

Lab Manual 11: Introduction to Organic Chemistry

General Chemistry for
Health Sciences Lab

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Table of Contents

License Page	3
Introduction	4
Goal of Lab 11: Introduction to Organic Chemistry	4
Theory and Background	4
Alkanes	8
The Basics of Organic Nomenclature: Naming Alkanes	13
Alkenes	18
Isomers of Alkenes	19
Alkynes	20
Aromatic Hydrocarbons	21
Alcohols	23
Naming Alcohols	24
Ethers	24
Aldehydes and Ketones	25
Carboxylic Acids and Esters	29
Computing Molecular Mass for a Covalent Compound	34
Organic Reactions: Aspirin Synthesis	35
Benefits and Side Effects of Aspirin	36
Lab Examples	36
Relations to Medicine and Everyday Life	47
Organic Compounds Found in Medicine	53
Carbon in Environment	54
References	54

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Introduction

In the early 19th century, Jöns Jacob Berzelius classified chemical compounds as inorganic and organic. Inorganic compounds are defined as compounds that do not contain carbon as a base element; they are minerals, and most of the inorganic compounds contain a metal. Since inorganic compounds are formed by ionic bonding by metals and nonmetals, they show extremely high melting and boiling points. Therefore, these molecules have a vast variety of applications. On the other hand, an organic compound is defined as any chemical compound that contains carbon as a principle element. It is believed that organic compounds came from living organisms at the beginning of the nineteenth century – this is the reason for the use of the word organic. However, this idea was shown to be incorrect when the German Chemist Friedrich Wöhler synthesized urea (organic compound) by heating an inorganic compound, ammonium cyanate.

Organic chemistry is a branch of chemistry that studies the structure, properties, and reactions of organic compounds. Organic compounds always contain carbon and hydrogen and can also contain elements such as oxygen, sulfur, nitrogen, and halogens. Organic compounds are important because all living matter contains carbon. There are many different organic molecules, which can be divided into two main categories: hydrocarbons and biological molecules. Examples of aliphatic hydrocarbons are propane, alcohol, and methane. Aromatic molecules are those made of rings of carbon atoms like benzene. Biological molecules are subject for the next lab and they are carbohydrates, lipids, amino acids, and proteins. So far, we have concentrated on learning about elements, inorganic compounds, their properties, relations, and their reactions. With this lab, we will focus on carbon-based elements.

Goal of Lab 11: Introduction to Organic Chemistry

The main objective of this lab is to start learning about the simplest organic compounds that contain only elements of carbon and hydrogen. In addition to carbon and hydrogen, so many organic compounds contain oxygen, sulfur, and nitrogen as functional groups. This lab explores organic compounds that contain functional groups. We will also explore other families of organic compounds such as aldehydes, ketones, and ether and their reactions. Chemical reactions of organic compounds will be explored by aspirin synthesis.

Theory and Background

All living things on earth are formed mostly of carbon compounds. The prevalence of carbon compounds in living things has led to the epithet “carbon-based” life. The truth is we know of no other kind of life. Early chemists regarded substances isolated from

organisms (plants and animals) as a different type of matter that could not be synthesized artificially, and these substances were thus known as *organic compounds*. The widespread belief called vitalism held that organic compounds were formed by a vital force present only in living organisms. The German chemist Friedrich Wohler was one of the early chemists to refute this aspect of vitalism, when, in 1828, he reported the synthesis of urea, a component of many body fluids, from nonliving materials. Since then, it has been recognized that organic molecules obey the same natural laws as inorganic substances, and the category of organic compounds has evolved to include both natural and synthetic compounds that contain carbon. Some carbon-containing compounds are *not* classified as organic, for example, carbonates and cyanides, and simple oxides, such as CO and CO₂. Although a single, precise definition has yet to be identified by the chemistry community, most agree that a defining trait of organic molecules is the presence of carbon as the principal element, bonded to hydrogen and other carbon atoms.

Today, organic compounds are key components of plastics, soaps, perfumes, sweeteners, fabrics, pharmaceuticals, and many other substances that we use every day. Figure 11.1 shows everyday examples of organic compounds.



Figure 11.1 All organic compounds contain carbon and most are formed by living things, although they are also formed by geological and artificial processes. [credit: as cited by *Chemistry 2e*. [Figure 20.1](#). OpenStax. [CC BY](#), (left) modification of work by Jon Sullivan, (left middle) modification of work by Deb Tremper, (right middle) modification of work by “annszyp”/Wikimedia Commons, (right) modification of work by George Shuklin.]

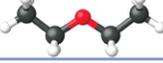
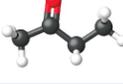
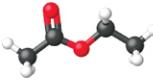
The value to us of organic compounds ensures that organic chemistry is an important discipline within the general field of chemistry. In this lab manual, we discuss why the element carbon gives rise to a vast number and variety of compounds, how those compounds are classified, and the role of organic compounds in representative biological and industrial settings.

The largest database of organic compounds lists about 10 million substances, which include compounds originating from living organisms and those synthesized by chemists. The number of potential organic compounds has been estimated at 10^{60} —an

astronomically high number. The existence of so many organic molecules is a consequence of the ability of carbon atoms to form up to four strong bonds to other carbon atoms, resulting in chains and rings of many different sizes, shapes, and complexities.

The simplest **organic compounds** contain only the elements carbon and hydrogen and are called hydrocarbons. Even though they are composed of only two types of atoms, there is a wide variety of hydrocarbons because they may consist of varying lengths of chains, branched chains, and rings of carbon atoms, or combinations of these structures. In addition, hydrocarbons may differ in the types of carbon-carbon bonds present in their molecules. Many hydrocarbons are found in plants, animals, and their fossils; other hydrocarbons have been prepared in the laboratory. We use hydrocarbons every day, mainly as fuels, such as natural gas, acetylene, propane, butane, and the principal components of gasoline, diesel fuel, and heating oil. The familiar plastics polyethylene, polypropylene, and polystyrene are also hydrocarbons. We can distinguish several types of hydrocarbons by differences in the bonding between carbon atoms. This leads to differences in geometries and in the hybridization of the carbon orbitals. [Table 11.1](#) summarizes the class of organic compounds will be covered in this lab.

Table 11.1 Summary of organic compounds

Compound Name	Structure of Compound and Functional Group (red)	Example	
		Formula	Name
alkene	$C=C$	C_2H_4	 ethene
alkyne	$C\equiv C$	C_2H_2	 ethyne
alcohol	$R-\overset{\cdot\cdot}{\underset{\cdot\cdot}{O}}-H$	CH_3CH_2OH	 ethanol
ether	$R-\overset{\cdot\cdot}{\underset{\cdot\cdot}{O}}-R'$	$(C_2H_5)_2O$	 diethyl ether
aldehyde	$R-\overset{\cdot\cdot}{\underset{\cdot\cdot}{\parallel}{C}}-H$	CH_3CHO	 ethanal
ketone	$R-\overset{\cdot\cdot}{\underset{\cdot\cdot}{\parallel}{C}}-R'$	$CH_3COCH_2CH_3$	 methyl ethyl ketone
carboxylic acid	$R-\overset{\cdot\cdot}{\underset{\cdot\cdot}{\parallel}{C}}-\overset{\cdot\cdot}{\underset{\cdot\cdot}{O}}-H$	CH_3COOH	 acetic acid
ester	$R-\overset{\cdot\cdot}{\underset{\cdot\cdot}{\parallel}{C}}-\overset{\cdot\cdot}{\underset{\cdot\cdot}{O}}-R'$	$CH_3CO_2CH_2CH_3$	 ethyl acetate
amine	$R-\overset{\cdot\cdot}{\underset{\cdot\cdot}{N}}-H$ $R-\overset{\cdot\cdot}{\underset{\cdot\cdot}{N}}-H$ $R-\overset{\cdot\cdot}{\underset{\cdot\cdot}{N}}-R''$ H R' R'	$C_2H_5NH_2$	 ethylamine
amide	$R-\overset{\cdot\cdot}{\underset{\cdot\cdot}{\parallel}{C}}-\overset{\cdot\cdot}{\underset{\cdot\cdot}{N}}-R'$ H	CH_3CONH_2	 acetamide

[credit: *Chemistry 2e*. [Table Summary of Organic Chemistry](#). OpenStax. [CC BY](#).]

A **bond angle** is the angle between any two bonds that include a common atom, usually measured in degrees. A **bond distance** (or bond length) is the distance between the nuclei of two bonded atoms along the straight line joining the nuclei. Bond distances are measured in Ångstroms ($1 \text{ \AA} = 10^{-10} \text{ m}$) or picometers ($1 \text{ pm} = 10^{-12} \text{ m}$, $100 \text{ pm} = 1 \text{ \AA}$). [Figure 11.2](#) illustrates the bond angle and bond length of a molecule. It is important to be able to describe molecular bonds in terms of their distances, angles, and relative arrangements in space because it helps to understand designing functional organic compounds with specific properties.

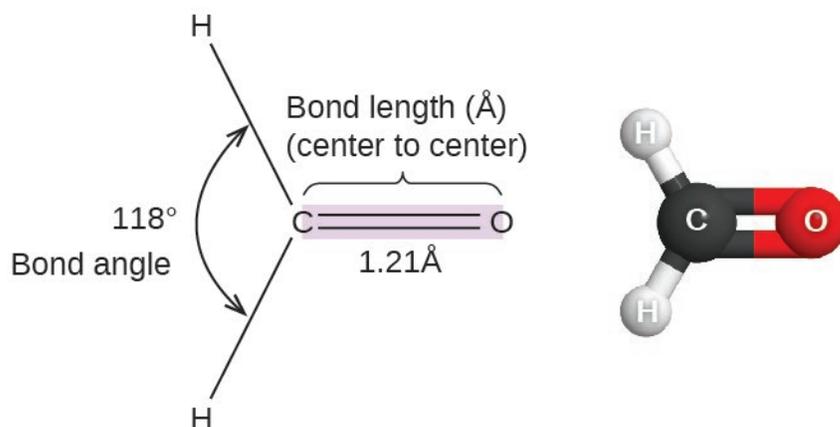


Figure 11.2 Bond distances (lengths) and angles are shown for the formaldehyde molecule, H₂CO. [credit: *Chemistry 2e*. [Figure 7.14](#). OpenStax. [CC BY](#).]

Valence shell electron-pair repulsion theory (VSEPR theory) enables us to predict the molecular structure, including approximate bond angles around a central atom, of a molecule from an examination of the number of bonds and lone electron pairs in its Lewis structure. The VSEPR model assumes that electron pairs in the valence shell of a central atom will adopt an arrangement that minimizes repulsions between these electron pairs by maximizing the distance between them. The electrons in the valence shell of a central atom form either bonding pairs of electrons, located primarily between bonded atoms, or lone pairs. The electrostatic repulsion of these electrons is reduced when the various regions of high electron density assume positions as far from each other as possible.

Alkanes

Alkanes, or **saturated hydrocarbons**, contain only single covalent bonds between carbon atoms. Each of the carbon atoms in an alkane has sp^3 hybrid orbitals and is bonded to four other atoms, each of which is either carbon or hydrogen. The Lewis structures and models of methane, ethane, and pentane are illustrated in [Figure 11.3](#). Carbon chains are usually drawn as straight lines in Lewis structures, but one has to remember that Lewis structures are not intended to indicate the geometry of molecules. Notice that the carbon atoms in the structural models (the ball-and-stick and space-filling models) of the pentane molecule do not lie in a straight line. Because of the sp^3 hybridization, the bond angles in carbon chains are close to 109.5° , giving such chains in an alkane a zigzag shape.

The structures of alkanes and other organic molecules may also be represented in a less detailed manner by condensed structural formulas (or simply, *condensed formulas*). Instead of the usual format for chemical formulas in which each element symbol appears just once, a condensed formula is written to suggest the bonding in the

molecule. These formulas have the appearance of a Lewis structure from which most or all of the bond symbols have been removed. Condensed structural formulas for ethane and pentane are shown at the bottom of Figure 11.3.

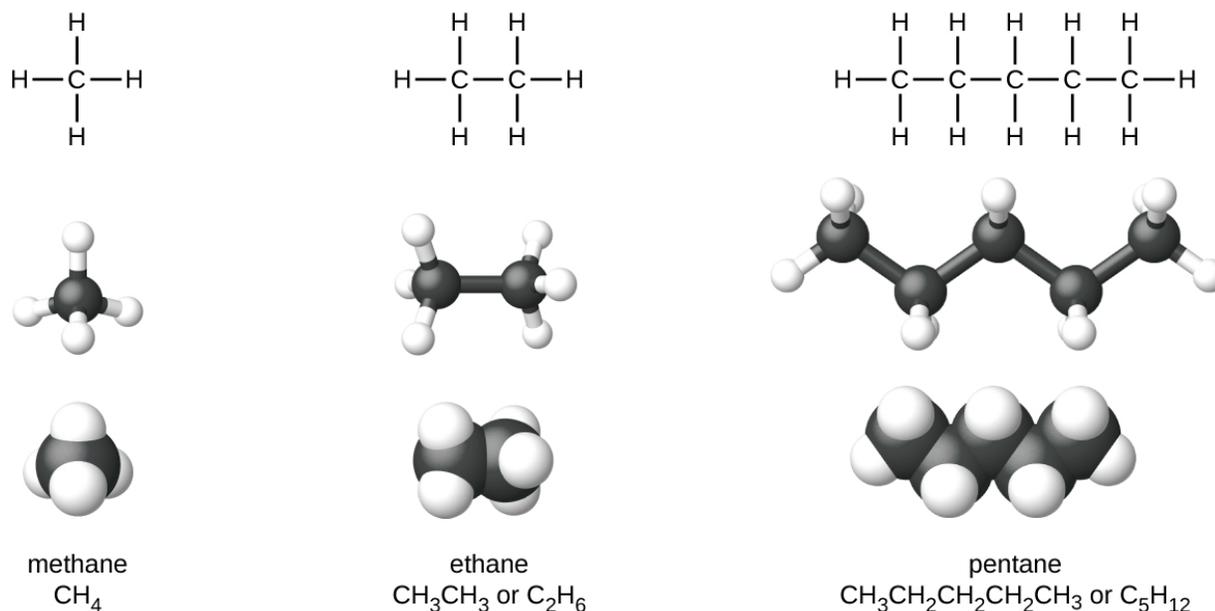


Figure 11.3 Pictured are the Lewis structures, ball-and-stick models, and space-filling models for molecules of methane, ethane, and pentane. [credit: *Chemistry 2e*. [Figure 20.2](#). OpenStax. [CC BY](#).]

A common method used by organic chemists to simplify the drawings of larger molecules is to use a **skeletal structure** (also called a line-angle structure). In this type of structure, carbon atoms are not symbolized with a C, but represented by each end of a line or bend in a line. Hydrogen atoms are not drawn if they are attached to a carbon. Other atoms besides carbon and hydrogen are represented by their elemental symbols. [Figure 11.4](#) shows three different ways to draw the same structure.

Alkane	Molecular Formula	Melting Point (°C)	Boiling Point (°C)	Phase at STP	Number of Structural Isomers
octane	C ₈ H ₁₈	-56.8	125.7	liquid	18
nonane	C ₉ H ₂₀	-53.6	150.8	liquid	35
decane	C ₁₀ H ₂₂	-29.7	174.0	liquid	75
tetradecane	C ₁₄ H ₃₀	5.9	253.5	solid	1858
octadecane	C ₁₈ H ₃₈	28.2	316.1	solid	60,523

[credit: *Chemistry 2e*. [Table 20.1](#). OpenStax. [CC BY](#).]

Hydrocarbons with the same formula, including alkanes, can have different structures. For example, two alkanes have the formula C₄H₁₀: They are called *n*-butane and 2-methylpropane (or isobutane), and have the following Lewis structures shown in Figure 11.5:

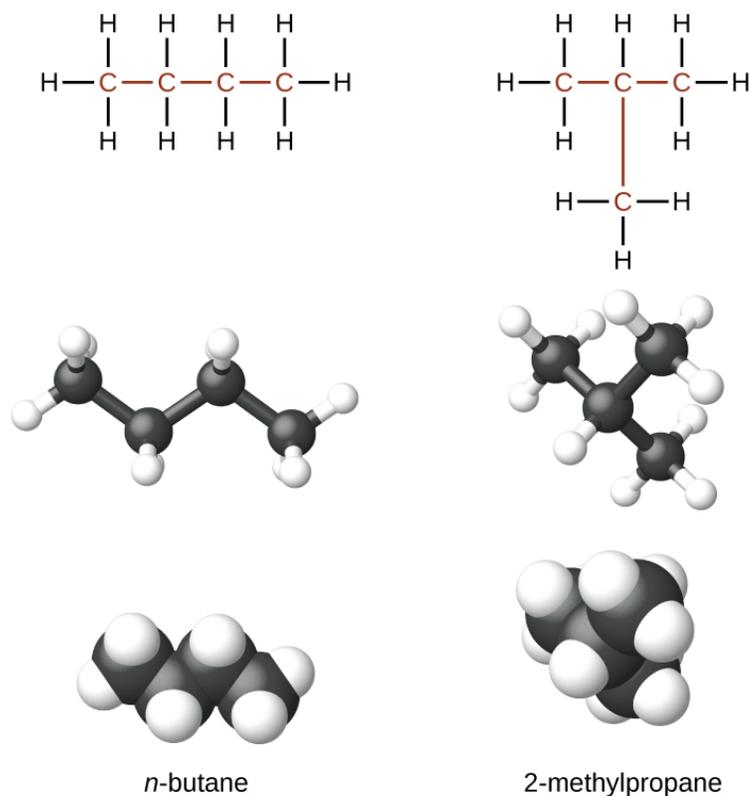


Figure 11.5 Lewis structures for two alkanes. [credit: *Chemistry 2e*. [Hydrocarbon Lewis structure examples](#). OpenStax. [CC BY](#).]

The compounds *n*-butane and 2-methylpropane are structural isomers (the term constitutional isomers is also commonly used). Constitutional isomers have the same molecular formula but different spatial arrangements of the atoms in their molecules. The *n*-butane molecule contains an *unbranched chain*, meaning that no carbon atom is bonded to more than two other carbon atoms. We use the term *normal*, or the prefix *n*, to refer to a chain of carbon atoms without branching. The compound 2-methylpropane has a branched chain (the carbon atom in the center of the Lewis structure is bonded to three other carbon atoms).

Identifying isomers from Lewis structures is not as easy as it looks. Lewis structures that look different may actually represent the same isomers. For example, the three structures in Figure 11.6 all represent the same molecule, *n*-butane, and hence are not different isomers. They are identical because each contains an unbranched chain of four carbon atoms.

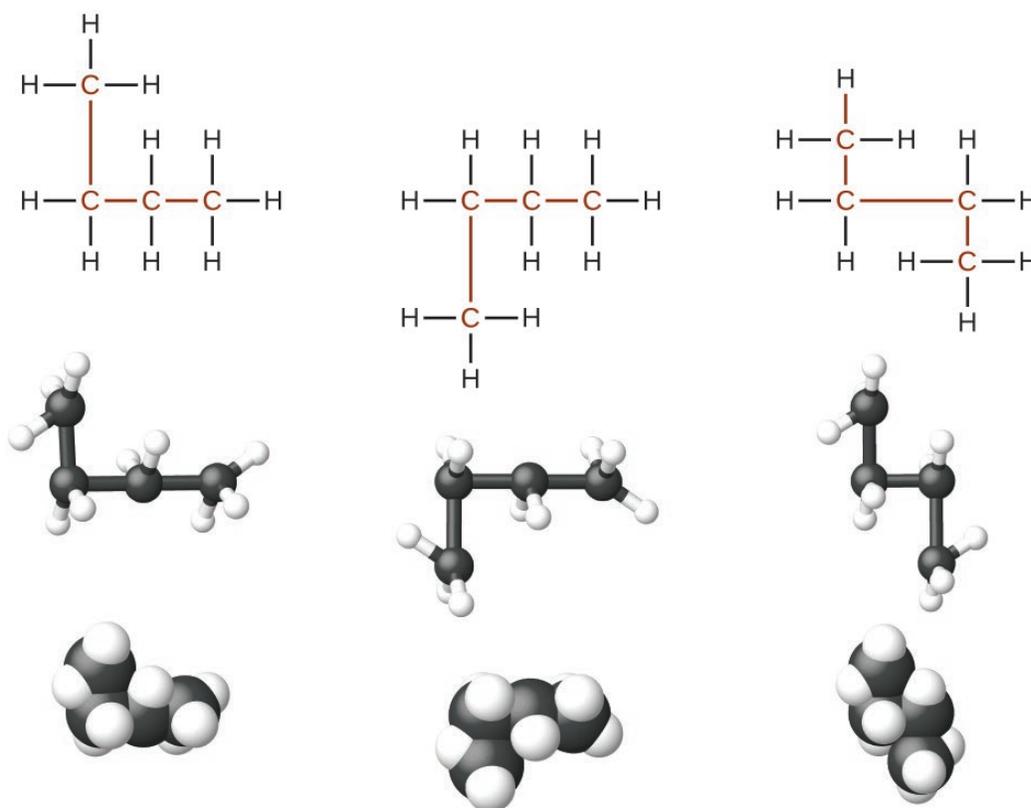


Figure 11.6 These three representations of the structure of *n*-butane are not isomers because they all contain the same arrangement of atoms and bonds. [credit: *Chemistry 2e*. [Figure 20.4](#). OpenStax. [CC BY](#).]

The Basics of Organic Nomenclature: Naming Alkanes

The International Union of Pure and Applied Chemistry (IUPAC) has devised a system of nomenclature that begins with the names of the alkanes and can be adjusted from there to account for more complicated structures. The nomenclature for alkanes is based on two rules:

1. To name an alkane, first identify the longest chain of carbon atoms in its structure. A two-carbon chain is called ethane; a three-carbon chain, propane; and a four-carbon chain, butane. Longer chains are named as follows: pentane (five-carbon chain), hexane (6), heptane (7), octane (8), nonane (9), and decane (10). These prefixes can be seen in the names of the alkanes described in [Table 11.2](#).
2. Add prefixes to the name of the longest chain to indicate the positions and names of **substituents**. Substituents are branches or functional groups that replace hydrogen atoms on a chain. The position of a substituent or branch is identified by the number of the carbon atom it is bonded to in the chain. We number the carbon atoms in the chain by counting from the end of the chain nearest the substituents. Multiple substituents are named individually and placed in alphabetical order at the front of the name. Figure 11.7 exemplifies organic nomenclature of Alkanes.

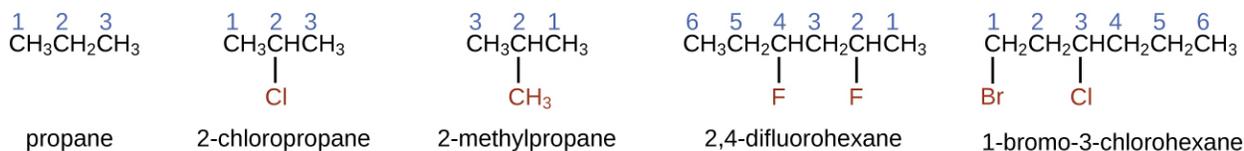


Figure 11.7 Examples of the naming convention for Alkanes. [credit: *Chemistry 2e*. [Illustration of organic nomenclature for Alkanes](#). OpenStax. [CC BY](#).]

When more than one substituent is present, either on the same carbon atom or on different carbon atoms, the substituents are listed alphabetically. Because the carbon atom numbering begins at the end closest to a substituent, the longest chain of carbon atoms is numbered in such a way as to produce the lowest number for the substituents. The ending *-o* replaces *-ide* at the end of the name of an electronegative substituent (in ionic compounds, the negatively charged ion ends with *-ide* like chloride; in organic compounds, such atoms are treated as substituents and the *-o* ending is used). The number of substituents of the same type is indicated by the prefixes *di-* (two), *tri-* (three), *tetra-* (four), and so on (for example, *difluoro-* indicates two fluoride substituents).

We call a substituent that contains one less hydrogen than the corresponding alkane an alkyl group. The name of an **alkyl group** is obtained by dropping the suffix *-ane* of the alkane name and adding *-yl* (Figure 11.8).

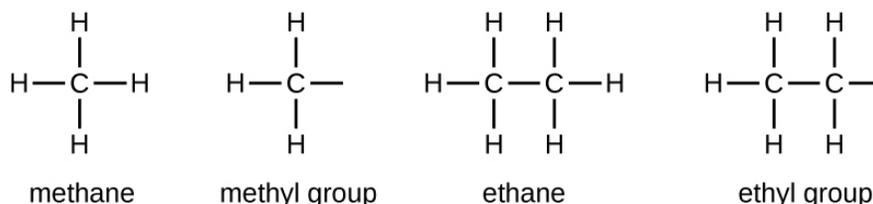


Figure 11.8 Illustration of how the name of an alkyl group stems from the structure. [credit: *Chemistry 2e*. [Alkyl naming examples for methyl and ethyl groups](#). OpenStax. [CC BY](#).]

The open bonds in the methyl and ethyl groups indicate that these alkyl groups are bonded to another atom.

Some hydrocarbons can form more than one type of alkyl group when the hydrogen atoms that would be removed have different “environments” in the molecule. This diversity of possible alkyl groups can be identified in the following way: The four hydrogen atoms in a methane molecule are equivalent; they all have the same environment. They are equivalent because each is bonded to a carbon atom (the same carbon atom) that is bonded to three hydrogen atoms. (It may be easier to see the equivalency in the ball and stick models in [Figure 11.3](#). Removal of any one of the four hydrogen atoms from methane forms a methyl group. Likewise, the six hydrogen atoms in ethane are equivalent ([Figure 11.3](#)) and removing any one of these hydrogen atoms produces an ethyl group. Each of the six hydrogen atoms is bonded to a carbon atom that is bonded to two other hydrogen atoms and a carbon atom. However, in both propane and 2-methylpropane, there are hydrogen atoms in two different environments, distinguished by the adjacent atoms or groups of atoms (Figure 11.9):

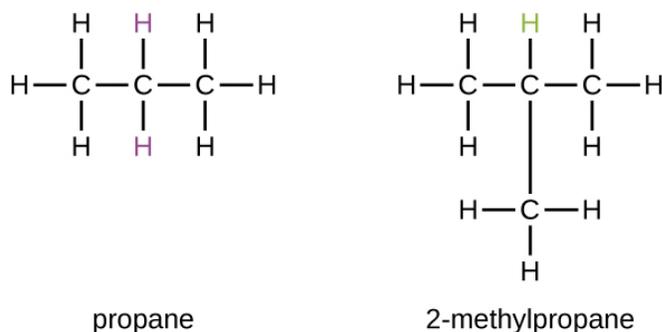


Figure 11.9 Illustration of hydrocarbons forming more than one of type of alkyl group with example of propane and 2-methylpropane. [credit: *Chemistry 2e*. [Hydrocarbons and alkyl group](#). OpenStax. [CC BY](#).]

Each of the six equivalent hydrogen atoms of the first type in propane and each of the nine equivalent hydrogen atoms of that type in 2-methylpropane (all shown in black) are bonded to a carbon atom that is bonded to only one other carbon atom. The two purple hydrogen atoms in propane are of a second type. They differ from the six hydrogen atoms of the first type in that they are bonded to a carbon atom bonded to two other carbon atoms. The green hydrogen atom in 2-methylpropane differs from the other nine hydrogen atoms in that molecule and from the purple hydrogen atoms in propane. The green hydrogen atom in 2-methylpropane is bonded to a carbon atom bonded to three other carbon atoms. Two different alkyl groups can be formed from each of these molecules, depending on which hydrogen atom is removed. The names and structures of these and several other alkyl groups are listed in Figure 11.10.

Alkyl Group	Structure
methyl	$\text{CH}_3\text{—}$
ethyl	$\text{CH}_3\text{CH}_2\text{—}$
<i>n</i> -propyl	$\text{CH}_3\text{CH}_2\text{CH}_2\text{—}$
isopropyl	$\begin{array}{c} \\ \text{CH}_3\text{CHCH}_3 \end{array}$
<i>n</i> -butyl	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{—}$
sec-butyl	$\begin{array}{c} \\ \text{CH}_3\text{CH}_2\text{CHCH}_3 \end{array}$
isobutyl	$\begin{array}{c} \text{CH}_3\text{CHCH}_2\text{—} \\ \\ \text{CH}_3 \end{array}$
<i>tert</i> -butyl	$\begin{array}{c} \\ \text{CH}_3\text{CCH}_3 \\ \\ \text{CH}_3 \end{array}$

Figure 11.10 This listing gives the names and formulas for various alkyl groups formed by the removal of hydrogen atoms from different locations. [credit: *Chemistry 2e*. [Figure 20.5](#). OpenStax. [CC BY](#).]

Note that alkyl groups do not exist as stable independent entities. They are always a part of some larger molecule. The location of an alkyl group on a hydrocarbon chain is indicated in the same way as any other substituent (Figure 11.11):

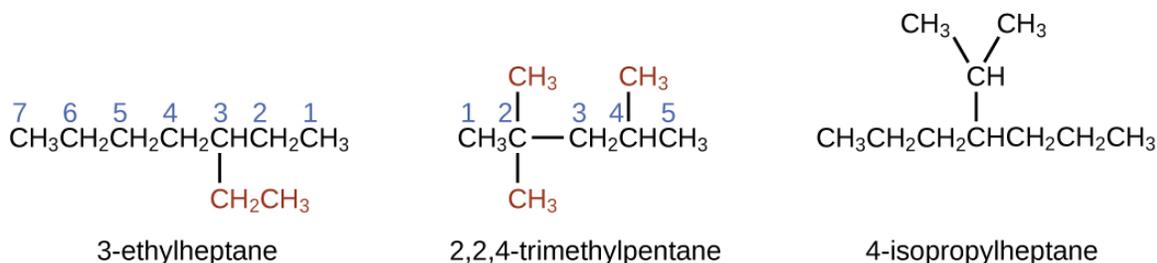
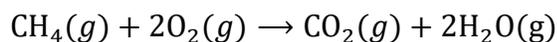


Figure 11.11 Examples of Alkyl group locations on a hydrocarbon chain. [credit: *Chemistry 2e*. [Alkyl group locations](#). OpenStax. [CC BY](#).]

Alkanes are relatively stable molecules, but heat or light will activate reactions that involve the breaking of C–H or C–C single bonds. Combustion is one such reaction:



Alkanes burn in the presence of oxygen, a highly exothermic oxidation-reduction reaction that produces carbon dioxide and water. As a consequence, alkanes are excellent fuels. For example, methane, CH_4 , is the principal component of natural gas. Butane, C_4H_{10} , used in camping stoves and lighters is an alkane. Gasoline is a liquid mixture of continuous- and branched-chain alkanes, each containing from five to nine carbon atoms, plus various additives to improve its performance as a fuel. Kerosene, diesel oil, and fuel oil are primarily mixtures of alkanes with higher molecular masses. The main source of these liquid alkane fuels is crude oil, a complex mixture that is separated by fractional distillation. Fractional distillation takes advantage of differences in the boiling points of the components of the mixture (see [Figure 11.12](#)). You may recall that boiling point is a function of intermolecular interactions, which was discussed in the chapter on solutions and colloids.

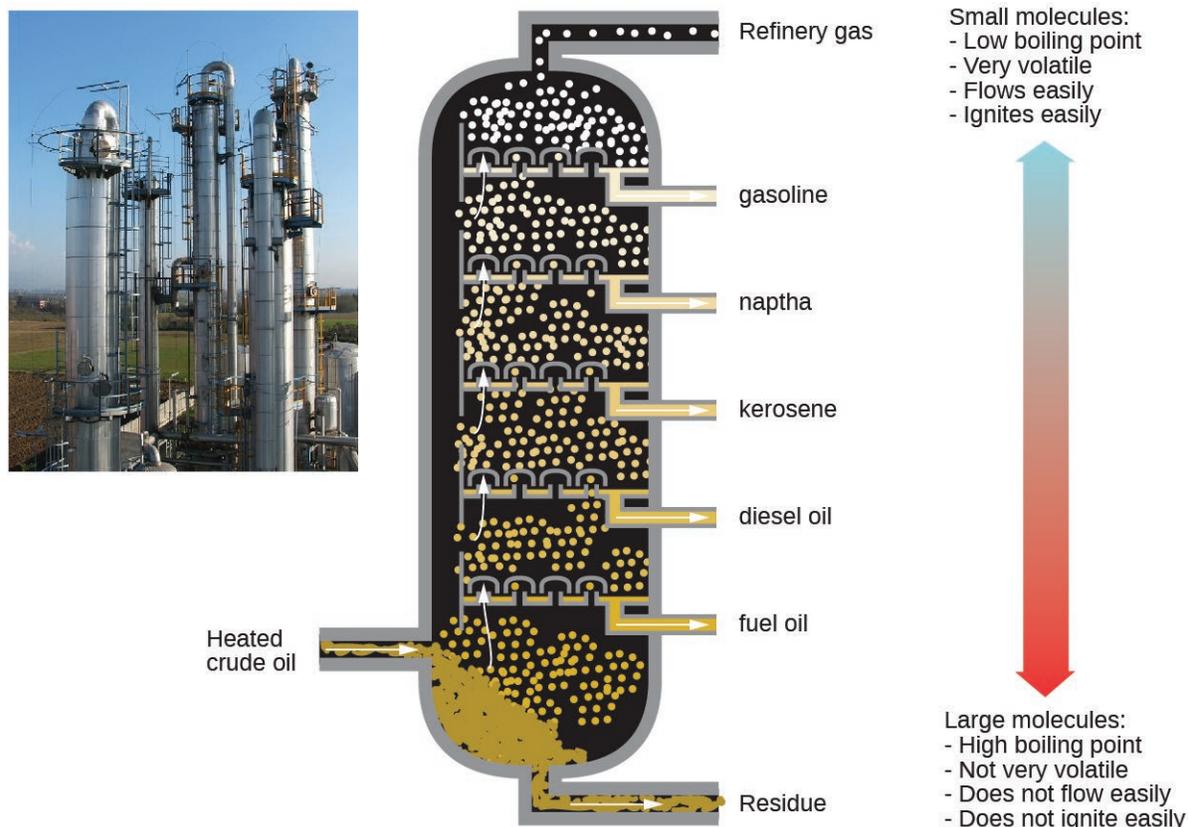


Figure 11.12 In a column for the fractional distillation of crude oil, oil heated to about 425 °C in the furnace vaporizes when it enters the base of the tower. The vapors rise through bubble caps in a series of trays in the tower. As the vapors gradually cool, fractions of higher, then of lower, boiling points condense to liquids and are drawn off. [credit: as cited by *Chemistry 2e*. [Figure 20.6](#). OpenStax. [CC BY](#), left: modification of work by Luigi Chiesa.]

In a **substitution reaction**, another typical reaction of alkanes, one or more of the alkane's hydrogen atoms is replaced with a different atom or group of atoms. No carbon-carbon bonds are broken in these reactions, and the hybridization of the carbon atoms does not change. In the Figure 11.13 example, the reaction between ethane and molecular chlorine depicted here is a substitution reaction:

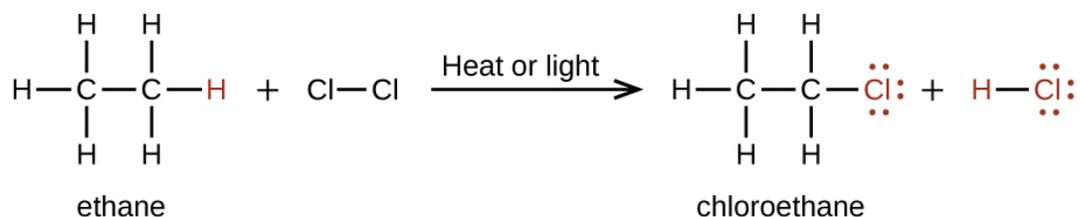


Figure 11.13 Example of a substitution reaction with a functional group. [credit: *Chemistry 2e*. [Substitution reaction](#). OpenStax. [CC BY](#).]

The C-Cl portion of the chloroethane molecule is an example of a **functional group**, the part or moiety of a molecule that imparts a specific chemical reactivity. The types of functional groups present in an organic molecule are major determinants of its chemical properties and are used as a means of classifying organic compounds as detailed in the remaining sections of this chapter.

To learn more about naming simple linear and cyclic alkanes, watch the [Naming Simple Alkanes video](#) from the Khan Academy.

Alkenes

Organic compounds that contain one or more double or triple bonds between carbon atoms are described as unsaturated. You have likely heard of unsaturated fats. These are complex organic molecules with long chains of carbon atoms, which contain at least one double bond between carbon atoms. Unsaturated hydrocarbon molecules that contain one or more double bonds are called **alkenes**. Carbon atoms linked by a double bond are bound together by two bonds, one σ bond and one π bond. Double and triple bonds give rise to a different geometry around the carbon atom that participates in them, leading to important differences in molecular shape and properties. The differing geometries are responsible for the different properties of unsaturated versus saturated fats.

Ethene, C_2H_4 , is the simplest alkene. Each carbon atom in ethene, commonly called ethylene, has a trigonal planar structure. The second member of the series is propene (propylene) in Figure 11.14; the butene isomers follow in the series. Four carbon atoms in the chain of butene allows for the formation of isomers based on the position of the double bond, as well as a new form of isomerism.

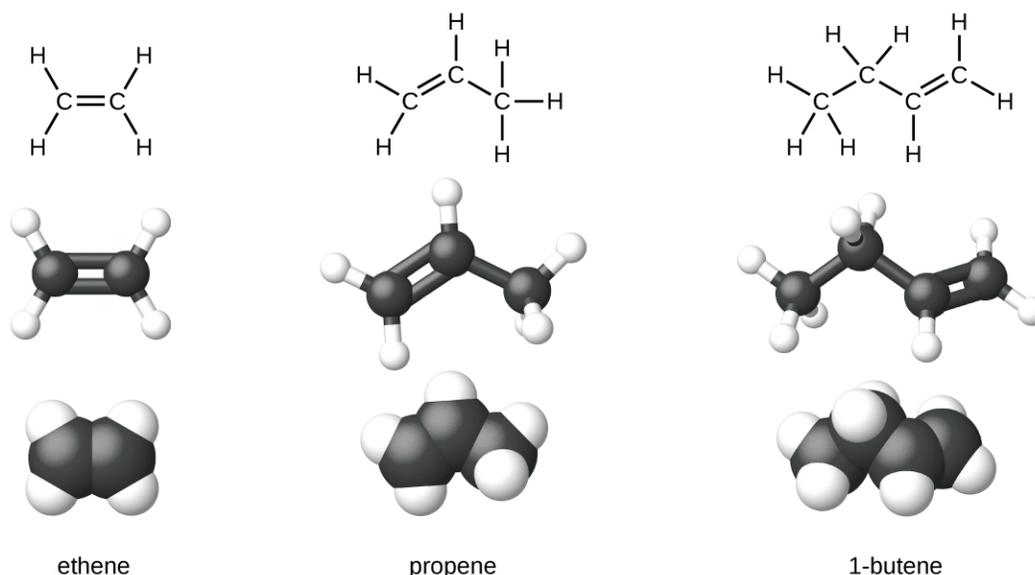


Figure 11.14 Expanded structures, ball-and-stick structures, and space-filling models for the alkenes ethene, propene, and 1-butene are shown. [credit: *Chemistry 2e*. [Figure 20.7](#). OpenStax. [CC BY](#).]

Ethylene (the common industrial name for ethene) is a basic raw material in the production of polyethylene and other important compounds. Over 135 million tons of ethylene were produced worldwide in 2010 for use in the polymer, petrochemical, and plastic industries. Ethylene is produced industrially in a process called cracking, in which the long hydrocarbon chains in a petroleum mixture are broken into smaller molecules.

The name of an alkene is derived from the name of the alkane with the same number of carbon atoms. The presence of the double bond is signified by replacing the suffix *-ane* with the suffix *-ene*. The location of the double bond is identified by naming the smaller of the numbers of the carbon atoms participating in the double bond (Figure 11.15):

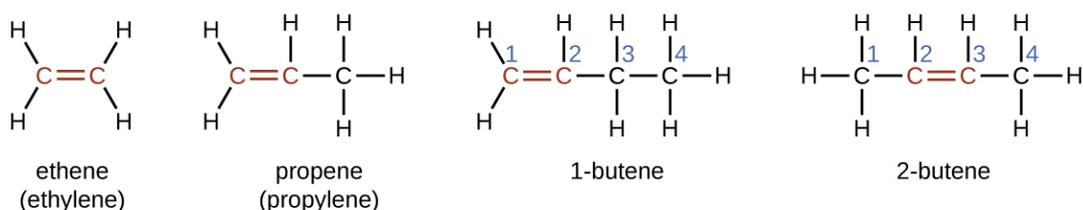


Figure 11.15 Examples of alkene naming convention. [credit: *Chemistry 2e*. [Alkene naming](#). OpenStax. [CC BY](#).]

Isomers of Alkenes

Molecules of 1-butene and 2-butene are structural isomers; the arrangement of the atoms in these two molecules differs. As an example of arrangement differences, the first carbon atom in 1-butene is bonded to two hydrogen atoms; the first carbon atom in 2-butene is bonded to three hydrogen atoms.

The compound 2-butene and some other alkenes also form a second type of isomer called a geometric isomer. In a set of geometric isomers, the same types of atoms are attached to each other in the same order, but the geometries of the two molecules differ. Geometric isomers of alkenes differ in the orientation of the groups on either side of a C=C bond.

Carbon atoms are free to rotate around a single bond but not around a double bond; a double bond is rigid. This makes it possible to have two isomers of 2-butene, one with both methyl groups on the same side of the double bond and one with the methyl groups on opposite sides. When structures of butene are drawn with 120° bond angles around the sp^2 -hybridized carbon atoms participating in the double bond, the isomers are apparent. The 2-butene isomer in which the two methyl groups are on the same side is called a *cis*-isomer; the one in which the two methyl groups are on opposite sides is called a *trans*-isomer (Figure 11.16). The different geometries produce different physical properties, such as boiling point, that may make separation of the isomers possible.

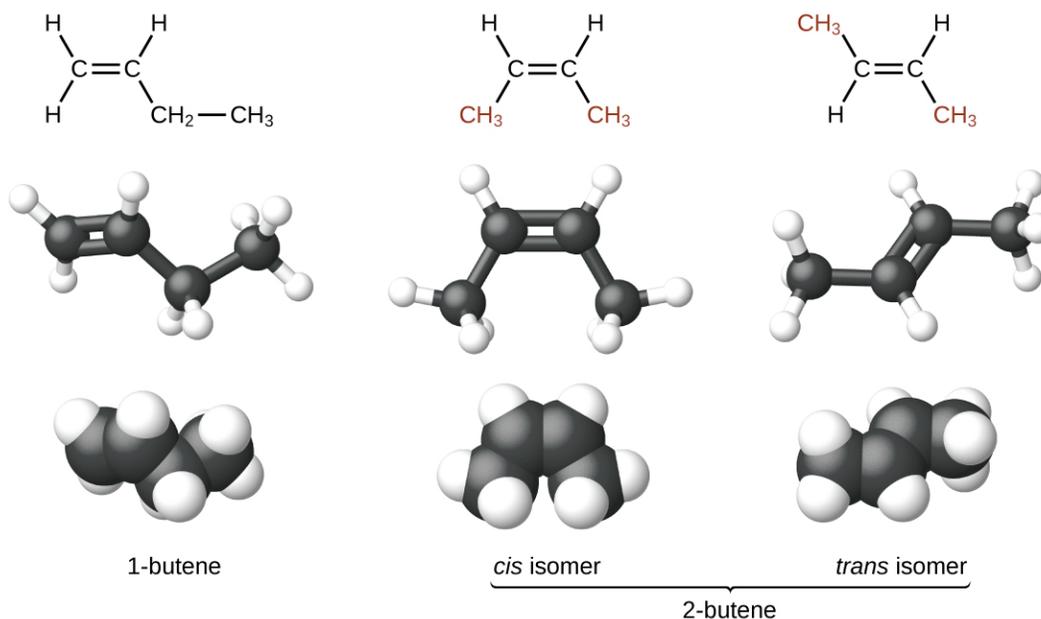


Figure 11.16 These molecular models show the structural and geometric isomers of butene. [credit: *Chemistry 2e*. [Figure 20.10](#). OpenStax. [CC BY](#).]

Alkenes are much more reactive than alkanes because the C=C moiety is a reactive functional group. A π bond, being a weaker bond, is disrupted much more easily than a σ bond. Thus, alkenes undergo a characteristic reaction in which the π bond is broken and replaced by two σ bonds. This reaction is called an **addition reaction**. The hybridization of the carbon atoms in the double bond in an alkene changes from sp^2 to sp^3 during an addition reaction. The example in Figure 11.17, halogens add to the double bond in an alkene instead of replacing hydrogen, as occurs in an alkane:

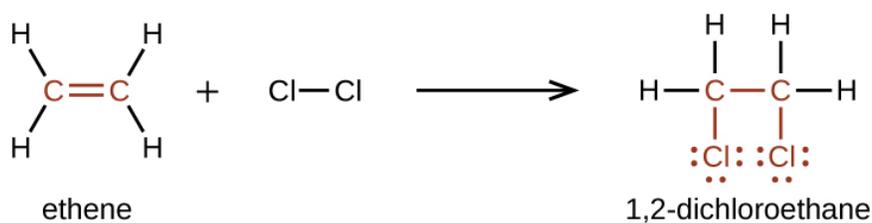


Figure 11.17 Illustration of an addition reaction example. [credit: *Chemistry 2e*. [Addition reaction](#). OpenStax. [CC BY](#).]

Alkynes

Hydrocarbon molecules with one or more triple bonds are called **alkynes**; they make up another series of unsaturated hydrocarbons. Two carbon atoms joined by a triple bond are bound together by one σ bond and two π bonds. The sp -hybridized carbons involved in the triple bond have bond angles of 180° , giving these types of bonds a

linear, rod-like shape. The simplest member of the alkyne series is ethyne, C_2H_2 , commonly called acetylene. Shown in Figure 11.18, the Lewis structure for ethyne, a linear molecule, is:



ethyne (acetylene)

Figure 11.18 Illustration of the Lewis structure for ethyne. [credit: *Chemistry 2e*. [Lewis structure for ethyne](#). OpenStax. [CC BY](#).]

The IUPAC nomenclature for alkynes is similar to that for alkenes except that the suffix *-yne* is used to indicate a triple bond in the chain. The following, for example, is called 1-butyne.



Chemically, the alkynes are similar to the alkenes. Since the $C \equiv C$ functional group has two π bonds, alkynes typically react even more readily, and react with twice as much reagent in addition reactions. Shown in Figure 11.19, the reaction of acetylene with bromine is a typical example:

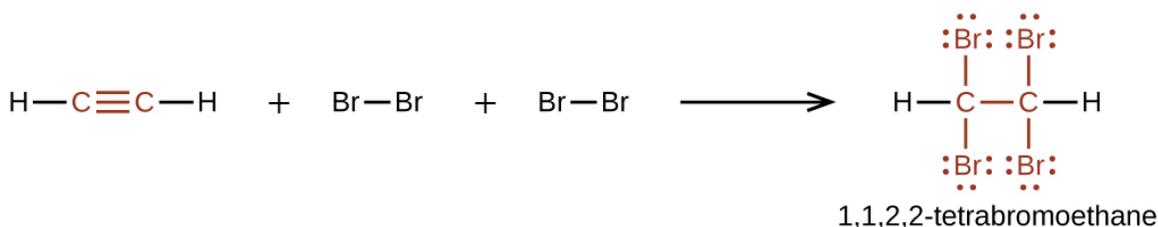


Figure 11.19 Illustration of alkyne reaction example of twice as much reagent in addition reaction. [credit: *Chemistry 2e*. [Alkyne reaction example](#). OpenStax. [CC BY](#).]

Acetylene and the other alkynes also burn readily. An acetylene torch takes advantage of the high heat of combustion for acetylene.

Aromatic Hydrocarbons

Benzene, C_6H_6 , is the simplest member of a large family of hydrocarbons, called **aromatic hydrocarbons**. These compounds contain ring structures and exhibit bonding that must be described using the resonance hybrid concept of valence bond theory or the delocalization concept of molecular orbital theory. The resonance structures for benzene, C_6H_6 , are illustrated in [Figure 11.20](#).

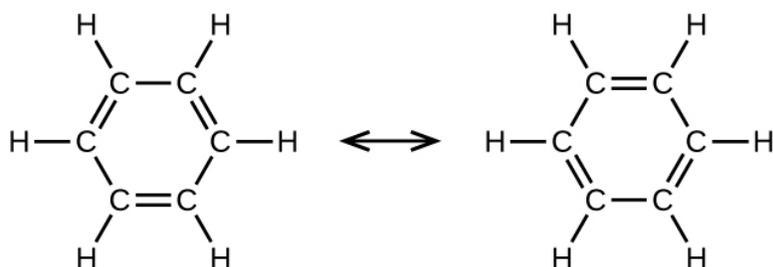


Figure 11.20 Illustration of benzene ring structure. [credit: *Chemistry 2e*. [Aromatic hydrocarbons](#). OpenStax. [CC BY](#).]

Valence bond theory describes the benzene molecule and other planar aromatic hydrocarbon molecules as hexagonal rings of sp^2 -hybridized carbon atoms with the unhybridized p orbital of each carbon atom perpendicular to the plane of the ring. Three valence electrons in the sp^2 hybrid orbitals of each carbon atom and the valence electron of each hydrogen atom form the framework of σ bonds in the benzene molecule. The fourth valence electron of each carbon atom is shared with an adjacent carbon atom in their unhybridized p orbitals to yield the π bonds. Benzene does not, however, exhibit the characteristics typical of an alkene. Each of the six bonds between its carbon atoms is equivalent and exhibits properties that are intermediate between those of a C–C single bond and a C = C double bond. To represent this unique bonding, structural formulas for benzene and its derivatives are typically drawn with single bonds between the carbon atoms and a circle within the ring as shown in Figure 11.21.

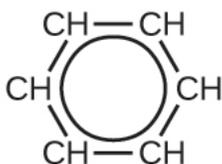


Figure 11.21 This condensed formula shows the unique bonding structure of benzene. [credit: *Chemistry 2e*. [Figure 20.11](#). OpenStax. [CC BY](#).]

There are many derivatives of benzene. The hydrogen atoms can be replaced by many different substituents. Aromatic compounds more readily undergo substitution reactions than addition reactions; replacement of one of the hydrogen atoms with another substituent will leave the delocalized double bonds intact. The illustrations in [Figure 11.22](#) are typical examples of substituted benzene derivatives.

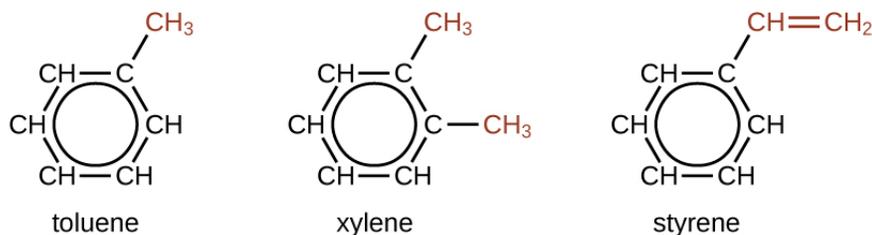


Figure 11.22 Three examples of substituted benzene derivatives. [credit: *Chemistry 2e*. [Toluene, xylene, and styrene](#). OpenStax. [CC BY](#).]

Toluene and xylene are important solvents and raw materials in the chemical industry. Styrene is used to produce the polymer polystyrene.

Alcohols

Incorporation of an oxygen atom into carbon- and hydrogen-containing molecules leads to new functional groups and new families of compounds. When the oxygen atom is attached by single bonds, the molecule is either an alcohol or ether.

Alcohols are derivatives of hydrocarbons in which an $-OH$ group has replaced a hydrogen atom. Although all alcohols have one or more hydroxyl ($-OH$) functional groups, they do not behave like bases such as $NaOH$ and KOH . $NaOH$ and KOH are ionic compounds that contain OH^- ions. Alcohols are covalent molecules; the $-OH$ group in an alcohol molecule is attached to a carbon atom by a covalent bond.

Ethanol, CH_3CH_2OH , also called ethyl alcohol, is a particularly important alcohol for human use. Ethanol is the alcohol produced by some species of yeast that is found in wine, beer, and distilled drinks. It has long been prepared by humans harnessing the metabolic efforts of yeasts in fermenting various sugars. Figure 11.23 illustrated the production of ethanol from yeast fermentation.

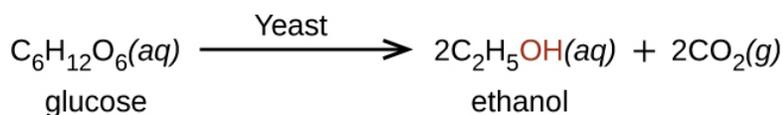


Figure 11.23 Ethanol produced from yeast fermenting in glucose. [credit: *Chemistry 2e*. [Yeast fermentation](#). OpenStax. [CC BY](#).]

Large quantities of ethanol are synthesized from the addition reaction of water with ethylene using an acid as a catalyst (Figure 11.24):

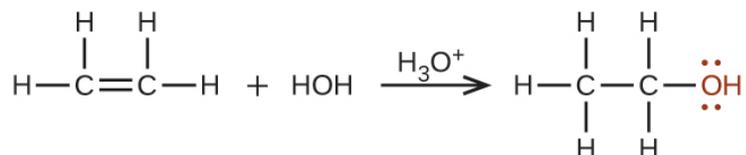


Figure 11.24 Ethanol synthesized with acid catalyst. [credit: *Chemistry 2e*. [Ethanol synthesis](#). OpenStax. [CC BY](#).]

Alcohols containing two or more hydroxyl groups can be made. The examples in Figure 11.25 include 1,2-ethanediol (ethylene glycol, used in antifreeze) and 1,2,3-propanetriol (glycerine, used as a solvent for cosmetics and medicines):

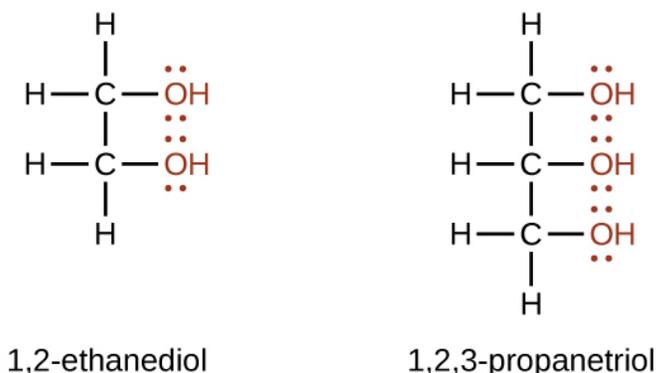


Figure 11.25 Alcohols with multiple hydroxyl groups. [credit: *Chemistry 2e*. [Alcohol group examples](#). OpenStax. [CC BY](#).]

Naming Alcohols

The name of an alcohol comes from the hydrocarbon from which it was derived. The final *-e* in the name of the hydrocarbon is replaced by *-ol*, and the carbon atom to which the *-OH* group is bonded is indicated by a number placed before the name.

Ethers

Ethers are compounds that contain the functional group *-O-*. Ethers do not have a designated suffix like the other types of molecules we have named so far. In the IUPAC system, the oxygen atom and the smaller carbon branch are named as an alkoxy substituent and the remainder of the molecule as the base chain, as in alkanes. As shown in the following compound, the red symbols represent the smaller alkyl group

and the oxygen atom, which would be named “methoxy.” The larger carbon branch would be ethane, making the molecule methoxyethane. Many ethers are referred to with common names instead of the IUPAC system names. For common names, the two branches connected to the oxygen atom are named separately and followed by “ether.” The common name for the compound shown in Figure 11.26 is ethylmethyl ether:

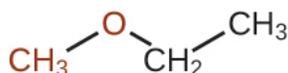


Figure 11.26 Illustration of compound commonly known as ethylmethyl ether. [credit: *Chemistry 2e*. [Ethylmethyl ether](#). OpenStax. [CC BY](#).]

Ethers can be obtained from alcohols by the elimination of a molecule of water from two molecules of the alcohol. For example, when ethanol is treated with a limited amount of sulfuric acid and heated to 140 °C, diethyl ether and water are formed (Figure 11.27):

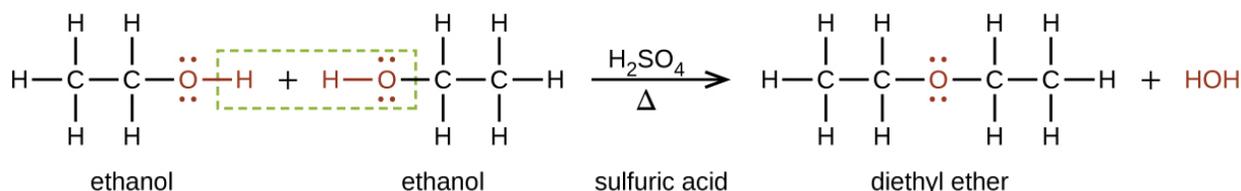


Figure 11.27 Formation of diethyl ether and water. [credit: *Chemistry 2e*. [Obtaining ether](#). OpenStax. [CC BY](#).]

In the general formula for ethers, R—O—R, the hydrocarbon groups (R) may be the same or different. Diethyl ether, the most widely used compound of this class, is a colorless, volatile liquid that is highly flammable. It was first used in 1846 as an anesthetic, but better anesthetics have now largely taken its place. Diethyl ether and other ethers are presently used primarily as solvents for gums, fats, waxes, and resins. *Tertiary*-butyl methyl ether, C₄H₉OCH₃ (abbreviated MTBE—italicized portions of names are not counted when ranking the groups alphabetically—so butyl comes before methyl in the common name), is used as an additive for gasoline. MTBE belongs to a group of chemicals known as oxygenates due to their capacity to increase the oxygen content of gasoline. To learn more, watch the [Ether Naming and Introduction video](#) from the Khan Academy.

Aldehydes and Ketones

Another class of organic molecules contains a carbon atom connected to an oxygen atom by a double bond, commonly called a carbonyl group. The trigonal planar carbon in the carbonyl group can attach to two other substituents leading to several subfamilies (aldehydes, ketones, carboxylic acids and esters) described in this section.

Both **aldehydes** and **ketones** contain a **carbonyl group**, a functional group with a carbon-oxygen double bond (see Figure 11.28). The names for aldehyde and ketone compounds are derived using similar nomenclature rules as for alkanes and alcohols, and include the class-identifying suffixes *-al* and *-one*, respectively:

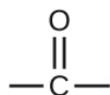


Figure 11.28 Carbon-oxygen double bond of a carbonyl group. [credit: *Chemistry 2e*. [Carbonyl group](#). OpenStax. [CC BY](#).]

In an aldehyde, the carbonyl group is bonded to at least one hydrogen atom. In a ketone, the carbonyl group is bonded to two carbon atoms. Figure 11.29 illustrates the grouping and bonding in an aldehyde and in a ketone.

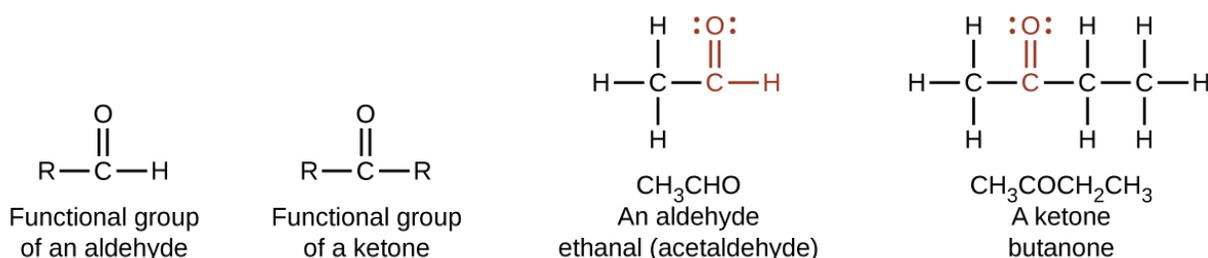


Figure 11.29 Depicted to the left are two representations of a functional group, the leftmost for an aldehyde and the next of a ketone. The two depictions to the right represent respective carbonyl group bonding. [credit: *Chemistry 2e*. [Aldehyde and ketone depictions](#). OpenStax. [CC BY](#).]

As text, an aldehyde group is represented as $-\text{CHO}$; a ketone is represented as $-\text{C}(\text{O})-$ or $-\text{CO}-$.

In both aldehydes and ketones, the geometry around the carbon atom in the carbonyl group is trigonal planar; the carbon atom exhibits sp^2 hybridization. Two of the sp^2 orbitals on the carbon atom in the carbonyl group are used to form σ bonds to the other carbon or hydrogen atoms in a molecule. The remaining sp^2 hybrid orbital forms a σ bond to the oxygen atom. The unhybridized p orbital on the carbon atom in the carbonyl group overlaps a p orbital on the oxygen atom to form the π bond in the double bond.

Like the $\text{C}=\text{O}$ bond in carbon dioxide, the $\text{C}=\text{O}$ bond of a carbonyl group is polar (recall that oxygen is significantly more electronegative than carbon, and the shared electrons are pulled toward the oxygen atom and away from the carbon atom). Many of the reactions of aldehydes and ketones start with the reaction between a Lewis base and

the carbon atom at the positive end of the polar C=O bond to yield an unstable intermediate that subsequently undergoes one or more structural rearrangements to form the final product (Figure 11.30).

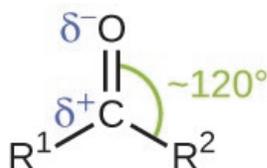


Figure 11.30 The carbonyl group is polar, and the geometry of the bonds around the central carbon is trigonal planar. [credit: *Chemistry 2e*. [Figure 20.14](#). OpenStax. [CC BY](#).]

The importance of molecular structure in the reactivity of organic compounds is illustrated by the reactions that produce aldehydes and ketones. We can prepare a carbonyl group by oxidation of an alcohol—for organic molecules, oxidation of a carbon atom is said to occur when a carbon-hydrogen bond is replaced by a carbon-oxygen bond. The reverse reaction—replacing a carbon-oxygen bond by a carbon-hydrogen bond—is a reduction of that carbon atom. Recall that oxygen is generally assigned a -2 oxidation number unless it is elemental or attached to a fluorine. Hydrogen is generally assigned an oxidation number of $+1$ unless it is attached to a metal. Since carbon does not have a specific rule, its oxidation number is determined algebraically by factoring the atoms it is attached to and the overall charge of the molecule or ion. In general, a carbon atom attached to an oxygen atom will have a more positive oxidation number and a carbon atom attached to a hydrogen atom will have a more negative oxidation number. This should fit nicely with your understanding of the polarity of C–O and C–H bonds. The other reagents and possible products of these reactions are beyond the scope of this chapter, so we will focus only on the changes to the carbon atoms (Figure 11.31).

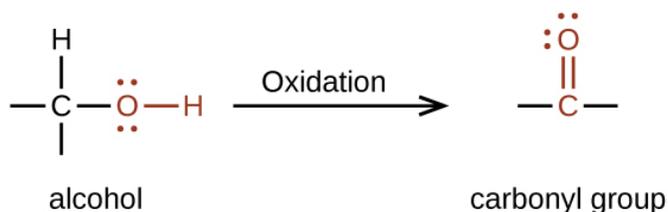


Figure 11.31 Illustration of changes to carbon atoms from oxidation. [credit: *Chemistry 2e*. [Carbon atoms and oxidation](#). OpenStax. [CC BY](#).]

Aldehydes are commonly prepared by the oxidation of alcohols whose $-OH$ functional group is located on the carbon atom at the end of the chain of carbon atoms in the alcohol ([Figure 11.32](#)).

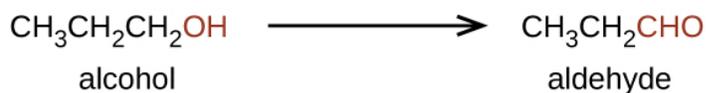


Figure 11.32 Illustration of alcohol to aldehyde reaction. [credit: *Chemistry 2e*. [Alcohol to aldehyde reaction](#). OpenStax. [CC BY](#).]

Alcohols that have their -OH groups in the middle of the chain are necessary to synthesize a ketone, which requires the carbonyl group to be bonded to two other carbon atoms (Figure 11.33).

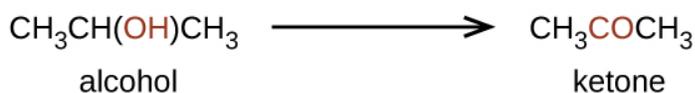


Figure 11.33 Illustration of alcohol to ketone reaction. [credit: *Chemistry 2e*. [Alcohol to ketone reaction](#). OpenStax. [CC BY](#).]

An alcohol with its -OH group bonded to a carbon atom that is bonded to no or one other carbon atom will form an aldehyde. An alcohol with its -OH group attached to two other carbon atoms will form a ketone. If three carbons are attached to the carbon bonded to the -OH, the molecule will not have a C-H bond to be replaced, so it will not be susceptible to oxidation.

Formaldehyde, an aldehyde with the formula HCHO, is a colorless gas with a pungent and irritating odor. It is sold in an aqueous solution called formalin, which contains about 37% formaldehyde by weight. Formaldehyde causes coagulation of proteins, so it kills bacteria (and any other living organism) and stops many of the biological processes that cause tissue to decay. Thus, formaldehyde is used for preserving tissue specimens and embalming bodies. It is also used to sterilize soil or other materials. Formaldehyde is used in the manufacture of Bakelite, a hard plastic having high chemical and electrical resistance.

Dimethyl ketone, CH₃COCH₃, commonly called acetone, is the simplest ketone. It is made commercially by fermenting corn or molasses, or by oxidation of 2-propanol. Acetone is a colorless liquid. Among its many uses are as a solvent for lacquer (including fingernail polish), cellulose acetate, cellulose nitrate, acetylene, plastics, and varnishes; as a paint and varnish remover; and as a solvent in the manufacture of pharmaceuticals and chemicals.

Carboxylic Acids and Esters

The odor of vinegar is caused by the presence of acetic acid, a carboxylic acid, in the vinegar. The odor of ripe bananas and many other fruits is due to the presence of esters, compounds that can be prepared by the reaction of a carboxylic acid with an alcohol. Because esters do not have hydrogen bonds between molecules, they have lower vapor pressures than the alcohols and carboxylic acids from which they are derived (see Figure 11.34).

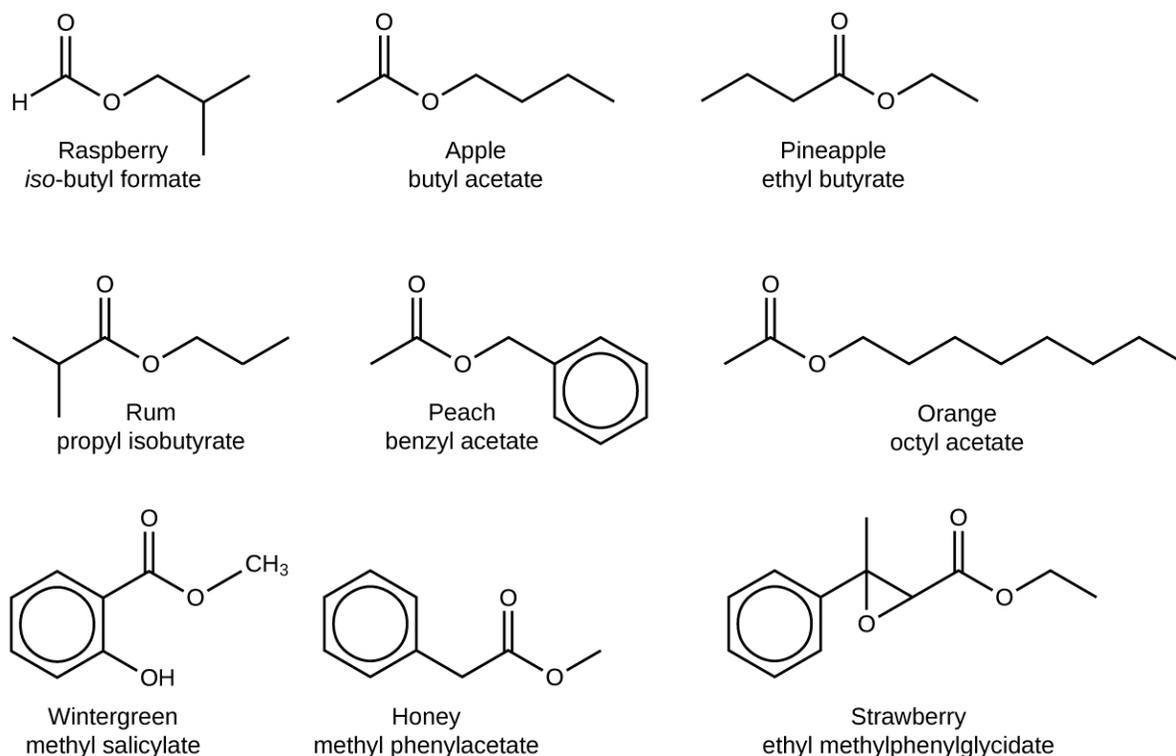


Figure 11.34 Esters are responsible for the odors associated with various plants and their fruits. [credit: *Chemistry 2e*. [Figure 20.15](#). OpenStax. [CC BY](#).]

Both **carboxylic acids** and **esters** contain a carbonyl group with a second oxygen atom bonded to the carbon atom in the carbonyl group by a single bond. In a carboxylic acid, the second oxygen atom also bonds to a hydrogen atom. In an ester, the second oxygen atom bonds to another carbon atom. The names for carboxylic acids and esters include prefixes that denote the lengths of the carbon chains in the molecules and are derived following nomenclature rules similar to those for inorganic acids and salts (see these examples in [Figure 11.35](#)).

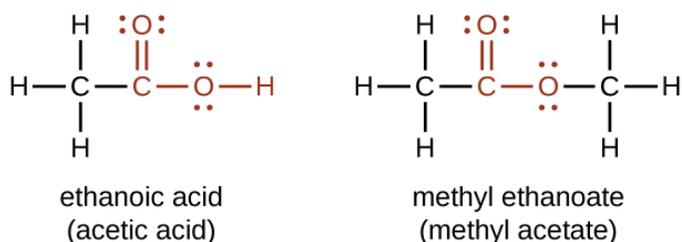


Figure 11.35 Nomenclature examples for acetic acid and methyl acetate. [credit: *Chemistry 2e*. [Acids and salts nomenclature](#). OpenStax. [CC BY](#).]

The functional groups for an acid and for an ester are shown in red in these formulas.

The hydrogen atom in the functional group of a carboxylic acid will react with a base to form an ionic salt (Figure 11.36):

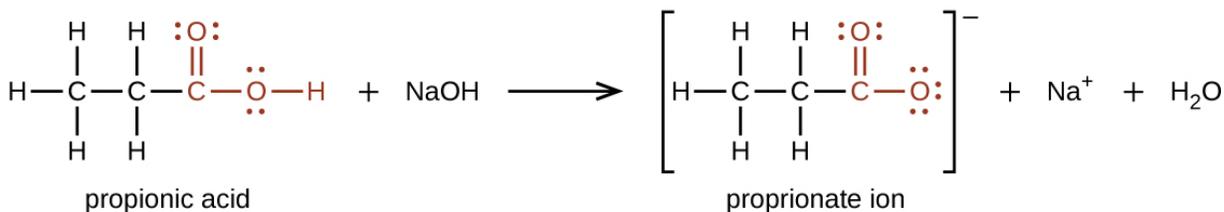


Figure 11.36 Formation of ionic salt. [credit: *Chemistry 2e*. [Ionic salt](#). OpenStax. [CC BY](#).]

Carboxylic acids are weak acids (see the chapter on acids and bases), meaning they are not 100% ionized in water. Generally, only about 1% of the molecules of a carboxylic acid dissolved in water are ionized at any given time. The remaining molecules are undissociated in solution.

We prepare carboxylic acids by the oxidation of aldehydes or alcohols whose -OH functional group is located on the carbon atom at the end of the chain of carbon atoms in the alcohol (Figure 11.37):

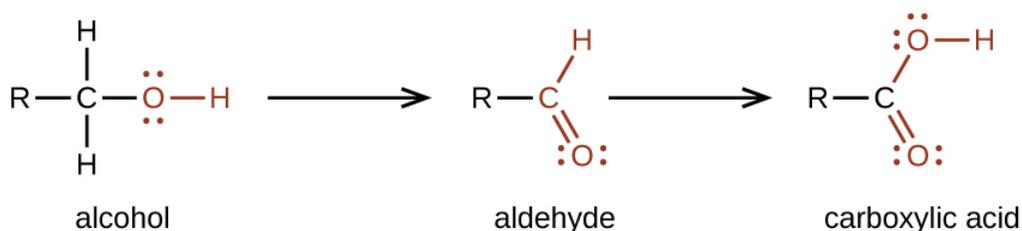


Figure 11.37 Preparation of carboxylic acids by oxidation. [credit: *Chemistry 2e*. [Preparation of carboxylic acids](#). OpenStax. [CC BY](#).]

Esters are produced by the reaction of acids with alcohols. For example, the ester ethyl acetate, $\text{CH}_3\text{CO}_2\text{CH}_2\text{CH}_3$, is formed when acetic acid reacts with ethanol (Figure 11.38):

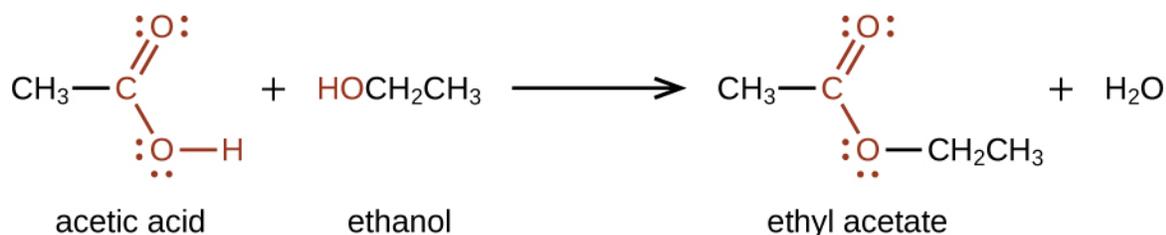
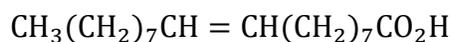


Figure 11.38 Formation of ester ethyl acetate. [credit: *Chemistry 2e*. [Ester ethyl acetate](#). OpenStax. [CC BY](#).]

The simplest carboxylic acid is formic acid, HCO_2H , known since 1670. Its name comes from the Latin word *formicus*, which means “ant”; it was first isolated by the distillation of red ants. It is partially responsible for the pain and irritation of ant and wasp stings and is responsible for a characteristic odor of ants that can be sometimes detected in their nests.

Acetic acid, $\text{CH}_3\text{CO}_2\text{H}$, constitutes 3–6% vinegar. Cider vinegar is produced by allowing apple juice to ferment without oxygen present. Yeast cells present in the juice carry out the fermentation reactions. The fermentation reactions change the sugar present in the juice to ethanol, then to acetic acid. Pure acetic acid has a penetrating odor and produces painful burns. It is an excellent solvent for many organic and some inorganic compounds, and it is essential in the production of cellulose acetate, a component of many synthetic fibers such as rayon.

The distinctive and attractive odors and flavors of many flowers, perfumes, and ripe fruits are due to the presence of one or more esters ([Figure 11.39](#)). Among the most important of the natural esters are fats (such as lard, tallow, and butter) and oils (such as linseed, cottonseed, and olive oils), which are esters of the trihydroxyl alcohol glycerine, $\text{C}_3\text{H}_5(\text{OH})_3$, with large carboxylic acids, such as palmitic acid, $\text{CH}_3(\text{CH}_2)_{14}\text{CO}_2\text{H}$, stearic acid, $\text{CH}_3(\text{CH}_2)_{16}\text{CO}_2\text{H}$, and oleic acid,



Oleic acid is an unsaturated acid; it contains a $\text{C}=\text{C}$ double bond. Palmitic and stearic acids are saturated acids that contain no double or triple bonds.



Figure 11.39 Over 350 different volatile molecules (many members of the ester family) have been identified in strawberries. [credit: Rebecca Siegel as cited in *Chemistry 2e*. [Figure 20.16](#). OpenStax. [CC BY](#).]

Amines are molecules that contain carbon-nitrogen bonds. The nitrogen atom in an amine has a lone pair of electrons and three bonds to other atoms, either carbon or hydrogen. Various nomenclatures are used to derive names for amines, but all involve the class-identifying suffix *-ine* as illustrated here for a few simple examples (Figure 11.40):

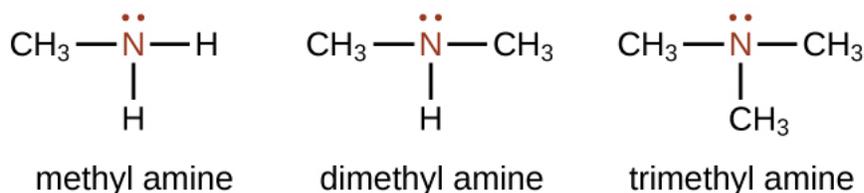


Figure 11.40 Nomenclature examples for methyl, dimethyl, and trimethyl amine. [credit: *Chemistry 2e*. [Amine nomenclature](#). OpenStax. [CC BY](#).]

In some amines, the nitrogen atom replaces a carbon atom in an aromatic hydrocarbon. Pyridine ([Figure 11.41](#)) is one such heterocyclic amine. A heterocyclic compound contains atoms of two or more different elements in its ring structure.

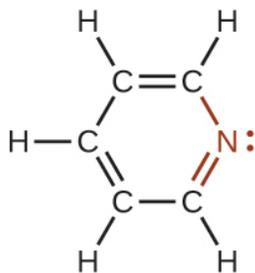


Figure 11.41 The illustration shows one of the resonance structures of pyridine. [credit: *Chemistry 2e*, Figure 20.17. OpenStax. [CC BY](#).]

Like ammonia, amines are weak bases due to the lone pair of electrons on their nitrogen atoms (Figure 11.42):

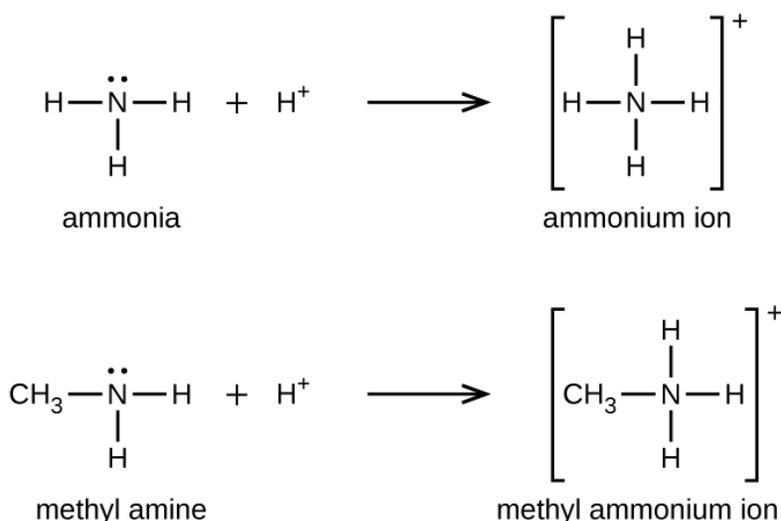


Figure 11.42 Illustration of amines as weak bases. [credit: *Chemistry 2e*, [Amine basicity](#). OpenStax. [CC BY](#).]

The basicity of an amine's nitrogen atom plays an important role in much of the compound's chemistry. Amine functional groups are found in a wide variety of compounds, including natural and synthetic dyes, polymers, vitamins, and medications such as penicillin and codeine. They are also found in many molecules essential to life, such as amino acids, hormones, neurotransmitters, and DNA.

Amides are molecules that contain nitrogen atoms connected to the carbon atom of a carbonyl group. Like amines, various nomenclature rules may be used to name amides, but all include use of the class-specific suffix *-amide* ([Figure 11.43](#)):

Figure 11.45. Molecules of this compound are composed of 13 carbon atoms, 18 hydrogen atoms, and 2 oxygen atoms. Following the approach described above, the average molecular mass for this compound is therefore:

Element	Quantity		Average atomic mass (amu)	=	Subtotal (amu)
C	13	×	12.01	=	156.13
H	18	×	1.008	=	18.144
O	2	×	16.00	=	32.00
Molecular mass					206.27

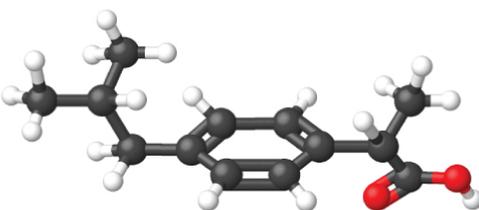


Figure 11.45 Molecular mass compound structure and components [credit: *Chemistry 2e*. [Example 3.1 Computing Molecular Mass for a Covalent Compound](#). OpenStax. [CC BY](#).]

Organic Reactions: Aspirin Synthesis

Aspirin is one of the most used over-the-counter drugs in the world. In the 19th century, scientists discovered that a compound named salicin from the willow tree gave pain relief. Naturally when salicin is ingested, it moves into the digestive system and later is converted into salicylic acid by the help of enzymes. Later, scientists found a way to convert salicin to salicylic acid in the lab environment. However, salicylic acid contains phenol and carboxylic acid groups. Therefore, it was irritating to the stomach. In 1899, the Bayer Company in Germany developed a derivative of salicylic, called acetylsalicylic acid, with less side effects and patented the product as aspirin.

Aspirin can be synthesized by the reaction between salicylic acid and acetic anhydride. The chemical name for aspirin is acetylsalicylic acid and can be seen in Figure 11.46. The molecular mass of an aspirin molecule, $C_9H_8O_4$, is the sum of the atomic masses of nine carbon atoms, eight hydrogen atoms, and four oxygen atoms, which amounts to 180.15 amu.

Element	Quantity		Average atomic mass (amu)	=	Subtotal (amu)
C	9	×	12.01	=	108.09
H	8	×	1.008	=	8.064
O	4	×	16.00	=	64.00
Molecular mass					180.15

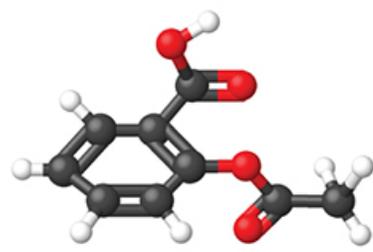


Figure 11.46 The average mass of an aspirin molecule is 180.15 amu. The model shows the molecular structure of aspirin, $C_9H_8O_4$. [credit: *Chemistry 2e*. [Figure 3.3](#). OpenStax. [CC BY](#).]

During the reaction with the use of an acid catalyst like H_2SO_4 , the hydroxyl group of salicylic acid reacts with acetic anhydride and produces an ester structure, which is a functional group found in the aspirin. When reaction is completed, there remains some unreacted salicylic acid and, thus, acetic anhydride can stay as an end product. Therefore, the final product must go through a purification (crystallization) step.

The theoretical yield of aspirin can be calculated once the limiting reactant is identified. In both cases, reaction stoichiometry must be used. The limiting reagent is the reactant that is completely used during the reaction. Once one reactant is completely consumed, the reaction stops. The mole of the product is always determined by the starting mole of the limiting reactant. Therefore, the theoretical yield of aspirin must be calculated from the amount of the limiting reactant.

Benefits and Side Effects of Aspirin

Among the many known biochemical activities of aspirin is its role as an anticoagulant. Aspirin (acetylsalicylic acid) is very effective at inhibiting the aggregation of platelets. It is routinely administered during a heart attack or stroke to reduce the adverse effects. Physicians sometimes recommend that patients at risk for cardiovascular disease take a low dose of aspirin daily as a preventive measure. However, aspirin can also lead to serious side effects, including increasing the risk of ulcers. A patient is well-advised to consult a physician before beginning any aspirin regimen.

The active form of aspirin is its metabolite, sulfasalicylic acid. An overdose of aspirin causes acidosis due to the acidity of this metabolite. Metabolic acidosis can also result from uremia, which is the retention of urea and uric acid. Metabolic acidosis can also arise from diabetic ketoacidosis, wherein an excess of ketone bodies are present in the blood.

Lab Examples

EXAMPLE 9.1: DRAWING SKELETAL STRUCTURES

Draw the skeletal structures for the below two molecules labelled (a) and (b) in Figure 11.47.

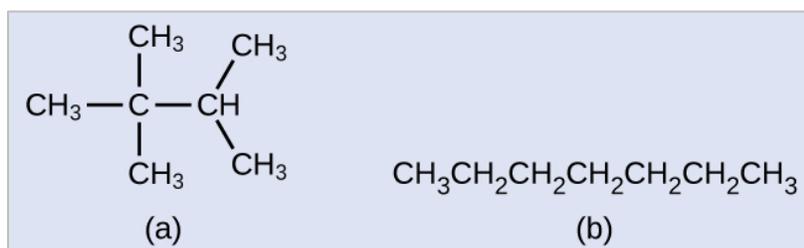


Figure 11.47 (a) Branched molecule and (b) straight chain molecule. [credit: *Chemistry 2e*. [Example 20.1](#). OpenStax. [CC BY](#).]

Solution

Shown in Figure 11.48, each carbon atom is converted into the end of a line or the place where lines intersect. All hydrogen atoms attached to the carbon atoms are left out of the structure (although we still need to recognize they are there):

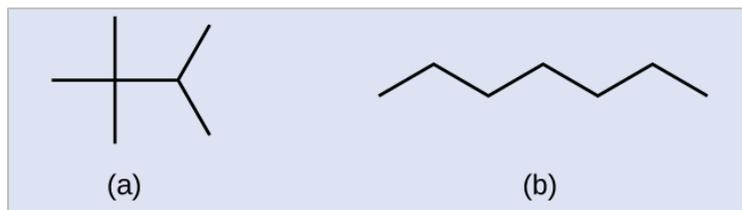


Figure 11.48 (a) Branched skeleton structure that looks like a plus sign with line segments extending up and to the right and down and to the left of the rightmost point of the plus sign. (b) Zig zag pattern of six-line segments. [credit: *Chemistry 2e*. [Example 20.1](#). OpenStax. [CC BY](#).]

Check Your Learning

Draw the skeletal structures for the below two molecules labelled (a) and (b) in Figure 11.49. The answer is illustrated in Figure 11.50.

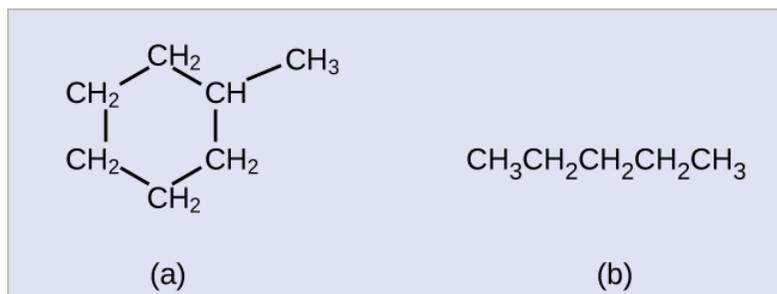


Figure 11.49 (a) Five -CH_2 groups and one -CH group bonded in a hexagonal ring. A -CH_3 group is above and to the right of the ring, bonded to the ring on the -CH group appearing at the upper right portion of the ring. (b) Straight chain molecule composed of $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$. [credit: *Chemistry 2e*. [Example 20.1](#). OpenStax. [CC BY](#).]

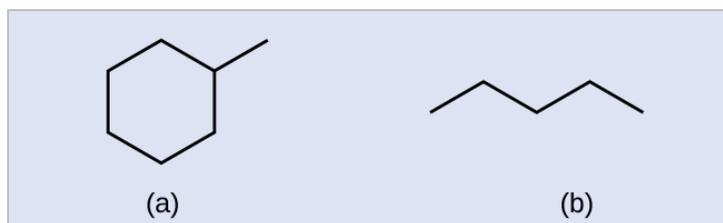
ANSWER:

Figure 11.50 (a) Hexagon with a vertex at the top. The vertex just to the right has a line segment attached that extends up and to the right. (b) Horizontally oriented zigzag pattern with four-line segments forming two peaks and one trough. [credit: *Chemistry 2e*. [Example 20.1](#). OpenStax. [CC BY](#).]

EXAMPLE 9.2: INTERPRETING SKELETAL STRUCTURES

Identify the chemical formula of the molecule represented in Figure 11.51.

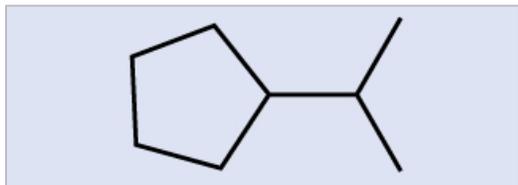


Figure 11.51 Pentagon with a vertex pointing right, from which a line segment extends with two-line segments attached at its right end, one extending up and to the right, and the other extending down and to the right. [credit: *Chemistry 2e*. [Example 20.2](#). OpenStax. [CC BY](#).]

Solution

Shown in Figure 11.52, there are eight places where lines intersect or end, meaning that there are eight carbon atoms in the molecule. Since we know that carbon atoms tend to make four bonds, each carbon atom will have the number of hydrogen atoms that are required for four bonds. This compound contains 16 hydrogen atoms for a molecular formula of C_8H_{16} .

Location of the hydrogen atoms:

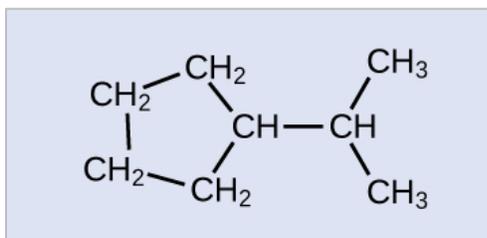


Figure 11.52 Ring of four $-CH_2$ groups and one $-CH$ group in a pentagonal shape. From the $-CH$ group, which is at the right side of the pentagon, a $-CH$ is bonded. From this $-CH$, a $-CH_3$ group is bonded above and to the right and a second is bonded below and to the right. [credit: *Chemistry 2e*. [Example 20.2](#). OpenStax. [CC BY](#).]

Check Your Learning

Identify the chemical formula of the molecule represented in Figure 11.53:

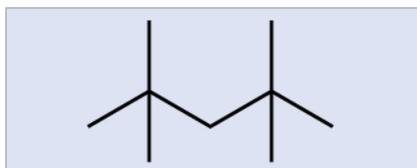


Figure 11.53 Skeleton model with zig zag pattern that rises, falls, rises, and falls again left to right through the center of the molecule. From the two risen points, line segments extend both up and down, creating four branches. [credit: *Chemistry 2e*. [Example 20.2](#). OpenStax. [CC BY](#).]

ANSWER:C₉H₂₀**EXAMPLE 9.3: NAMING HALOGEN-SUBSTITUTED ALKANES**

Name the molecule whose structure is shown in Figure 11.54, for solution for which is illustrated in Figure 11.55. Also, what is missing in Figure 11.54?

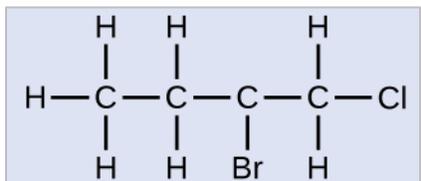


Figure 11.54 Structure of a C atom bonded to the H atoms and another C atom. This second C atom is bonded to two H atoms and another C atom. This third C atom is bonded to an H atom, a Br atom, and another C atom. This fourth C atom is bonded to two H atoms and a Cl atom. [credit: *Chemistry 2e*. [Example 20.3](#). OpenStax. [CC BY](#).]

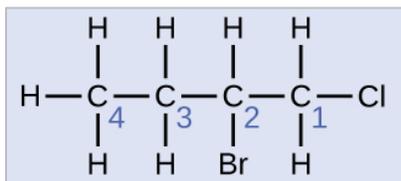
Solution

Figure 11.55 Structure of a C atom bonded to the H atoms and another C atom. This second C atom is bonded to two H atoms and another C atom. This third C atom is bonded to an H atom, a Br atom, and another C atom. This fourth C atom is bonded to two H atoms and a Cl atom. The C atoms are numbered 4, 3, 2, and 1 from left to right. [credit: *Chemistry 2e*. [Example 20.3](#). OpenStax. [CC BY](#).]

The missing component in Figure 11.54 is the H atom bonded to the second C.

The four-carbon chain is numbered from the end with the chlorine atom. This puts the substituents on positions 1 and 2 (numbering from the other end would put the substituents on positions 3 and 4). Four carbon atoms means that the base name of this compound will be butane. The bromine at position 2 will be described by adding 2-bromo-; this will come at the beginning of the name, since bromo- comes before chloro- alphabetically. The chlorine at position 1 will be described by adding 1-chloro-, resulting in the name of the molecule being 2-bromo-1-chlorobutane.

Check Your Learning

Name the below molecule shown in Figure 11.56.

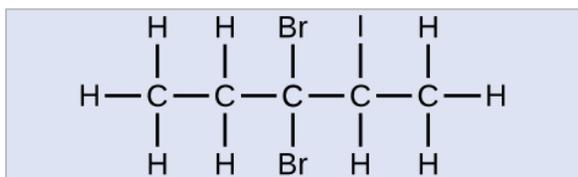


Figure 11.56 Structure of a C atom bonded to three H atoms and another C atom. This second C atom is bonded to two H atoms and a third C atom. The third C atom is bonded to two Br atoms and a fourth C atom. This C atom is bonded to an H atom, and I atom, and a fifth C atom. This last C atom is bonded to three H atoms. [credit: *Chemistry 2e*. [Example 20.3](#). OpenStax. [CC BY](#).]

ANSWER:

3,3-dibromo-2-iodopentane

EXAMPLE 9.4: NAMING SUBSTITUTED ALKANES

Name the molecule whose structure is shown in Figure 11.57.

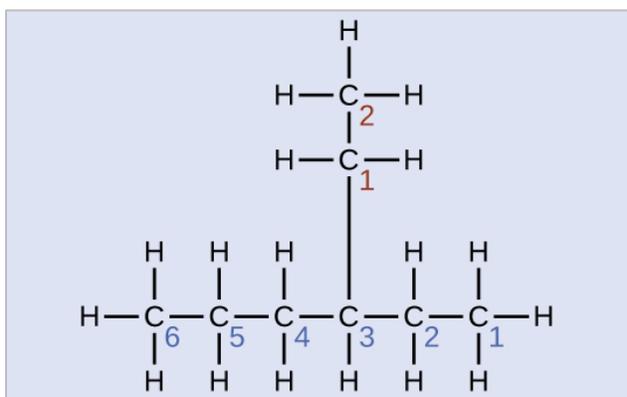


Figure 11.57 A chain of six carbon atoms, numbered 6, 5, 4, 3, 2, and 1 is shown. Bonded above carbon 3, a chain of two carbons is shown, numbered 1 and 2 moving upward. H atoms are present directly above, below, left and right of all carbon atoms in positions not already taken up in bonding to other carbon atoms. [credit: *Chemistry 2e*. [Example 20.4](#). OpenStax. [CC BY](#).]

Solution

The longest carbon chain runs horizontally across the page and contains six carbon atoms (this makes the base of the name hexane, but we will also need to incorporate the name of the branch). In this case, we want to number from right to left (as shown by the blue numbers) so the branch is connected to carbon 3 (imagine the numbers from left to right—this would put the branch on carbon 4, violating our rules). The branch

attached to position 3 of our chain contains two carbon atoms (numbered in red)—so we take our name for two carbons eth- and attach -yl at the end to signify we are describing a branch. Putting all the pieces together, this molecule is 3-ethylhexane.

Check Your Learning

Name the below molecule shown in Figure 11.58.

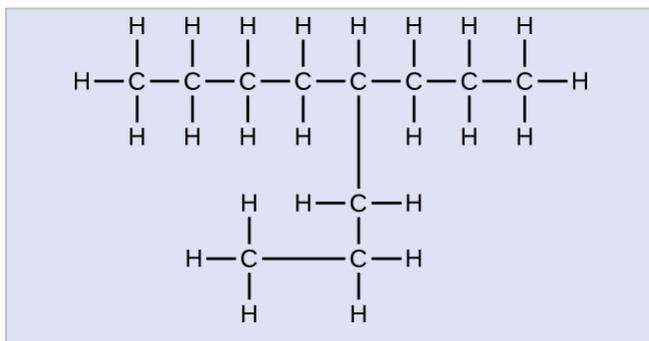


Figure 11.58 Structure of C atom bonded to three H atoms and another C atom. This C atom is bonded to two H atoms and third C atom. The third C atom is bonded to two H atoms and a fourth C atom. The fourth C atom is bonded to two H atoms and a fifth C atom. This C atom is bonded to an H atom, a sixth C atom in the chain, and another C atom which appears to branch off the chain. The C atom in the branch is bonded to two H atoms and another C atom. This C atom is bonded to two H atoms and another C atom. This third C atom appears to the left of the second and is bonded to three H atoms. The sixth C atom in the chain is bonded to two H atoms and a seventh C atom. The seventh C atom is bonded to two H atoms and an eighth C atom. The eighth C atom is bonded to three H atoms. [credit: *Chemistry 2e*. [Example 20.4](#). OpenStax. [CC BY](#).]

ANSWER:

4-propyloctane

EXAMPLE 9.5: ALKENE REACTIVITY AND NAMING

Provide the IUPAC names for the reactant and product of the halogenation reaction shown in Figure 11.59.

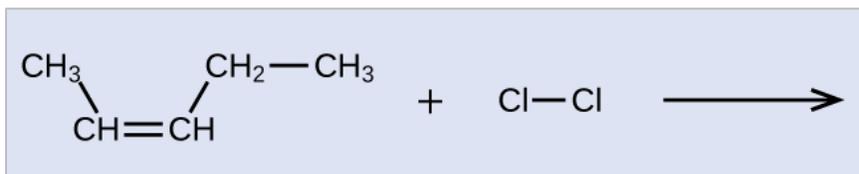


Figure 11.59 The left side of a reaction and arrow are shown with an empty product side. On the left, -CH₃ is bonded down and to the right to -CH which has a double bond to another -CH. The second -CH is bonded up and to the right to -CH₂ which is also bonded to CH₃. A plus sign is shown with a Cl atom bonded to a Cl atom following it. This is also followed by a reaction arrow. [credit: *Chemistry 2e*. [Example 20.5](#). OpenStax. [CC BY](#).]

Solution

The reactant is a five-carbon chain that contains a carbon-carbon double bond, so the base name will be pentene. We begin counting at the end of the chain closest to the double bond—in this case, from the left—the double bond spans carbons 2 and 3, so the name becomes 2-pentene. Since there are two carbon-containing groups attached to the two carbon atoms in the double bond—and they are on the same side of the double bond—this molecule is the cis-isomer, making the name of the starting alkene cis-2-pentene. The product of the halogenation reaction will have two chlorine atoms attached to the carbon atoms that were a part of the carbon-carbon double bond (Figure 11.60).

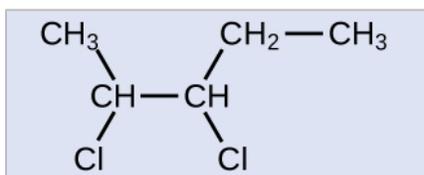


Figure 11.60 CH₃ is bonded down and to the right to -CH which is bonded down and to the left to Cl. -CH is also bonded to another -CH which is bonded down and to the right to Cl and up and to the right to -CH₂. -CH₂ is also bonded to -CH₃. [credit: *Chemistry 2e*. [Example 20.5](#). OpenStax. [CC BY](#).]

This molecule is now a substituted alkane and will be named as such. The base of the name will be pentane. We will count from the end that numbers the carbon atoms where the chlorine atoms are attached as 2 and 3, making the name of the product 2,3-dichloropentane.

Check Your Learning

Provide names for the reactant and product of the reaction shown in Figure 11.61.

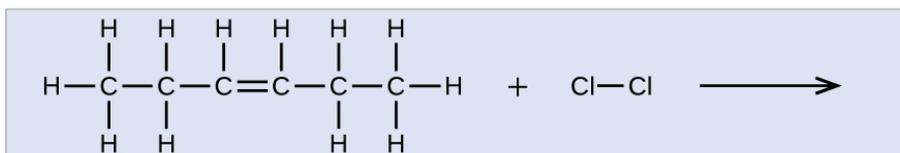


Figure 11.61 This shows a C atom bonded to three H atoms and another C atom. This second C atom is bonded to two H atoms and a third C atom. This third C atom is bonded to one H atom and also forms a double bond with a fourth C atom. This fourth C atom is bonded to one H atom and a fifth C atom. This fifth C atom is bonded to two H atoms and a sixth C atom. This sixth C atom is bonded to three H atoms. There is a plus sign followed by a Cl atom bonded to another Cl atom. There is a reaction arrow. No products are shown. [credit: *Chemistry 2e*. [Example 20.5](#). OpenStax. [CC BY](#).]

ANSWER:

reactant: cis-3-hexene

product: 3,4-dichlorohexane

EXAMPLE 9.6: STRUCTURE OF ALKYNES

Describe the geometry and hybridization of the carbon atoms shown below in Figure 11.62.

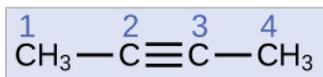


Figure 11.62 Structural formula with $-\text{CH}_3$ bonded to a C atom, which is triple bonded to another C atom which is bonded to $-\text{CH}_3$. Each C atom is labeled 1, 2, 3, and 4 from left to right. [credit: *Chemistry 2e*. [Example 20.6](#). OpenStax. [CC BY](#).]

Solution

Carbon atoms 1 and 4 have four single bonds and are thus tetrahedral with sp^3 hybridization. Carbon atoms 2 and 3 are involved in the triple bond, so they have linear geometries and would be classified as sp hybrids.

Check Your Learning

Identify the hybridization and bond angles at the carbon atoms in the molecule shown below in Figure 11.63.

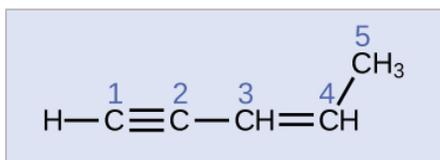


Figure 11.63 Structural formula with an H atom bonded to a C atom. The C atom has a triple bond with another C atom which is also bonded to $-\text{CH}$. The $-\text{CH}$ has a double bond with another $-\text{CH}$ which is also bonded up and to the right to $-\text{CH}_3$. Each C atom is labeled 1, 2, 3, 4, or 5 from left to right. [credit: *Chemistry 2e*. [Example 20.6](#). OpenStax. [CC BY](#).]

ANSWER:

carbon 1: sp , 180° ; carbon 2: sp , 180° ; carbon 3: sp^2 , 120° ; carbon 4: sp^2 , 120° ; carbon 5: sp^3 , 109.5°

EXAMPLE 9.7: STRUCTURE OF AROMATIC HYDROCARBONS

One possible isomer created by a substitution reaction that replaces a hydrogen atom attached to the aromatic ring of toluene with a chlorine atom is shown here. Draw two other possible isomers in which the chlorine atom replaces a different hydrogen atom attached to the aromatic ring shown below in [Figure 11.64](#).

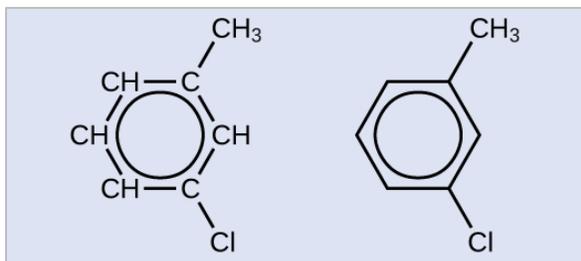


Figure 11.64 Two structural formulas are shown. The first has a six-carbon hydrocarbon ring in which four of the carbon atoms are each bonded to only one H atom. At the upper right of the ring, the carbon that does not have a bonded H atom has a $-\text{CH}_3$ group attached. The C to the lower right has a Cl atom attached. A circle is at the center of the ring. The second molecule has a hexagon with a circle inside. From a vertex of the hexagon at the upper right a CH_3 group is attached. From the vertex at the lower right, a Cl atom is attached. [credit: *Chemistry 2e*. [Example 20.7](#). OpenStax. [CC BY](#).]

Solution

Since the six-carbon ring with alternating double bonds is necessary for the molecule to be classified as aromatic, appropriate isomers can be produced only by changing the positions of the chloro-substituent relative to the methyl-substituent (Figure 11.65):

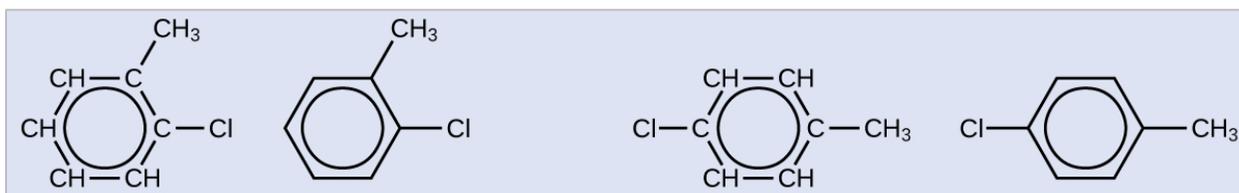


Figure 11.65 Two pairs of structural formulas are shown. The first has a six-carbon hydrocarbon ring in which four of the C atoms are each bonded to only one H atom. At the upper right of the ring, the C atom that does not have a bonded H atom has a $-\text{CH}_3$ group attached. The C atom to the right has a Cl atom attached. A circle is at the center of the ring. The second molecule in the first pair has a hexagon with a circle inside. From a vertex of the hexagon at the upper right a $-\text{CH}_3$ group is attached. From the vertex at the right, a Cl atom is attached. The second pair first shows a six-carbon hydrocarbon ring in which four of the C atoms are each bonded to only one H atom. A Cl atom is attached to the left-most C atom and a $-\text{CH}_3$ group is attached to the right-most C atom. A circle is at the center of the ring. The second molecule in the pair has a hexagon with a circle inside. A $-\text{CH}_3$ group is attached to a vertex on the right side of the hexagon and to a vertex on the left side, a Cl atom is bonded. [credit: *Chemistry 2e*. [Example 20.7](#). OpenStax. [CC BY](#).]

Check Your Learning

Draw three isomers of a six-membered aromatic ring compound substituted with two bromines. The answer is illustrated below in [Figure 11.66](#).

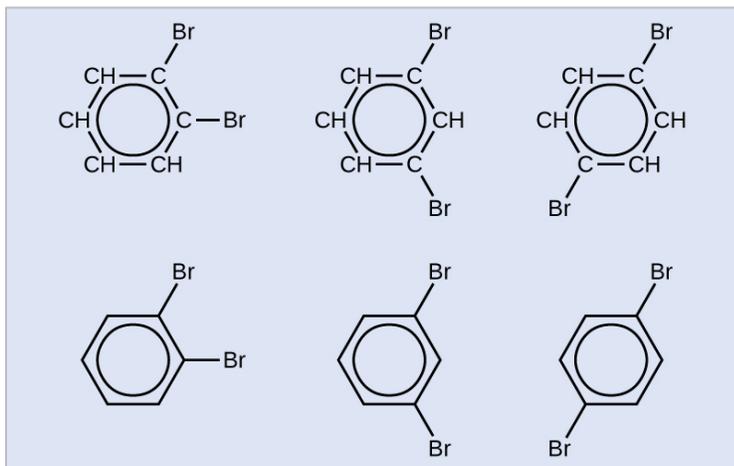
ANSWER:

Figure 11.66 Three pairs of structural formulas are shown. The first has a six-carbon hydrocarbon ring in which four of the C atoms are each bonded to only one H atom. At the upper right and right of the ring, the two C atoms that do not have bonded H atoms have one Br atom bonded each. A circle is at the center of the ring. Beneath this structure, a similar structure is shown which has a hexagon with a circle inside. From vertices of the hexagon at the upper right and right single Br atoms are attached. The second has a six-carbon hydrocarbon ring in which four of the C atoms are each bonded to only one H atom. At the upper right and lower right of the ring, the two C atoms that do not have bonded H atoms have a single Br atom bonded each. A circle is at the center of the ring. Beneath this structure, a similar structure is shown which has a hexagon with a circle inside. From vertices of the hexagon at the upper right and lower right single Br atoms are attached. The third has a six-carbon hydrocarbon ring in which four of the C atoms are each bonded to only one H atom. At the upper right and lower left of the ring, the two C atoms that do not have bonded H atoms have Br atoms bonded. A circle is at the center of the ring. Beneath this structure, a similar structure is shown which has a hexagon with a circle inside. From vertices of the hexagon at the upper right and lower left, single Br atoms are attached. [credit: *Chemistry 2e*. [Example 20.7](#). OpenStax. [CC BY](#).]

EXAMPLE 9.8: NAMING ALCOHOLS

Consider the example shown below in Figure 11.67. How should it be named?

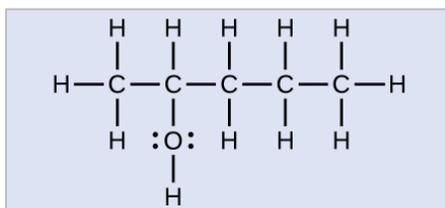


Figure 11.67 Molecular structure of a hydrocarbon chain with a length of five C atoms. The first C atom (from left to right) is bonded to three H atoms. The second C atom is bonded on one H atom and an O atom which is also bonded to an H atom. The O atom has two sets of electron dots. The third C atom is bonded to two H atoms. The fourth C atom is bonded to two H atoms. The fifth C atom is bonded to three H atoms. All bonds shown are single. [credit: *Chemistry 2e*. [Example 20.8](#). OpenStax. [CC BY](#).]

Solution

The carbon chain contains five carbon atoms. If the hydroxyl group was not present, we would have named this molecule pentane. To address the fact that the hydroxyl group is present, we change the ending of the name to -ol. In this case, since the -OH is attached to carbon 2 in the chain, we would name this molecule 2-pentanol.

Check Your Learning

Name the molecule shown below in Figure 11.68.

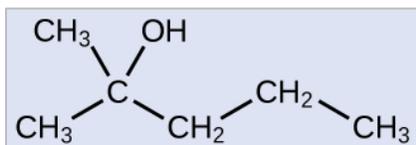


Figure 11.68 Structure with a -CH₃ group bonded up and to the right to a C atom. The C atom is bonded down and to the right to a -CH₂. The -CH₂ group is bonded up and to the right to a -CH₂ group. The -CH₂ group is bonded down and to the right to a -CH₃. The second C atom (from left to right) is bonded to a -CH₃ group and an -OH group. [credit: *Chemistry 2e*. [Example 20.8](#). OpenStax. [CC BY](#).]

ANSWER

2-methyl-2-pentanol

EXAMPLE 9.9: NAMING ETHERS

Provide the IUPAC and common name for the ether below shown in Figure 11.69.

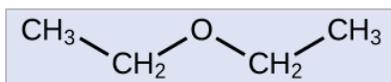


Figure 11.69 Molecular structure with a CH₃ group bonded down and to the right to a CH₂ group. The CH₂ group is bonded up and to the right to an O atom. The O atom is bonded down and to the right to a CH₂ group. The CH₂ group is bonded up and to the right to a CH₃ group. [credit: *Chemistry 2e*. [Example 20.9](#). OpenStax. [CC BY](#).]

Solution

IUPAC: The molecule is made up of an ethoxy group attached to an ethane chain, so the IUPAC name would be ethoxyethane.

Common: The groups attached to the oxygen atom are both ethyl groups, so the common name would be diethyl ether.

Check Your Learning

Provide the IUPAC and common name for the ether below shown in [Figure 11.70](#).

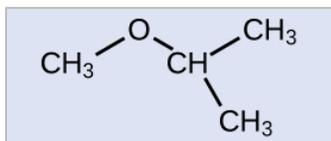


Figure 11.70 Molecular structure with a -CH_3 group bonded up and to the right to an O atom. The O atom is bonded down and to the right to a -CH group. The -CH group is bonded up and to the right to a -CH_3 group. The -CH group is also bonded down and to the right to another -CH_3 group. [credit: *Chemistry 2e*, Example 20.9. OpenStax. [CC BY](#).]

ANSWER

IUPAC: 2-methoxypropane; common: isopropylmethyl ether

Relations to Medicine and Everyday Life

CHEMISTRY IN EVERYDAY LIFE: RECYCLING PLASTICS

Polymers (from Greek words poly meaning “many” and mer meaning “parts”) are large molecules made up of repeating units, referred to as monomers. Polymers can be natural (starch is a polymer of sugar residues and proteins are polymers of amino acids) or synthetic [like polyethylene, polyvinyl chloride (PVC), and polystyrene]. The variety of structures of polymers translates into a broad range of properties and uses that make them integral parts of our everyday lives. Adding functional groups to the structure of a polymer can result in significantly different properties.

An example of a polymerization reaction is shown in Figure 11.71. The monomer ethylene (C_2H_4) is a gas at room temperature, but when polymerized, using a transition metal catalyst, it is transformed into a solid material made up of long chains of $\text{-CH}_2\text{-}$ units called polyethylene. Polyethylene is a commodity plastic used primarily for packaging (bags and films).

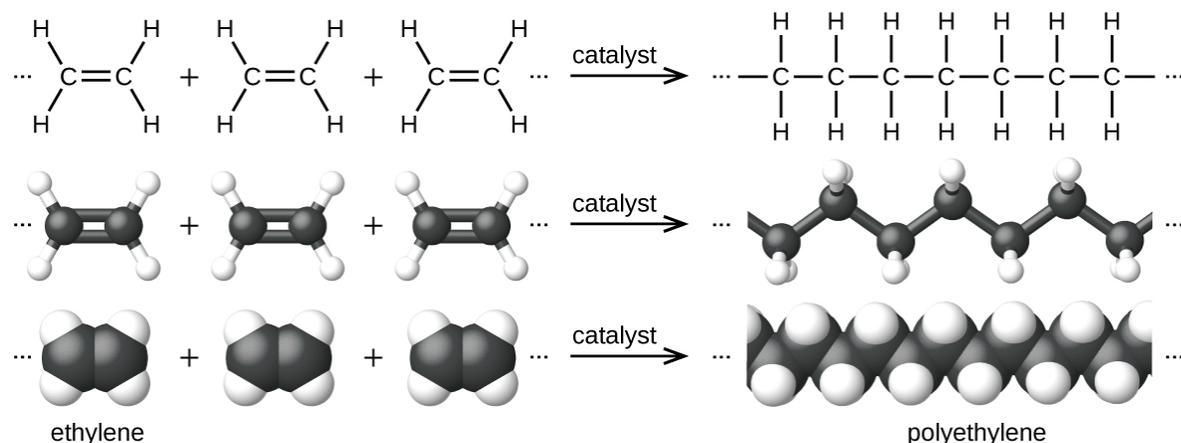


Figure 11.71 The reaction for the polymerization of ethylene to polyethylene. [credit: *Chemistry 2e*, Figure 20.8. OpenStax. [CC BY](#).]

Polyethylene is a member of one subset of synthetic polymers classified as plastics. Plastics are synthetic organic solids that can be molded; they are typically organic polymers with high molecular masses. Most of the monomers that go into common plastics (ethylene, propylene, vinyl chloride, styrene, and ethylene terephthalate) are derived from petrochemicals and are not very biodegradable, making them candidate materials for recycling. Recycling plastics helps minimize the need for using more of the petrochemical supplies and also minimizes the environmental damage caused by throwing away these nonbiodegradable materials.

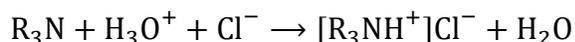
Plastic recycling is the process of recovering waste, scrap, or used plastics, and reprocessing the material into useful products. For example, polyethylene terephthalate (soft drink bottles) can be melted down and used for plastic furniture, in carpets, or for other applications. Other plastics, like polyethylene (bags) and polypropylene (cups, plastic food containers), can be recycled or reprocessed to be used again. Many areas of the country have recycling programs that focus on one or more of the commodity plastics that have been assigned a recycling code (see Figure 11.72). These operations have been in effect since the 1970s and have made the production of some plastics among the most efficient industrial operations today.

 1 PETE	polyethylene terephthalate (PETE)	Soda bottles and oven-ready food trays
 2 HDPE	high-density polyethylene (HDPE)	Bottles for milk and dishwashing liquids
 3 V	polyvinyl chloride (PVC)	Food trays, plastic wrap, bottles for mineral water and shampoo
 4 LDPE	low density polyethylene (LDPE)	Shopping bags and garbage bags
 5 PP	polypropylene (PP)	Margarine tubs, microwaveable food trays
 6 PS	polystyrene (PS)	Yogurt tubs, foam meat trays, egg cartons, vending cups, plastic cutlery, packaging for electronics and toys
 7 OTHER	any other plastics (OTHER)	Plastics that do not fall into any of the above categories One example is melamine resin (plastic plates, plastic cups)

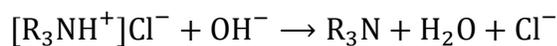
Figure 11.72 Each type of recyclable plastic is imprinted with a code for easy identification. [credit: *Chemistry 2e*. [Figure 20.9](#). OpenStax. [CC BY](#).]

HOW SCIENCES INTERCONNECT: ADDICTIVE ALKALOIDS

Since ancient times, plants have been used for medicinal purposes. One class of substances, called alkaloids, found in many of these plants has been isolated and found to contain cyclic molecules with an amine functional group. These amines are bases. They can react with H_3O^+ in a dilute acid to form an ammonium salt, and this property is used to extract them from the plant:



The name alkaloid means “like an alkali.” Thus, an alkaloid reacts with acid. The free compound can be recovered after extraction by reaction with a base:



The structures of many naturally occurring alkaloids have profound physiological and psychotropic effects in humans. Shown in [Figure 11.73](#), examples of these drugs include nicotine, morphine, codeine, and heroin. The plant produces these substances, collectively called secondary plant compounds, as chemical defenses against the numerous pests that attempt to feed on the plant.

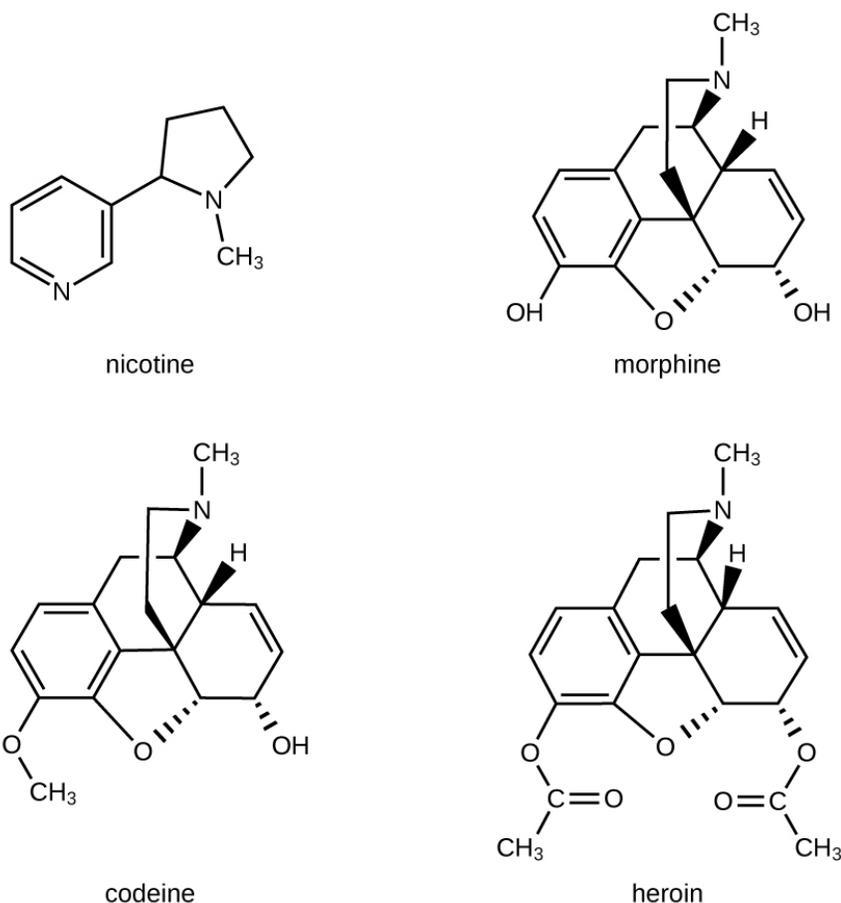


Figure 11.73 Molecular structures of nicotine, morphine, codeine, and heroin. These large structures share some common features, including rings. In the complex structures of morphine, codeine, and heroin, bonds to some O atoms in the structures are indicated with dashed wedges and bonds to some H atoms and N atoms are shown as solid wedges. [credit: *Chemistry 2e*. [Addictive alkaloids examples](#). OpenStax. [CC BY](#).]

In these diagrams, as is common in representing structures of large organic compounds, carbon atoms in the rings and the hydrogen atoms bonded to them have been omitted for clarity. The solid wedges indicate bonds that extend out of the page. The dashed wedges indicate bonds that extend into the page. Notice that small changes to a part of the molecule change the properties of morphine, codeine, and heroin. Morphine, a strong narcotic used to relieve pain, contains two hydroxyl functional groups, located at the bottom of the molecule in this structural formula. Changing one of these hydroxyl groups to a methyl ether group forms codeine, a less potent drug used as a local anesthetic.

If both hydroxyl groups are converted to esters of acetic acid, the powerfully addictive drug heroin results (Figure 11.74).



Figure 11.74 Poppies can be used in the production of opium, a plant latex that contains morphine from which other opiates, such as heroin, can be synthesized. [credit: Karen Roe as cited in *Chemistry 2e*. [Figure 20.19](#). OpenStax. [CC BY](#).]

CHEMISTRY IN EVERYDAY LIFE: KEVLAR

Kevlar (Figure 11.75) is a synthetic polymer made from two monomers 1,4-phenylenediamine and terephthaloyl chloride (Kevlar is a registered trademark of DuPont). Kevlar's first commercial use was as a replacement for steel in racing tires. Kevlar is typically spun into ropes or fibers. The material has a high tensile strength-to-weight ratio (it is about 5 times stronger than an equal weight of steel), making it useful for many applications from bicycle tires to sails to body armor.

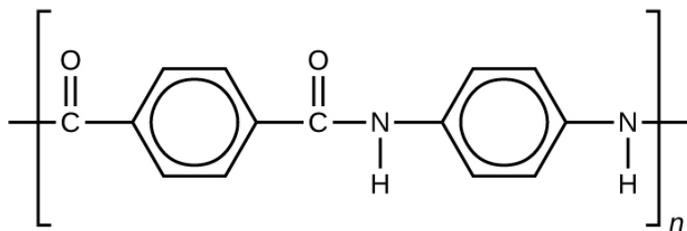


Figure 11.75 This illustration shows the formula for polymeric Kevlar. [credit: *Chemistry 2e*. [Figure 20.22](#). OpenStax. [CC BY](#).]

The material owes much of its strength to hydrogen bonds between polymer chains. These bonds form between the carbonyl group oxygen atom (which has a partial negative charge due to oxygen's electronegativity) on one monomer and the partially positively charged hydrogen atom in the N–H bond of an adjacent monomer in the polymer structure (see dashed line in Figure 11.76). There is additional strength derived from the interaction between the unhybridized p orbitals in the six-membered rings, called aromatic stacking.

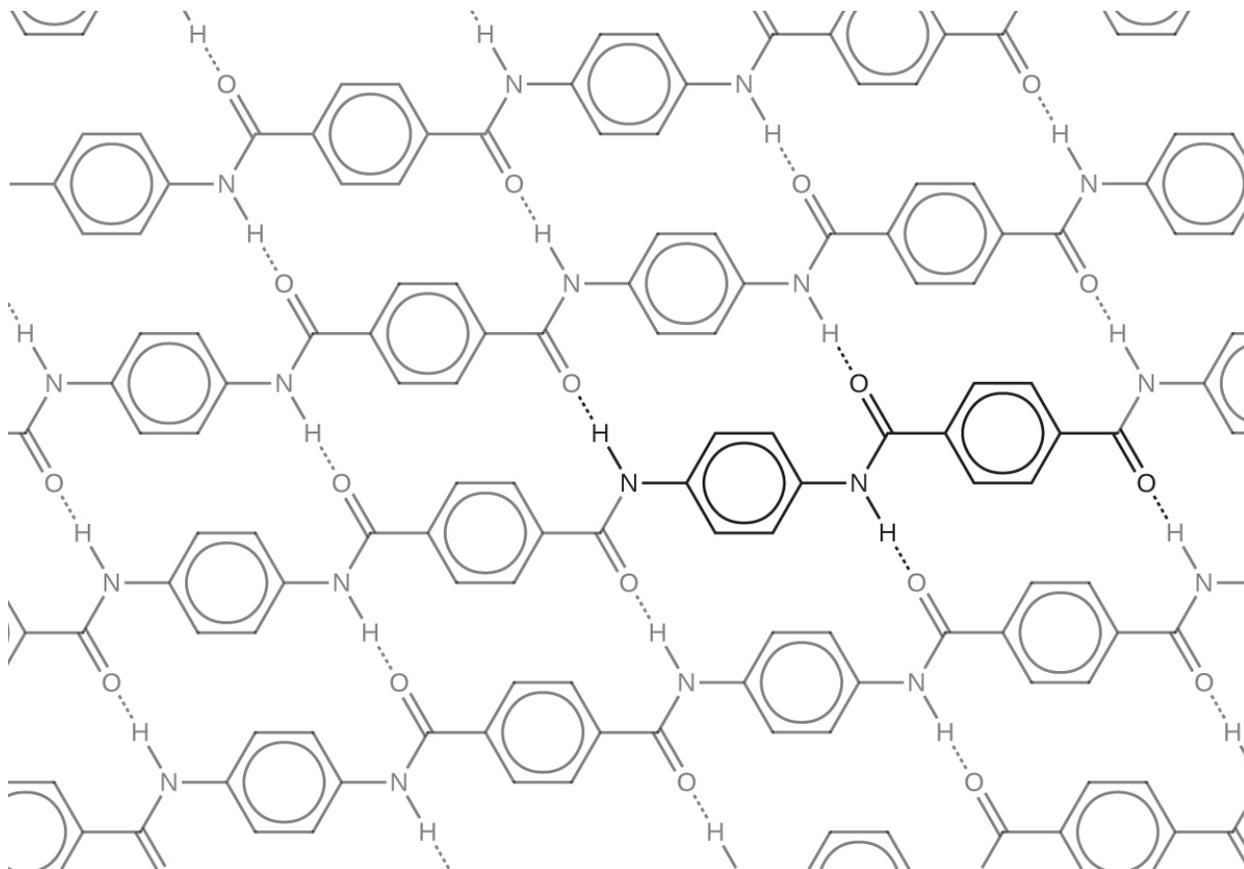


Figure 11.76 The diagram shows the polymer structure of Kevlar, with hydrogen bonds between polymer chains represented by dotted lines. [credit: *Chemistry 2e*. [Figure 20.23](#). OpenStax. [CC BY](#).]

Kevlar may be best known as a component of body armor, combat helmets, and face masks. Since the 1980s, the US military has used Kevlar as a component of the PASGT (personal armor system for ground troops) helmet and vest. Kevlar is also used to protect armored fighting vehicles and aircraft carriers. Civilian applications include protective gear for emergency service personnel such as body armor for police officers and heat-resistant clothing for fire fighters. Kevlar based clothing is considerably lighter and thinner than equivalent gear made from other materials ([Figure 11.77](#)).



Figure 11.77 (a) These soldiers are sorting through pieces of a Kevlar helmet that helped absorb a grenade blast. Kevlar is also used to make (b) canoes and (c) marine mooring lines. [credit: as cited in *Chemistry 2e*. [Figure 20.24](#). OpenStax. [CC BY](#), (a) modification of work by “Cla68”/Wikimedia Commons, (b) modification of work by “OakleyOriginals”/Flickr, (c) modification of work by Casey H. Kyhl.]

In addition to its better-known uses, Kevlar is also often used in cryogenics for its very low thermal conductivity (along with its high strength). Kevlar maintains its high strength when cooled to the temperature of liquid nitrogen ($-196\text{ }^{\circ}\text{C}$).

Even though organic compounds are found in living matter, organic compounds are found in so many products that we use every day such as gasoline, medicines, creams, perfumes, textile, and plastics. Vegetable oil is an organic compound. Solid alkanes that are used as waxy coatings on fruits and vegetable oils to retain moisture and inhibit mold, methane, and propane are used as a burner that can go to a combustion reaction. Ethylene, another organic compound, is used to accelerate the ripening of fruits and is used in antifreeze for cars to raise the boiling point or decrease the freezing point of water in a radiator.

Alcohols have hydroxyl functional groups commonly found in nature and are used in industry. Vegetables and fruits are fermented to produce ethanol, which are used to make alcoholic beverages. Organic compounds that contain thiol groups give strong smell to onions and garlic. So, many odors and flavors come from a carbon-oxygen double bond called carbonyl group. These functional groups in food produce unique smells, such as vanilla and cinnamon.

Organic Compounds Found in Medicine

Organic compounds are very common ingredients to make medicines and drugs. The medication used to induce anesthesia is called an anesthetic drug that prevents the feeling of other sensations during surgical operations. One of the earliest anesthetic drugs used in medicine was diethyl ether, currently not used because it is flammable and produces side effects. Anesthetics such as Forane, Ethrane, and Penthrane have been developed that are not flammable, even though they contain ether groups, but addition of halogen groups reduces the volatility and flammability of the ether. An example of another anesthetic drug is epidural and used for childbirth and nerve blocks for dental procedures.

Hand sanitizers are used to kill most bacteria and viruses when washing the hands is not possible. Many hand sanitizers use ethanol as an active ingredient. The ethanol in hand sanitizers is a fire hazard, because of the flammability of the alcohol. Some of the sanitizers are alcohol free; they contain triclosan as an active ingredient, which contains functional aromatic groups that are considered hazardous for the environment. The FDA is considering the band of usage.

Carbon in Environment

Hydrocarbons, which are carbon containing compounds, are the primary source of energy for the universe, and some of the hydrocarbons on Earth are found in nature are used as fuels. Fossil fuels are used as energy sources and carbon is produced when coal, oil, and gas are burned. CO₂, methane and together with other gases, trap heat radiating from Earth toward space. These gases have a critical function to maintain Earth's temperature. When greenhouse gases levels increase due to increased industrial applications, trapping too much heat changes nature's balance to regulate our climate. In addition, deforestation, cutting down trees for any reason, or large-scale wildfires that causes trees to burn are other contributing factors to increased CO₂ levels in the atmosphere. This causes global warming because the number of trees decreases to absorb excess carbon dioxide.

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