791
CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ Cl	1-chloropentane	108 <i>Increases</i>	0.882 <i>Increases</i>
CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ Br	1-bromopentane	130	1.218
CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ I	1-iodopentane	155	1.516

Properties and Uses of Halocarbons

Note that each alkyl chloride has a **higher boiling point** and a **higher density** than the alkane with the same number of carbon atoms.

Note also that the boiling points and densities **increase** as the halogen changes from fluorine to chlorine, bromine, and iodine.

8.1 – Alkyl Halides and Aryl Halides

This trend occurs primarily because the halogens from fluorine to iodine have **increasing** numbers of **electrons** that lie farther from the halogen nucleus. These electrons shift position easily and, as a result, the halogen-substituted hydrocarbons have an **increasing tendency** to form **temporary dipoles**.

Because the dipoles attract each other, the energy needed to separate the molecules also increases. Thus, the boiling points of halogen-substituted alkanes **increase** as the size of the halogen atom increases.

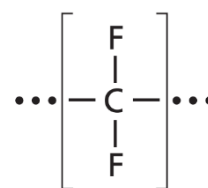
Uses of Halocarbons

Although halocarbons are primarily man-made, there are a few natural sources. Organic iodides found in humans are essential for healthy **thyroid** function.

Halogen atoms bonded to carbon atoms are more reactive than the hydrogen atoms they replace. For this reason, alkyl halides are often used as **starting materials** in the chemical industry.

Alkyl halides are also used as **solvents** and **cleaning** agents because they readily dissolve nonpolar molecules, such as **greases**.

Polytetrafluoroethene (PTFE) is a plastic made from gaseous tetrafluoroethylene. It is made up of hundreds of units. PTFE provides a **nonstick surface** for many kitchen items, including bakeware.



PTFE

A **plastic** is a polymer that can be heated and molded while relatively soft. Another plastic commonly called **vinyl** is **polyvinyl chloride (PVC)**. It can be manufactured soft or hard, as thin sheets, or molded into objects.

Substitution Reactions

Table 3 Substitution Reactions	
Generic Substitution Reaction $R-CH_3 + X_2 \rightarrow R-CH_2X + HX$ where X is fluorine, chlorine, or bromine	Example of General Substitution Reaction (Halogenation) $C_2H_6 + Cl_2 \rightarrow C_2H_5Cl + HCl$ Ethane Chloroethane
General Alkyl Halide-Alcohol Reaction $R-X + OH^- \rightarrow R-OH + X^-$ Alkyl halide Alcohol	Example of an Alkyl Halide-Alcohol Reaction $CH_3CH_2Cl + OH^- \rightarrow CH_3CH_2OH + Cl^-$ Chloroethane Ethanol
General Alkyl Halide-Ammonia Reaction $R-X + NH_3 \rightarrow R-NH_2 + HX$ Alkyl halide Amine	Example of an Alkyl Halide-Ammonia Reaction $CH_3(CH_2)_6CH_2Br + NH_3 \rightarrow CH_3(CH_2)_6CH_2NH_2 + HBr$ 1-Bromooctane 1-Octanamine

8.1 – Alkyl Halides and Aryl Halides

Many halocarbons are manufactured through **substitution reactions**. The substituted halocarbons can then undergo further reactions.

The ultimate source of nearly all synthetic organic compounds is **petroleum**. Petroleum is a fossil fuel that consists almost entirely of hydrocarbons, especially alkanes.

A **substitution reaction** is one in which one atom or a group of atoms in a molecule is replaced by another atom or group of atoms. With alkanes, hydrogen atoms can be replaced by atoms of halogens, typically **chlorine** or **bromine**, in a process called **halogenation**.

(2-bromo-2-chloro-1,1,1-trifluoroethane) is a halogenated hydrocarbon commonly called **halothane**. It was first used as a general **anesthetic** (مخدر) in the 1950s.

Equations for organic reactions are sometimes shown in **generic form**. **Table 3** shows the generic form of a substitution reaction. In this reaction, **X** can be **fluorine**, **chlorine**, or **bromine**, but not iodine. Iodine does not react well with alkanes.

Chemists convert naturally occurring alkanes to halocarbons by substituting halogens for the hydrogen atoms in the alkanes. **Halogenation** is the process where a halogen atom substitutes a hydrogen atom in an alkane. We can write a general reaction for halogenation as follows:

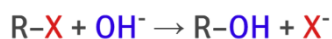


Further Substitution

Alkyl halides can undergo further substitution reactions. Other functional groups substitute the halogen atoms in the alkyl halides in these reactions.

General Alkyl Halide-Base Reaction

When reacting an alkyl halide with a basic solution, the hydroxyl group (-OH) substitutes for the halogen atom in the alkyl halide (R-X) forming an alcohol (R-OH).

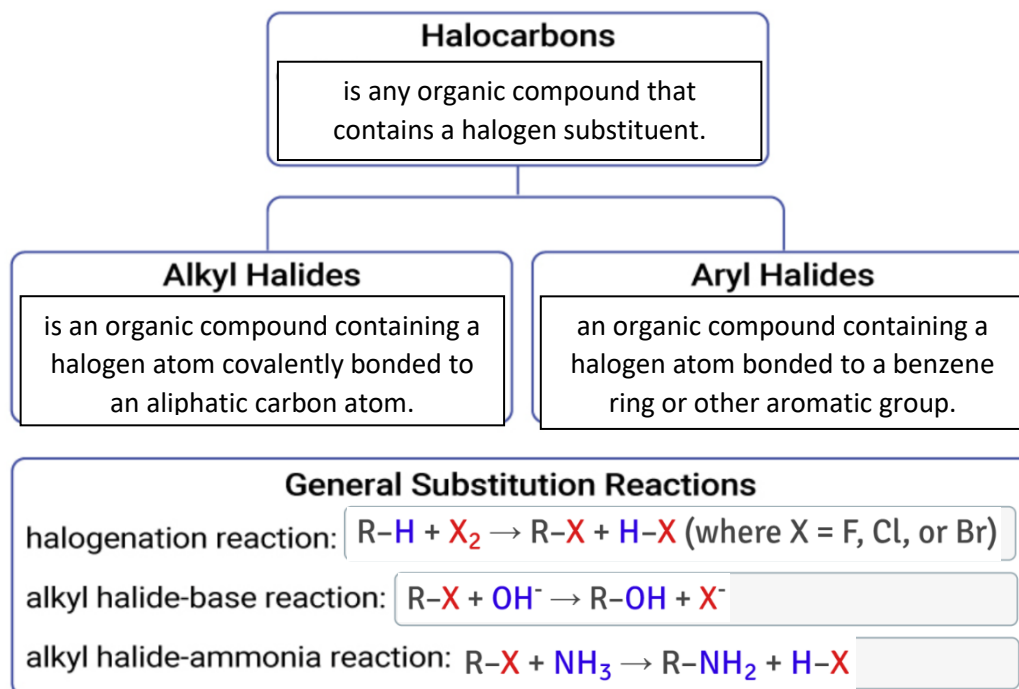


General Alkyl Halide-Ammonia Reaction

When reacting an alkyl halide with ammonia (NH_3), the amino group (-NH_2) substitutes for the halogen atom in the alkyl halide (R-X) forming an alkyl amine (R-NH_2).



8.1 – Alkyl Halides and Aryl Halides



8.2 – Alcohols, Ethers, and Amines

Alcohols

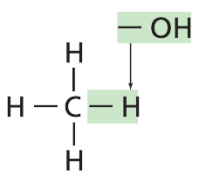
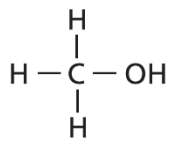
Oxygen atom has **six** valence electrons, it commonly forms **two** covalent bonds to gain a stable octet. An oxygen atom can form a double bond with a carbon atom, replacing two hydrogen atoms, or it can form one single bond with a carbon atom and another single bond with another atom, such as hydrogen.

Recall that substituted hydrocarbons form when a **functional group** replaces one or more hydrogen atoms in a hydrocarbon.

The functional groups in **alcohols**, **ethers**, and **esters** all have oxygen in common. These substituted hydrocarbons all contain the elements carbon (C), hydrogen (H), and oxygen (O).

Hydroxyl group (–OH) – is an oxygen-hydrogen group covalently bonded to a carbon atom.

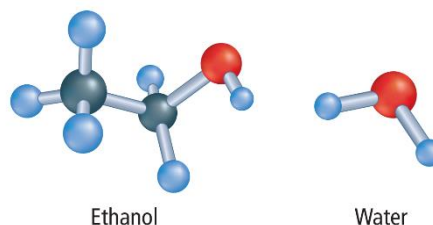
Alcohol – is a substituted hydrocarbon with a hydroxyl functional group (–OH).

Table 4 Alcohols	
General Formula	Simple Alcohol and Simple Hydrocarbon
ROH R represents carbon chains or rings bonded to the functional group	 Methane (CH₄) Alkane  Methanol (CH₃OH) Alcohol

The hydroxyl groups of alcohol molecules are moderately **polar**, as with water, and are able to form hydrogen bonds with the hydroxyl groups of other alcohol molecules. Due to this hydrogen bonding, alcohols have much **higher boiling points** than hydrocarbons of similar shape and size.

Ethanol and carbon dioxide are produced by yeasts when they ferment sugars, such as those in grapes and bread dough. Ethanol is

- a gasoline additive
- found in alcoholic beverages and medicinal products.
- used to swab skin before an injection is given as it is an effective antiseptic.
- an important starting material for the synthesis of more complex organic compounds.



8.2 – Alcohols, Ethers, and Amines

Because of polarity and hydrogen bonding, ethanol is completely **miscible** with water. Once they are mixed, it is difficult to separate water and ethanol completely.

Denatured alcohol is ethanol to which small amounts of noxious materials, such as aviation gasoline or other organic solvents, have been added. Ethanol is denatured in order to make it unfit to drink.

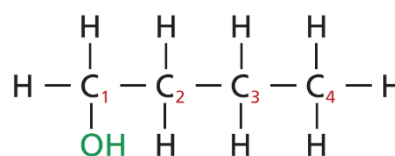
Because of their polar hydroxyl groups, alcohols make **good solvents** for other polar organic substances. For example, methanol, the smallest alcohol, is a common industrial solvent found in some **paint strippers** (مزيلات الطلاء), and 2-butanol is found in some stains (الأصباغ) and varnishes (الورنيش).

The names of alcohols are based on alkane names, like the names of alkyl halides.

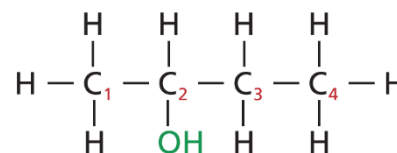
- CH_4 is methane and CH_3OH is methanol;
- CH_3CH_3 is ethane and $\text{CH}_3\text{CH}_2\text{OH}$ is ethanol.

When naming a simple alcohol based on an alkane carbon chain, the IUPAC rules call for naming the parent carbon chain or ring first and then changing the **-e** at the end of the name to **-ol** to indicate the presence of a hydroxyl group.

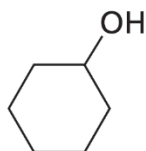
In alcohols of three or more carbon atoms, the hydroxyl group can be at two or more positions. To indicate the position, a number is added.



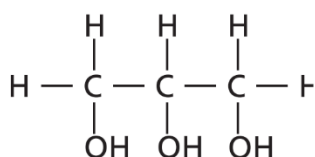
a. 1-Butanol



b. 2-Butanol



c. Cyclohexanol



d. 1,2,3-Propanetriol (glycerol)

This compound is called **cyclohexanol**. It is a poisonous compound used as a solvent for certain plastics and in the manufacture of insecticides (المبيدات الحشرية).

A carbon chain can also have more than one hydroxyl group. To name these compounds, **prefixes** such as **di-**, **tri-**, and **tetra-** are used before the **-ol** to indicate the number of hydroxyl groups present.

The full alkane name, including **-ane**, is used before the prefix.

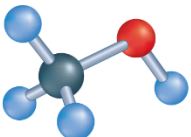
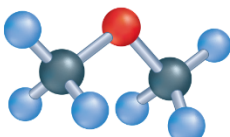
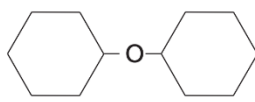
Glycerol is often used as an **antifreeze** and as an airplane **deicing fluid**.

8.2 – Alcohols, Ethers, and Amines

Ethers

Ethers are another group of organic compounds in which oxygen is bonded to carbon. An **ether** is an organic compound containing an oxygen atom bonded to two carbon atoms.

Ethers have the general formula **ROR'**. The simplest ether is one in which oxygen is bonded to two methyl groups.

Table 5 Ethers	
General Formula	Methanol and Methyl ether
ROR' where R and R' represent carbon chains or rings bonded to functional groups	 Methanol bp = 65°C  Methyl ether bp = -25°C
Examples of Ethers	
 Cyclohexyl ether	$CH_3CH_2CH_2 - O - CH_2CH_2CH_3$ Propyl ether
$CH_3CH_2 - O - CH_2CH_2CH_2CH_3$ Butyl ethyl ether	$CH_3CH_2 - O - CH_3$ Ethyl methyl ether

The term ether was first used in chemistry as a name for **ethyl ether**, the volatile, highly flammable substance that was commonly used as an **anesthetic** (مخدر) in surgery from 1842 until the twentieth century.

Because ethers have **no hydrogen** atoms bonded to the oxygen atom, their molecules cannot form hydrogen bonds with each other. Therefore, ethers are generally **more volatile** and have much **lower boiling points** than alcohols of similar size and mass.

Ethers are much **less soluble** in water than alcohols because they have no hydrogen to donate to a hydrogen bond. However, the oxygen atom can act as a hydrogen bond **receptor** for the hydrogen atoms of water molecules.

When naming ethers that have **two identical** alkyl chains bonded to oxygen, first name the alkyl group and then add the word **ether**.

If the two alkyl groups are **different**, the groups are listed in **alphabetical order** and then followed by the word **ether**. Look at Table 5 again.

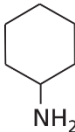
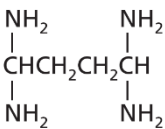
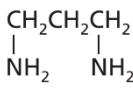
8.2 – Alcohols, Ethers, and Amines

Amines

Amines contain nitrogen atoms bonded to carbon atoms in aliphatic chains or aromatic rings and have the general formula RNH_2 , as shown in Table 6.

Chemists consider amines to be derivatives of ammonia (NH_3). Amines are considered **primary**, **secondary**, or **tertiary** amines depending on whether one, two, or three of the hydrogens in ammonia have been replaced by organic groups.

When naming amines, the $-\text{NH}_2$ (amino) group is indicated by the suffix **-amine**. When necessary, the position of the amino group is designated by a number, as shown in the examples in Table 6.

Table 6 Amines		
General Formula		
RNH_2		
where R represents a carbon chain or ring bonded to the functional group		
Examples of Amines		
 Cyclohexylamine	 Ethylamine	 Aniline
 1,1,4,4-Butanetetraamine	 1,3-Propanediamine	

When only one amino group is present, the final **-e** of the root hydrocarbon is dropped, as in **1-butanamine**. If more than one amino group is present, the prefixes **di-**, **tri-**, **tetra-**, and so on are used to indicate the number of groups.

The amine **aniline** is used in the production of dyes with deep shades of color. The common name **aniline** is derived from the plant from which it was historically obtained.

Cyclohexylamine and **ethylamine** are important in the manufacture of pesticides (المبيدات الحشرية), plastics, pharmaceuticals, and rubber that is used to make tires.

All volatile amines have **odors** that humans find **offensive**, and amines are responsible for many of the odors characteristic of **dead, decaying organisms**. Two amines found in decaying human remains are **putrescine** and **cadaverine**.

Specially trained animals are used to locate human remains using these distinctive odors. Sniffer dogs are often used after catastrophic events and in forensic investigations.

8.3 – Carbonyl Compounds

Organic Compounds Containing the Carbonyl Group

Carbonyl compounds contain a **double-bonded** oxygen in the functional group. A **carbonyl group** is the arrangement in which an oxygen atom is double-bonded to a carbon atom.

This group is the functional group in organic compounds known as **aldehydes** and **ketones**.

Aldehydes

An **aldehyde** is an organic compound in which a carbonyl group located at the **end** of a carbon chain is bonded to a **carbon** atom on one side and a **hydrogen** atom on the other.

Aldehydes have the general formula ***CHO**, where ***** represents an **alkyl group** or a hydrogen atom, as shown in Table 7. Aldehydes are formally named by changing the final **-e** of the name of the alkane with the same number of carbon atoms to the suffix **-al**.

Table 7 Aldehydes	
General Formula	Examples of Aldehydes
$*CHO$ *represents an alkyl group or a hydrogen atom	$\begin{array}{c} \text{O} \\ \parallel \\ \text{H}-\text{C}-\text{H} \end{array}$ Methanal (formaldehyde) $\begin{array}{c} \text{H} \quad \text{O} \\ \quad \parallel \\ \text{H}-\text{C}-\text{C}-\text{H} \\ \\ \text{H} \end{array}$ Ethanal (acetaldehyde)
$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}- \end{array}$ Carbonyl group	$\begin{array}{c} \text{H} \\ \\ \text{C}_6\text{H}_5-\text{C}=\text{O} \end{array}$ Benzaldehyde $\begin{array}{c} \text{H} \\ \\ \text{C}_6\text{H}_4-\text{C}=\text{O} \\ \\ \text{OH} \end{array}$ Salicylaldehyde $\begin{array}{c} \text{H} \quad \text{H} \quad \text{O} \\ \quad \quad \parallel \\ \text{C}_6\text{H}_5-\text{C}=\text{C}-\text{C}-\text{H} \end{array}$ Cinnamaldehyde

Because the carbonyl group in an aldehyde **always** occurs **at the end** of a carbon chain, no numbers are used in the name unless branches or additional functional groups are present.

- **Methanal** is also commonly called **formaldehyde**.
- **Ethanal** has the common name **acetaldehyde**.

Scientists often use the common names of organic compounds because they are familiar to chemists.

An aldehyde molecule contains a **polar, reactive** structure. However, like ethers, aldehyde molecules cannot form hydrogen bonds among themselves because the molecules have no hydrogen atoms bonded to an oxygen atom.

Therefore, aldehydes have **lower boiling points** than alcohols with the same number of carbon atoms.

8.3 – Carbonyl Compounds

Water molecules can form hydrogen bonds with the oxygen atom of aldehydes, so aldehydes are **more soluble in water than alkanes** but not as soluble as alcohols or amines.

Formaldehyde has been used for **preservation** for many years. Industrially, large quantities of formaldehyde are reacted with urea to manufacture a type of **grease-resistant, hard plastic** used to make buttons, appliance and automotive parts, and electrical outlets, as well as the glue that holds the layers of plywood together.

Benzaldehyde and salicylaldehyde, shown in **Table 7**, are two components that give **almonds** their natural flavor. The aroma and flavor of cinnamon, a spice that comes from the bark of a tropical tree, are produced largely by cinnamaldehyde.

Ketones

A **ketone** is an organic compound in which the carbon of the carbonyl group is bonded to two other carbon atoms. The carbon atoms on either side of the carbonyl group are bonded to other atoms.

The simplest ketone, commonly known as **acetone**, has only hydrogen atoms bonded to the side carbons, as shown in Table 8.

Table 8 Ketones	
General Formula	Examples of Ketones
$\begin{array}{c} \text{O} \\ \parallel \\ \text{R} - \text{C} - \text{R}' \end{array}$ where R and R' represent carbon chains or rings bonded to functional groups	$\begin{array}{c} \text{H} & \text{O} & \text{H} \\ & \parallel & \\ \text{H} - \text{C} - & \text{C} & - \text{C} - \text{H} \\ & & \\ \text{H} & & \text{H} \end{array}$ 2-Propanone (acetone) $\begin{array}{c} \text{H} & \text{O} & \text{H} & \text{H} \\ & \parallel & & \\ \text{H} - \text{C} - & \text{C} & - \text{C} & - \text{C} - \text{H} \\ & & & \\ \text{H} & & \text{H} & \text{H} \end{array}$ 2-Butanone (methyl ethyl ketone)

Ketones are formally named by changing the **-e** at the end of the alkane name to **-one**, and including a number before the name to indicate the position of the ketone group.

Ketones and **aldehydes** share many chemical and physical properties because their structures are similar. Ketones are **polar** molecules and are **less reactive** than aldehydes. For this reason, ketones are popular **solvents** for other moderately **polar** substances, including waxes, plastics, paints, lacquers, varnishes, and glues.

Like aldehydes, ketone molecules cannot form hydrogen bonds with each other but can form hydrogen bonds with water molecules. Therefore, ketones are somewhat **soluble** in water. **Acetone** is completely miscible with water.

8.3 – Carbonyl Compounds

Carboxylic Acids

A **carboxylic acid** is an organic compound that has a carboxyl group. A **carboxyl group** consists of a carbonyl group bonded to a hydroxyl group.

Table 9 Carboxylic Acids

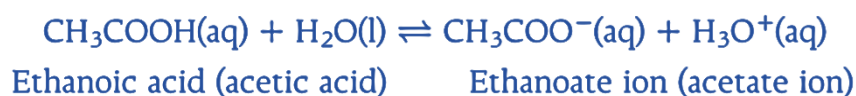
General Formula	Examples of Carboxylic Acids
$\begin{array}{c} \text{O} \\ \parallel \\ * - \text{C} - \text{OH} \end{array}$ where * represents a hydrogen atom, carbon chain or ring bonded to the functional group	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \parallel \\ \text{H} - \text{C} - \text{C} - \text{OH} \\ \\ \text{H} \end{array}$ Ethanoic acid (acetic acid) $\begin{array}{c} \text{O} \\ \parallel \\ \text{H} - \text{C} - \text{O} - \text{H} \end{array}$ Methanoic acid (formic acid)

Acetic acid the acid found in vinegar. Although many carboxylic acids have common names, the formal name is formed by changing the **-ane** of the parent alkane to **-anoic acid**. Thus, the formal name of acetic acid is **ethanoic acid**.

A carboxyl group is usually represented in condensed form by writing **–COOH**. For example, ethanoic acid can be written as **CH₃COOH**.

The simplest carboxylic acid consists of a carboxyl group bonded to a single hydrogen atom HCOOH. Its formal name is **methanoic acid**, but it is more commonly known as **formic acid**. Some insects produce formic acid as a **defense** mechanism.

Carboxylic acids are **polar** and **reactive**. Those that dissolve in water ionize weakly to produce hydronium ions, the anion of the acid in equilibrium with water, and the unionized acid. The ionization of ethanoic acid is an example.



Carboxylic acids can ionize in water solution because the two oxygen atoms are **highly electronegative** and attract electrons away from the hydrogen atom in the **–OH** group.

As a result, the hydrogen proton can transfer to another atom that has a pair of electrons not involved in bonding, such as the oxygen atom of a water molecule. Because they ionize in water, soluble carboxylic acids **turn blue litmus paper red** and have a **sour taste**.

Some important carboxylic acids, such as **oxalic acid** and **adipic acid**, have two or more carboxyl groups. An acid with two carboxyl groups is called a **dicarboxylic acid**.

8.3 – Carbonyl Compounds

Others have additional functional groups such as hydroxyl groups, as in the **lactic acid** found in yogurt. Typically, these acids are **more soluble** in water and often **more acidic** than acids with only a carboxyl group.

Organic Compounds Derived from Carboxylic Acids

Several classes of organic compounds have structures in which the hydrogen or the hydroxyl group of a carboxylic acid is replaced by a different atom or group of atoms. The two most common classes are **esters** and **amides**.

Esters

An **ester** is any organic compound with a carboxyl group in which the hydrogen of the hydroxyl group has been replaced by an alkyl group.

The name of an ester is formed by writing the name of the alkyl group followed by the name of the acid with the **-ic** acid ending replaced by **-ate**.

Table 10 Esters	
General Formula	Example of an Ester
$\begin{array}{c} \text{O} \\ \parallel \\ * - \text{C} - \text{O} - \text{R} \end{array}$ Ester group	$\begin{array}{c} \text{Ethanoate group} \qquad \text{Propyl group} \\ \text{CH}_3 - \overset{\text{O}}{\parallel} \text{C} - \text{O} - \text{CH}_2\text{CH}_2\text{CH}_3 \\ \text{Ester group} \\ \text{Propyl ethanoate} \\ \text{(propyl acetate)} \end{array}$

Note how the name propyl results from the structural formula. The name shown in parentheses is based on the name acetic acid, the **common name** for ethanoic acid.

Esters are **polar** molecules and many are **volatile** and **sweet-smelling**. Many kinds of esters are found in the natural **fragrances** (العطور) and flavors of flowers and fruits.

The aroma of strawberries is due in part to **methyl hexanoate**. **Ethyl butanoate** contributes to the aroma of pineapple. Most natural aromas and flavors are mixtures of esters, aldehydes, and alcohols.

some of these flavors can be **imitated** by a single ester structure. Consequently, esters are manufactured for use as **flavors** in many foods and beverages and as fragrances in candles, perfumes, and other scented items.

8.3 – Carbonyl Compounds

Amides

An **amide** is an organic compound in which the **–OH** group of a carboxylic acid is replaced by a **nitrogen** atom bonded to other atoms.

Amides are named by writing the name of the alkane with the same number of carbon atoms, and then replacing the final **-e** with **-amide**. Thus, the amide shown in Table 11 is called ethanamide, but it can also be named **acetamide** from its common name, acetic acid.

Table 11 Amides

General Formula	Examples of Amides
Amide group	Ethanamide (acetamide) Acetaminophen

The amide functional group is found repeated many times in natural proteins and some synthetic materials. For example, you might have used a **nonaspirin** pain reliever containing **acetaminophen**. In the acetaminophen structure, notice that the amide (**–NH–**) group connects a carbonyl group and an aromatic group.

One important amide is **caramide** (**NH₂CONH₂**), or **urea**, as it is commonly known. Urea is an end product in the metabolic breakdown of proteins in mammals. It is found in the blood, bile, milk, and perspiration (عرق) of mammals.

When proteins are broken down, amino groups (**NH₂**) are removed from the amino acids. The amino groups are then converted to ammonia (**NH₃**) molecules that are toxic to the body. The toxic ammonia is converted to nontoxic urea in the liver. The urea is filtered out of the blood in the kidneys and passed from the body in urine.

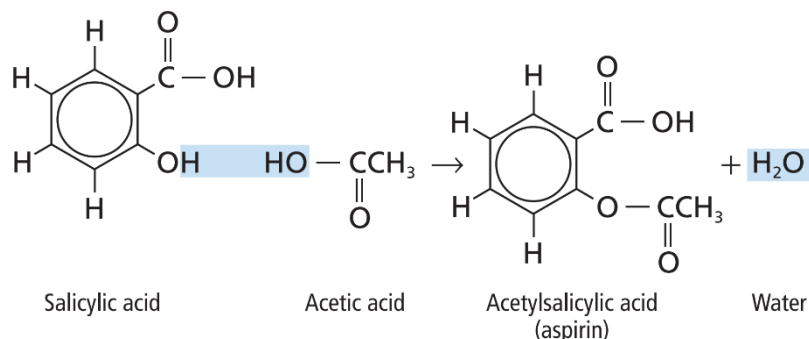
Because of the high nitrogen content of urea and because it is easily converted to ammonia in the soil, urea is a common **commercial fertilizer**. Urea is also used as a protein supplement for ruminant animals, such as cattle and sheep. These animals use urea to produce proteins in their bodies.

Condensation Reactions

In a **condensation reaction**, two smaller organic molecules combine to form a more complex molecule, accompanied by the loss of a small molecule such as water. Typically, the molecule lost is formed from one particle from each of the reactant molecules.

8.3 – Carbonyl Compounds

Many laboratory syntheses and industrial processes involve the reaction of two organic reactants to form a larger organic product. To synthesize aspirin, two organic molecules are combined in a condensation reaction to form a larger molecule.



In essence, a condensation reaction is an **elimination reaction** in which a bond is formed between two atoms not previously bonded to each other. The most common condensation reactions involve the combining of **carboxylic acids** with other organic molecules.

A common way to synthesize an **ester** is by a condensation reaction between a **carboxylic acid** and an **alcohol**. Such a reaction can be represented by the following general equation.



8.4 – Other Reactions of Organic Compounds

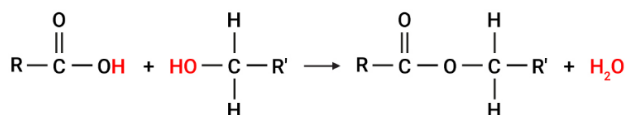
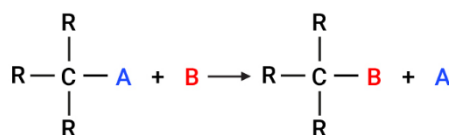
Classifying Reactions of Organic Substances

Classifying the chemical reactions of organic compounds makes predicting products of reactions much easier. Organic compounds undergo different chemical reactions that can change them from an unsaturated to a saturated form and vice versa. These reactions differ in their:

- **mechanisms** (replace/add/remove)
- **kinds of atoms reacting** ($\text{H}_2/\text{H}_2\text{O}/\text{HX}$)

We can change organic compounds into other different organic compounds either by **substitution** or **condensation** reactions.

Substitution reaction – a chemical reaction where one atom or group of atoms replaces another atom or group of atoms.



Condensation reaction – a chemical reaction where two or more small organic molecules combine to form a single molecule.

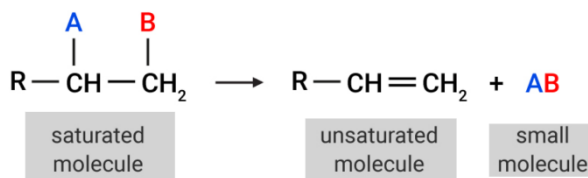
Two other important types of reactions by which organic compounds can be changed into different compounds are **elimination** reactions and **addition** reactions.

Elimination Reactions

Alkenes are more reactive than **alkanes**. Changing an alkane to its corresponding alkene will make it a more reactive substance. This process is called **elimination**.

Elimination reaction – is when two atoms or groups of atoms are removed from two adjacent carbon atoms in a molecule to form a new molecule.

Elimination reactions involve breaking two single bonds, mainly in saturated compounds, to produce an unsaturated compound.



Elimination reactions can change:

- a **saturated** molecule (alkane) to an unsaturated molecule (alkene) by converting a C–C single bond to a C=C double bond
- an **unsaturated** molecule (alkene) to a more unsaturated molecule (alkyne) by converting a C=C double bond to a C≡C triple bond

8.4 – Other Reactions of Organic Compounds

One of the products of the elimination reactions is a small molecule. A small molecule can be:

- a hydrogen gas molecule (H_2)
- a water molecule (H_2O)
- a hydrogen halide molecule (HX)

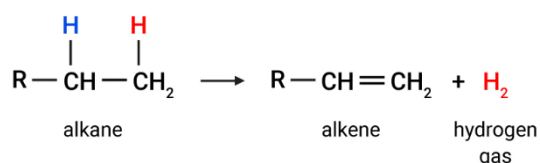
Based on the kind of atoms or groups of atoms that leave the molecules during elimination reactions, there are three types of elimination reactions:

#1 Dehydrogenation Reactions

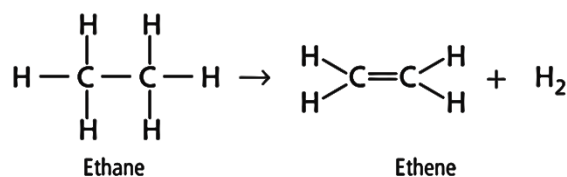
A **dehydrogenation reaction** is a chemical reaction that involves the removal of two hydrogen atoms from an alkane.

The products of this reaction are:

- an **unsaturated** molecule
- a hydrogen gas molecule (H_2)



Ethene, the starting material for the playground equipment, is produced by the dehydrogenation of ethane. Low density polyethylene (LDPE) is made from gaseous ethene under high pressure in the presence of a catalyst.



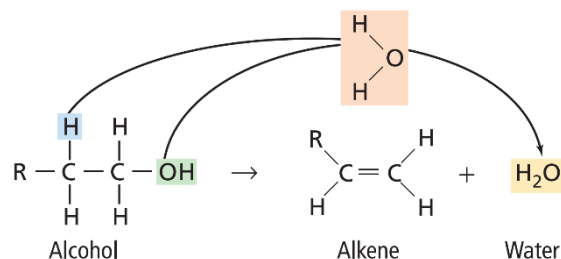
LDPE is used for playground equipment because it is easy to mold into various shapes, it is easy to dye into many colors, and it is durable. The name polyethylene comes from ethylene, which is the common name for ethene.

#2 Dehydration Reactions

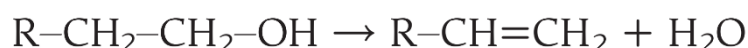
A **dehydration reaction** is a chemical reaction that involves the removal of a hydrogen atom and a hydroxyl group ($-\text{OH}$) from an alcohol.

The products of this reaction are:

- an **unsaturated** molecule
- a water molecule (H_2O)



Dehydration reaction is an elimination reaction in which the atoms removed form water. The generic form of this dehydration reaction can be written as follows.



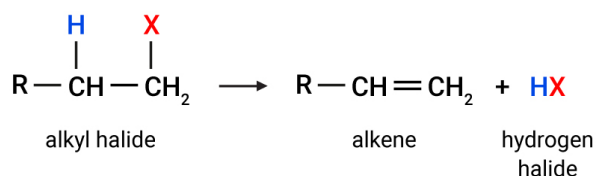
8.4 – Other Reactions of Organic Compounds

#3 Dehydrohalogenation Reactions

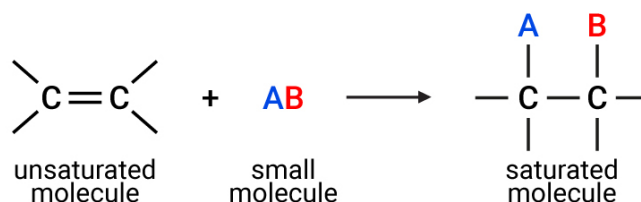
A **dehydrohalogenation reaction** is a chemical reaction that involves the removal of a hydrogen atom and a halogen from an alkyl halide.

The products of this reaction are:

- an **unsaturated** molecule
- a hydrogen halide (**HX**) molecule
(where **X** = F, Cl, or Br)



Addition Reactions



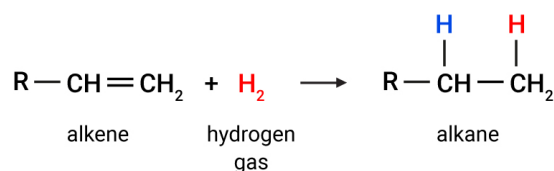
An **addition reaction** is when two atoms or groups of atoms are added to an unsaturated molecule forming a single product. Addition reactions typically involve **double-bonded** carbon atoms in alkenes or **triple-bonded** carbon atoms in alkynes.

Addition reactions occur because double and triple bonds have a rich concentration of electrons. Therefore, molecules and ions that attract electrons tend to form bonds that use some of the electrons from the multiple bonds.

Based on the kind of atoms or groups of atoms added to the unsaturated molecules during addition reactions, there are four types of addition reactions:

#1 Hydrogenation Reactions

A **hydrogenation reaction** is a chemical reaction that involves the addition of two hydrogen atoms to an unsaturated compound.



The product of this reaction is a **saturated** compound.

Hydrogenation of unsaturated compounds needs a **catalyst** to proceed. Examples of catalysts used in hydrogenation reactions include

- platinum (**Pt**),
- palladium (**Pd**),
- and nickel (**Ni**).

8.4 – Other Reactions of Organic Compounds

Catalysts are usually needed in the hydrogenation of alkenes because the reaction's activation energy is too large without them. Catalysts such as powdered platinum or palladium provide a surface that adsorbs the reactants and makes their electrons more available to bond to other atoms.

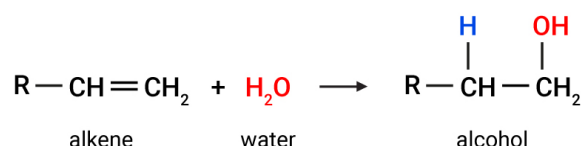
Hydrogenation reactions are commonly used to convert the **liquid unsaturated fats** found in oils from plants such as **soybean**, **corn**, and **peanuts** into saturated fats that are solid at room temperature. These hydrogenated fats are then used to make **margarine** (الزمن) and solid shortening.

#2 Hydration Reactions

A **hydration reaction** is a chemical reaction that involves the addition of a hydrogen atom and a hydroxyl group (–OH) from a water molecule to an unsaturated compound.

The product of this reaction is

- a **saturated** compound.



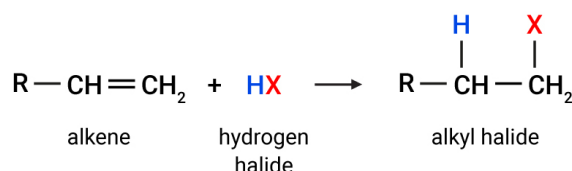
A hydration reaction is the opposite of a dehydration reaction.

#3 Hydrohalogenation Reactions

A **hydrohalogenation reaction** is a chemical reaction that involves the addition of a hydrogen atom and a halogen from a **hydrogen halide** molecule to an unsaturated compound.

The product of this reaction is

- a **saturated** compound.



The generic equation for this reaction is shown below.

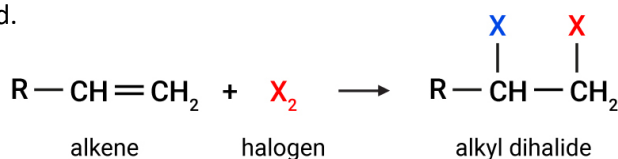


#4 Halogenation Reactions

A **halogenation reaction** is a chemical reaction that involves the addition of two halogen atoms from a halogen molecule to an unsaturated compound.

The product of this reaction is

- a **saturated** compound.



8.4 – Other Reactions of Organic Compounds

Table 12 Summary of Addition Reactions

Reactant Alkene	Addition Reactant	Product
$\begin{array}{c} \text{R} \quad \text{H} \\ \diagdown \quad \diagup \\ \text{C} = \text{C} \\ \diagup \quad \diagdown \\ \text{H} \quad \text{R}' \end{array}$	Water (hydration)	Alcohol
	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{O} \end{array}$	$\begin{array}{c} \text{H} \quad \text{OH} \\ \quad \\ \text{R}-\text{C}-\text{C}-\text{R}' \\ \quad \\ \text{H} \quad \text{H} \end{array}$
	Hydrogen (hydrogenation)	Alkane
	$\text{H}-\text{H}$	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{R}-\text{C}-\text{C}-\text{R}' \\ \quad \\ \text{H} \quad \text{H} \end{array}$
	Hydrogen halide	Alkyl halide
	$\text{H}-\text{X}$	$\begin{array}{c} \text{H} \quad \text{X} \\ \quad \\ \text{R}-\text{C}-\text{C}-\text{R}' \\ \quad \\ \text{H} \quad \text{H} \end{array}$
	Halogen	Alkyl dihalide
	$\text{X}-\text{X}$	$\begin{array}{c} \text{X} \quad \text{X} \\ \quad \\ \text{R}-\text{C}-\text{C}-\text{R}' \\ \quad \\ \text{H} \quad \text{H} \end{array}$

Summary

Type of Reaction	Name of Reaction	Generic Equation
Elimination	Dehydrogenation	$\text{R}-\text{CH}_2-\text{CH}_3 \rightarrow \text{R}-\text{CH}=\text{CH}_2 + \text{H}_2$
	Dehydration	$\text{R}-\text{CH}_2-\text{CH}_2\text{OH} \rightarrow \text{R}-\text{CH}=\text{CH}_2 + \text{H}_2\text{O}$
	Dehydrohalogenation	$\text{R}-\text{CH}_2-\text{CH}_2\text{X} \rightarrow \text{R}-\text{CH}=\text{CH}_2 + \text{HX}$
Addition	Hydrogenation	$\text{R}-\text{CH}=\text{CH}_2 + \text{H}_2 \rightarrow \text{R}-\text{CH}_2-\text{CH}_3$
	Hydration	$\text{R}-\text{CH}=\text{CH}_2 + \text{H}_2\text{O} \rightarrow \text{R}-\text{CH}_2-\text{CH}_2\text{OH}$
	Hydrohalogenation	$\text{R}-\text{CH}=\text{CH}_2 + \text{HX} \rightarrow \text{R}-\text{CHX}-\text{CH}_3$
	Halogenation	$\text{R}-\text{CH}=\text{CH}_2 + \text{X}_2 \rightarrow \text{R}-\text{CHX}-\text{CH}_2\text{X}$

The file summarizes only the required learning outcomes for the EOT3 exam this year.

CHAPTER 8

SUBSTITUTED HYDROCARBONS

CHAPTER SUMMARY

Resources

- *Substituted Hydrocarbons and Their Reactions, Chapter 22, from Glencoe Chemistry: Matter and Change ©2017*
- *Alefed.com*

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