Hydrocarbon Compounds

22.1 Hydrocarbons

Hydrocarbons contain only the elements carbon and hydrogen.

Reading Strategy

Concept Map A concept map helps you organize concepts using visual relationships and linking words. Mapping out these connections helps you think about how information fits together.

As you read Lesson 22.1, use the concept map below to organize information about hydrocarbons.

EXTENSION Draw structural formulas to show the difference between the two types of alkanes.

Sample answer:

straight-chain: \[
\overbrace{\text{H}_3\text{C} - \text{C} - \text{H}}^{\text{straight-chain:}}
\]

branched-chain: \[
\overbrace{\text{H}_3\text{C} - \text{C} - \text{CH}_3}^{\text{branched-chain:}}
\]

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Lesson Summary

Organic Chemistry and Hydrocarbons  Hydrocarbons are carbon-containing organic compounds that provide a source of energy.
- Carbon has four valence electrons, so a carbon atom always forms four covalent bonds.
- Hydrocarbons are nonpolar molecules.

Alkanes  Alkanes are hydrocarbons that contain only single covalent bonds, either straight-chain or branched.
- A homologous series is a group of compounds that differ from each other by the same unit of change.
- A substituent is an atom or group of atoms that takes the place of a hydrogen atom on a parent hydrocarbon molecule.

After reading Lesson 22.1, complete the following questions.

Organic Chemistry and Hydrocarbons

1. What is organic chemistry?
   
   **It is the study of the chemistry of carbon compounds.**

2. Organic compounds that contain only carbon and hydrogen are called
   
   **hydrocarbons**.

3. Is the following sentence true or false? Hydrogen atoms are the only atoms that can bond to the carbon atoms in a hydrocarbon.  **false**

4. Circle the letter of each statement that is true about carbon’s ability to form bonds.
   
   a. Carbon atoms have four valence electrons.
   b. Carbon atoms always form three covalent bonds.
   c. Carbon atoms can form stable bonds with other carbon atoms.

Alkanes

5. Is the following sentence true or false? Alkanes contain only single covalent bonds.  **true**

6. What is the simplest alkane?  **methane**

7. What are straight-chain alkanes?
   
   **They contain any number of carbon atoms, one after another, in a straight chain.**

8. The names of all alkanes end with the suffix **-ane**.
Match the name of the straight-chain alkane with the number of carbon atoms it contains.

9. nonane  a. 3  
10. propane  b. 4  
11. heptane  c. 7  
12. butane  d. 9

13. The straight-chain alkanes form a(n) homologous series because there is an incremental change of a CH₂ group from one compound in the series to the next.

14. Circle the letter of each condensed structural formula for pentane.
   a. C₅H₁₂  
   b. CH₃CH₂CH₂CH₂CH₃  
   c. CH₃(CH₂)₃CH₃  
   d. C — C — C — C — C

15. The IUPAC system uses prefixes to show the number of carbon atoms in a straight-chain alkane.

16. A(n) substituent is an atom or group of atoms that replaces a hydrogen in a hydrocarbon molecule.

17. Alkyl groups are named by removing the -ane ending of the parent hydrocarbon and adding -yl.

18. What is a branched-chain alkane?
   
   It is an alkane with one or more alkyl groups.

19. Circle the letter of the correct IUPAC name for the molecule below.

   CH₃   CH₃  
   CH₃ — C — CH₂ — CH — CH₃  
   CH₃       

   a. 2,2,4-triethylpentane  
   b. 3-methylpentane  
   c. 2,2,4-trimethylpentane

20. Draw a condensed structural formula for 2-methylhexane.

   CH₃ — CH — CH₂ — CH₂ — CH₂ — CH₃ or C — C — C — C — C — C

   CH₃  
   C

21. Why are hydrocarbon molecules, such as alkanes, nonpolar?

   Hydrocarbon molecules, such as alkanes, are nonpolar because the electron pair in a carbon–hydrogen or a carbon–carbon bond is shared almost equally by the nuclei of the atoms involved.

22. Hydrocarbons and other nonpolar molecules are not attracted to water or polar molecules.
22.2 Unsaturated Hydrocarbons

**Essential Understanding**
An unsaturated hydrocarbon has at least one double or triple carbon-carbon bond.

**Reading Strategy**

**Venn Diagram**
A Venn diagram is a useful tool in visually organizing related information. A Venn diagram shows which characteristics the concepts share and which characteristics are unique to each concept.

As you read Lesson 22.2, use the Venn diagram to compare alkenes and alkynes.

![Venn Diagram](image)

**Lesson Summary**

**Alkenes**
An alkene is a hydrocarbon that contains at least one carbon-carbon double covalent bond.

**Alkynes**
An alkyne is a hydrocarbon that contains at least one carbon-carbon triple covalent bond.

> The simplest alkyne is ethyne, which is also called acetylene.

After reading Lesson 22.2, complete the following questions.

**Alkenes**

1. What is an alkene?
   
   *It is a hydrocarbon containing one or more carbon-carbon double covalent bonds.*
2. Organic compounds that contain the maximum number of hydrogen atoms per carbon atom are called **saturated** compounds.

3. Which family of hydrocarbons contains only saturated compounds? **alkanes**

4. Circle the letter of the correct name for the alkene shown below.

   \[
   \begin{array}{cccc}
   \text{CH}_3 & \text{C} & \text{C} & \text{CH}_3 \\
   \text{CH}_3 & & \text{CH}_2\text{CH}_3 \\
   \end{array}
   \]

   a. 2,3-dimethyl-3-pentene
   b. 2-methyl-3-methyl-2-pentene
   c. 2,3-dimethyl-2-pentene
   d. 3-ethyl-2-methyl-2-butene

5. Is the following sentence true or false? Rotation can occur around a carbon-carbon double bond. **false**

**Alkynes**

6. Hydrocarbons that contain one or more **triple** covalent bonds between carbons are called alkynes.

7. **Ethyne** is the simplest alkyne, and is also known by the common name **acetylene**.

8. What are the major attractive forces between alkane, alkene, or alkyne molecules? The major forces are weak van der Waals forces.

9. Complete the table below with the names of the indicated alkanes, alkenes, and alkynes. For the alkenes and alkynes, assume that the multiple bond occurs between the first two carbons.

<table>
<thead>
<tr>
<th>No. of carbons</th>
<th>Alkane</th>
<th>Alkene</th>
<th>Alkyne</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₆</td>
<td>hexane</td>
<td>1-hexene</td>
<td>1-hexyne</td>
</tr>
<tr>
<td>C₇</td>
<td>heptane</td>
<td>1-heptene</td>
<td>1-heptyne</td>
</tr>
<tr>
<td>C₈</td>
<td>octane</td>
<td>1-octene</td>
<td>1-octyne</td>
</tr>
</tbody>
</table>

10. Is the following sentence true or false? The angle between the carbon atoms in a carbon–carbon triple bond is 120°. **false**
22.3 Isomers

**Essential Understanding** Isomers are hydrocarbons that have the same molecular formula but different molecular structures.

**Reading Strategy**

**Frayer Model** The Frayer Model is a vocabulary development tool. The center of the diagram shows the concept being defined, while the quadrants around the concept are used for providing the details. Use this model when you want to understand a vocabulary term in more detail.

As you read Lesson 22.3, use the Frayer Model below. Place the term isomers in the center of the model. Read the heading in each quadrant. Write details about isomers under each heading. Use the details to improve your understanding of isomers.

<table>
<thead>
<tr>
<th>Definition in your own words</th>
<th>Facts/characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compounds with the same molecular formula but different structural formulas</td>
<td>Different types include constitutional isomers and stereoisomers. Stereoisomers include cis-, trans-, and enantiomers.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Examples</th>
<th>Nonexamples</th>
</tr>
</thead>
<tbody>
<tr>
<td>butane and 2-methylpropane trans-2-pentene, cis-2-pentene</td>
<td>2-methyl-1-butene</td>
</tr>
</tbody>
</table>

**EXTENSION** Draw an example of a constitutional isomer, and the cis- and trans- forms of a stereoisomer.

*Sample answer:*

**constitutional isomer:**

\[
\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_3
\]

or

\[
\text{CH}_3-\text{CH}_2-\text{CH}_3-\text{CH}_3
\]

**trans-:**

\[
\text{CH}_3-\text{C}==\text{C}-\text{CH}_2\text{CH}_3
\]

**cis-:**

\[
\text{CH}_3-\text{C}==\text{C}-\text{CH}_3\text{CH}_2\text{CH}_3
\]
Lesson Summary

Constitutional Isomers  Constitutional isomers, or structural isomers, have the same chemical formula, but their atoms are joined in different arrangements.

- Even though they have the same formula, they have different chemical and physical properties.

Stereoisomers  Stereoisomers have all atoms bonded in the same order but arranged differently in space.

- *Cis-trans* isomers, or geometric isomers, are isomers that result from different arrangements of groups around a double bond.

- Enantiomers, or optical isomers, are mirror images of one another and have the same physical properties.

After reading Lesson 22.3, complete the following questions.

Constitutional Isomers

1. What are structural isomers?
   
   *They are compounds that have the same molecular formula, but the atoms are joined together in a different order.*

2. Is the following sentence true or false? Structural isomers have the same physical properties.  
   false  

3. How many structural isomers are there for C₄H₁₀?  
   two  

4. Name the structural isomers of C₄H₁₀  
   *butane and 2-methylpropane*

5. In general, what determines which of two structural isomers will have the lower boiling point?  
   In general, the more highly branched structure will have the lower boiling point.

Stereoisomers

6. Stereoisomers differ only in the position of their atoms in space.

7. What two things need to be present for geometric isomers to exist?
   
   a.  
   *a double bond*

   b.  
   *at least one substituent on each carbon of the double bond*
8. What are the names of the molecules represented by the ball-and-stick models below?

![cis-2-butene](image1)  
![trans-2-butene](image2)

9. Objects that are __symmetrical__ will produce a reflection that is indistinguishable from the original object.

10. Mirror images of a right hand and a left hand cannot be __superimposed__.

11. What is an asymmetric carbon?

   It is a carbon with four different atoms or groups attached.

12. Is the following sentence true or false? The relationship of optical isomers is similar to that between right and left hands. __true__

13. Look at Figure 22.9 on page 708. Why are these two molecules optical isomers?

   They contain an asymmetric carbon atom.

14. Circle the two asymmetric carbons in the structure shown below.

   ![structure](image3)

22.4 Hydrocarbon Rings

**Essential Understanding** In some hydrocarbon compounds, the two ends of a carbon chain are attached to form a ring.

**Lesson Summary**

**Cyclic Hydrocarbons** Hydrocarbons that contain a carbon ring are called cyclic hydrocarbons.

- Cyclic hydrocarbons can be saturated or unsaturated.
- Cycloalkanes are cyclic hydrocarbons with only single bonds.
Aromatic Hydrocarbons  Aromatic hydrocarbons are usually stable compounds with ring structures in which electrons are shared by many atoms.

- The most important organic ring compound is the hydrocarbon benzene, $C_6H_6$, which is drawn as a six-carbon ring with three double bonds.
- All aromatic hydrocarbons contain at least one benzene ring.

After reading Lesson 22.4, answer the following questions.

Cyclic Hydrocarbons

1. What is a cyclic hydrocarbon?

   **It is a compound that contains a hydrocarbon ring.**

2. The most abundant cyclic hydrocarbons contain five________ or six________ carbons.

3. Is the following sentence true or false? Cyclic hydrocarbons that contain only single carbon-carbon bonds are called cycloalkanes. **true**

4. What are the names of the cyclic hydrocarbons represented below?

   a. cyclohexane  
   b. cyclopentane  
   c. cyclobutane  
   d. cyclopropane

Aromatic Hydrocarbons

5. What is the origin of the name aromatic compounds?

   **Many aromatic compounds have pleasant odors.**

6. Benzene has the chemical formula $C_6H_6$________.

7. Is the following sentence true or false? Any substance that has carbon-carbon bonding like that of benzene is called an aromatic compound. **true**

8. Another name for an aromatic compound is a(an) arene________.

9. What does it mean to say that benzene exhibits resonance?

   **Two equally valid structures can be drawn for benzene.**

10. Molecules that exhibit resonance are more stable________ than similar molecules that do not exhibit resonance.

11. The actual bonds in a benzene ring are identical hybrids________ of single and double bonds.

12. When a benzene ring________ is a substituent on an alkane, it is called a phenyl group.
13. Circle the letter of the name of the compound shown below.

\[
\text{CH}_2\text{CH}_3
\]

a. ethylhexene
b. dimethylbenzene
c. ethylbenzene

14. Derivatives of benzene that have two substituents are called disubstituted benzenes.

15. Why do disubstituted benzenes always have three structural isomers?

There are three possible positions for the two substituents.

Match the terms for naming a disubstituted benzene with the substituent positions they represent.

16. meta  a. 1, 2
17. ortho  b. 1, 3
18. para  c. 1, 4

19. What is another name for the dimethylbenzenes? xylenes

### 22.5 Hydrocarbons From Earth’s Crust

Hydrocarbons in natural gas, petroleum, and coal provide much of the world’s energy.

**Lesson Summary**

**Natural Gas** Natural gas contains methane, ethane, and other alkanes.

- When enough oxygen is present, natural gas burns with a clean, blue flame to produce carbon dioxide, water, and heat.
- Incomplete combustion of natural gas produces soot and carbon monoxide.

**Petroleum** Petroleum contains straight-chain and branched alkanes, aromatics, and other organic compounds.

- Petroleum refining uses boiling point to distill crude oil into fractions.
- One fraction is gasoline, the most commonly used petroleum product.
- Some fractions are cracked, or broken down, into smaller molecules to make products like paints and plastics.
Coal  Over millions of years, intense heat and pressure slowly changed plant remains into coal.

- The types of coal include lignite, which has a high water content; bituminous, or soft coal; and anthracite, or hard coal, which is an excellent fuel source.
- Coals contain much more carbon than hydrogen and leaves soot when burned.

**After reading Lesson 22.5, answer the following questions.**

**Natural Gas**

1. What are fossil fuels?
   - **They are carbon-based fuels derived from the decay of organisms.**

2. List three factors needed to produce fossil fuels from organic residue.
   - a. **pressure**
   - b. **bacterial action**
   - c. **heat**

3. Petroleum and natural gas contain mostly **aliphatic** hydrocarbons.

4. What are the four main components of natural gas?
   - **methane, ethane, propane, and butane**

5. Which noble gas is found in natural gas? **helium**

6. Fill in the missing reactants and products in the equation for the combustion of methane.
   
   \[
   \text{CH}_4(g) + 2 \text{O}_2(g) \rightarrow \text{CO}_2(g) + 2 \text{H}_2\text{O}(g) + \text{heat} \]

7. Propane and butane are sold in **liquid** form to be used as **heating** fuels.

8. Complete combustion of a hydrocarbon produces a blue flame; incomplete combustion produces a yellow flame.

9. What toxic gas is formed during incomplete combustion of a hydrocarbon? **carbon monoxide**

**Petroleum**

10. The first oil well was drilled in **Pennsylvania** in the late 1850s.

11. Is the following sentence true or false? Petroleum is commercially useful without refining. **false**

12. How is petroleum refined? **It is refined by fractional distillation. Compounds are collected according to their boiling points.**

13. Circle the letter of the distillation fraction that represents the highest percent of crude oil.
   - a. natural gas
   - b. gasoline
   - c. kerosene
   - d. lubricating oil
14. Using a catalyst and heat to break hydrocarbons down into smaller molecules is called cracking.

15. Complete the table below about four fractions obtained from crude oil. Indicate where each fraction will be collected from the fractionating column shown at the right.

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Composition of carbon chains</th>
<th>Where in column?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel fuel</td>
<td>$C_{15}$ to $C_{18}$</td>
<td>C</td>
</tr>
<tr>
<td>Gasoline</td>
<td>$C_{5}$ to $C_{12}$</td>
<td>A</td>
</tr>
<tr>
<td>Kerosene</td>
<td>$C_{12}$ to $C_{15}$</td>
<td>B</td>
</tr>
<tr>
<td>Lubricating oil</td>
<td>$C_{16}$ to $C_{36}$</td>
<td>D</td>
</tr>
</tbody>
</table>

**Coal**

16. Peat is the intermediate material that is the first stage in coal formation.

17. Name the three types of coal and the carbon content of each.
   a. **lignite:** about 30%
   b. **bituminous:** 35%–85%
   c. **anthracite:** > 85%

18. Is the following sentence true or false? Coal mines in North America are usually at least a kilometer below Earth’s surface. **false**

19. Coal consists primarily of aromatic compounds of extremely high molar mass.

20. Aromatic compounds produce more soot when burned than do aliphatic fuels.

21. What major air pollutants are produced by burning coal that contains sulfur? $SO_2$ and $SO_3$

22. List four products that can be obtained by distilling coal.
   a. **coal gas**
   b. **coal tar**
   c. **coke**
   d. **ammonia**

23. Which of these products can be distilled further? **coal tar**
Guided Practice Problem

Answer the following questions about Practice Problem 3.

Name these compounds according to the IUPAC system.

\[ \text{a. } \text{CH}_2 - \text{CH}_2 - \text{CH} - \text{CH}_2 - \text{CH}_3 \]
\[ \text{CH}_3 \quad \text{CH}_2 \quad \text{CH}_3 \]

\[ \text{b. } \text{CH}_3 - \text{CH}_2 - \text{CH} - \text{CH}_3 \]

Use the steps on page 702 to name each compound.

Step 1. How long is the longest string of carbon atoms? What is the name of the parent hydrocarbon structure?

a. 6; hexane

b. 4; butane

Step 2. From which side will you number the carbon chain? Why?

a. It should be numbered from the right, because the substituent is closer to this end.

b. It should be numbered from the right, because the substituent is closer to this end.

Step 3. What are the names and positions of the substituents?

a. 3-ethyl

b. 2-methyl

Step 4. Explain why neither name will contain a prefix.

Each compound has only one substituent.

Step 5. Does the name contain any commas or hyphens?

a. The name contains one hyphen, after the 3. It contains no commas.

b. The name contains one hyphen, after the 2. It contains no commas.

Step 6. What is the complete name of each compound?

a. 3-ethylhexane

b. 2-methylbutane

Extra Practice

Circle the symmetric carbon, if there is one, in each of these structures.

\[ \text{a. } \text{CH}_3 - \text{CH} - \text{CH} - \text{CH}_3 \]
\[ \text{CH}_3 \quad \text{CH}_3 \]

\[ \text{b. } \text{CH}_3 - \text{CH} - \text{CH}_2 - \text{CH}_2 \]
\[ \text{CH}_3 \quad \text{CH}_3 \]

[Image of symmetric carbon]
Fill in the tables below with the structural formula and condensed structural formula for the alkenes and alkanes.

<table>
<thead>
<tr>
<th>Name</th>
<th>Ethene</th>
<th>Propene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>$\text{C}_2\text{H}_4$</td>
<td>$\text{C}_3\text{H}_6$</td>
</tr>
</tbody>
</table>
| Complete structural formula | \[
\text{\begin{tabular}{c}
  H \\
  C = C \\
  H \\
\end{tabular}}\]
| Condensed structural formula | $\text{CH}_2\text{CH}_2$ | $\text{CH}_2\text{CHCH}_3$ |

<table>
<thead>
<tr>
<th>Name</th>
<th>Propane</th>
<th>Butane</th>
<th>Ethane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>$\text{C}_3\text{H}_8$</td>
<td>$\text{C}<em>4\text{H}</em>{10}$</td>
<td>$\text{C}_2\text{H}_6$</td>
</tr>
</tbody>
</table>
| Complete structural formula | \[
\text{\begin{tabular}{c}
  H \\
  | \\
  | \\
  | \\
  H \\
\end{tabular}}\]
| Condensed structural formula | $\text{CH}_3\text{CH}_2\text{CH}_3$ | $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ | $\text{CH}_3\text{CH}_3$ |
For Questions 1–11, complete each statement by writing the correct word or words. If you need help, you can go online.

22.1 Hydrocarbons

1. Because carbon has four valence electrons, a carbon atom always forms four covalent bonds.
2. The carbon atoms in an alkane can be arranged in a straight chain or in a chain that has branches.

22.2 Unsaturated Hydrocarbons

3. At least one carbon-carbon bond in an alkene is a double covalent bond.
4. At least one carbon-carbon bond in an alkyne is a triple covalent bond.

22.3 Isomers

5. Constitutional isomers differ in physical properties such as boiling point and melting point. They also have different chemical reactivities.
6. Two types of stereoisomers are cis-trans isomers and enantiomers.

22.4 Hydrocarbon Rings

7. In some hydrocarbon compounds, the carbon chain forms a ring.
8. In a benzene molecule, the bonding electrons between carbon atoms are shared evenly around the ring.

22.5 Hydrocarbons From Earth’s Crust

9. Natural gas is an important source of alkanes of low molar mass.
10. Petroleum refining begins with the distillation of crude oil into fractions according to boiling point.
11. Coal is classified by its hardness and carbon content.

If You Have Trouble With…

<table>
<thead>
<tr>
<th>Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>See Page</td>
<td>695</td>
<td>696</td>
<td>704</td>
<td>705</td>
<td>707</td>
<td>708</td>
<td>711</td>
<td>712</td>
<td>714</td>
<td>715</td>
<td>717</td>
</tr>
</tbody>
</table>
Review Key Ideas

Use the following terms to complete the concept map: alkene, alkane, alkyne, enantiomers, constitutional isomers, aromatic compounds, cracking, cis-trans isomers, cis configuration, trans configuration, hydrocarbons, coal.
Review Key Vocabulary

Write C if the sentence is correct or I if the sentence is incorrect. For each incorrect definition, cross out the incorrect word(s) and write the word(s) that make the definition correct.

1. A group of compounds forms a **homologous series** if there is a constant increment of change in molecular structure from one compound in the series to the next. **C**

2. An atom or group of atoms that can take the place of a carbon atom on a parent hydrocarbon molecule is called a **substituent**. **I**

3. A hydrocarbon that contains one or more carbon-carbon triple covalent bonds is called an **alkyne**. **I**

4. **Constitutional isomers** are compounds that have the same molecular formula, but the atoms are joined together differently. **C**

5. Pairs of molecules that are mirror images and are superimposable are called **enantiomers**, or optical isomers. **I**

6. An **aromatic compound**, or arene, is defined as an organic compound that contains a benzene ring or other ring in which the bonding is like that of benzene. **C**

7. **Cracking** is a controlled process by which coals are broken down or rearranged into smaller, more useful molecules. **I**