3.1 Carbon Chains

Figure A3.1: A vehicle burns more fuel in the winter than in the summer.

For many people, getting up at 5:00 a.m. on a Saturday morning is not exactly the best way to start a weekend; but if you play hockey, you have to practise when your team is able to get ice time. In the winter, this can mean getting up hours before the Sun rises and hopping into a cold vehicle to drive to the arena.

Although this does not sound like a story about chemistry, many of the products involved in an early morning hockey practice are made up of a large number of **carbon-based compounds**. The gasoline used to fuel the car, the plastic used to manufacture the hockey equipment, the synthetic material used to make the uniforms, the medications (like Aspirin, Tylenol, and Advil) players use to treat minor injuries, the breakfasts quickly eaten by players on the way, and even the molecules that make up the body are all carbon-based compounds.

carbon-based compound: a compound primarily made up of carbon atoms

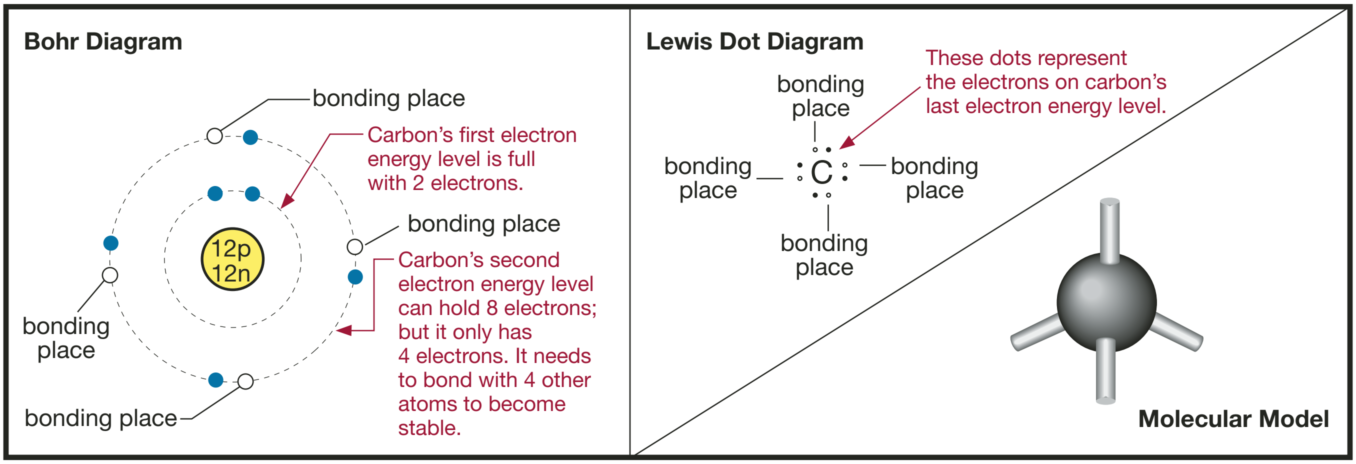
organic chemistry: the study of compounds composed of carbon

Most of the molecules in all living things on Earth are carbon based. This strong presence of carbon-based compounds in organic matter is why the study of these compounds was originally called **organic chemistry**.

Figure A3.2: Molecules in all living things are mostly carbon-based.

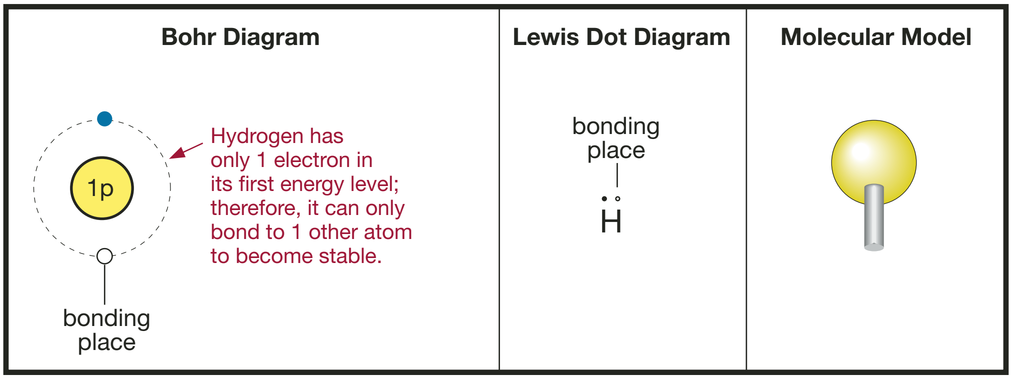
Fats, proteins, and sugars are all made of carbon chains. Why is carbon such an important building block of living and non-living things on Earth? To answer this question, you need to look at the carbon atom itself.

The Carbon Atom



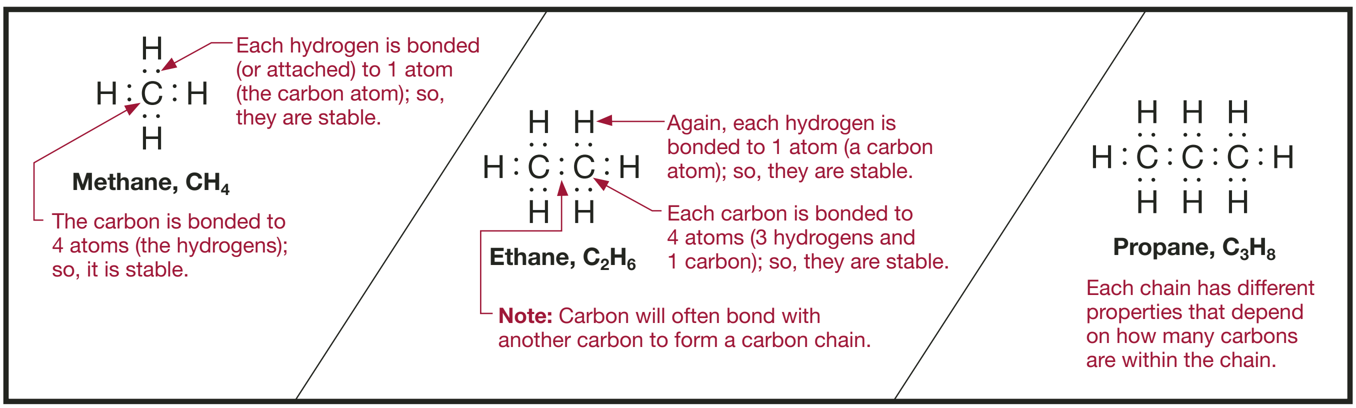
Recall that an atom is most stable when its outer electron energy level is filled with electrons. Carbon has four valence electrons and four empty spots in its outer electron energy level. Carbon needs to form four bonds with other atoms to become stable. Compare a carbon atom to another atom like hydrogen.

The Hydrogen Atom



Hydrogen only requires one electron to fill its outer electron energy level. This means that it bonds to only one other atom to become stable. Because carbon needs to form four bonds to be stable, it is able to form many bonds with other atoms. This gives carbon the ability to produce a large variety of compounds.

Carbon Chains



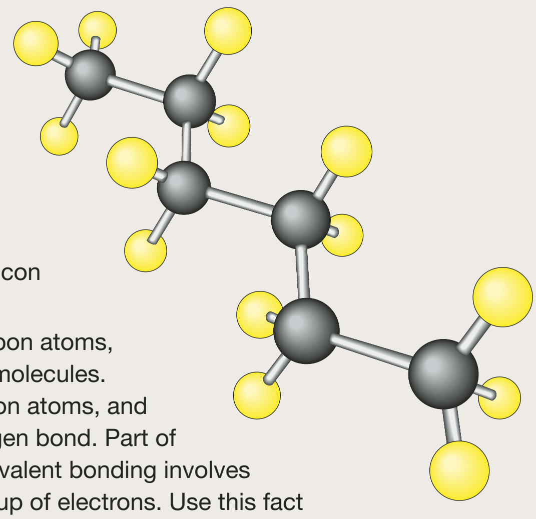
By adding another carbon to the chain, you get a new compound with slightly different properties. The carbon chains in products made from plastics consist of thousands of carbon atoms.

DID YOU KNOW?

Not all carbon-based compounds are considered to be organic. Carbonates, carbides, and oxides of carbon are carbon-based compounds that are inorganic.

Practice

1. Draw Lewis dot diagrams of the following atoms. Determine the number of bonds each atom needs to form to become stable.
   a. carbon **b.** oxygen **c.** fluorine **d.** nitrogen
2. Of the atoms in question 1, hypothesize which atom is capable of producing the largest variety of compounds. State a reason for your choice.
3. Of the atoms in question 1, hypothesize which atom is the most limited in its ability to produce a large variety of compounds. State a reason for your choice.
4. Closely study the molecular model on the right. The black balls represent carbon, and the yellow balls represent hydrogen.



   a. Draw the Lewis dot diagram of this molecule.
   b. How many hydrogen atoms does it take to stabilize all of the carbon atoms in this molecule?
   c. Write the chemical formula for this compound.
5. **a.** Draw a Lewis dot diagram of the silicon atom.
   b. Make a list of the similarities and the differences between the silicon atom and the carbon atom.
   c. There are many more silicon atoms within Earth's crust than carbon atoms, yet there are more carbon-based molecules than silicon-based molecules. Long chains of silicon atoms are not as stable as chains of carbon atoms, and the silicon-hydrogen bond is not as strong as the carbon-hydrogen bond. Part of the reason for these observations has to do with the fact that covalent bonding involves the mutual attraction of the nuclei of two atoms for a shared group of electrons. Use this fact and the answers to the preceding questions to suggest why there are many more carbon-based molecules on Earth than silicon-based molecules.

DID YOU KNOW?

The term *organic* refers to substances that are created by living things, and the term *chemistry* refers to the study of matter. If you put these together, then *organic chemistry* must refer to the study of matter created by living things. This was the original definition of organic chemistry; but it was changed because of a scientific discovery.

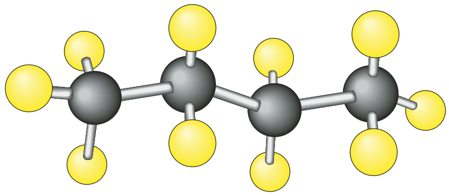
Scientists believed for a very long time that carbon compounds were too complex for scientists to produce in the laboratory. However, in 1828, a chemist named Friedrich Wöhler discovered a way to artificially make a carbon compound, called urea, in a laboratory. This discovery resulted in the production of more complex carbon compounds, and it forced scientists to change the meaning of the term *organic chemistry*. It is now defined as the study of carbon-based molecules rather than the study of matter created by living things.

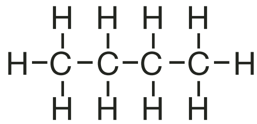
Figure A3.3: Friedrich Wöhler (1800–1882)

The Simplest Carbon Compounds—Hydrocarbons

Since Wöhler's discovery, scientists and technologists have dedicated an immense amount of time and effort in investigating and designing synthetic organic molecules to develop products. Take a look at these molecules and their associated products.

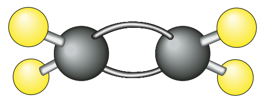
Butane

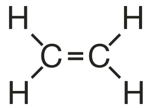




Butane is used as a fuel in barbecue lighters.

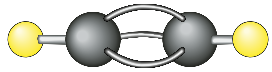
Ethene





Ethene is the starting compound used to produce polyethylene, which is used to make plastic bags.

Ethyne



$H-C\equiv C-H$

Ethyne is the starting compound for polyvinyl chloride (PVC), which is used to make rain gear.

A few observations you might make while looking at these compounds are as follows:

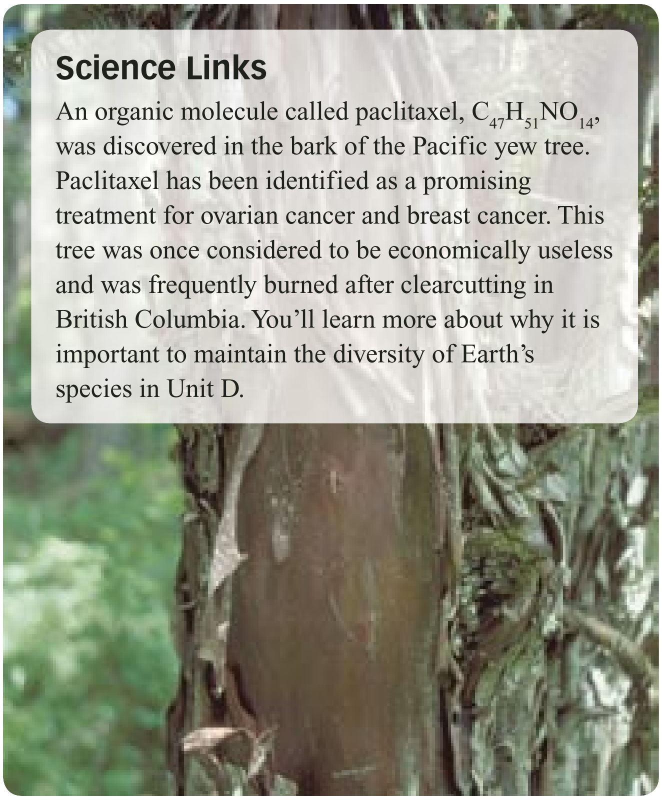
- The only atoms involved are carbon and hydrogen.
- The organic molecules contain single, double, or triple bonds.

hydrocarbon: an organic molecule containing only carbon and hydrogen atoms

The organic molecules you will be exploring in this chapter are all part of a class of organic molecules called the **hydrocarbons**. This name appropriately describes the molecules that belong to this category because they all are made up of only carbon and hydrogen atoms. Hydrocarbons are the simplest group of organic compounds. To understand organic chemistry, you first need to have a good grasp of hydrocarbons because all other organic molecules are very similar.

DID YOU KNOW?

During the winter months, hydrocarbons in the form of fluids leaking from vehicles tend to accumulate on roadways. When the snow and ice melt, these hydrocarbons can find their way into lakes and rivers during the spring run-off. This sudden increase in pollutants every spring creates extra challenges for the facilities that supply Albertans with fresh drinking water.

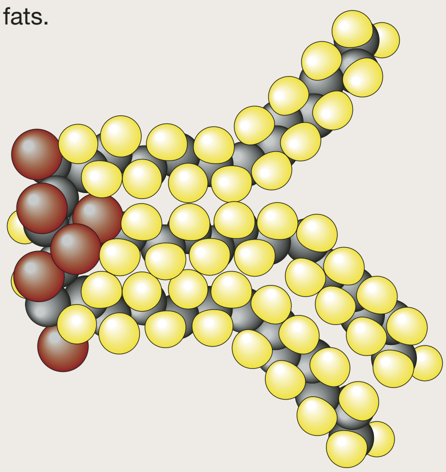


Science Links

An organic molecule called paclitaxel, $C_{47}H_{51}NO_{14}$, was discovered in the bark of the Pacific yew tree. Paclitaxel has been identified as a promising treatment for ovarian cancer and breast cancer. This tree was once considered to be economically useless and was frequently burned after clearcutting in British Columbia. You'll learn more about why it is important to maintain the diversity of Earth's species in Unit D.

Practice

6. Explain how a scientific discovery resulted in the need to change the definition of organic chemistry.
7. Define *hydrocarbon*.
8. A plant has the ability to produce a large variety of complex organic molecules such as oils, proteins, and fats.

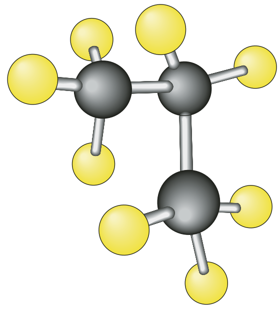


   a. Hypothesize why it is difficult today to make molecules like the one pictured.
   b. About 40% of the world's medicines are organic compounds that were discovered in natural species. This trend is continuing. Every day, new medicines are developed from organic molecules. Why is it important to prevent species from becoming extinct?

Alkanes

Propane, commonly used for barbecuing, is an example of the simplest group of hydrocarbons. These compounds have only single bonds between carbon atoms. This family of molecules is called **alkanes**.

Propane, C_3H_8

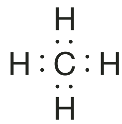
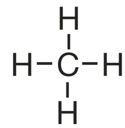
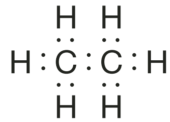
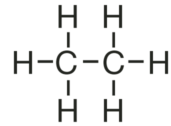
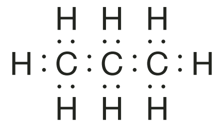
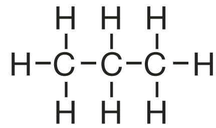
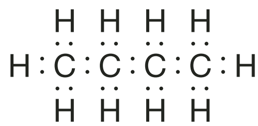
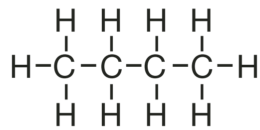


alkane: a hydrocarbon that contains only carbon-carbon single bonds; C_nH_{2n+2}

Each carbon in an alkane is bonded to four other atoms. As a result of the number of hydrogen atoms bonded to the carbon atoms in a hydrocarbon, alkanes have the general chemical formula C_nH_{2n+2}, where n represents the number of carbon atoms in the hydrocarbon.

Figure A3.4: Propane is a gas sold to consumers in refillable cylinders. Many barbecues use propane as a fuel.

ALKANES

Compound	Chemical Formula	Lewis Dot Diagram	Complete Structural Diagram	Condensed Structural Diagram
methane	CH_4			CH_4
ethane	C_2H_6			CH_3-CH_3
propane	C_3H_8			$CH_3-CH_2-CH_3$
butane	C_4H_{10}			$CH_3-CH_2-CH_2-CH_3$

The alkanes depicted are called **continuous-chain alkanes** because the carbon atoms form one chain of consecutive carbon atoms. These hydrocarbons can be represented in several ways:

- a chemical formula—shows the number of carbon and hydrogen atoms in the molecule; includes chemical symbols
- a Lewis dot diagram—shows the sharing of valence electrons between hydrogen and carbon atoms as a pair of dots; includes chemical symbols
- a **complete structural diagram**—shows covalent bonds between atoms as a short line; includes chemical symbols
- a **condensed structural diagram**—shows carbon-carbon bonds but omits carbon-hydrogen bonds; includes chemical symbols

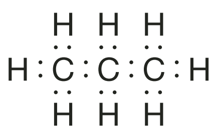
continuous-chain alkane: an alkane consisting of one simple chain of carbon atoms

complete structural diagram: a diagram of a molecule that uses a short line to show the bonds that exist due to the sharing of a pair of electrons between atoms

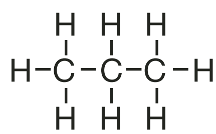
condensed structural diagram: a diagram of a molecule that uses a short line to show carbon-carbon bonds but uses the chemical formula for carbon-hydrogen bonds

Here are examples of the diagrams.

Various Diagrams of Propane, C_3H_8



Lewis Dot Diagram



Complete Structural Diagram

$CH_3-CH_2-CH_3$

Condensed Structural Diagram

Naming Continuous-Chain Alkanes

There are under half a million compounds that do not contain carbon. By comparison, there are in excess of ten million compounds that do contain carbon. Each day, new organic compounds are added to this huge list. Just as each new compound has its own unique structure and set of properties, each compound needs its own characteristic name. People such as pharmacists need a systematic way to name these compounds.

As a result, scientists use a system that allows them to accurately describe the size and structure of each organic molecule. The International Union of Pure and Applied Chemistry (also known as IUPAC) has developed a system for naming organic compounds. This system involves the use of a **prefix** and a **suffix** to convey specific meaning.

Prefixes indicate the number of carbons within a carbon chain, and suffixes indicate the family the molecule belongs to. Different families have different molecular structures.

prefix: the first syllable in the name of an organic molecule that indicates the number of carbon atoms in the molecule

suffix: the second syllable in the name of an organic molecule that indicates the family of the organic molecule

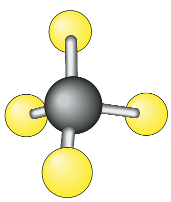
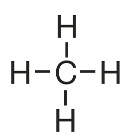
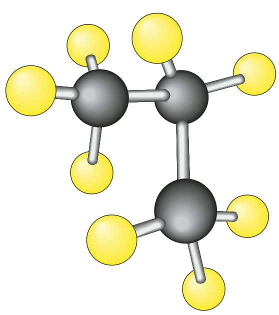
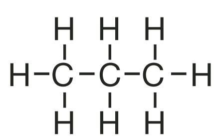
PREFIXES FOR CONTINUOUS CHAINS

Number of Carbons Within the Chain	Prefix
1	meth
2	eth
3	prop
4	but
5	pent
6	hex
7	hept
8	oct
9	non
10	dec

Figure A3.5: Many medicines dispensed by pharmacists are carbon-based compounds.

To name an alkane, you need to match the correct prefix that describes the number of carbon atoms in the longest continuous chain to the suffix for the group. Alkanes have single bonds between the carbon atoms and are described by the suffix *-ane*.

Examples of Naming Continuous Alkanes

Molecular Model	Complete Structural Diagram	Naming Procedure
		This molecule has only **1** carbon atom. Therefore, it is named **meth**ane.
		This molecule has **3** carbon atoms in the chain. Therefore, it is named **prop**ane.

Note: All of the prefixes you need to know are summarized for you on page 556 and in the Science Data Booklet.

COMMON ALKANES AND THEIR APPLICATIONS

Name	Formula	Applications
*meth*ane	$CH_4(g)$	gaseous fuel
*eth*ane	$C_2H_6(g)$	gaseous fuel, starting compound for plastics
*prop*ane	$C_3H_8(g)$	gaseous fuel
*but*ane	$C_4H_{10}(g)$	gaseous fuel
*pent*ane	$C_5H_{12}(l)$	solvents
*hex*ane	$C_6H_{14}(l)$	solvents, liquid fuel
*hept*ane	$C_7H_{16}(l)$	solvents, liquid fuel
*oct*ane	$C_8H_{18}(l)$	solvents, liquid fuel
*non*ane	$C_9H_{20}(l)$	liquid fuel
*dec*ane	$C_{10}H_{22}(l)$	liquid fuel

primary ingredients in gasoline (pentane to octane)

ingredients for jet fuel and diesel fuel (nonane and decane)

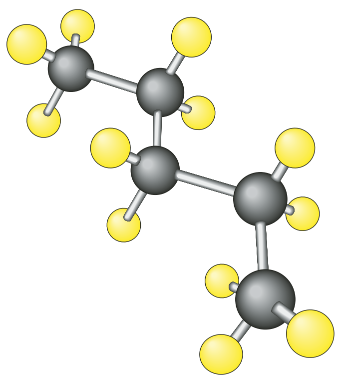
Simplified Structural Diagrams

The structural diagrams of many compounds can become very complex and difficult to draw. Scientists have developed shortcuts to make drawing and reading these structures easier. The following shows increasing simplification starting with the molecular model and ending with the **line structural diagram**.

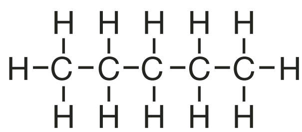
line structural diagram: a diagram of a molecule that only uses a short line to show the bonds between carbon atoms

Simplifying the Diagrams for Pentane, C_5H_{12}

Molecular Model



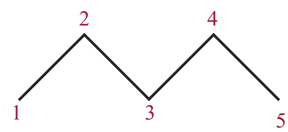
Complete Structural Diagram



Condensed Structural Diagram

$CH_3-CH_2-CH_2-CH_2-CH_3$

Line Structural Diagram



The end of each segment in the line structural diagram represents a carbon atom. Each of the five carbon atoms have been numbered for you.

This diagram assumes that a sufficient number of hydrogen atoms are attached to each carbon, so you do not have to add hydrogens to this diagram.

The diagram for the molecular model of pentane, C_5H_{12}, communicates the most information; but it is the most difficult to draw. The line structural diagram is the easiest to draw; but it communicates the least amount of detail. Most students prefer the complete structural diagram or the condensed structural diagram because they provide a compromise between detail and ease of drawing.

Practice

9. Define each term.

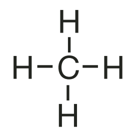
- **a.** alkane
- **b.** continuous-chain alkane
- **c.** Lewis dot diagram
- **d.** complete structural diagram
- **e.** condensed structural diagram
- **f.** line structural diagram

10. Earlier, you were shown examples of three hydrocarbons: butane, ethene, and ethyne. Which of these compounds is classified as an alkane?

11. Draw the Lewis dot diagram, the complete structural diagram, and the line structural diagram for ethane. Explain the differences and similarities that exist between each type of diagram.

12. Explain how a continuous-chain alkane is named.

13. Copy and complete the following table:

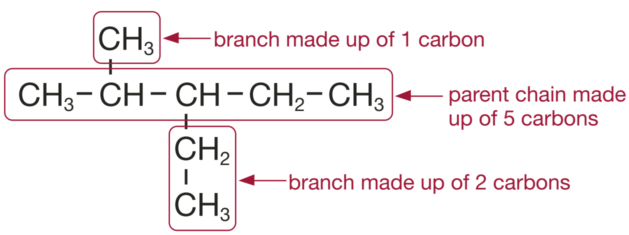
Chemical Formula	Name	Lewis Dot Diagram	Complete Structural Diagram	Application
	ethane			
C_5H_{12}				
	hexane			
				

14. Describe why it is sometimes necessary to simplify the representation of hydrocarbon molecules with line structural diagrams.

Branched Alkanes

Hydrocarbons do not always form continuous-chain alkanes. Carbon atoms are like building blocks, and there are a variety of ways they can be arranged. They often form a long chain with smaller carbon branches attached to them. This kind of hydrocarbon is called a **branched alkane**.

branched alkane: an alkane consisting of a long chain with smaller carbon branches attached to it



Branched alkanes can become complex. Each new branch attached to the parent chain contributes to a molecule's uniqueness and to its own set of properties. The main reason so many organic compounds exist is that there are so many possible locations for branches.

DID YOU KNOW?

While alkanes are important, they do not usually occur in living systems. One exception to this trend is methane. Methane is released by cows and other animals in the form of burps, flatulence, and the decomposition of their wastes. The methane released by livestock accounts for nearly 50% of the methane emissions due to human activity. Since methane is a greenhouse gas that contributes to global warming, many people regard this as cause for concern. One solution is to harvest the methane from animal wastes and use it as a fuel in agricultural operations.

Naming Branched Alkanes

IUPAC has also developed a system for naming branched alkanes. To name a branched alkane, follow these steps:

step 1: Find the longest continuous chain of carbon atoms in the molecule. Circle this chain and label it the parent chain. Name the parent chain as though it is a continuous-chain alkane. For example, a parent chain containing six carbons is called hexane.

step 2: Find all of the branches and circle them individually. Each branch is called an **alkyl group**. Name each group with the prefix that corresponds to the number of carbons within the group; then end its name with the suffix *-yl*. For example, one carbon in the branch is called methyl and two carbons in the branch is called ethyl.

alkyl group: a branch of a larger molecule consisting of an alkane with one hydrogen removed

step 3: To communicate where each branch is on the parent chain, number the carbons on the parent chain starting at the end nearest the first branch. Assign each branch the appropriate number. For example, *2-methyl* means that there is a methyl group on carbon 2.

step 4: Communicate how many of each branch type exists in the molecule. To do this, refer to the following table.

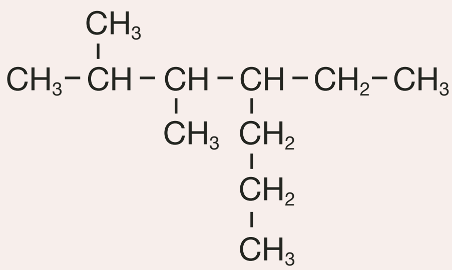
Number of Branches in the Chain	Prefix
1	no prefix
2	di
3	tri
4	tetra
5	penta
6	hexa
7	hepta
8	octa

For example, *dimethyl* means you have two methyl branches in the chain.

step 5: Put the name together, starting with the alkyl groups (in alphabetical order) and ending with the parent chain.

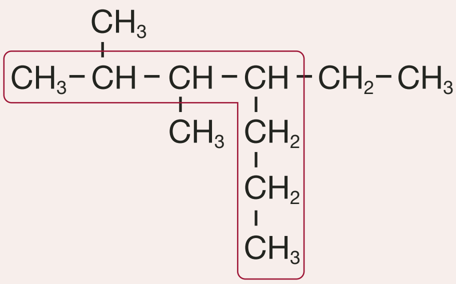
Example Problem 3.1

Name the following compound.



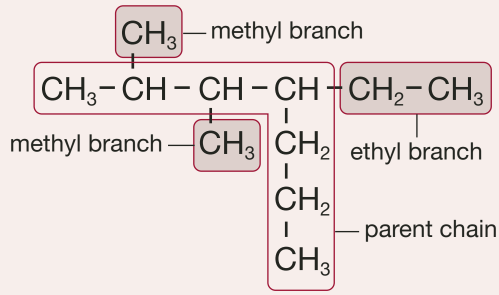
Solution

step 1: Find the longest chain and name it. Be aware that the longest chain may not be in a straight line.



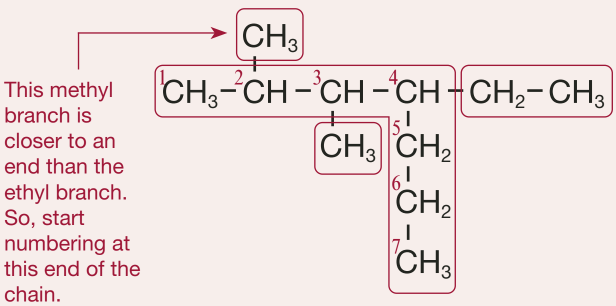
The longest chain has seven carbons. Therefore, the parent molecule is heptane.

step 2: Find all branches and name them.



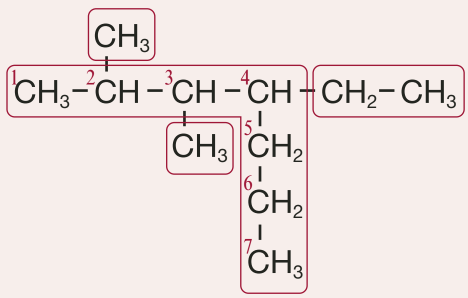
This molecule has two methyl branches and one ethyl branch.

step 3: Number the parent chain.



This molecule has a methyl branch on carbon 2, a methyl branch on carbon 3, and an ethyl branch on carbon number 4.

step 4: Organize branch types and numbers.



Because there are two methyl branches (one on carbon 2 and one on carbon 3), this becomes 2,3-dimethyl. Because there is one ethyl branch on carbon 4, this becomes 4-ethyl. (No *mono* prefix is required.)

step 5: Put the name together.

Parent chain: heptane
Branches: 2,3-dimethyl and 4-ethyl

Place the branches in alphabetical order and end with the parent chain. Do not include the prefixes (e.g., *di* and *tri*) when alphabetizing. Therefore, the name of the compound is **4-ethyl-2,3-dimethylheptane**.

Note that there are commas between numbers and hyphens between numbers and letters.

The Importance of the IUPAC Naming System

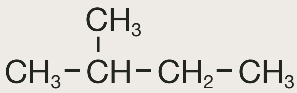
As you saw in Example Problem 3.1, a systematic approach is required to properly name an organic compound. You may wonder why so much effort is put into this process. Why not just use the simple chemical formula for this compound?

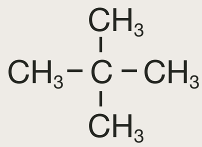
The answer is that the simple chemical formula of the compound in Example Problem 3.1 is $C_{10}H_{22}(l)$. This could mislead you into thinking that this compound was decane, a continuous-chain alkane with a much simpler structure. Due to the fact that carbon atoms can form four single bonds, there are many possible arrangements for a given number of carbon and hydrogen atoms. The IUPAC naming system makes sure that you correctly identify the compound.

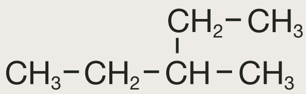
Figure A3.6: A systematic approach for naming organic compounds is essential in the health-care industry.

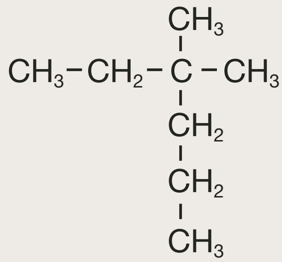
Practice

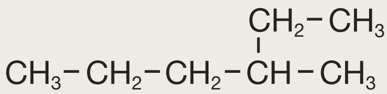
15. Provide the IUPAC name for each compound given.

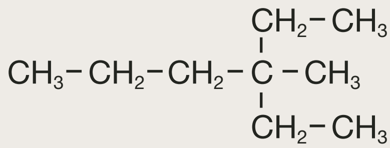
a. 

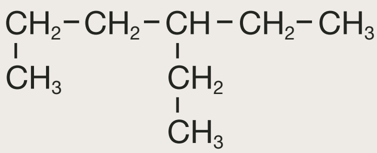
b. 

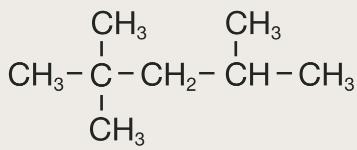
c. 

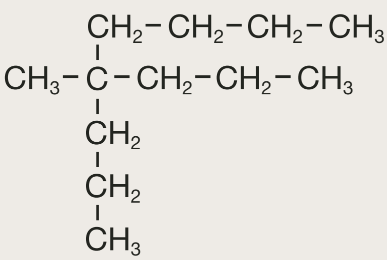
d. 

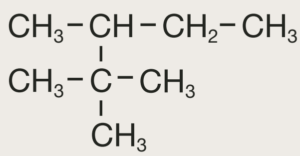
e. 

f. 

g. 

h. 

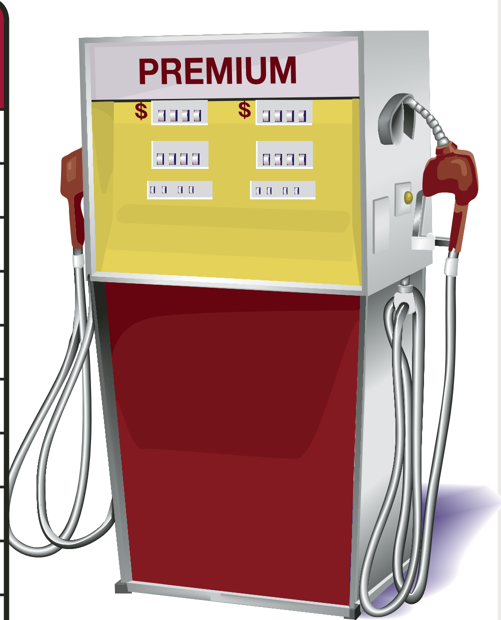
i. 

j. 

Use the following information to answer questions 16 to 18.

Gasoline is a complex mixture of over 500 hydrocarbons. The alkanes, either straight chain or branched, make the greatest contribution to this mixture. The following table lists the most common alkanes that occur in gasoline

Compound	Complete Structural Diagram	Line Structural Diagram	Chemical Formula
butane			
pentane			
hexane			
heptane			
2-methylbutane			
2,2-dimethylpropane			
2,2-dimethylbutane			
2,2-dimethylpentane			
2,2,3-trimethylpentane			
2,2,4-trimethylpentane			



16. Copy and complete the table in your notebook.

17. Check your answers to question 16 by finding images of the molecular model for each compound on the Internet. One possible search strategy is to enter the name of the compound and restrict your search to images. In each case, print an image of the molecular model for the compound and compare it to your complete structural diagram. Remember, the model may need to be rotated to match the orientation you chose for your answers.

18. Carefully examine the chemical formula for each of your answers in question 16.

a. Does each compound have a unique chemical formula?

b. Explain why the IUPAC name of a compound is a better description of the compound than the chemical formula.

3.1 *Summary*

The basic unit for organic chemistry is a chain of carbon atoms. There are a large variety of carbon compounds, and each compound has its own unique properties. Scientists have created a system to name organic compounds that uses prefixes and suffixes to convey information about the molecule's structure.

The simplest organic molecules are hydrocarbons because they consist of only carbon and hydrogen atoms. The simplest hydrocarbons are called alkanes. These hydrocarbons contain only single bonds between the carbon atoms. There are two types of alkanes: continuous-chain alkanes and branched alkanes.

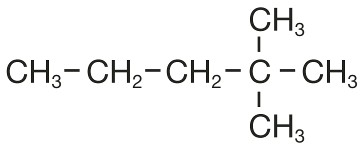
3.1 Questions

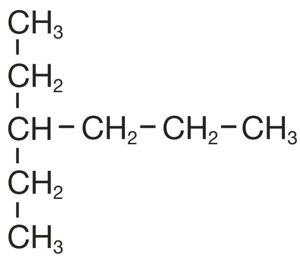
Knowledge

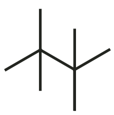
1. Define each of the following terms.
   a. carbon chain
   b. branched alkane
   c. condensed structural diagram
   d. line structural diagram
   e. parent chain
   f. alkyl group
2. Explain why there are a large variety of carbon compounds on Earth.
3. Explain the importance of systems and standards such as the IUPAC rules regarding the naming of hydrocarbons.

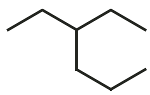
Applying Concepts

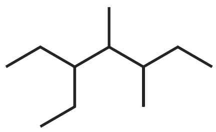
4. Name the following compounds.

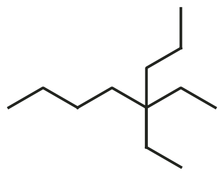
a. 

b. 

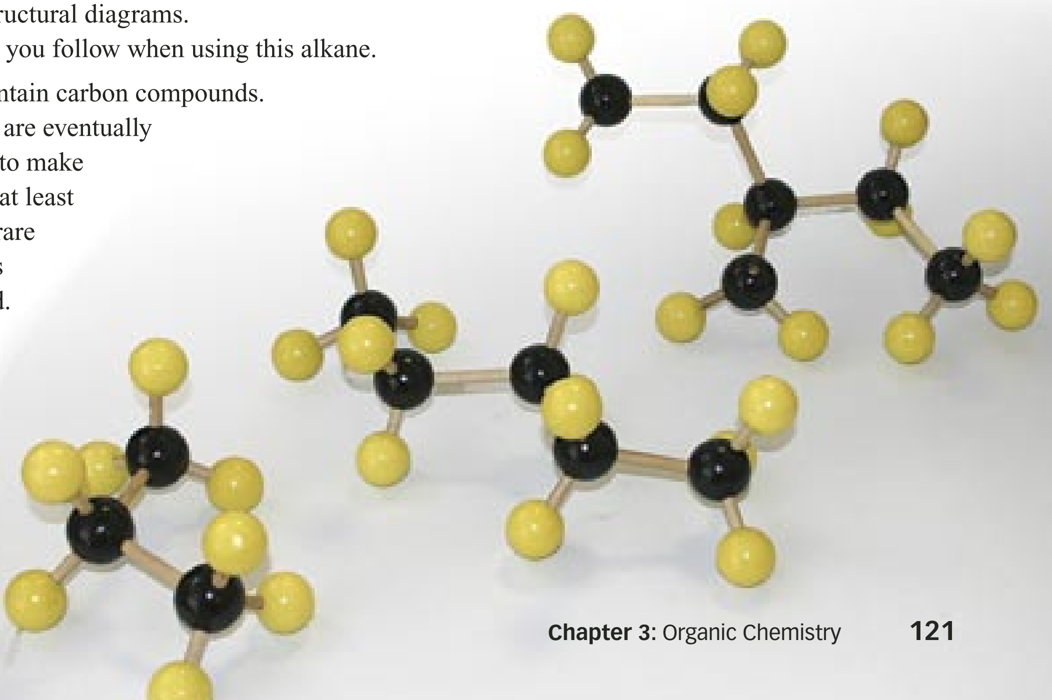
c. 

d. 

e. 

f. 

5. Draw a condensed structural diagram and line structural diagram for each of the following compounds.
   a. 3-ethylhexane
   b. 2,2-dimethylbutane
   c. 3-ethyl-2-methylpentane
   d. 3,4,5-trimethylheptane
   e. 3,4-dimethyl-4-propylheptane
   f. 2,4,6-trimethyloctane
   g. 3-ethyl-4,6-dimethyl-5-propyloctane
6. a. Identify an alkane used in your home.
   b. Draw its complete and line structural diagrams.
   c. Describe any safety measures you follow when using this alkane.
7. Many of the products you use contain carbon compounds. If the world's petroleum reserves are eventually depleted, it will be very difficult to make these compounds. Make a list of at least ten products that would become rare and quite expensive if the world's petroleum reserves were depleted.



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Legend: t = top, m = middle, b = bottom, l = left, r = right

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