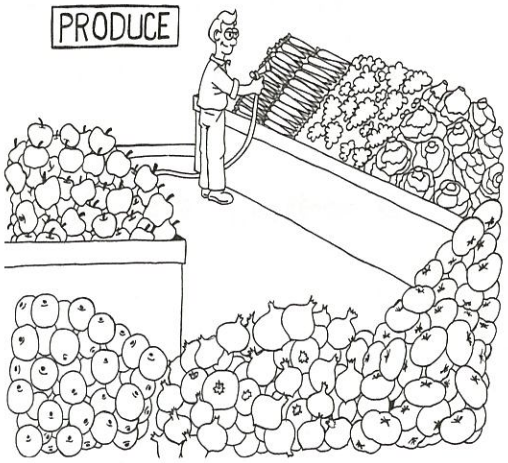
Organic Chemistry

TOPIC 11

What You Know About Organic Chemistry

What does organic *mean?*

Although your grocery store might have a special "organic section" with specially grown foods, chances are more than just the food is organic! To chemists, *organic* refers to substances containing the element carbon. So in this picture the plastic racks, rubber hose, polyester shirt, and even the man are organic as well! Look around your classroom to see how many organic substances you can identify.



TOPIC 11

Organic Chemistry

Vocabulary

addition reaction
alcohol
aldehyde
alkane
alkene
alkyne
amide
amine
amino acid
esterification
ester
ether
fermentation
functional group
hydrocarbon
isomer
ketone
organic acid
organic halide
polymer
polymerization
saponification
saturated
substitution reaction
unsaturated

Topic Overview

Organic chemistry is the study of carbon and most carbon compounds. The name *organic* is a remnant of a time when it was thought that carbon compounds could only be made by living things; hence the term *organic*. Today it is widely recognized that organic chemistry contains far more compounds than only those made by living things. The number of organic compounds is enormous. Tens of thousands of new organic compounds are discovered every year, and there seems to be no end in sight to future discoveries.

The number of carbon compounds far exceeds the number of inorganic compounds. Why can carbon form so many compounds? The answer lies in the ability of carbon atoms to bond with other carbon atoms to form chains, rings, and networks. In this topic you will be introduced to the wide variety of organic compounds and the types of reactions that they undergo.

Memory Jogger

Substances that are covalently bonded form molecules. They generally have low melting and boiling points, and are poor conductors of heat and electricity. They are generally nonpolar and tend to dissolve in nonpolar solvents. Covalently bonded substances tend to react more slowly than ionic compounds.

Bonding of Carbon Atoms

The ability of carbon to form many different compounds is based, to a large extent, on the tendency of carbon atoms to covalently bond with other carbon atoms and form chains. This process can be continued indefinitely, leading to chains of thousands of carbon atoms. Figure 11-1 shows electron dot diagrams of the ground state and the bonded state of a carbon atom and a three-dimensional representation of a tetrahedron with a carbon atom at its center. Note that when carbon bonds, the formerly paired electrons occupy separate orbitals, enabling carbon atoms to form four covalent bonds.

Study the diagram of carbon in Figure 11-1. Note that when carbon is in the bonded state it has four potential sites for covalent bonds. Although the

angle between adjacent electrons appears to be 90°, the atom is actually three dimensional, and the electrons are located at the corners of a tetrahedron with an angle of 109.5° between each pair of electrons.

Figure 11-2 shows carbon atoms sharing electrons to form a chain. In such diagrams, a single line is often used to represent the pair of shared electrons (C–C). When one pair of electrons is shared between two carbon atoms, the bond is called a single covalent bond (Figure 11-2A). Organic compounds containing only single bonds are said to be **saturated.**

Sometimes carbon atoms can share two pairs of electrons, forming a double covalent bond (Figure 11-2B) or even three pairs of electrons in a triple covalent bond (Figure 11-2C). Compounds containing one or more double or triple covalent bonds are called **unsaturated** compounds. In Figure 11-2, double and triple covalent bonds are represented by double and triple lines, respectively.

The chains of carbon atoms can be open or closed. Figure 11-3 shows six carbon atoms in both an open chain and a closed chain.

Carbon atoms can also bond with other carbon atoms forming three-dimensional networks. Diamonds are made of networks of carbon atoms in which each carbon atom is bonded to four other carbon atoms in a characteristic network structure. As recent discoveries have shown, carbon atoms can be arranged in large networks in which each carbon atom is bonded with a single bond to two other carbon atoms and with a double bond to one other carbon atom. The most common of these forms is buckminsterfullerene, also called a buckyball, which contains 60 carbon atoms forming a pattern similar to that on a soccer ball. The carbon atoms form a framework, and the inside of the network is empty space.

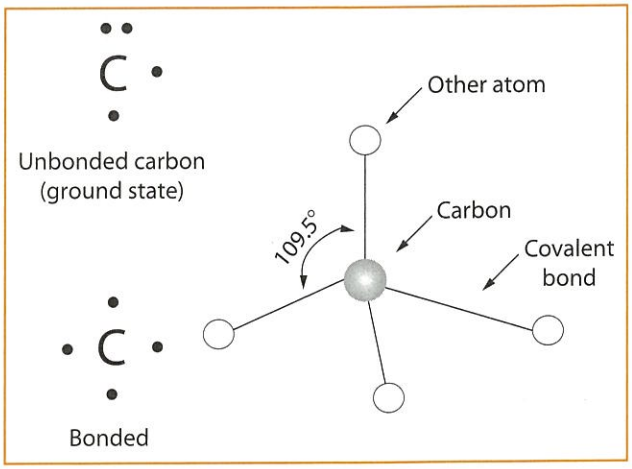


Figure 11-1. Lewis diagrams of carbon and bonded carbon: Carbon forms four equivalent covalent bonds. The tetrahedral molecular shape allows for equal spacing between these bonds.

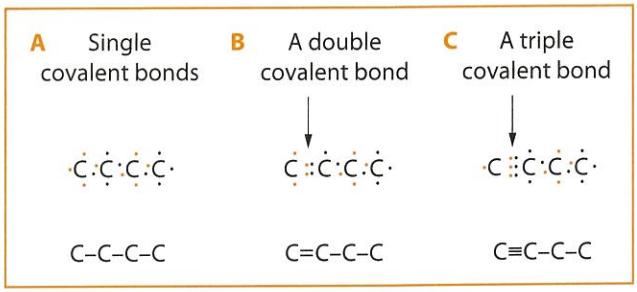


Figure 11-2. Carbon atoms share electrons in covalent bonds to form chains

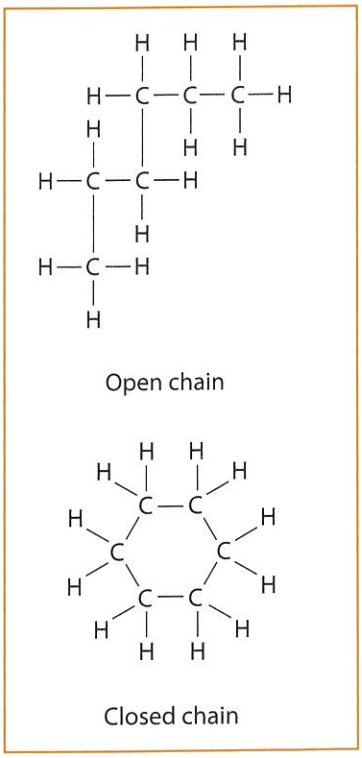


Figure 11-3: Open and closed carbon chains

Structural Formulas The molecular formula shows the kind and number of atoms in a compound. For example, the molecular formula C_3H_8 tells the reader that the compound contains three carbon atoms and eight hydrogen atoms. Structural formulas attempt to show not only the kinds and numbers of atoms but also the bonding patterns and approximate shapes of molecules. Figure 11-4 shows the molecular formulas and structural formulas for two organic compounds. It is important to remember that these structural formulas are two-dimensional representations of three-dimensional molecules. Each carbon atom can be pictured as the center of a tetrahedron, and a short line can represent each of its covalent bonds.

Hydrocarbons

Although there exists an extremely large number of organic compounds, the study of these compounds is simplified because they can be classified into groups called homologous series, the members of which have related

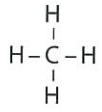
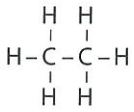
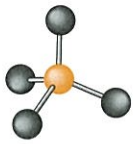
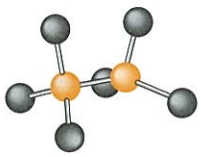
	Methane	Ethane
Molecular Formula	CH_4	C_2H_6
Structural Formula		
Condensed Structural Formula	CH_4	CH_3CH_3
Ball-and-Stick Model		
Space-Filling Model		

Figure 11-4. Various formulas and models of two organic compounds

structures and properties. A homologous series of compounds is a group of related compounds in which each member differs from the one before it by the same additional unit.

Hydrocarbons are organic compounds that contain only atoms of hydrogen and carbon. These compounds are the parent compounds from which many other organic compounds are derived. Alkanes, alkenes, and alkynes are three important homologous series of hydrocarbons. By studying these series you will more easily understand other organic series closely related to them.

Alkanes

The **alkanes** are a homologous series of saturated hydrocarbons that release energy when burned. Methane (CH_4), the first member of the series, comprises about 90% of natural gas, which is used to heat many homes. The second member, ethane (C_2H_6), accounts for most of the rest of natural gas. Propane (C_3H_8) is familiar as a home heating fuel and is also used for outdoor grills and camping equipment. The fourth alkane, butane (C_4H_{10}), is found in disposable lighters.

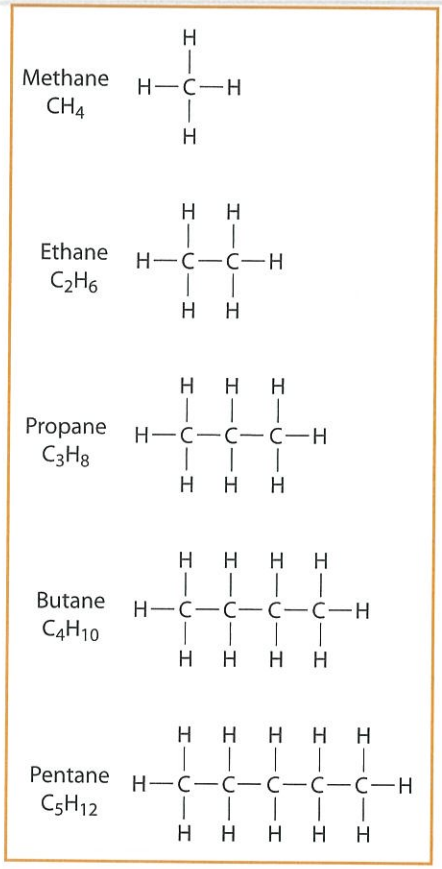


Figure 11-5. The first five members of the alkane family

As the number of carbons increases in the alkane series, the boiling point increases. Chains of five to 12 carbon atoms are found in gasoline. Home heating oils contain 10 to 16 carbon atoms in chains. Paraffin wax, common in candles, contains 20 or more carbon atoms per chain, while road tar (asphalt) may contain 40 carbons in a chain. The names and molecular and structural formulas of the first five members of this series are found in Figure 11-5.

Study the formulas for the members of the alkane series shown in Figure 11-5. Notice that there is a constant relationship between each succeeding member. Ethane has one more carbon atom and two more hydrogen atoms than the preceding member, methane. The same relationship exists between propane and ethane, and butane and propane. This relationship, in which each successive member differs by one carbon atom and two hydrogen atoms (CH_2), from the previous member, defines the nature of a homologous series.

Alkenes

The same relationship between successive members can be found in the homologous series of alkenes. Each member of the **alkene** series contains one double covalent bond.

Because there must be at least two carbon atoms to form a double bond, there is no alkene corresponding to methane of the alkane

series. Ethene, the first member of the alkene series, has the formula C_2H_4. The addition of CH_2 to ethene produces propene (C_3H_6), the second member of the series. Note that the names of the members of the alkene series are derived from the names of the alkane chains with the same number of carbon atoms. The alkenes are named from the corresponding alkane by replacing the *-ane* of the alkane name to *-ene*. For example, the four carbon chain of the alkane series is butane, while butene is the four carbon chain of the alkene series. The first two alkenes are shown in Figure 11-6.

Alkenes provide chemists with starting materials to make other organic compounds. Probably the most important of these is ethene, whose common name is ethylene. When ethylene units are attached to each other to make very long chains, the product is polyethylene, a common plastic.

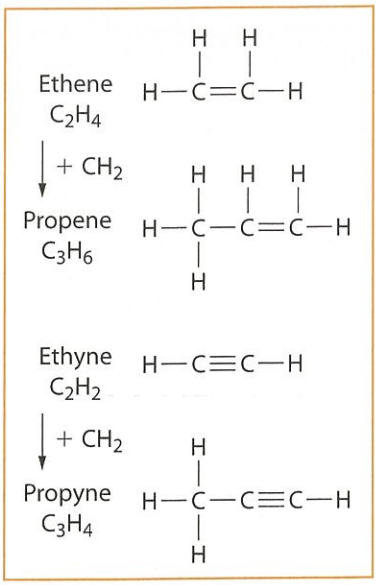


Figure 11-6. Some members of the alkene and alkyne families

Alkynes

The **alkynes** are a homologous series of unsaturated hydrocarbons that contain one triple bond. The naming of the alkyne series repeats the pattern observed in the alkenes. To find the alkyne name, use the corresponding name from the alkane series, and change the *-ane* ending to *-yne*. Thus the first member of the series is ethyne (C_2H_2), as shown in Figure 11-6.

The alkynes, like the alkenes, provide chemists with starting materials to make other organic compounds. The first member of the series, ethyne, is commonly known as acetylene, used as a fuel in welding torches.

General Formulas

In every homologous series there is a definite relationship between the number of carbon and hydrogen atoms. Note that in the alkene series, there are always twice as many hydrogen atoms as carbon atoms. Hence it is possible to show this by writing C_nH_{2n}, the general formula of alkenes. If it is known that a certain alkene contains 10 carbon atoms, then it will contain 20 hydrogen atoms.

Each corresponding member of the alkane series has two more hydrogen atoms than found in the alkenes. C_4H_8 is the formula of butene, but C_4H_{10} is the formula of butane. The general formula of the alkanes shows this change by adding two hydrogen atoms to the general formula, C_nH_{2n+2}. Ethyne (C_2H_2) has two fewer hydrogens than are present in ethene (C_2H_4). In a similar way, all alkynes have two fewer hydrogen atoms than the corresponding alkenes. This is shown in the general formula of the alkynes, C_nH_{2n-2}. These relationships are summarized in Table Q of the *Reference Tables for Physical Setting/Chemistry*. (R)

Review Questions — Set 11.1

1. All organic compounds must contain the element

(1) hydrogen
(2) nitrogen
(3) carbon
(4) oxygen

2. Which element is composed of atoms that can form more than one covalent bond with one another?

(1) hydrogen
(2) helium
(3) carbon
(4) calcium

3. What is the total number of valence electrons in a carbon atom in the ground state?

(1) 12 (2) 2 (3) 6 (4) 4

4. Which property is generally characteristic of an organic compound?

(1) low melting point
(2) high melting point
(3) soluble in polar solvents
(4) insoluble in nonpolar solvents

5. In general, which property do organic compounds share?

(1) high melting point
(2) high electrical conductivity
(3) readily soluble in water
(4) slow reaction rate

6. A hydrocarbon molecule containing one triple covalent bond is classified as an

(1) alkene (3) alkyne
(2) alkane (4) alkadiene

7. What is the total number of hydrogen atoms in a molecule of butene?

(1) 10 (2) 6 (3) 8 (4) 4

8. By how many carbon atoms does each member of a homologous series differ from the previous member?

(1) 1 (2) 2 (3) 3 (4) 4

9. Which of the following is a saturated hydrocarbon?

(1) ethene (3) propene
(2) ethyne (4) propane

10. What is the total number of pairs of electrons shared between the two adjacent carbon atoms in an ethyne molecule?

(1) 1 (2) 2 (3) 3 (4) 4

11. Which compound is a member of the same homologous series as C_3H_6?

(1) C_2H_4 (3) C_3H_4
(2) C_2H_6 (4) C_3H_8

12. Which hydrocarbon is a member of the series with the general formula C_nH_{2n-2}?

(1) ethyne (3) butane
(2) ethene (4) benzene

13. Which compound belongs to the alkene series?

(1) C_2H_2 (3) C_6H_6
(2) C_2H_4 (4) C_6H_{14}

14. Which type of bond occurs in a saturated hydrocarbon molecule?

(1) single covalent (3) triple covalent
(2) double covalent (4) ionic

15. Which type of bonds and solids are characteristic of organic compounds?

(1) ionic bonds and ionic solids
(2) ionic bonds and molecular solids
(3) covalent bonds and ionic solids
(4) covalent bonds and molecular solids

16. The four single bonds of a carbon atom are directed in space toward the corners of a

(1) regular tetrahedron
(2) regular octahedron
(3) square plane
(4) trigonal bipyramid

17. In which group could the hydrocarbons all belong to the same homologous series?

(1) C_2H_2, C_2H_4, C_2H_6 (3) C_2H_4, C_2H_6, C_3H_6
(2) C_2H_4, C_3H_4, C_4H_8 (4) C_2H_4, C_3H_6, C_4H_8

18. Which formula represents butane?

(1) CH_3CH_3 (3) $CH_3CH_2CH_2CH_3$
(2) $CH_3CH_2CH_3$ (4) $CH_3CH_2CH_2CH_2CH_3$

Isomers

Each of the alkanes listed on Figure 11-5 is composed of a continuous chain of carbon atoms. However, beginning with butane there is more than one way of combining the carbon and hydrogen atoms. In Figure 11-7, structural formulas show two different ways in which four carbon atoms and 10 hydrogen atoms can be combined. Not only can the carbon atoms be attached to each other in a continuous chain of four atoms, but they can also be arranged in a chain of three carbon atoms, with the fourth attached to the middle carbon. When a molecular formula can be represented by more than one structural arrangement, the compounds are called **isomers.** Isomers, while having the same molecular formula, have different chemical and physical properties. The boiling point of *n*-butane is 0.5°C, while its isomer boils at −10°C.

As the number of carbon atoms increases, so does the number of possible isomers. While butane has two isomers, octane (C_8H_{18}) has 18, and decane ($C_{10}H_{22}$) has 75. It is this ability to form isomers that is largely responsible for the large number of organic compounds.

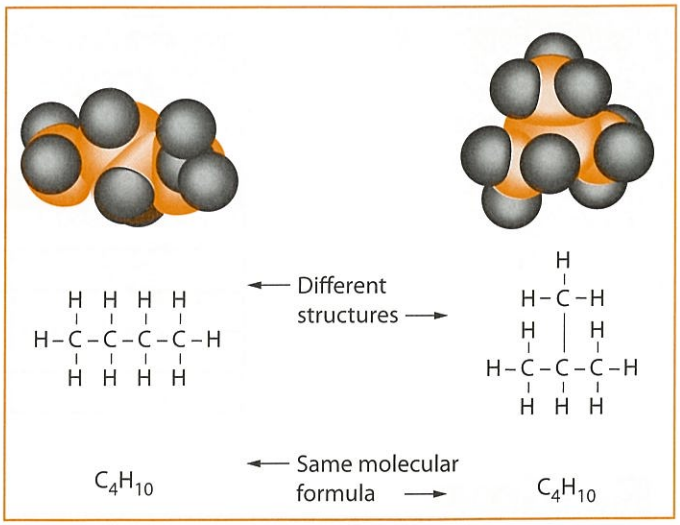


Figure 11-7. **Isomers of butane**

Naming Organic Compounds

When carbon atoms are attached to each other in one continuous chain, the compounds are called straight-chain hydrocarbons. This arrangement is called the normal form, and the letter *n*- precedes the name (*n*-butane). Compounds with branched chains must be given names that are different from the straight-chain name because they have different chemical and physical properties. The rules for naming organic compounds are governed by the International Union of Pure and Applied Chemistry (IUPAC). The following rules will produce names of branched compounds that are approved by the IUPAC.

1. Each compound is named by finding the longest continuous chain of carbon atoms. In the structure on the top in Figure 11-8, the longest chain consists of three carbon atoms, and, hence the compound is named as a derivative of propane, the third alkane. In the second example, the longest continuous chain consists of six carbon atoms, and the compound will be named as a hexane. Note that the chain does not have to appear as a straight chain, but it must be continuous.
2. While the name for the longest chain in the first example is propane, there is a CH_3 group attached to the chain. How should it be named? A group that contains one less hydrogen atom than an alkane with the same number of carbon atoms is classified as one of the alkyl groups, with a group name derived from the name of its corresponding alkane. Thus, the CH_3 that is attached to the propane belongs to the methyl group, so called because, like methane, it has one carbon atom. Table 11-1 shows the relationship between the alkanes and the common alkyl groups. The compound in the first example is called methyl propane. There is no need to identify the location of the methyl group because it can only be attached to the central carbon.
3. If necessary, the location of the alkyl group is shown by assigning numbers to the carbon atoms in the longest chain. The carbon chain must be numbered from the end that will give the lowest number for the attached group. In the second example, the compound should be named 2-methyl hexane rather than 5-methyl hexane.
4. There may be more than one of the same type of group attached to the parent chain. A prefix is used to indicate the number of attached groups of each type that are present. If two methyl groups are attached, the prefix *di*- will be used. *Tri*- will indicate three, and *tetra*-, four. In addition, commas are used to indicate the specific carbon to which each group is attached. For example, if two methyl groups are attached to the second carbon atom in a five-carbon chain, and another methyl

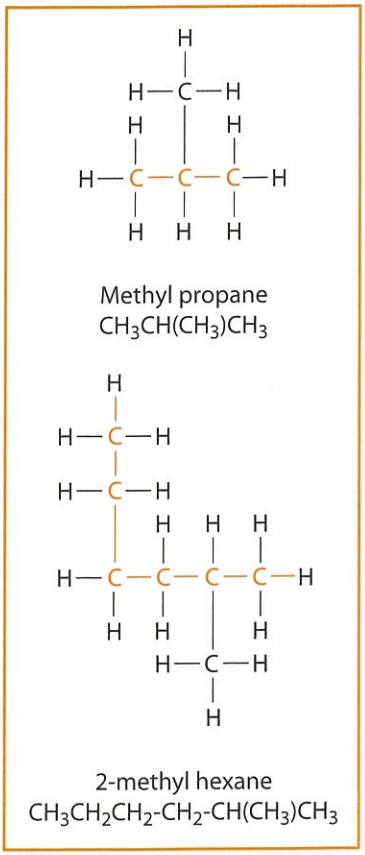


Figure 11-8. **Naming organic compounds**

group is attached to the third carbon atom, the compound would be 2,2,3-trimethyl pentane. When more than one group is attached to the parent chain, the chain must be numbered in such a way to produce the smaller total value of the attached chains.

Table 11-1. Relationship of Alkanes and Alkyl Groups

Alkane		Alkyl Group	
Name	**Formula**	**Name**	**Formula**
methane	CH_4	methyl	CH_3
ethane	C_2H_6	ethyl	C_2H_5
n-propane	C_3H_8	*n*-propyl	C_3H_7

Review Questions — Set 11.2

19. Which compound is an isomer of C_4H_9OH?

(1) $C_3H_7CH_3$ (3) $C_2H_5COOC_2H_5$

(2) $C_2H_5OC_2H_5$ (4) CH_3COOH

20. Which compound is an isomer of CH_3CH_2OH?

(1) CH_3COOH (3) CH_3OCH_3

(2) $CH_3CH_2CH_3$ (4) CH_3COCH_3

21. Which formula represents an isomer of the compound propanoic acid (CH_3CH_2COOH)?

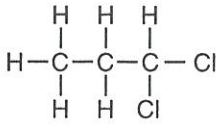
(1) $CH_3CH_2CH_2OH$

(2) $CH_3CH_2CH_2COOH$

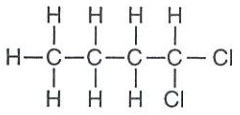
(3) $CH_3CH(OH)CH_2OH$

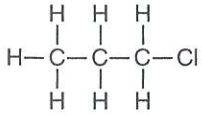
(4) CH_3COOCH_3

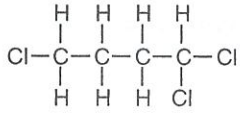
22. Given the compound:

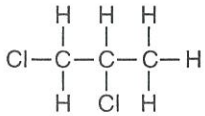


Which structural formula represents an isomer?

(1) 

(3) 

(2) 

(4) 

23. Which compounds are isomers?

(1) CH_3Br and CH_2Br_2

(2) CH_3OH and CH_3CH_2OH

(3) CH_3OH and CH_3CHO

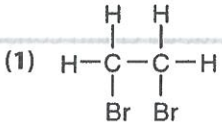
(4) CH_3OCH_3 and CH_3CH_2OH

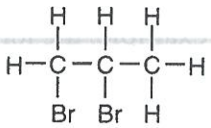
24. An *–ol* suffix indicates that an –OH group has been added to a hydrocarbon. Which formula represents 1,2-ethanediol?

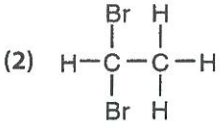
(1) $C_2H_4(OH)_2$ (3) $Ca(OH)_2$

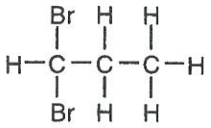
(2) $C_3H_5(OH)_3$ (4) $Co(OH)_3$

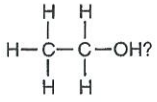
25. Which structural formula represents 1,1-dibromopropane?

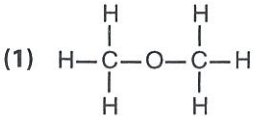
(1) 

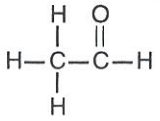
(3) 

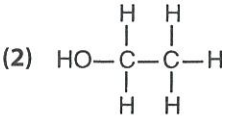
(2) 

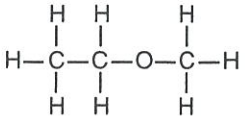
(4) 

26. Which is an isomer of 

(1) 

(3) 

(2) 

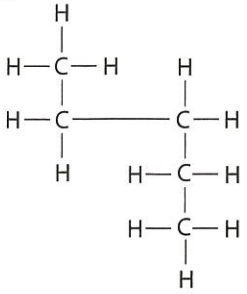
(4) 

27. Which compound has the molecular formula C_5H_{12}?

(1) butane (3) 2,2-dimethyl butane

(2) pentane (4) 2,2-dimethyl pentane

28. Which is the correct IUPAC name for the hydrocarbon with the structural formula shown below?



(1) 1-methyl-2-ethylenethane
(2) 1-propylethane
(3) *n*-propane
(4) *n*-pentane

29. Write the structural formula for 3-methyl pentane.

30. Write the structural formula for 2, 2-dimethyl hexane.

31. Write the structural formula for 2-methyl, 3-ethyl hexane.

32. Write the structural formula for 2,2,3-trimethyl heptane.

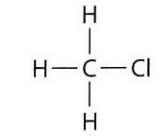
33. Write the structural formula for 3,3-dimethyl, 4-ethyl octane.

Functional Groups

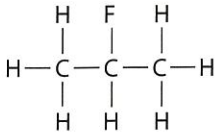
Although hydrocarbons are the most basic organic compounds, many other organic compounds form when other atoms replace one or more hydrogen atoms in a hydrocarbon. These atoms or groups of atoms, called **functional groups,** replace hydrogen atoms in a hydrocarbon and give the compound distinctive physical and chemical properties. The naming of these compounds is made easy because they derive their names from the hydrocarbon with the corresponding number of carbon atoms.

Halides

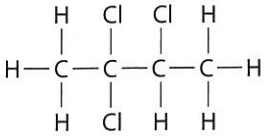
When any of the halogens (F, Cl, Br, or I) replaces a hydrogen atom in an alkane, the compound is called an **organic halide,** or halocarbon. The functional group of an organic halide is the halogen that is attached to the chain. Organic halides are often used as organic solvents and are found in some pesticides. They are named by citing the location of the halogen attached to the chain. Figure 11-9 shows some examples of halocarbons and shows how the chain is numbered when necessary to show the location of the halogen.



Chloromethane
CH_3Cl



2-fluoropropane
CH_3CHFCH_3



2,2,3-trichlorobutane
$CH_3\text{-}CCl_2CHClCH_3$

Figure 11-9. Some typical organic halides

Alcohols

Alcohols are organic compounds in which one or more hydrogen atoms of a hydrocarbon are replaced by an –OH group. The –OH group is called a hydroxyl group and is the functional group that gives alcohols their specific chemical and physical properties. Although the –OH group resembles the hydroxide ion of inorganic bases, it does not form an ion in water. Hence, alcohols are nonelectrolytes and do not turn indicators characteristic acid or basic colors. While these hydroxyl groups do not form ions in solution, they are quite polar. This polarity allows alcohols to be soluble in water, which is also polar.

There are several different types of alcohols. The type is dependent on the number of hydroxyl groups in the compound and on the position of each hydroxyl group on the main carbon chain.

Classification of Alcohols Alcohols are classified as primary, secondary, or tertiary based on whether the hydroxyl group is attached to a primary,

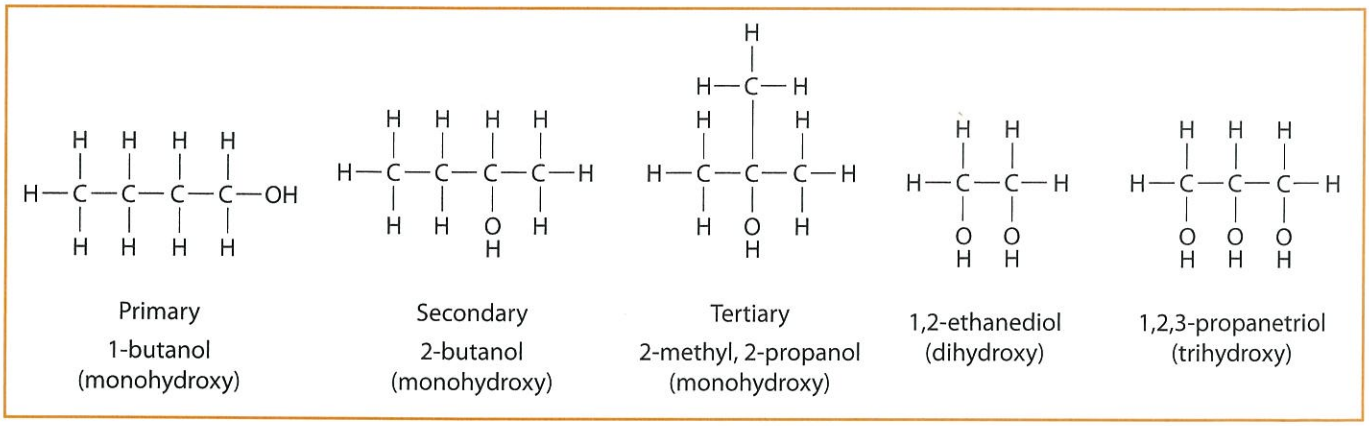


Figure 11-10. **Some representative alcohols**

secondary, or tertiary carbon atom. Primary carbon atoms are attached directly to only one other carbon atom and are located at the end of a chain or branch. Secondary carbon atoms are directly attached to two other carbon atoms. Tertiary carbon atoms are attached directly to three other carbon atoms.

Alcohols are classified according to the carbon atom to which the hydroxyl group is attached. A primary alcohol has a hydroxyl group attached to a primary carbon atom at the end of the chain. Primary alcohols are represented by *R*–OH or RCH_2OH, where the *R* represents a hydrocarbon chain in which a hydrogen atom is replaced by the functional group shown.

A secondary alcohol has a hydroxyl group attached to a secondary carbon atom. Secondary alcohols can be represented by *R*–CH(OH)–*R*′, where *R* and *R*′ represent two hydrocarbon chains.

A tertiary alcohol has a hydroxyl group attached to a tertiary carbon atom. A tertiary alcohol can be represented by $R_1R_2R_3COH$.

Dihydroxy and Trihydroxy Alcohols Alcohols can also be classified by the number of hydroxyl groups that are attached to the carbon chain. In addition to alcohols that have one hydroxyl group (monohydroxy), there are families of alcohols with two or more attached groups. Ethylene glycol, also known as antifreeze, is the common name for a dihydroxy (two hydroxyl groups) alcohol. Its proper name is 1,2-ethanediol. 1,2,3-propanetriol is another common substance, glycerol, which is used as a moistening agent in cosmetics. Figure 11-10 shows examples of the various types of alcohols.

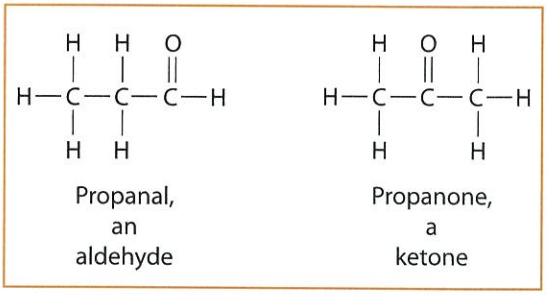


Figure 11-11. **An aldehyde and a ketone:** Both aldehydes and ketones contain the carbonyl group.

Other Substituted Hydrocarbons

Aldehydes When an oxygen atom is attached to a carbon chain by a double covalent bond, it is called a carbonyl group (–C=O). **Aldehydes** are organic compounds in which the carbonyl group is found on the end carbon (a primary carbon), as shown in Figure 11-11. Aldehydes are named by substituting *−al* in place of the final *−e* of the corresponding alkane name. The first member of the series has the IUPAC name methanal. Its common name is formaldehyde, and it is used as a preservative. An aldehyde can be recognized from

its structural formula by the presence of a double bonded oxygen atom together with a hydrogen atom attached to an end carbon.

Ketones A **ketone** is formed when the carbonyl group (–C=O) is found on an interior carbon atom that is attached to two other carbon atoms, as shown in Figure 11-11. Ketones are named by replacing the final *–e* from the corresponding alkane name with *–one*. The first ketone is formed by a carbonyl group attached to the central carbon atom of a chain of three carbon atoms. Its IUPAC name is propanone. The common name of propanone is acetone. Ketones are often used as solvents. The carbonyl group is quite polar, allowing the ketone to dissolve in water. The remainder of the molecule causes the ketone to be soluble in other organic compounds.

Ethers **Ethers** are a series of organic compounds in which two carbon chains are joined together by an oxygen atom bonded between two carbon atoms. The general formula is written *R*–O–*R'* to show the oxygen bridge between the two carbon chains. Structures and common and IUPAC names for some ethers are shown in Figure 11-12.

Organic Acids **Organic acids** are a homologous series of organic compounds whose functional group is a carboxyl group (–COOH). Organic acids derive their names from the corresponding hydrocarbons by replacing the *–e* with *–oic acid*. Thus the two-carbon hydrocarbon is ethane, while the corresponding acid is ethanoic acid. Ethanoic acid is commonly known as acetic acid, which is found in vinegar. Although most organic compounds are nonelectrolytes, organic acids are generally weak electrolytes.

Esters **Esters** are organic compounds whose type formula is *R*–CO–O*R'*. The *R*–CO–O– part of the formula comes from an organic acid, and the *R'* part of the formula comes from an alcohol. Esters have strong, fragrant aromas and are responsible for the odors of many foods and flavorings, such as pineapples, bananas, wintergreen, and oranges.

Amines Perhaps the easiest way to understand amines is as a derivative of ammonia. An **amine** is formed when one or more of the hydrogen atoms of ammonia are replaced by an alkyl group. To name an amine, the *–e* ending of the alkane name is changed to end in *–amine*, and the alkane chain is numbered to show the location of the amine group. Figure 11-13 shows the relation of amines to ammonia. Amines are important biological chemicals present in the B vitamins, hormones, and anesthetics. They are also used commercially in the preparation of dyes.

Amino Acids Like all organic acids, **amino acids** contain the carboxylic group (–COOH) but also contain an amine group. The amine group is attached to the carbon atom that is adjacent to the acid group (Figure 11-14). The remainder of the molecule is represented by *R*, which indicates the side chain. There are ten essential amino acids that the body must obtain through diet because it cannot synthesize them. The remaining amino acids can be synthesized. Amino acids are the building blocks of protein.

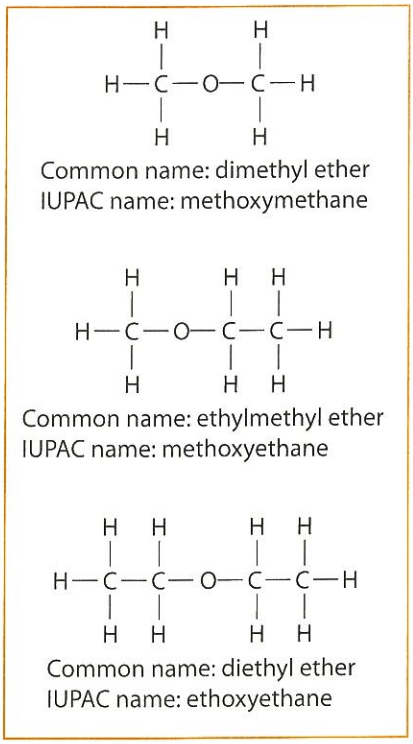


Figure 11-12. Some common ethers

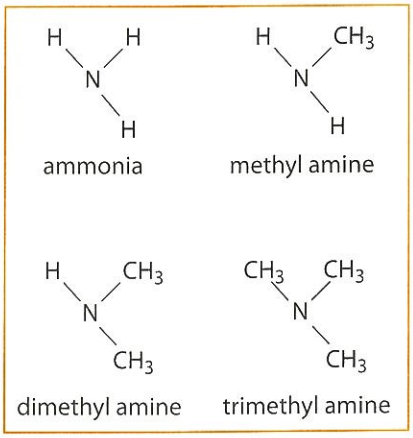


Figure 11-13. The relation of amines and ammonia

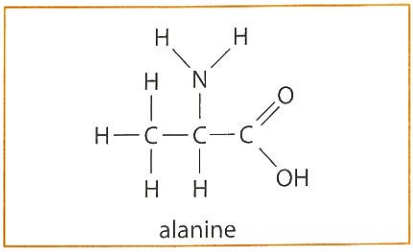


Figure 11-14. An amino acid: Amino acids have both an acid group and an amine group.

Digging Deeper

Proteins are extremely long chains of amino acids. They have molecular masses well over 100 000 atomic mass units. These proteins are different sequences of 20 different amino acids, providing an almost infinite variety of combinations. Proteins compose the tendons and contractile myosin of our muscles, the hemoglobin in our blood, and many essential enzymes and hormones.

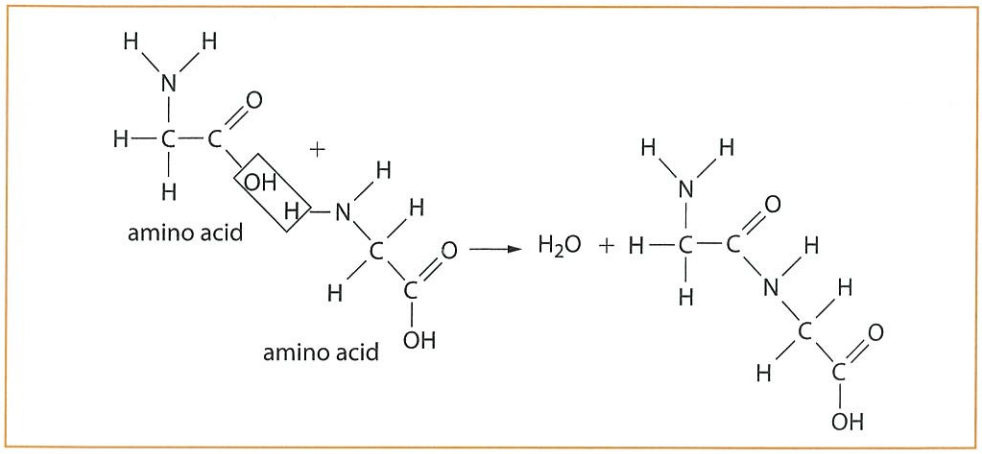


Figure 11-15. Formation of an amide: Two amino acids combine to form an amide (peptide).

Amides When one of the hydrogen atoms of the amino group reacts with the –OH of an organic acid, a condensation reaction occurs. This reaction produces water and an **amide**, which is a compound formed by the combination of the two amino acids. Look at Figure 11-15. Peptide bonding holds amino acid molecules together, forming long protein chains. While organic chemists call this linkage an amide, biologists refer to it as a peptide link. Additional condensation reactions occur, first producing a polypeptide. Eventually the chain is long enough to be a protein.

Review Questions — Set 11.3

34. When the name of an alcohol is derived from the corresponding alkane, the final *–e* of the name of the alkane should be replaced by the suffix

(1) *–al* (2) *–ol* (3) *–one* (4) *–ole*

35. In a secondary alcohol, the carbon bonded to the –OH group must also be bonded to

(1) one carbon atom (3) three carbon atoms
(2) two carbon atoms (4) four carbon atoms.

36. Which class of compounds has the general formula *R*–O–*R'*?

(1) esters (3) ethers
(2) alcohols (4) aldehydes

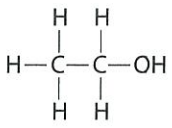
37. The formula $C_5H_{11}OH$ represents an

(1) acid (3) ether
(2) ester (4) alcohol

38. The general formula R–COOH represents a class of compounds called

(1) alkanes (3) acids
(2) alkenes (4) alcohols

39. Which structural formula represents a secondary alcohol?

(1)


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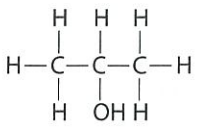
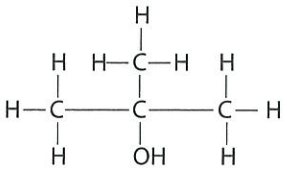


(2)


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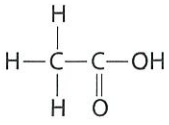
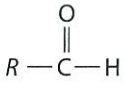
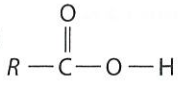
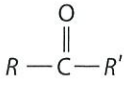


40. Which is the general formula for an aldehyde?

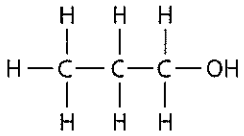
(1)


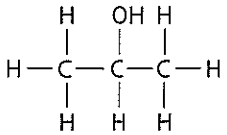
(3)


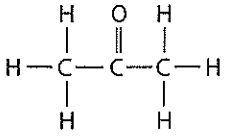
(2) $R-OH$

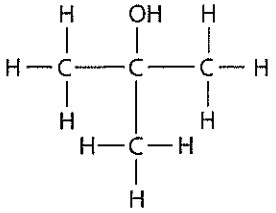
(4)


41. Which structural formula represents a tertiary alcohol?

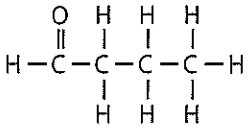
(1) 

(2) 

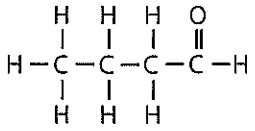
(3) 

(4) 

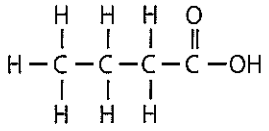
42. Given a formula representing a compound:



Which formula represents an isomer of this compound?



(1)



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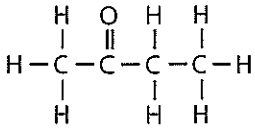

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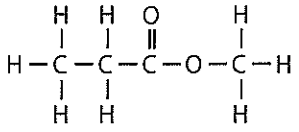
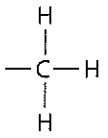
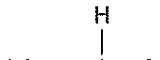
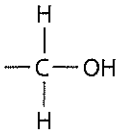


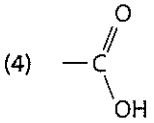
(4)

43. Which functional group is found in all organic acids?

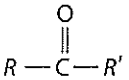
(1) 

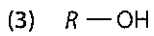
(3) 

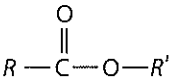
(2) 

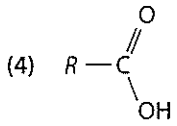
(4) 

44. Which general formula represents a ketone?

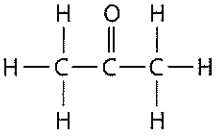
(1) 

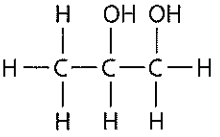
(3) 

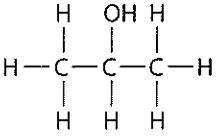
(2) 

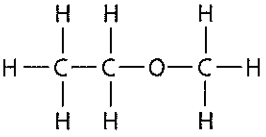
(4) 

45. Which structural formula represents a monohydroxy alcohol?

(1) 

(2) 

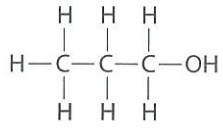
(3) 

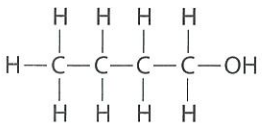
(4) 

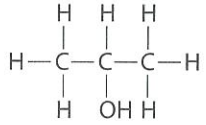
46. The molecule  is a member of a class of organic compounds called

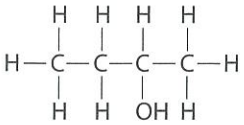
(1) ethers
(2) ketones
(3) alcohols
(4) aldehydes

47. Which is the structural formula for 2-propanol?

(1) 

(3) 

(2) 

(4) 

48. Functional groups are used to classify

(1) inorganic compounds.
(2) organic compounds.
(3) heterogeneous mixtures.
(4) homogeneous mixtures.

Organic Reactions

Organic reactions generally occur more slowly than inorganic reactions. When covalently bonded substances react, they must first break relatively strong existing bonds before making new bonds.

Combustion

Perhaps the most common type of organic reaction is combustion. Almost all organic compounds will burn. When sufficient oxygen is present, hydrocarbons will burn to produce water and carbon dioxide. Propane, commonly used in outdoor grills, burns according to the following equation.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

When the supply of oxygen is limited, carbon monoxide may be produced instead of carbon dioxide.

$$2C_3H_8(g) + 7O_2(g) \rightarrow 6CO(g) + 8H_2O(g)$$

When carbon dioxide is produced the reaction is called complete combustion, while incomplete combustion describes the production of carbon monoxide and water.

Substitution

A **substitution reaction** involves the replacement of one or more of the hydrogen atoms in a saturated hydrocarbon with another atom or group. For example, halogen atoms can replace hydrogen atoms in saturated hydrocarbons. When ethane reacts with chlorine in a substitution reaction, the products of the reaction are chloroethane and hydrogen chloride.

$$C_2H_6 + Cl_2 \rightarrow C_2H_5Cl + HCl$$

Because all of the bonding sites on a saturated hydrocarbon are filled, chlorine must first remove a hydrogen atom from the hydrocarbon chain, forming hydrogen chloride. The removal of a hydrogen atom from the chain provides an open bond site where a chlorine atom can then attach itself.

Addition

Addition reactions involve adding one or more atoms at a double or triple bond. When ethene and chlorine react, the double bond of the ethene is opened and a chlorine atom is added to each carbon atom.

$$C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2$$

Unsaturated hydrocarbons can also react with hydrogen by addition reactions. In this case, the final product is a saturated hydrocarbon.

$$C_2H_4 + H_2 \rightarrow C_2H_6$$

Esterification

Esterification is the reaction between an organic acid and an alcohol to produce an ester plus water. An example of an esterification reaction between acetic acid and ethanol to produce the ester ethyl ethanoate is shown in Figure 11-16. Sulfuric acid is used as a dehydrating agent. It removes two hydrogen atoms and an oxygen atom to form water, with the remaining fragments combining to form the ester. Esters are named by using the alkyl name of the alcohol followed by the acid group modified to end in *−oate*. The ester produced by the reaction of methanol with ethanoic acid is methyl ethanoate.

Saponification

When an ester reacts with an inorganic base to produce an alcohol and a soap, the reaction is called a **saponification** reaction (Figure 11-17). One of the most common saponification reactions involves the reaction of a fat with a strong base such as sodium hydroxide. The products of this reaction are soap and glycerol.

Fermentation

Fermentation is a chemical process in which yeast cells secrete the enzyme zymase and break the six-carbon chain of sugars into carbon dioxide and two-carbon fragments of alcohol. The following equation shows what happens during fermentation.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

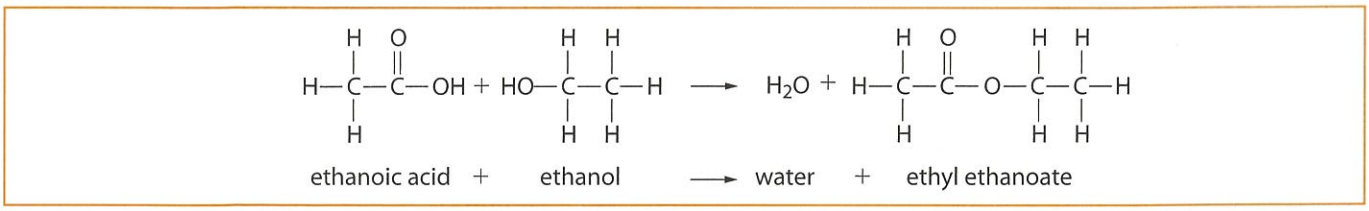


Figure 11-16. Esterification: An acid and an alcohol react to produce water and an ester.

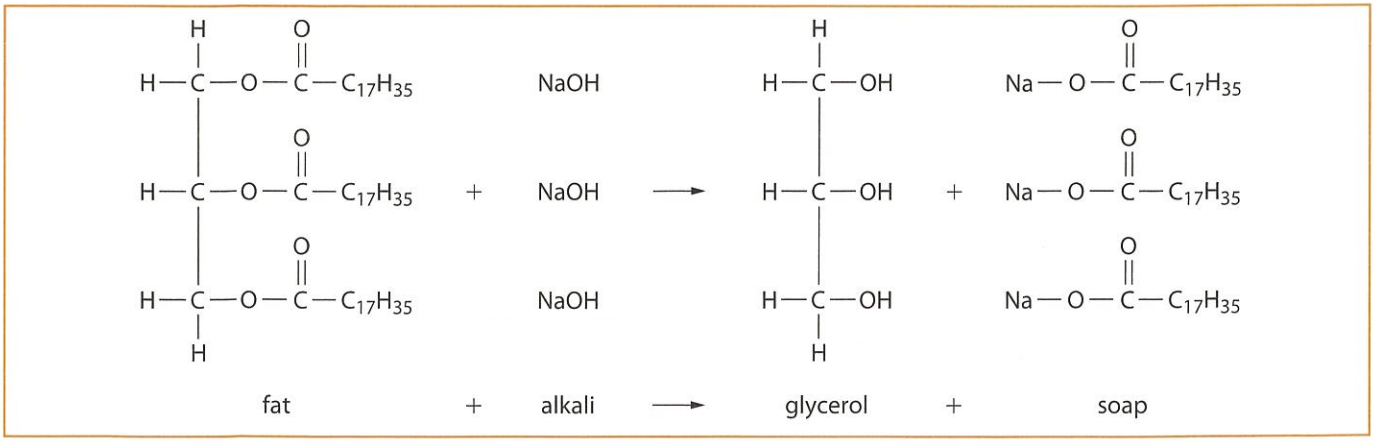


Figure 11-17. Saponification: A fat and an alkali react to produce glycerol and a soap, which is a salt of a fatty acid.

Polymerization

Polymers are organic compounds made up of chains of smaller units covalently bonded together. The formation of these large polymer molecules is called **polymerization,** and each individual unit of a polymer is called a monomer. Synthetic plastics such as nylon, rayon, and polyethylene, are the best-known polymers. There are also many naturally occurring polymers, such as proteins, starches, and cellulose.

Addition Polymerization Addition polymerization reactions involve the joining of monomers of unsaturated compounds. When the double bond between the carbon atoms of ethene breaks, the resulting bond site is called a free radical because of the two unbonded electrons. These electrons can bond with similar open bonds of adjacent molecules to form long chains. A typical addition polymerization reaction can be shown as follows.

$$n C_2H_2 \rightarrow (C_2H_2)_n$$

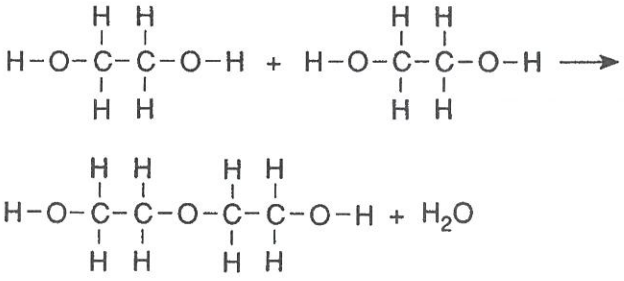
Condensation Polymerization Condensation polymerization reactions result from the bonding of monomers by removing water from hydroxyl groups and joining the monomers by an ether or ester linkage.

Review Questions — Set 11.4

49. Which type of reaction do ethane molecules and ethene molecules undergo when they react with chlorine?

(1) Ethane and ethene both react by addition.
(2) Ethane and ethene both react by substitution.
(3) Ethane reacts by substitution and ethene reacts by addition.
(4) Ethane reacts by addition and ethene reacts by substitution.

50. Which type of reaction is represented by the following equation?



(1) condensation polymerization
(2) addition polymerization
(3) esterification
(4) saponification

51. Which substance is made up of monomers joined together in long chains?

(1) ketone
(2) protein
(3) ester
(4) acid

52. Which equation represents a substitution reaction?

(1) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
(2) $C_2H_4 + Br_2 \rightarrow C_2H_4Br_2$
(3) $C_3H_6 + H_2 \rightarrow C_3H_8$
(4) $C_4H_{10} + Cl_2 \rightarrow C_4H_9Cl + HCl$

53. When C_3H_8 burns completely in an excess of oxygen, the products formed are

(1) CO and H_2O
(2) CO_2 and H_2O
(3) CO and H_2
(4) CO_2 and H_2

54. Molecules of propene combine in a chemical reaction to produce a single molecule. The reaction is called

(1) substitution
(2) saponification
(3) polymerization
(4) esterification

55. The reaction represented by

$$CH_3CHCH_2 + Br_2 \rightarrow CH_3CHBrCH_2Br$$

is an example of

(1) fermentation
(2) addition
(3) substitution
(4) saponification

56. What are the products of a fermentation reaction?

(1) an ester and water
(2) a salt and water
(3) an alcohol and carbon dioxide
(4) a soap and glycerol

57. Which equation represents an addition reaction?

(1) $CH_4 + O_2 \rightarrow CO_2 + 2H_2O$
(2) $C_2H_6 + Br_2 \rightarrow C_2H_5Br + HBr$
(3) $C_3H_6 + Cl_2 \rightarrow C_3H_6Cl_2$
(4) $C_4H_{10} + Cl_2 \rightarrow C_4H_9Cl + HCl$

58. Which hydrocarbon will undergo a substitution reaction with chlorine?

(1) methane
(2) ethyne
(3) propene
(4) butene

59. The equation

$$CH_3OH + CH_3OH \rightarrow CH_3OCH_3 + H_2O$$

illustrates the

(1) oxidation of alcohols to form a ketone
(2) oxidation of alcohols to form an acid
(3) dehydration of alcohols to form a polymer
(4) dehydration of alcohols to form an ether

60. Which type of reaction is represented by the following equation?

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

(1) saponification
(2) polymerization
(3) esterification
(4) fermentation

61. Which process usually produces water as one of the products?

(1) cracking
(2) hydrolysis
(3) addition polymerization
(4) condensation polymerization

62. Esterification is the reaction of an acid with

(1) water
(2) an alcohol
(3) a base
(4) a salt

63. (a) Write the structure of two different amino acids.

(b) Show how these two acids would combine to become an amide (show a peptide linkage).

64. Write a word equation for a saponification reaction.

65. Explain the difference between a substitution reaction and an addition reaction.

For each substance in questions 66 through 70, write the number of the organic reaction, chosen from the list below, that will produce this substance.

Organic Reactions

(1) esterification
(2) saponification
(3) polymerization
(4) fermentation
(5) substitution
(6) halogen addition

66. ethanol

67. glycerol

68. methyl ethanoate

69. polyethylene

70. dichloromethane

Practice Questions for the New York Regents Exam

Directions

Review the Test–Taking Strategies section of this book. Then answer the following questions. Read each question carefully and answer with a correct choice or response.

Part A

1 In the alkane series, each molecule contains
(1) only one double bond
(2) two double bonds
(3) one triple bond
(4) all single bonds

2 Which kind of bond is most common in organic compounds?
(1) covalent (3) hydrogen
(2) ionic (4) metallic

3 A carbon atom in an alkane has a total of
(1) two covalent bonds (3) four covalent bonds
(2) two ionic bonds (4) four ionic bonds

4 What is the maximum number of covalent bonds that a carbon atom can form?
(1) 1 (2) 2 (3) 3 (4) 4

5 A hydrocarbon molecule is saturated if the molecule contains
(1) single covalent bonds only
(2) only one double covalent bond
(3) a triple covalent bond
(4) single and double covalent bonds

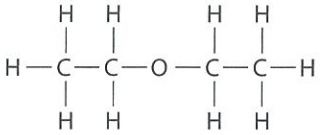
6 Which statement explains why the element carbon forms so many compounds?
(1) Carbon atoms combine readily with oxygen.
(2) Carbon atoms have a high electronegativity value.
(3) Carbon atoms readily form ionic bonds with other carbon atoms.
(4) Carbon atoms readily form covalent bonds with other carbon atoms.

7 In the alkane family, each member differs from the preceding member by one carbon atom and two hydrogen atoms. Such a series of hydrocarbons is called
(1) a homologous series
(2) a periodic series
(3) an actinide series
(4) a lanthanide series

8 Which formula represents an unsaturated hydrocarbon?
(1) CH_4 (3) C_3H_8
(2) C_2H_4 (4) C_4H_{10}

9 The products of condensation polymerization are a polymer and
(1) carbon dioxide (3) ethanol
(2) water (4) glycerol

10 Which type of compound is represented by the structural formula shown below?

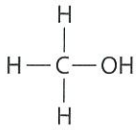


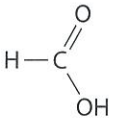
(1) a ketone (3) an ester
(2) an aldehyde (4) an ether

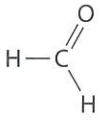
11 If a hydrocarbon molecule contains a triple bond, its IUPAC name ends in
(1) *-ane* (2) *-ene* (3) *-one* (4) *-yne*

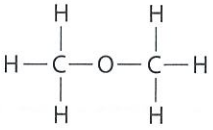
12 Which compound is an organic acid?
(1) CH_3OH (3) CH_3COOH
(2) CH_3OCH_3 (4) CH_3COOCH_3

13 Which is the structural formula of an aldehyde?

(1) 

(3) 

(2) 

(4) 

14 Which general formula represents an ether?
(1) *R*–OH (3) *R*–O–*R′*
(2) *R*–CHO (4) *R*–COOH

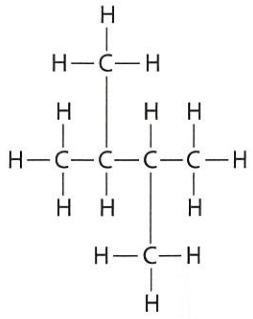
15 What are the products of a fermentation reaction?
(1) an alcohol and carbon monoxide
(2) an alcohol and carbon dioxide
(3) a salt and water
(4) a salt and an acid

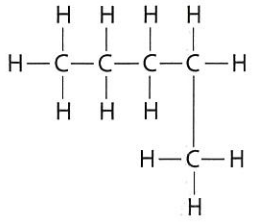
TOPIC 11 Organic Chemistry

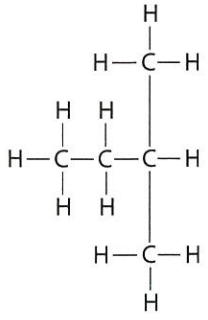
Part B-1

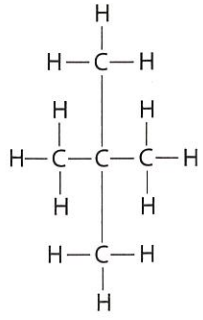
16 Which compounds are isomers?
(1) 1-propanol and 2-propanol
(2) methanoic acid and ethanoic acid
(3) methanol and methanal
(4) ethane and ethanol

17 Which is the correct structural formula for 2, 2-dimethylpropane?

(1)


(2)


(3)


(4)


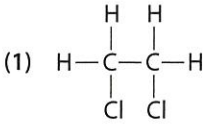
18 What is the chemical process illustrated by the following equation?

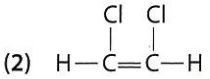
$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

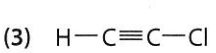
(1) fermentation
(2) saponification
(3) esterification
(4) polymerization

19 Which reaction is used to produce polyethylene $(C_2H_4)_n$ from ethylene?
(1) addition polymerization
(2) substitution
(3) condensation polymerization
(4) reduction

20 Which structural formula represents the product formed from the reaction of Cl_2 and C_2H_4?

(1)


(2)


(3)


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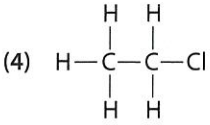


21 Methanol is classified as a
(1) monohydroxy alcohol
(2) secondary alcohol
(3) tertiary alcohol
(4) dihydroxy alcohol

22 What is the total number of pairs of electrons that one carbon atom shares with the other carbon atom in the molecule C_2H_4?
(1) 1
(2) 2
(3) 3
(4) 4

23 To be classified as a tertiary alcohol, the functional –OH group is bonded to a carbon atom that must be bonded to how many other carbon atoms?
(1) 1
(2) 2
(3) 3
(4) 4

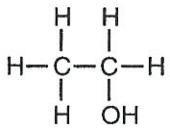
24 A student investigated four different substances in the solid phase. The table below is a record of the characteristics (marked with an *X*) exhibited by each substance. Which substance has characteristics most like those of an organic compound?

	Substance			
Characteristic Tested	**A**	**B**	**C**	**D**
High melting point	X		X	
Low melting point		X		X
Soluble in water	X			X
Insoluble in water		X	X	
Decomposed under high heat		X		
Stable under high heat	X		X	X
Electrolyte	X			X
Nonelectrolyte		X	X	

(1) A (2) B (3) C (4) D

25 Which hydrocarbon is a member of the alkene family?
(1) C_2H_2
(2) C_3H_6
(3) C_4H_{10}
(4) C_5H_{12}

26 Which structural formula represents a dihydroxy alcohol?

(1)


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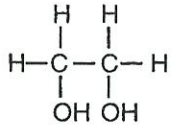

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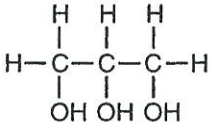
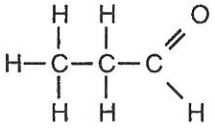
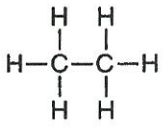
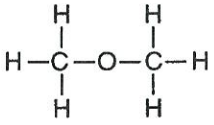
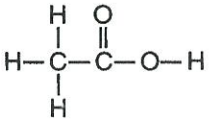


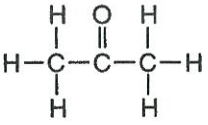
(4)


27 Which organic compound will dissolve in water to produce a solution that will turn blue litmus red?

(1)


(2)


(3)


(4)


28 The compound 1,2-ethanediol is a
(1) monohydroxy alcohol
(2) dihydroxy alcohol
(3) primary alcohol
(4) secondary alcohol

29 Which formula represents a ketone?
(1) CH_3COOH
(2) C_2H_5OH
(3) CH_3COCH_3
(4) CH_3COOCH_3

30 The compounds CH_3OCH_3 and CH_3CH_2OH have different functional groups. Therefore, these compounds have different
(1) percent composition by mass.
(2) numbers of atoms per molecule.
(3) chemical properties.
(4) gram-formula masses.

Parts B–2 and C

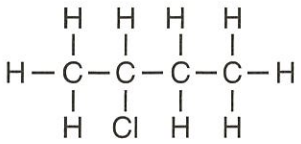
Base your answers to questions 31 through 34 on the condensed structural formula below.

$$CH_3CH_2CHCH_2$$

31 Draw the structural formula for this compound.

32 State the IUPAC name for the compound you have drawn in question 31.

33 The formula below represents a product formed when HCl reacts with $CH_3CH_2CHCH_2$



What is the IUPAC name for this product?

34 In question 33, what type of organic reaction takes place to produce the organic product in the diagram?

Base your answers to questions 35 through 37 on the information below.

Given the reaction between 1-butene and chlorine gas:

$$C_4H_8 + Cl_2 \rightarrow C_4H_8Cl_2$$

35 Which type of chemical reaction is represented by this equation?

36 Draw the structural formula of the product, 1,2-dichlorobutane.

37 Identify the homologous series of hydrocarbons to which the organic reactant belongs.

Base your answers for questions 38 and 39 on the information below.

Given the balanced equation for an organic reaction between butane and chlorine:

$$C_4H_{10} + Cl_2 \rightarrow C_4H_9Cl + HCl$$

38 Identify the type of organic reaction shown.

39 Draw a structural formula for the organic product.

Base your answers to questions 40 and 41 on the information below.

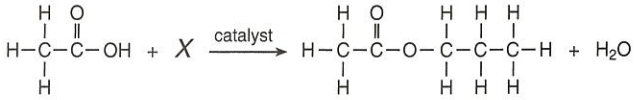
Many esters have distinctive odors, which lead to their widespread use as artificial flavorings and fragrances. For example, methyl butanoate has an odor similar to pineapple and ethyl methanoate has an odor similar to raspberry.

40 Draw a structural formula for the ester that has an odor similar to pineapple.

41 What is the chemical name for the alcohol that reacts with methanoic acid to produce the ester that has an odor similar to raspberry?

Base your answers to questions 42 through 46 on the information below.

The incomplete equation below represents an esterification reaction. The alcohol is represented by X.



42 Circle only the acid functional group.

43 Write the IUPAC name for the reactant represented by its structural formula in this equation.

44 Draw the structural formula for the alcohol represented in this equation.

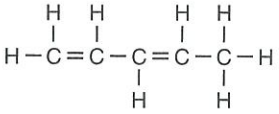
45 State the name of the alcohol represented by X.

46 Name the organic product of this reaction.

Base your answers to questions 47 and 48 on the following information.

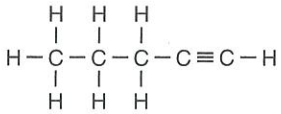
Two hydrocarbons that are isomers of each other are represented by the structural formulas and molecular formulas below.

Hydrocarbon 1



C_5H_8

Hydrocarbon 2



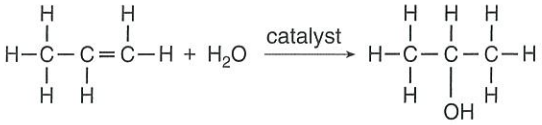
C_5H_8

47 Explain, in terms of bonds, why these hydrocarbons are unsaturated.

48 Explain, in terms of structural formulas and molecular formulas, why these hydrocarbons are isomers of each other.

Base your answers to questions 49 through 51 on the following information.

In one industrial organic reaction, C_3H_6 reacts with water in the presence of a catalyst. This reaction is represented by the balanced equation below.



49 Explain, in terms of bonding, why C_3H_6 is classified as an unsaturated hydrocarbon.

50 Write the IUPAC name for the organic reactant.

51 Identify the class of organic compound to which the product of the reaction belongs.