The Element Carbon

Carbon's properties allow it to form an almost infinite variety of compounds, many of which are essential to life on Earth. In fact, carbon may be more important to life than any other element. This is because carbon forms the backbone of almost every molecule that living organisms use or make, from the simplest sugars to the most complex proteins and DNA.

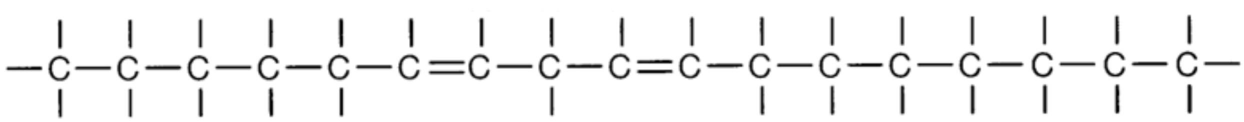
The periodic table tells us that carbon has four valence electrons—exactly half the number of a full outer orbit. Carbon's half full valence shell and relatively small size give it several unique bonding properties.

First, since carbon needs four more electrons to fill its outer orbit, it will form exactly four covalent bonds with other atoms. These bonds may take the form of four single bonds, two double bonds, a double bond and two single bonds, or a triple bond and one single bond.

Carbon is one of the few elements that forms four bonds, and the only element that bonds in such a variety of combinations.

A carbon atom is relatively small, so its valence electrons are relatively close to its nucleus. This closeness allows carbon to form short, strong covalent bonds. In addition, carbon is small enough to share one, two, or three pairs of electrons with other atoms.

Unlike other small elements, carbon will not form a diatomic molecule (C_2). Instead, carbon atoms typically form long chains, as shown below.



The bonds in these chains are short, strong, and covalent, which makes the chains very stable. Carbon is one of the few elements that can successfully form such long chains of atoms.

Long chains of carbon atoms form the basis for a large variety of compounds, including most of the molecules that living organisms make or use. In fact, many of life's important molecules have carbon chains that are very long. For example, a single strand of human DNA can have a chain of well over a million atoms!

Organic Chemistry

In the early 1800s, chemists proposed that living organisms had some "vital force" that allowed them to produce the carbon compounds found in nature. According to this theory, called **vitalism**, a compound that was produced in an organism was one that could not be synthesized in a laboratory.

From the word organism, the compounds of life were classified as organic. Organic compounds were thought to have different properties and obey different laws than other compounds, which were called inorganic.

In 1828, a German chemist named Friedrich Wöhler synthesized urea in his laboratory. Urea is a carbon compound produced in humans and other animals, and it is the principal component of urine.

Wöhler's laboratory synthesis of urea helped to convince other scientists to abandon the vitalism theory. They decided that the compounds of a living organism did not depend on some mysterious, invisible force. Instead they concluded that life's compounds were unique simply because they contained the element carbon.

In general, an **organic compound** is one that contains the element carbon, and **organic chemistry** is the study of carbon-based compounds.

It is important to note that not all carbon-containing compounds are organic. Inorganic carbon compounds include the oxides of carbon (such as carbon dioxide) and compounds that contain the carbonate ion.

Hydrocarbons

Hydrocarbons are organic molecules that contain only carbon and hydrogen. Most hydrocarbons make excellent fuels. They react readily with oxygen to produce carbon dioxide and water, releasing energy and light in the process.

Properties of Hydrocarbons

Hydrocarbons contain only two kinds of bonds: carbon-carbon bonds and carbon-hydrogen bonds. Both carbon-carbon and carbon-hydrogen bonds are nonpolar. Thus, hydrocarbons are very nonpolar molecules, or molecules without positive and negative ends.

Being nonpolar gives hydrocarbons many important properties. Hydrocarbons

- are poor conductors of electricity
- have a low density
- have low boiling points and melting points
- do not dissolve in water

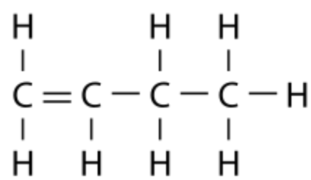
Most of Earth's hydrocarbons exist in deposits of natural gas and petroleum. Natural gas is mostly the hydrocarbon methane, and petroleum is a complex mixture of several hydrocarbons. Both natural gas and petroleum were formed from the compressed, decomposed remains of ancient plants and animals, and so they are called **fossil fuels**.

Hydrocarbon Structures and Formulas

There are thousands of different hydrocarbons that exist. This large number is possible because of the bonding versatility of the carbon atom. The carbon atoms in a hydrocarbon can form single, double, or triple bonds. They can form straight chains, branched chains, or rings. These different combinations allow carbon and hydrogen to form a great variety of compounds.

There are several ways to represent a hydrocarbon. The simplest of these ways is with a **molecular formula**. A molecular formula tells us the name and number of the atoms in a compound. For example, the formula C_4H_8 tells us that the molecule is a hydrocarbon with 4 carbon atoms and 8 hydrogen atoms.

Unfortunately, the molecular formula for a hydrocarbon provides no information about the arrangement of the atoms in the molecule. A more descriptive way to represent an organic molecule is with its **structural formula**. For example, here is the structural formula for one arrangement of C_4H_8:



This formula tells us that a double bond connects the 2 carbon atoms at one end of the molecule. The other carbon atoms are connected with single bonds.

Because structural formulas provide excellent ways to describe and visualize the bonds in an organic molecule, they are often the formula of choice. However, they do have drawbacks.

Structural formulas can be complex and unwieldy, especially for large organic molecules. For this reason, chemists often use a **condensed structural formula**. A condensed structural formula is similar to a structural formula, but it does not include all the dashes that represent the bonds. Typically, it includes dashes for the carbon-carbon bonds, but not for the carbon-hydrogen bonds.

$$CH_2 = CH - CH_2 - CH_3$$

This condensed structural formula represents the same arrangement of C_4H_8 that was shown previously. For complex molecules, a condensed structural formula may be easier to interpret.

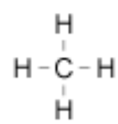
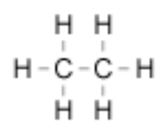
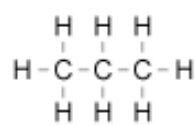
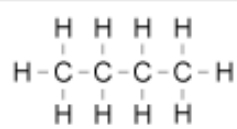
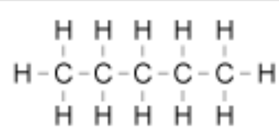
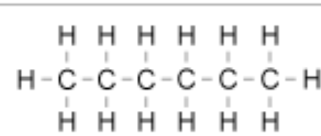
Alkanes

Methane gas is used as a fuel in natural gas appliances. Propane is used in gas barbecues. Butane is used in lighters. Octane is a component in the gasoline that runs your car. All of these hydrocarbons belong to the **alkane** family of hydrocarbons, along with many other compounds.

An alkane is a hydrocarbon with only single bonds.

Straight-chain Alkanes

When an alkane's carbon-carbon bonds can be connected with a single line, the alkane is called a **straight-chain alkane**. The diagram below shows the straight-chain alkanes that have between 1 and 6 carbon atoms.

Name	Formula	Structure	State (at room temp.)
Methane	CH_4		Gas
Ethane	C_2H_6		Gas
Propane	C_3H_8		Gas
Butane	C_4H_{10}		Gas
Pentane	C_5H_{12}		Liquid
Hexane	C_6H_{14}		Liquid

Notice that, except for methane, each alkane has two $-CH_3$ groups, one at each end of the molecule, and different numbers of $-CH_2-$ groups in between. This pattern in alkanes gives rise to an important mathematical principle. If an alkane contains n carbon atoms, then it will also contain $2n+2$ hydrogen atoms.

Another way of expressing this principle is with a **general formula**. The general formula for alkanes is

$$C_nH_{2n+2}$$

Example 1
Determine the general formula for the alkane that has 10 carbon atoms.

Because alkanes contain only single bonds, they always contain the maximum number of hydrogen atoms possible for their number of carbon atoms. To emphasize this, alkanes are often described as **saturated hydrocarbons**. A saturated hydrocarbon is one whose carbon skeleton is filled to capacity with hydrogen atoms.

Naming Straight-chain Alkanes

The name of any straight-chain alkane consists of two parts.

1. A root part that tells you how many carbon atoms the alkane has.

2. The suffix *–ane*.

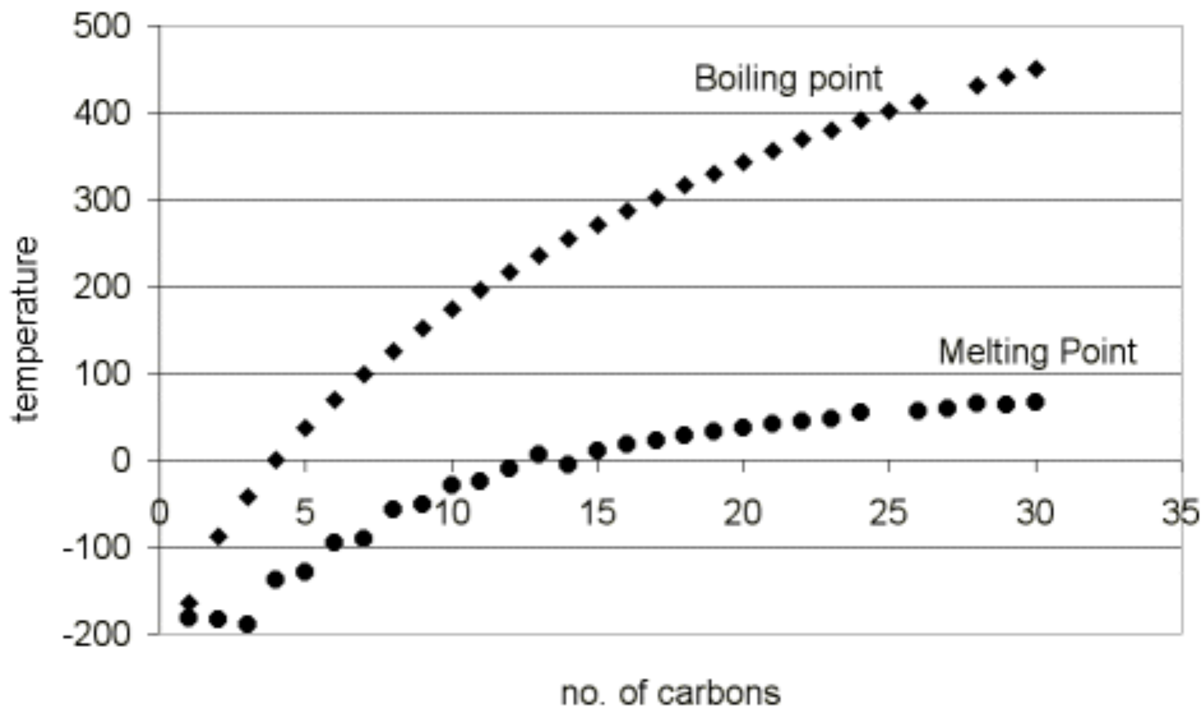
The table below lists the root words for chains of 1 to 10 carbon atoms.

Number of Carbon Atoms	Root Word	Number of Carbon Atoms	Root Word
1	meth–	6	hex–
2	eth–	7	hept–
3	prop–	8	oct–
4	but–	9	non–
5	pent–	10	dec–

Example 2
Write the name of the straight-chain alkane with 8 carbon atoms.

Properties of Alkanes

Low molecular mass alkanes are gases at room temperature and normal atmospheric pressure. As the molecular mass increases, hydrocarbons become liquids and then solids. The graph below illustrates the melting and boiling points of the alkanes as the number of carbon atoms increases.



Example 3
At what temperature would propane gas become a liquid?

Worksheet #1

1. Draw structural formulas for each of the following straight-chain alkanes:

    a) Heptane

    b) Octane

    c) Nonane

    d) Decane

2. Write condensed structural formulas for the first 10 alkanes (methane to decane).

3. Based on the graph of melting and boiling points of alkanes, predict the physical state of each of the following:

    a) Octane at $200°C$

    b) Methane at $20°C$

    c) An alkane with 20 carbon atoms at $0°C$.