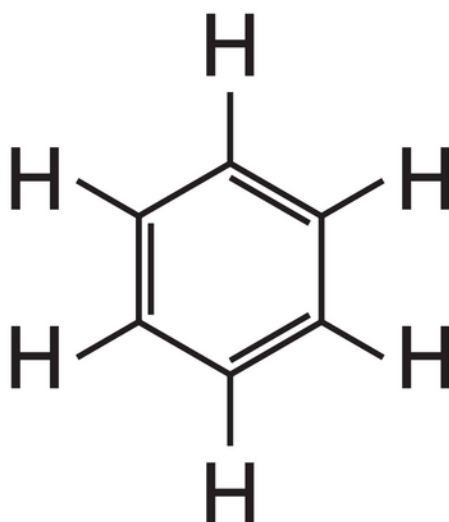


CHAPTER 7

HYDROCARBONS



CHAPTER SUMMARY

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SECTION 1:
INTRODUCTION TO HYDROCARBONS

SECTION 2:
ALKANES

SECTION 3:
ALKENES AND ALKYNES

SECTION 4:
HYDROCARBON ISOMERS

SECTION 5:
AROMATIC HYDROCARBONS



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7.1 – Introduction to Hydrocarbons

Organic Compounds

Hydrocarbons are carbon-containing organic compounds that provide a source of energy and raw materials. The gasoline and diesel fuel that are used in cars, trucks, and buses are hydrocarbons.

Disproving Vitalism

Many scientists **incorrectly** believed in vitalism to describe organic compounds. The theory states that:

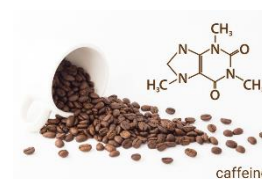
- *Scientists can't synthesize organic compounds in the laboratory from inorganic compounds*
- *The synthesis of organic compounds requires a vital force provided by divine powers*

But the German chemist, Friedrich Wöhler, was the first to disprove vitalism. Wöhler synthesized the organic compound **urea** ($\text{CO}(\text{NH}_2)_2$) from an aqueous solution of an inorganic compound.

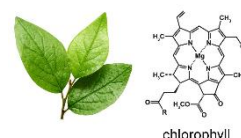
This experiment **discredited** vitalism and proved that chemists can **synthesize** organic compounds in the laboratory.

Organic Chemistry

Organic chemistry studies the structure, properties, composition, reactions, and preparation of carbon-containing compounds. **Organic compounds are the compounds that contain the element carbon.**



Caffeine ($\text{C}_8\text{H}_{10}\text{N}_4\text{O}_2$) and **Chlorophyll** ($\text{C}_{55}\text{H}_{72}\text{O}_5\text{N}_4\text{Mg}$) are examples of organic compounds.



Some compounds contain carbon but are considered **inorganic compounds**. Examples include:

- | | | |
|------------------------|--|------------------------------|
| • Carbon oxides | Carbon monoxide, CO, and carbon dioxide, CO_2 . | |
| • Carbonates | Compounds composed of CO_3^{2-} . | (Na_2CO_3) |
| • Cyanides | Compounds composed of CN^- . | (NaCN) |
| • Carbides | Compounds composed of carbon and a metal. | (SiC_2) |

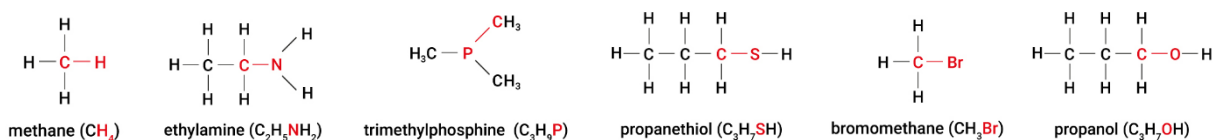
Carbon is found in **group 14** of the periodic table. It can bond to **four** other elements and form thousands of different compounds.

The electron configuration of a carbon element is ($1s^2 2s^2 2p^2$). The carbon atom attains stability by sharing its four valence electrons and filling its outer energy level to satisfy **octet rule**.

A carbon atom can form **four covalent bonds** with other elements or with other carbon atoms. Carbon can form **single, double, and triple** covalent bonds.

7.1 – Introduction to Hydrocarbons

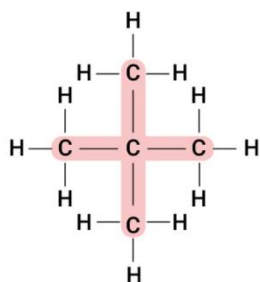
Carbon atoms can chemically bond with **hydrogen** atoms, **carbon** atoms, and atoms of other elements that are near carbon in the periodic table, especially **nitrogen**, **oxygen**, **sulfur**, **phosphorus**, and the **halogens**.



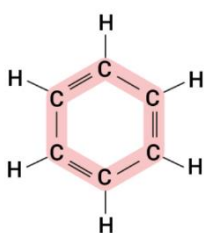
Most importantly, carbon atoms also bond to other carbon atoms and form chains from two to thousands of carbon atoms in length.

Also, because carbon forms four bonds, it forms complex, **branched-chain structures**, **ring structures**, and even **cage-like structures**. With all of these bonding possibilities, chemists have identified millions of different organic compounds and are synthesizing more every day.

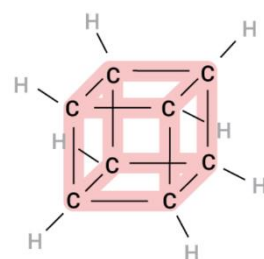
Branched-Chain Organic Compound



Organic Ring Compound



Cage-Like Organic Compound



Hydrocarbons

The simplest organic compounds are **hydrocarbons**, which **contain only the elements carbon and hydrogen**. Thousands of hydrocarbons are composed only of the elements carbon and hydrogen.

The simplest hydrocarbon molecule, CH_4 , consists of a carbon atom bonded to four hydrogen atoms. This substance, called **methane**, is an excellent fuel and is the main component of natural gas.

Models and hydrocarbons

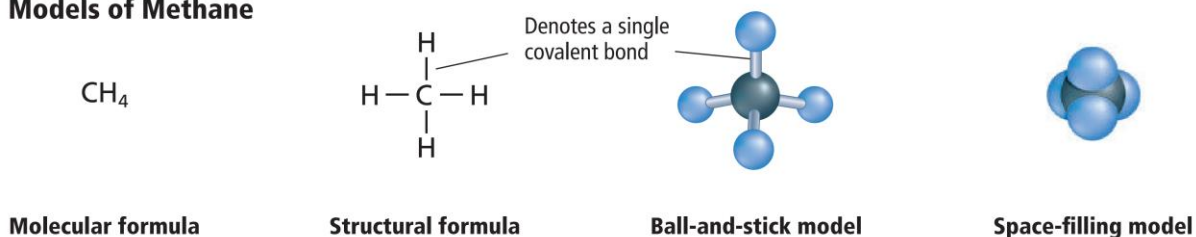
Chemists represent organic molecules in a variety of ways. The four different ways to represent a methane molecule shown in the next page are:

- Molecular formula
- Structural formula
- Ball-and-stick model
- Space-filling model

Each method provides different information about the compounds.

7.1 – Introduction to Hydrocarbons

Models of Methane



Covalent bonds are represented by a single straight line, which denotes **two** shared electrons. Most often, chemists use the type of model that best shows the information they want to highlight.

As shown in the figure,

- **Molecular formulas** give no information about the geometry of the molecule.
- **Structural formulas** show the general arrangement of atoms in the molecule but not the exact, three-dimensional geometry.
- The **ball-and-stick model** demonstrates the geometry of the molecule clearly,
- The **space-filling model** gives a more realistic picture of what a molecule would look like if you could see it.

Multiple Carbon-Carbon Bonds

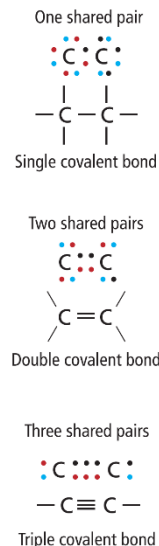
In the nineteenth century, before chemists understood bonding and the structure of organic substances, they experimented with hydrocarbons obtained from heating animal fats and plant oils.

They classified these hydrocarbons according to a chemical test in which they mixed each hydrocarbon with bromine and then measured how much reacted with the hydrocarbon.

Some hydrocarbons would react with a small amount of bromine, some would react with more, and some would not react with any amount of bromine.

Chemists called the hydrocarbons that reacted with bromine **unsaturated hydrocarbons** in the same sense that an unsaturated aqueous solution can dissolve more solute. Hydrocarbons that did not react with bromine were said to be **saturated**.

Now we know that hydrocarbons that reacted with bromine had double or triple covalent bonds. Those compounds that did not react with bromine had only single covalent bonds.



• and • = carbon electrons
• = electron from another atom

Saturated hydrocarbon: *contain only single bonds between carbon atoms.*

Unsaturated hydrocarbon: *has at least one double or triple bond between carbon atoms.*

7.1 – Introduction to Hydrocarbons

Refining Hydrocarbons

Fossil fuels are the primary sources of hydrocarbons. Fossil fuels include:

- **Petroleum**

Petroleum is a naturally occurring complex mixture of hydrocarbons and trace amounts of other substances found under the Earth's surface. **Crude oil** is the liquid part of petroleum.

- **Natural Gas**

Natural gas is a naturally occurring hydrocarbon gas mixture composed primarily of **methane** with small amounts of other simple hydrocarbons that have from two to five carbon atoms.

Petroleum formed from the remains of microorganisms that lived in Earth's oceans millions of years ago. Over time, the remains formed thick layers of mud-like deposits on the ocean floor.

Heat from Earth's interior and the tremendous pressure of overlying sediments transformed this mud into oil-rich shale and natural gas. In certain kinds of geological formations, the petroleum ran out of the shale and collected in pools deep in Earth's crust.

Natural gas, which formed at the same time and in the same way as petroleum, is usually found with petroleum deposits.

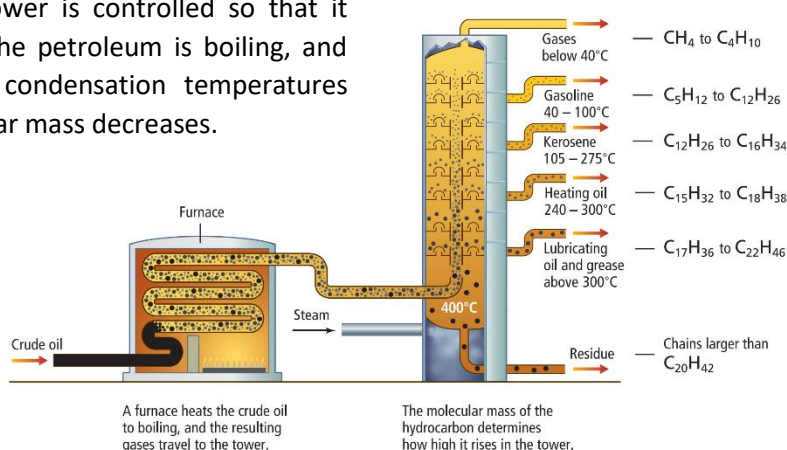
Fractional Distillation

Unlike natural gas, petroleum is a **complex** mixture containing more than a thousand different compounds. For this reason, raw petroleum, sometimes called **crude oil**, has little practical use.

Petroleum is much more useful to humans when it is **separated** into simpler components or fractions. Separation is carried out in a process called **fractional distillation**, also called **fractionation**, which involves boiling the petroleum and collecting components or fractions as they condense at different temperatures.

The temperature inside the fractionating tower is controlled so that it remains near 400°C at the bottom, where the petroleum is boiling, and gradually decreases toward the top. The condensation temperatures (boiling points) generally decrease as molecular mass decreases.

This diagram of a fractionating tower shows that fractions with lower boiling points, such as gasoline and gaseous products, are drawn off in the cooler regions near the top of the tower. Oils and greases, having much higher boiling points, stay near the bottom of the tower and are drawn off there.

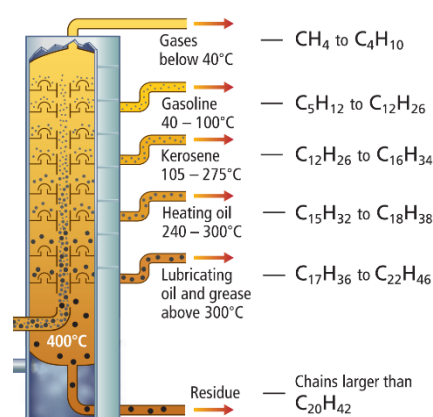


7.1 – Introduction to Hydrocarbons

The figure gives the names of the typical fractions separated from petroleum, along with their boiling points, hydrocarbon size ranges, and common uses.

Unfortunately, fractional distillation towers do not yield fractions in the same proportions that they are needed.

For example, distillation hardly yields the amount of gasoline desired. However, it yields more of the heavier oils than the market demands.



Many years ago, petroleum chemists and engineers developed a process to help match the supply with the demand.

Cracking: is the process in which heavier fractions are converted to gasoline by breaking their large molecules into smaller molecules. It is done in the **absence of oxygen** and in the **presence of a catalyst**.

In addition to breaking heavier hydrocarbons into molecules of the size range needed for gasoline, cracking also produces **starting materials** for the synthesis of many different products, including

- plastic products,
- films,
- and synthetic fabrics.

Rating Gasoline

None of the petroleum fractions is a pure substance. Gasoline is not a pure substance, but rather a mixture of hydrocarbons. Most molecules with single covalent bonds in gasoline have 5 to 12 carbon atoms.

The gasoline fraction that is distilled from petroleum is modified by adjusting its composition and adding substances to improve its performance in today's automobile engines and to reduce pollution from car exhaust.

It is critical that the gasoline-air mixture in the cylinder of an automobile engine ignite at exactly the right instant and burn evenly. If it ignites too early or too late, much energy will be wasted, fuel efficiency will drop, and the engine will wear out prematurely.

Most straight-chain hydrocarbons burn **unevenly** and tend to ignite from heat and pressure before the piston is in the proper position and the spark plug fires. This early ignition causes a rattling or pinging noise called **knocking**.

In the late 1920s, an antiknock, or octane rating, system for gasoline was established, resulting in the octane ratings posted on gasoline pumps.

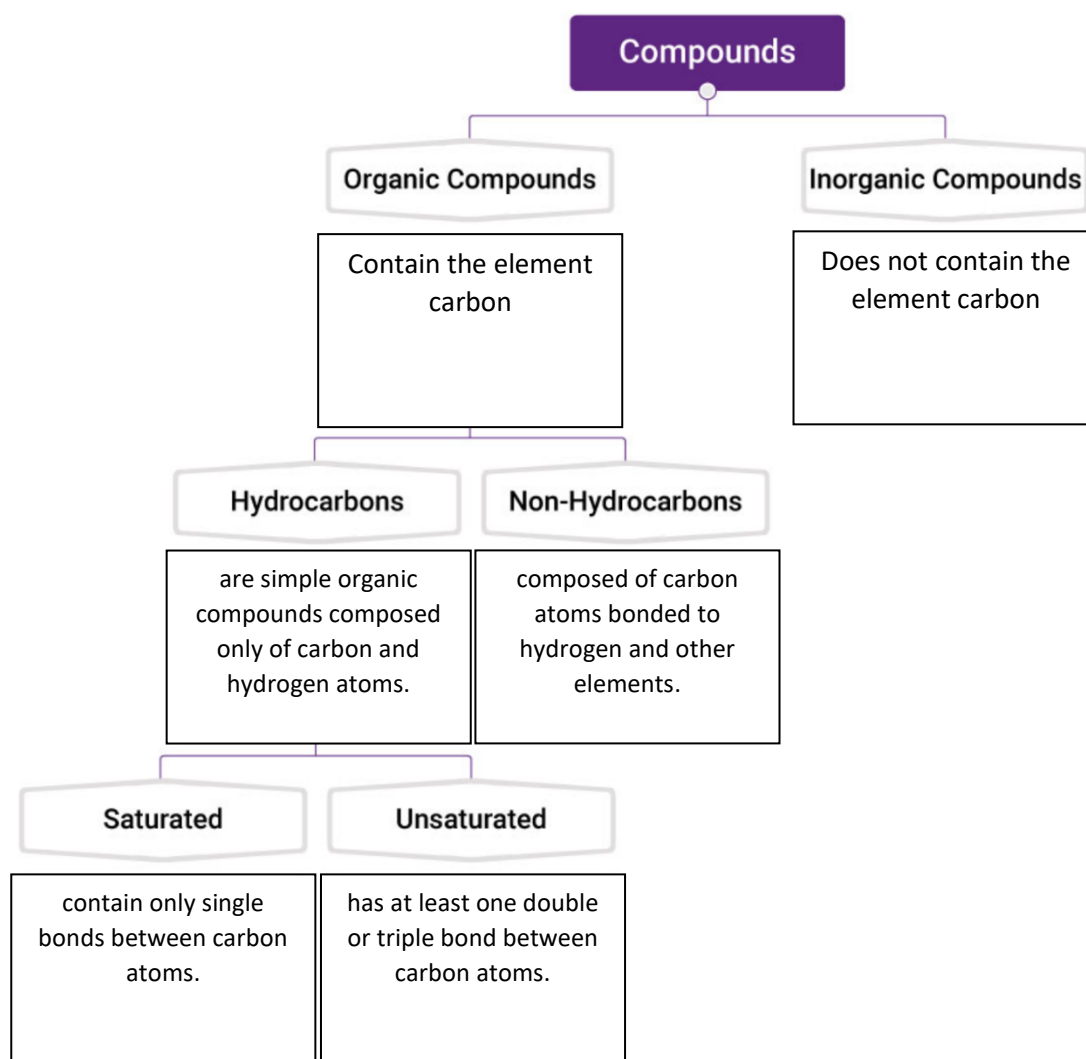
7.1 – Introduction to Hydrocarbons

Octane ratings are used to give the antiknock rating of fuel.

- Mid-grade gasoline for cars has an octane rating of about 89.
- Aviation fuel has an octane rating of about 100.
- Racing fuel has an octane rating of about 110.

Premium gasoline has ratings of 91 or higher. Several factors determine which octane rating a car needs, including

- how much the piston compresses the air-fuel mixture
- the altitude at which the car is driven.

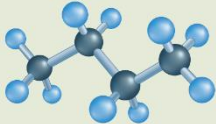
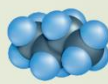


7.2 – Alkanes

Straight-Chain Alkanes

Alkanes are saturated hydrocarbons that contain only single covalent bonds between carbon atoms.

The general formula for **alkanes** is C_nH_{2n+2} . In this formula, n represents the number of carbon atoms in the alkane molecule.

Molecular Formula	Structural Formula	Ball-and-Stick Model	Space-Filling Model
Ethane (C_2H_6)	<pre> H H H — C — C — H H H </pre>		
Propane (C_3H_8)	<pre> H H H H — C — C — C — H H H H </pre>		
Butane (C_4H_{10})	<pre> H H H H H — C — C — C — C — H H H H H </pre>		

Name	Molecular Formula	Condensed Structural Formula
Methane	CH_4	CH_4
Ethane	C_2H_6	CH_3CH_3
Propane	C_3H_8	$CH_3CH_2CH_3$
Butane	C_4H_{10}	$CH_3CH_2CH_2CH_3$
Pentane	C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$
Hexane	C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$
Heptane	C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
Octane	C_8H_{18}	$CH_3(CH_2)_6CH_3$
Nonane	C_9H_{20}	$CH_3(CH_2)_7CH_3$
Decane	$C_{10}H_{22}$	$CH_3(CH_2)_8CH_3$

Methane is the smallest member of alkanes. It is used as a fuel in homes and science labs and is a product of many biological processes.

Propane, also known as LP (**liquefied propane**) gas, is sold as a fuel for cooking and heating.

Butane is used as fuel in small lighters and in some torches. It is also used in the manufacture of synthetic rubber.

7.2 – Alkanes

Naming Straight-Chain Alkanes

Straight-chain alkanes consist of carbon atoms bonded to each other in a straight line with no side branches. The names of straight-chain alkanes are divided into two parts.

1. Alkanes with five or more carbons in a chain have names that use a **prefix** derived from the Greek or Latin word for the number of carbons in each chain.
Because methane, ethane, propane, and butane were named before alkane structures were known, their names do not have numerical prefixes.
2. The **suffix -ane** indicates the presence of single covalent bonds between carbon atoms.

Table 2 in the previous page shows the names and structures of the first ten alkanes.

Condensed structural formulas, save space by not showing how the hydrogen atoms branch off from the carbon atoms. Condensed formulas can be written in several ways. In **Table 2**, the lines between carbon atoms have been eliminated to save space.

In **Table 2**, you can see that $\text{—CH}_2\text{—}$ is a repeating unit in the chain of carbon atoms. Note, for example, that pentane has one more $\text{—CH}_2\text{—}$ unit than butane.

You can further condense structural formulas by writing the $\text{—CH}_2\text{—}$ unit in **parentheses** followed by a **subscript** to show the number of units, as is done with octane, nonane, and decane.

Homologous series: is a series of compounds that differ from one another by a repeating unit.

A homologous series has a **fixed** numerical relationship among the numbers of atoms. For alkanes, the relationship between the numbers of carbon and hydrogen atoms can be expressed as

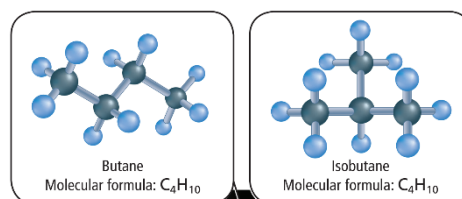


where n is equal to the number of carbon atoms in the alkane.

Given the number of carbon atoms in an alkane, you can write the molecular formula for any alkane. For example, **heptane** has **seven** carbon atoms, so its formula is $\text{C}_7\text{H}_{2(7)+2}$, or C_7H_{16} .

Branched-Chain Alkanes

The alkanes discussed so far in this chapter are called **straight-chain** alkanes because the carbon atoms are bonded to each other in a single line.



Both structures shown have the same molecular formula, C_4H_{10} , but they represent different substances that have different physical and chemical properties.

7.2 – Alkanes

Carbon atoms can bond to one, two, three, or even four other carbon atoms. This property makes possible a variety of branched-chain alkanes.

- Butane** – used in lighters and in torches.
- Isobutane** – used as an environmentally-safe refrigerant
used as a propellant in products such as shaving gel.

In addition to these applications, both butane and isobutane are used as raw materials for many chemical processes.

Alkyl Groups

The order and arrangement of atoms in an organic molecule determine its identity. This is a basic principle of organic chemistry. Therefore, the name of an organic compound must also accurately describe the molecular structure of the compound.

When naming branched-chain alkanes, the **longest continuous** chain of carbon atoms is called the **parent chain**. All **side** branches are called **substituent groups** because they appear to substitute for a hydrogen atom in the straight chain.

Each alkane-based substituent group branching from the parent chain is named for the straight-chain alkane that has the same number of carbon atoms as the substituent. The ending **-ane** is replaced with the letters **-yl**. An alkane-based substituent group is called an **alkyl group**. Several alkyl groups are shown in Table 3.

Table 3 Common Alkyl Groups					
Name	Methyl	Ethyl	Propyl	Isopropyl	Butyl
Condensed structural formula	CH_3-	CH_3CH_2-	$\text{CH}_3\text{CH}_2\text{CH}_2-$	$\text{CH}_3\underset{\text{ }}{\text{CH}}\text{CH}_3$	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2-$
Structural formula	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \end{array}$	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \end{array}$	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \end{array}$	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ -\text{C}-\text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H} \end{array}$	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \end{array}$

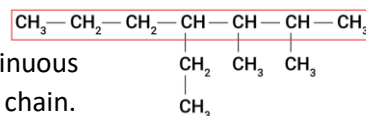
7.2 – Alkanes

Naming Branched-Chain Alkanes

To name organic structures, chemists use the following systematic rules approved by the International Union of Pure and Applied Chemistry (IUPAC).

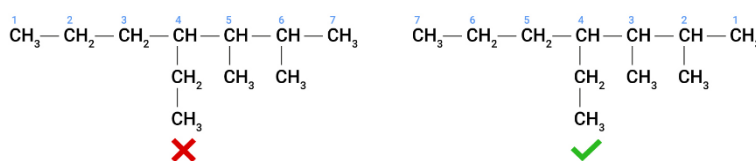
Step 1: Identify the Parent Chain.

Find the **parent chain** by counting carbon atoms in the longest, continuous chain. Use the name of the straight-chain alkane to name the parent chain.



Step 2. Number the Carbon Atoms in the Parent Chain.

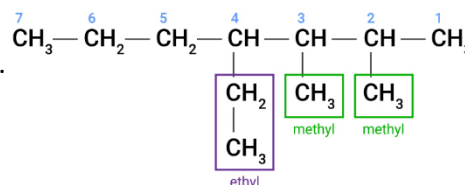
Number the carbon atoms in the parent chain to locate the position of the alkyl groups. This numbering should give the alkyl groups the lowest position numbers.



The lower position numbers are 2, 3 and 4. Use these position numbers to locate the alkyl groups.

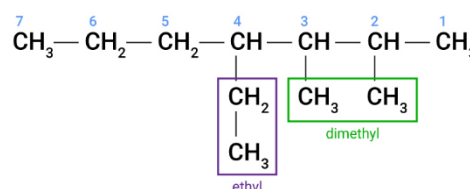
Step 3. Name the Substituent Alkyl Groups.

Name the alkyl groups branching out from the parent chain.



Step 4. Use Prefixes to Indicate if Alkyl Groups Appear more than Once.

If the same alkyl group branches out from the parent chain more than once, we use a prefix before the name of that alkyl group.



The position numbers should be written before the names of the alkyl groups.

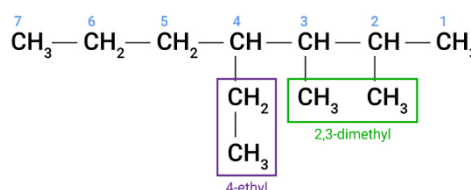
Step 5. Place the Substituent Alkyl Groups in Alphabetical Order.

When different alkyl groups are attached to the same parent chain, place the names of the alkyl groups in alphabetical order.

- Use commas to separate numbers.
- Use hyphens to separate numbers from words.

The prefixes are not considered when determining the alphabetical order of alkyl groups.

Based on the alphabetical order, “e” comes before “m”, so we name the ethyl group before the methyl group. In this example, the alkyl groups are named: 4-ethyl-2,3-dimethyl.

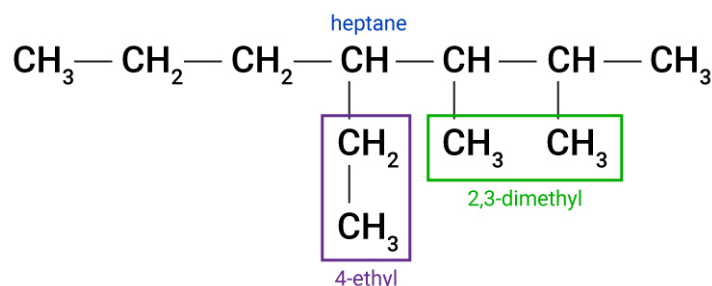


7.2 – Alkanes

Step 6. Write the Full Alkane Name.

Write the alkane's entire name by adding the name of the parent chain after the names of the alkyl groups. Don't add a space between the names of the alkyl groups and the name of the parent chain.

The name of this branched-chain alkane is **4-ethyl-2,3-dimethylheptane**.

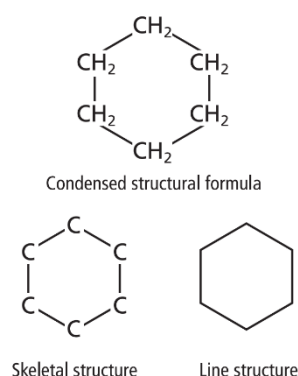


Cycloalkanes

One of the reasons that such a variety of organic compounds exists is that carbon atoms can form **ring structures**. An organic compound that contains a hydrocarbon ring is called a **cyclic hydrocarbon**. To indicate that a hydrocarbon has a ring structure, the prefix **cyclo-** is used with the hydrocarbon name. Thus, **cyclic hydrocarbons that contain only single bonds are called cycloalkanes**.

Cycloalkanes can have rings with **three, four, five, six**, or even more carbon atoms. The name for the six-carbon cycloalkane is **cyclohexane**. Cyclohexane, which is obtained from petroleum, is used in paint and varnish removers and for extracting essential oils to make perfume.

Note that cyclohexane (C_6H_{12}) has two fewer hydrogen atoms than straight-chain hexane (C_6H_{14}) because a valence electron from each of two carbon atoms is now forming a **carbon-carbon** bond rather than a carbon-hydrogen bond.



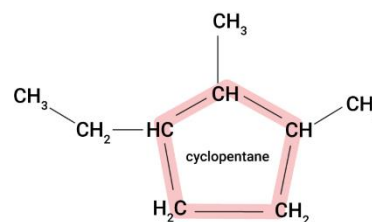
As shown in the figure, cyclic hydrocarbons such as cyclohexane are represented by **condensed, skeletal, and line structures**.

Line structures show only the carbon-carbon bonds with carbon atoms understood to be at each **vertex** of the structure. Hydrogen atoms are assumed to occupy the remaining bonding positions unless substituents are present. Hydrogens are also not shown in **skeletal structures**.

7.2 – Alkanes

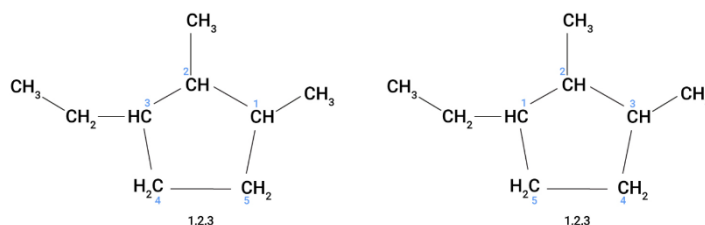
Naming Substituted Cycloalkanes

A substituted cycloalkane is a cycloalkane that has side chain(s) attached to the carbon ring. Substituted cycloalkanes are named by following the same IUPAC rules used for straight-chain alkanes, but with a few modifications.

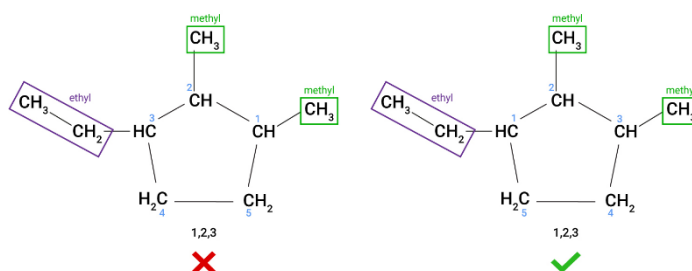


1. For substituted cycloalkanes, there is no need to find the parent chain. We always consider the ring to be the parent chain. Name the parent cycloalkane by counting carbon atoms found in the ring.
2. We number the ring to give the alkyl groups the lowest position numbers. Always start numbering from a carbon with a substituent alkyl group so that one of the branches is at position 1.

There is no need to add numbers if there is only one alkyl group.

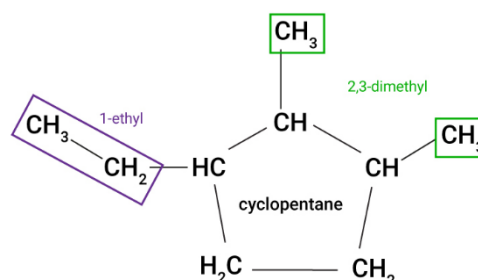


3. Name the alkyl groups branching out from the parent cycloalkane. In this example, three alkyl groups branch out from the parent cycloalkane. Based on the alphabetical order, “e” comes before “m”. So, we choose the numbering sequence that places the ethyl group before the methyl group.



4. Write the full name by adding the name of the parent cycloalkane after the names of the alkyl groups. Do not add a space between the names of the alkyl groups and the name of the parent chain.

This substituted cycloalkane is named
1-ethyl-2,3-dimethylcyclopentane.



7.2 – Alkanes

Properties of Alkanes

The structure of a molecule affects its properties. For example, the **O–H** bonds in a water molecule are **polar**, and because the **H–O–H** molecule has a bent geometry, the molecule itself is polar.

Thus, water molecules can form hydrogen bonds with each other. As a result, the boiling and melting points of water are much **higher** than those of other substances having similar molecular mass and size.

All of the bonds in alkanes are between either a **carbon atom** and a **hydrogen atom** or between two carbon atoms. A bond between two identical atoms, such as carbon, can never be polar.

Also, the **C–H** bonds have only a **small** electronegativity difference and are **nonpolar**. Because **all of the bonds in alkanes are nonpolar**, alkane molecules are nonpolar, which makes them good solvents for other nonpolar substances.

Many solvents—used as thinners for paints, coatings, waxes, photocopier toners, adhesives, and printer press inks—contain alkanes and cycloalkanes.

Physical Properties of Alkanes

The **intermolecular forces** determine the physical properties of molecules like their boiling point and melting point. Alkanes consist of nonpolar carbon-carbon and carbon-hydrogen bonds resulting in nonpolar molecules.

Refer to Table 4, and note that the molecular mass of methane (16 amu) is close to the molecular mass of water (18 amu).

Table 4 Comparing Physical Properties		
Substance and formula	Water (H ₂ O)	Methane (CH ₄)
Molecular mass	18 amu	16 amu
State at room temperature	liquid	gas
Boiling point	100°C	–162°C
Melting point	0°C	–182°C

Also, water and methane molecules are similar in size. However, when you compare the melting and boiling points of methane to those of water, you can see evidence that the molecules differ in some significant way.

These temperatures differ greatly because methane molecules have little **intermolecular** attraction compared to water molecules. This difference in attraction can be explained by the fact that methane molecules are **nonpolar** and do not form hydrogen bonds with each other, whereas water molecules are **polar** and freely form hydrogen bonds.

The difference in polarity and hydrogen bonding also explains the **immiscibility** of alkanes and other hydrocarbons with water. If you try to dissolve alkanes, such as lubricating oils, in water, the two liquids separate almost immediately into two phases.

This separation happens because the attractive forces between alkane molecules are stronger than the attractive forces between the alkane and water molecules. Therefore, alkanes are more soluble in solvents composed of nonpolar molecules like themselves than in water, a polar solvent.

7.2 – Alkanes

Chemical Properties of Alkanes

The main chemical property of alkanes is their **low reactivity**. Molecules such as alkanes, in which atoms are connected by nonpolar bonds, have no charge. As a result, they have little attraction for ions or polar molecules.

The low reactivity of alkanes can also be attributed to the relatively strong **C–C** and **C–H** bonds.

7.3 – Alkenes and Alkynes

Alkenes

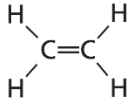
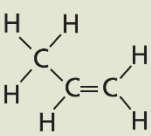
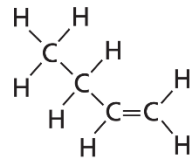
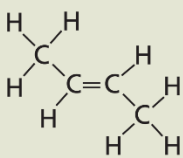
Alkenes are unsaturated hydrocarbons that contain one or more **double** covalent bonds between carbon atoms in a chain.

The **simplest** alkene has two carbon atoms double bonded to each other. The remaining four electrons—two from each carbon atom—are shared with four hydrogen atoms to give the molecule **ethene** (C_2H_4).

Alkenes with only **one double** bond constitute a **homologous series**. A homologous series has a **fixed** numerical relationship among the numbers of atoms.

The general formula for alkenes is C_nH_{2n} , where ***n*** represents the number of carbon atoms in the alkene molecule. Each alkene has twice as many hydrogen atoms as carbon atoms.

Each alkene has two fewer hydrogen atoms than the corresponding alkane because two electrons now form the second covalent bond and are no longer available for bonding to hydrogen atoms.

Table 5 Examples of Alkenes				
Name	Ethene	Propene	1-Butene	2-Butene
Molecular formula	C_2H_4	C_3H_6	C_4H_8	C_4H_8
Structural formula				
Condensed structural formula	$\text{CH}_2=\text{CH}_2$	$\text{CH}_3\text{CH}=\text{CH}_2$	$\text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2$	$\text{CH}_3\text{CH}=\text{CHCH}_3$

Naming Straight-Chain Alkenes

Alkenes are named in much the same way as alkanes. Their names are formed by changing the **-ane** ending of the corresponding alkane to **-ene**.

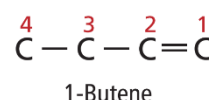
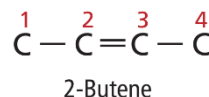
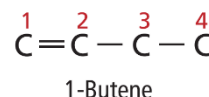
- An **alkane** with two carbons is named **ethane**.
- An **alkene** with two carbons is named **ethene**.

Ethene and propene have older, more **common** names: **ethylene** and **propylene**, respectively.

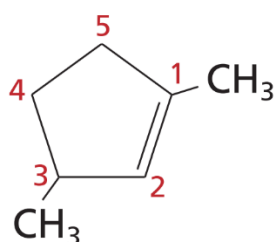
7.3 – Alkenes and Alkynes

When naming higher alkenes with four or more carbon atoms, you have to include the location of the double bond in the name.

- Number the carbons in the parent chain to give the **lowest** number to the first carbon in the double bond.
- Include the number of the first carbon in the double bond in the name of the alkene.



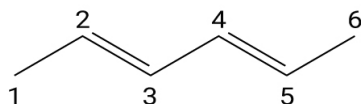
Note that the third structure is not “3-butene” because it is identical to the first structure, 1-butene. It is important to recognize that 1-butene and 2-butene are two **different** substances, each with its own properties.



Cyclic alkenes are named in much the same way as cyclic alkanes; however, carbon number 1 must be one of the carbons connected by the double bond.

The name of the compound shown is **1,3-dimethylcyclopentene**.

2,4 - hexadiene



2,4: the positions of the first carbons of the two double bonds

hexa-: six carbons in the parent chain

-di-: two double bonds in the parent chain

-ene: hydrocarbon is an alkene

Naming Branched-chain Alkenes

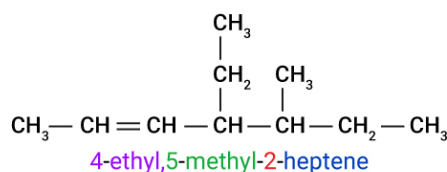
When naming branched-chain alkenes, follow the IUPAC rules for naming branched-chain alkanes, but with two exceptions:

- **First**, in alkenes, the parent chain is always the longest chain that contains the double bond, whether or not it is the longest chain of carbon atoms.
- **Second**, the position of the double bond, not the branches, determines how the chain is numbered.

Some unsaturated hydrocarbons contain more than one double (or triple) bond. The number of double bonds in such molecules is shown by using a **prefix** (*di-*, *tri-*, *tetra-*, and so on) before the suffix **-ene**. The positions of the bonds are numbered in a way that gives the lowest set of numbers.

The positions of the double bonds in alkenes are numbered in a way that gives the **lowest** set of numbers. This is true of both branched and straight-chain alkenes.

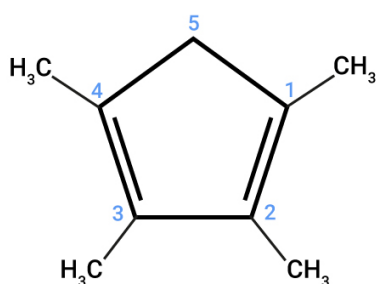
7.3 – Alkenes and Alkynes



substituent position number + substituent name + substituent position number + substituent name + C=C position number + parent name
 alphabetical order

To name **branched-cyclic** alkenes:

- with one double bond, add the prefix **cyclo-** before the name of the alkene
- with more than one double bond, add a number **prefix** before the suffix **-ene**



1,2,3,4-tetramethyl-1,3-cyclopentadiene

1,2,3,4: the positions of the methyl groups
tetra-: four methyl groups present
-methyl-: identifies the alkyl group
1,3: the positions of the two double bonds
-cyclo-: parent chain is a ring structure
-pent-: five carbon atoms in the parent chain
-di-: two double bonds in the parent chain
-ene: hydrocarbon is an alkene

Properties and Uses of Alkenes

Like alkanes, alkenes are **nonpolar** and therefore have **low solubility** in water as well as relatively **low melting** and **boiling** points.

However, alkenes are **more reactive** than alkanes because the second covalent bond increases the **electron density** between two carbon atoms, providing a good site for chemical reactivity. Reactants that attract electrons can pull the electrons away from the double bond.

Alkenes find many diverse uses in everyday life applications. **Ethylene** is the older and more common name of ethene (C_2H_4).

- Ethylene is a hormone produced naturally by plants. Ethylene **speeds up** the **ripening** of most fruits and vegetables.
- Ethylene is one of the most important hormones in the green leaves. Ethylene causes leaves to **fall** from deciduous trees during autumn preparing for winter.
- Ethylene is the starting material for plastic polyethylene. Plastic polyethylene interferes in the synthesis of many single-use products including:
 - plastic bags,
 - rope,
 - and milk jugs.

7.3 – Alkenes and Alkynes

Alkynes

Alkynes are unsaturated hydrocarbons that contain one or more **triple bonds** between carbon atoms in a chain. Triple bonds involve the sharing of three pairs of electrons. The simplest and most commonly used alkyne is **ethyne** (C_2H_2), which is widely known by its common name **acetylene**.

The general formula for alkynes is C_nH_{2n-2} . In this formula, n represents the number of carbon atoms in the alkyne molecule.

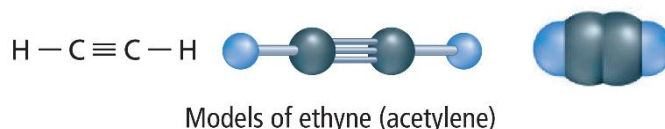


Table 6 Examples of Alkynes			
Name	Molecular Formula	Structural Formula	Condensed Structural Formula
Ethyne	C_2H_2	$H - C \equiv C - H$	$CH \equiv CH$
Propyne	C_3H_4	$\begin{array}{c} H \\ \\ H - C \equiv C - C - H \\ \\ H \end{array}$	$CH \equiv CCH_3$
1-Butyne	C_4H_6	$\begin{array}{c} H & H \\ & \\ H - C \equiv C - C - C - H \\ & \\ H & H \end{array}$	$CH \equiv CCH_2CH_3$
2-Butyne	C_4H_6	$\begin{array}{c} H & & H \\ & & \\ H - C - C \equiv C - C - H \\ & & \\ H & & H \end{array}$	$CH_3C \equiv CCH_3$

Properties and Uses of Alkynes

Alkynes have physical and chemical properties similar to those of alkenes. Alkynes undergo many of the reactions alkenes undergo. However, alkynes are generally **more reactive** than alkenes because the triple bonds of alkynes have even greater electron density than the double bonds of alkenes.

This cluster of electrons is effective at inducing dipoles in nearby molecules, causing them to become unevenly charged and thus reactive.

Ethyne—known commonly as **acetylene**—is a by-product of **oil refining** and is also made in large quantities by the reaction of **calcium carbide** (CaC_2) with water.

When supplied with enough oxygen, ethyne burns with an intensely hot flame that can reach temperatures as high as **3000°C**. Acetylene torches are commonly used in **welding** (اللحام).

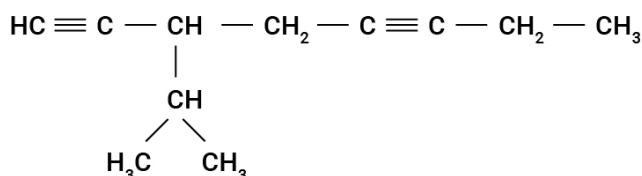
Because the triple bond makes alkynes reactive, simple alkynes like ethyne are used as starting materials in the manufacture of plastics and other organic chemicals used in industry.

7.3 – Alkenes and Alkynes

Naming Alkynes

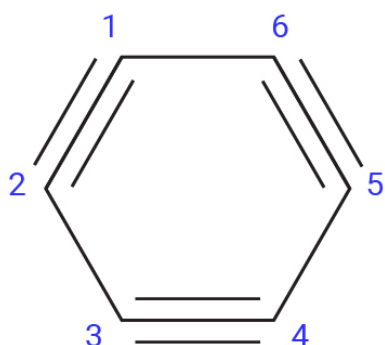
When naming branched-chain alkynes, follow the **IUPAC** rules used for naming alkenes.

If a branched-chain alkyne contains more than one triple bond just add a **number prefix** before the suffix **-yne**.



3-isopropyl-1,5-octadiyne

Like cycloalkenes, we name cycloalkynes by adding the prefix **cyclo-** to the names of straight-chain alkynes. Carbon number 1 must be one of the carbons connected by the triple bond.

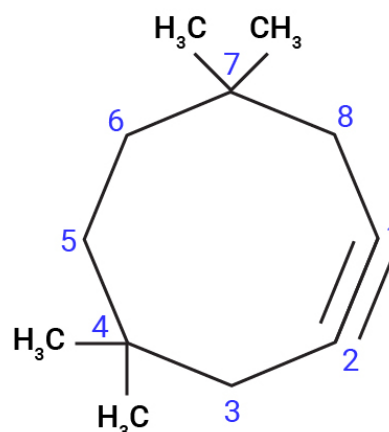


1,3,5-Cyclohexatriyne

- 1,3,5:** the first carbons of the three triple bonds
- cyclo-:** parent chain is a ring structure
- hexa-:** six carbon atoms in the parent chain
- tri-:** three triple bonds in the parent chain
- yne:** hydrocarbon is an alkyne

4,4,7,7-Tetramethylcyclooctyne

- 4,4,7,7:** the positions of the methyl groups
- tetra-:** four methyl groups present
- methyl-:** identifies the alkyl group
- cyclo-:** parent chain is a ring structure
- oct-:** eight carbon atoms in the parent chain
- yne:** hydrocarbon is an alkyne

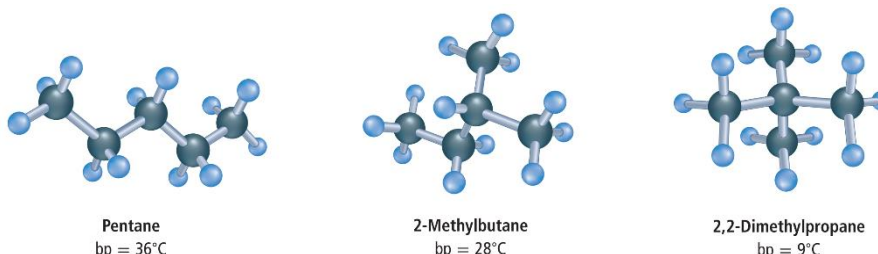


7.4 – Hydrocarbon Isomers

Structural Isomers

(المتشكلات البنائية)

Isomers are two or more compounds that have the same molecular formula but different molecular structures.



These compounds with the same molecular formula, C_5H_{12} , are **structural isomers**. However, these models represent three different arrangements of atoms and three different compounds. Note how their boiling points differ.

Isomers have the same chemical formula, but can differ in terms of **bonding, shape, and orientation**. The two main classes of isomers are:

- Structural isomers
- Stereoisomers

Structural isomers have the same chemical formula, but their atoms are bonded in different arrangements. Structural isomers have different chemical and physical properties despite having the same formula.

This observation supports one of the main principles of chemistry: *“The structure of a substance determines its properties”*.

As the number of carbons in a hydrocarbon increases, the number of possible structural isomers increases. For example, there are **nine** alkanes with the molecular formula C_7H_{16} . There are more than **300,000** structural isomers with the formula $C_{20}H_{42}$.

Stereoisomers

(المتشكلات الفراغية)

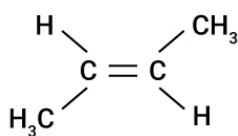
Stereoisomers are isomers in which all atoms are bonded in the same order but are arranged differently in space. There are two kinds of stereoisomers:

- Geometric isomers
- Optical isomers

(for enrichment)

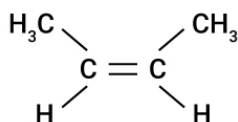
7.4 – Hydrocarbon Isomers

Geometric Isomers



Geometric isomers are compounds with the same chemical formula but **different** arrangements of groups around a double bond.

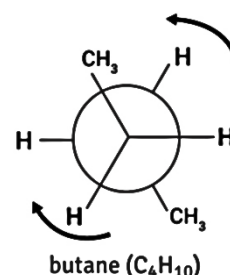
Geometric isomers occur in **alkenes** where the double bond prevents the rotation of groups.



In addition, each carbon atom in the alkene must be attached to two **different** groups to exhibit geometric isomers.

Alkanes do not have geometric isomers. When a single covalent bond connects two carbon atoms, the carbon atoms can **rotate freely**.

This free rotation about the C–C bond results in many different possible three-dimensional arrangements for the groups of atoms.



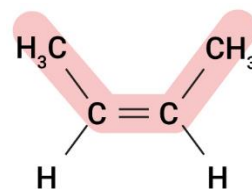
Alkenes exist in two different forms, known by **cis-** and **trans-**. The cis- and trans- forms are geometric isomers that differ in physical properties and some chemical properties.

Cis-Isomer

A **cis-isomer** forms when the groups are on the **same** side of the C=C bond.

For cis-2-butene:

- the two methyl groups are on the same side of the double bond
- dispersion forces between molecules are relatively stronger
- boiling point: 3.7°C
- melting point: –139°C

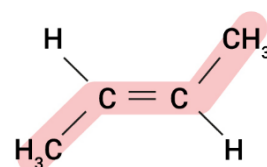


Trans-Isomer

A **trans-isomer** forms when the groups are on **opposite** sides of the C=C bond.

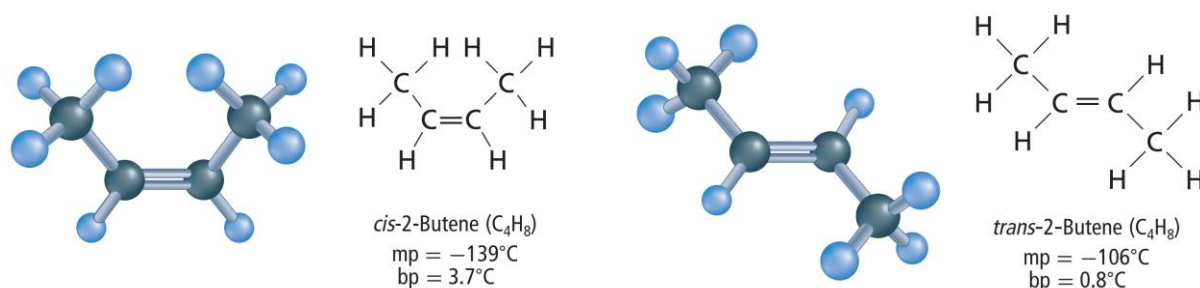
For trans-2-butene:

- the two methyl groups are on opposite sides of the double bond
- dispersion forces between molecules are relatively weaker
- boiling point: 0.8°C
- melting point: –106°C



7.4 – Hydrocarbon Isomers

The difference in geometry affects the isomers' physical properties, such as melting point and boiling point. Geometric isomers differ in some chemical properties as well. If the compound is biologically active, such as a drug, the **cis**- and **trans**- isomers usually have very different effects.



Compare the two possible structures of 2-butene shown.

The arrangement in which the two methyl groups are on the **same** side of the molecule is indicated by the prefix **cis**-. The arrangement in which the two methyl groups are on **opposite** sides of the molecule is indicated by the prefix **trans**-.

These terms derive from Latin:

- **cis** means on the same side.
- **trans** means across from.

Because the double-bonded carbon atoms cannot rotate, the cis- form cannot easily change into the trans- form.

Fats with trans isomers are called **trans fats**. Many pre-packaged foods are made with trans fats because they have a longer shelf life. Evidence suggests that trans fat increases the unhealthy form of cholesterol and decreases the healthy form, which increases the chance of heart disease.

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

7.5 – Aromatic Hydrocarbons

The Structure of Benzene

Natural dyes, like those found in the **fabrics** (أنسجة القماش), and essential **oils** for perfumes contain six-carbon ring structures. Compounds with these structures have been used for centuries.

By the middle of the nineteenth century, chemists had a basic understanding of the structures of hydrocarbons with single, double, and triple covalent bonds. However, certain hydrocarbon **ring** structures remained a mystery.

The simplest example of this class of hydrocarbon is **benzene**, which the English physicist **Michael Faraday** (1791–1867) first isolated in **1825** from the gases given off when either whale oil or coal was heated. Although chemists had determined that benzene's molecular formula was C_6H_6 , it was hard for them to determine what sort of hydrocarbon structure would give such a formula.

Chemists found it difficult to explain the structure of benzene due to the 1:1 ratio of carbon to hydrogen in its chemical formula. Chemists compared benzene (C_6H_6) to hexane (C_6H_{14}) and proposed that benzene must be an unsaturated hydrocarbon to account for the fewer hydrogen atoms.

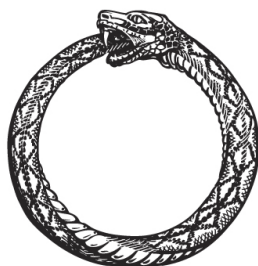
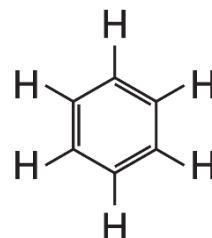
They proposed many different structures, including this one suggested in 1860.



Although this structure has a molecular formula of C_6H_6 , such a hydrocarbon would be unstable and extremely reactive because of its many double bonds. However, benzene was fairly unreactive, and it did not react in the ways that alkenes and alkynes usually react. For that reason, chemists reasoned that structures such as the one shown above must be **incorrect**.

Kekulé's Dream

In 1865, the German chemist **Friedrich August Kekulé** (1829–1896) proposed a different kind of structure for benzene—a **hexagon** of carbon atoms with **alternating** single and double bonds.



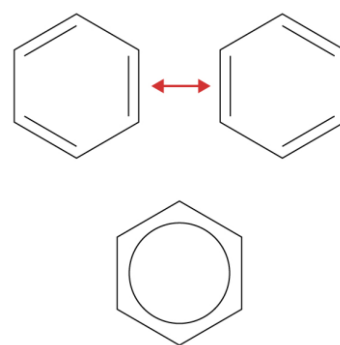
Kekulé was inspired by an Egyptian symbol of a **snake** eating its tail that came to him in a dream. The flat, hexagonal structure Kekulé proposed explained some of the properties of benzene, but it did not explain benzene's lack of reactivity.

7.5 – Aromatic Hydrocarbons

A Modern Model of Benzene

Chemists conducted more research and later confirmed the hexagonal ring structure of benzene proposed by Kekulé. However, benzene's unreactivity could not be explained until the **1930s**, when **Linus Pauling** proposed the theory of **hybrid orbitals**.

When applied to benzene, this theory predicts that the pairs of electrons that form the second bond of each of benzene's double bonds are **not localized** between only two specific carbon atoms as they are in alkenes. Instead, the electron pairs are **delocalized**, which means they are shared among all six carbons in the ring.



In this representation, the circle in the middle of the hexagon symbolizes the cloud formed by the three pairs of electrons.

The delocalization of electron pairs makes the benzene molecule chemically **stable** because electrons shared by six carbon nuclei are harder to pull away than electrons held by only two nuclei.

Benzene is a six-carbon ring compound joined together with alternating single and double bonds.

Benzene is a highly stable organic compound. The unique properties of benzene are due to its structure that differs from other carbon ring compounds.

- Benzene is a **colorless** liquid with a **sweet** odor.
- It is highly **volatile** (*evaporates quickly*) and dissolves slightly in water.
- The melting point of benzene is **5.5°C**, and its boiling point is **80.1°C**.
- Benzene is a good solvent for organic compounds but is highly **toxic**.

Aromatic Compounds

Aromatic Compound is an organic compound with one or more benzene rings in its structure.

Aliphatic Compound is an organic compound with carbon atoms joined by single, double, or triple bonds.

The term *aromatic* was originally used to describe pleasant-smelling oils derived from **spices**, **fruits**, and other plant parts that contained benzene-related compounds.

Hydrocarbons such as the **alkanes**, **alkenes**, and **alkynes** are called **aliphatic compounds** to distinguish them from aromatic compounds. The term *aliphatic* comes from the Greek word for **fat**. Early chemists obtained aliphatic compounds by heating animal fats.

7.5 – Aromatic Hydrocarbons

An aliphatic compound can be:

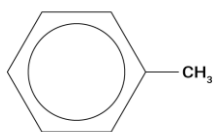
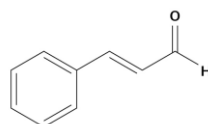
- a straight-chain hydrocarbon
- a branched-chain hydrocarbon
- a non-aromatic carbon ring

Cyclic hydrocarbons are considered aliphatic if the carbon ring is not aromatic (not a benzene ring).

Aromatic compounds contain **unsaturated** aromatic rings in their molecular structure. Aromatic compounds may consist of:

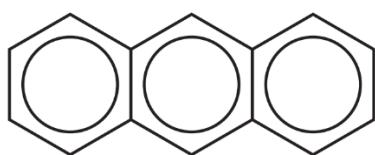
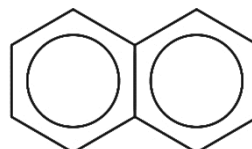
- a single benzene ring with **substituent groups**
- more than one benzene ring fused together

Cinnamaldehyde (C_9H_8O) is the organic compound responsible for the flavor and odor of cinnamon.



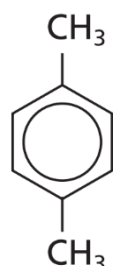
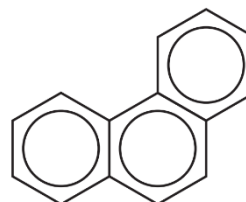
Methylbenzene (C_7H_8) is a solvent used to make paints and nail polish. We commonly refer to it as toluene.

Naphthalene is used to make dyes and as a moth repellent.



Anthracene is used to produce dyes and pigments.

Phenanthrene is present in the atmosphere due to the incomplete combustion of hydrocarbons.



Xylene p-Xylene (1,4-dimethylbenzene) is used to make polyester fibers and fabrics.

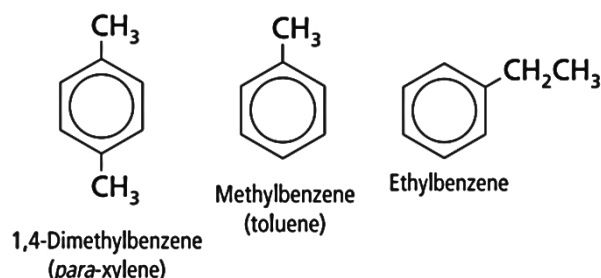
7.5 – Aromatic Hydrocarbons

Note that **naphthalene** has a structure that looks like **two** benzene rings arranged side by side. Naphthalene is an example of a **fused-ring system**, in which an organic compound has two or more cyclic structures with a common side.

Naming Substituted Aromatic Compounds

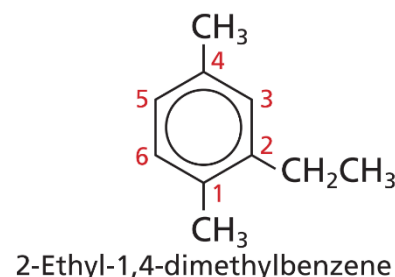
Aromatic compounds can have different groups attached to their carbon atoms. For example, **methylbenzene**, also known as **toluene**, consists of a methyl group attached to a benzene ring in place of one hydrogen atom.

Whenever you see something attached to an aromatic ring system, remember that the hydrogen atom is no longer there. Substituted benzene compounds are named in the same way as **cyclic alkanes**.



For example, **ethylbenzene** has a 2-carbon ethyl group attached, and **1,4-dimethylbenzene**, also known as **para-xylene**, has two methyl groups attached at positions 1 and 4.

Substituted benzene rings are numbered in a way that gives the **lowest-possible** numbers for the substituents



Carcinogens

Many aromatic compounds, particularly **benzene**, **toluene**, and **xylene**, were once commonly used as industrial and laboratory solvents. However, tests have shown that the use of such compounds should be limited because they can affect the health of people who are exposed to them regularly.

Health risks linked to aromatic compounds include

- respiratory ailments,
- liver problems,
- and damage to the nervous system.

Beyond these hazards, some aromatic compounds are **carcinogens**, which are substances that can cause cancer. The first known carcinogen was an aromatic substance discovered around the turn of the twentieth century in **chimney soot**.

7.5 – Aromatic Hydrocarbons

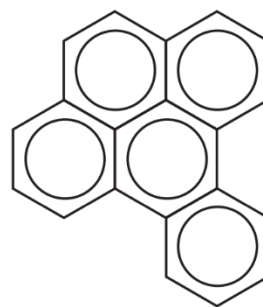
Chimney sweeps in Great Britain were known to have abnormally high rates of cancer. Scientists discovered that the cause of the cancer was the aromatic compound **benzopyrene**.

Benzopyrene is a cancer-causing chemical that is found in

- soot,
- cigarette smoke,
- and car exhaust.

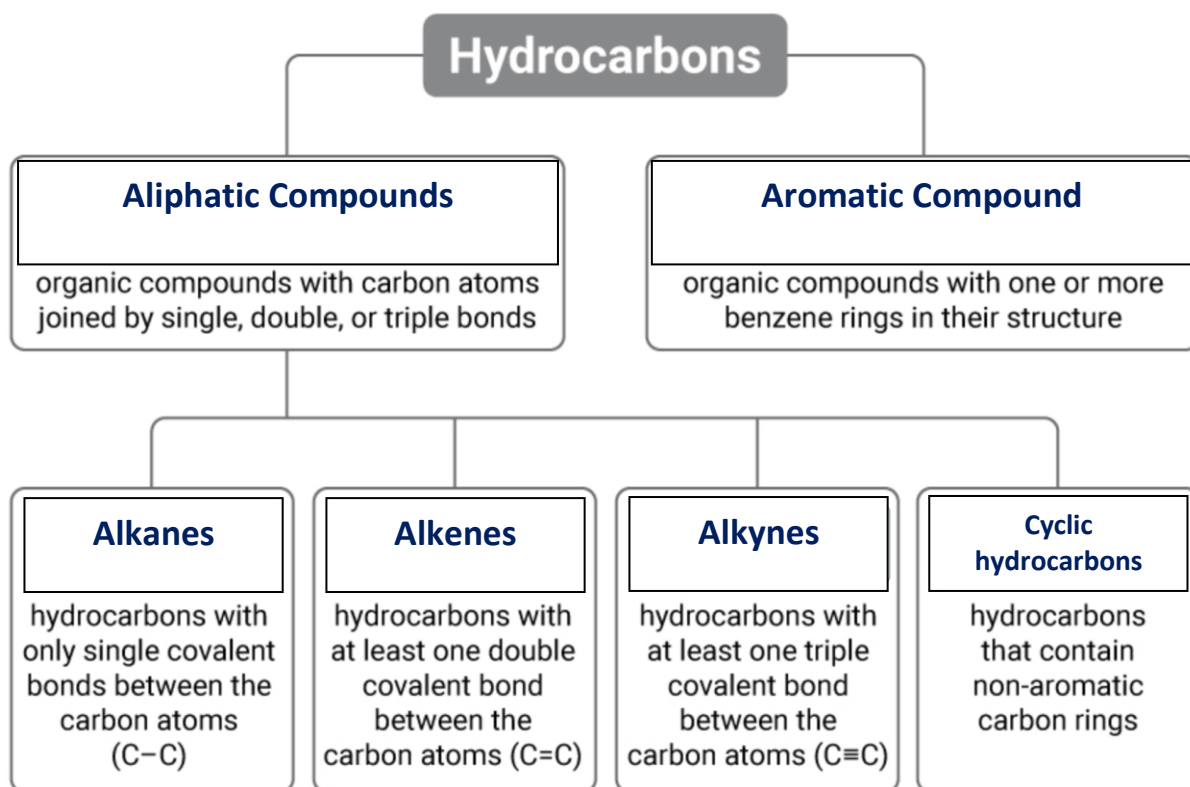
This compound is a by-product of the burning of complex mixtures of organic substances, such as wood and coal. Some aromatic compounds found in gasoline are also known to be carcinogenic.

السخام



Benzopyrene

7.5 – Aromatic Hydrocarbons



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

CHAPTER 7

HYDROCARBONS

CHAPTER SUMMARY

Resources

- Hydrocarbons, Chapter 21, from Glencoe Chemistry: Matter and Change ©2017

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