Chemistry for Changing Times
11th Edition
Hill and Kolb

Chapter 9
Organic Chemistry

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Organic Chemistry

Organic chemistry is defined as the chemistry of carbon compounds. Of tens of millions of known chemical compounds, over 95% are compounds of carbon.

The Unique Carbon Atom

Carbon is unique in that carbon atoms can bond to each other to form long chains and rings.

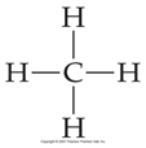
Hydrocarbons

Hydrocarbons are the simplest organic compounds. As their name implies, they are composed entirely of carbon and hydrogen.

Alkanes

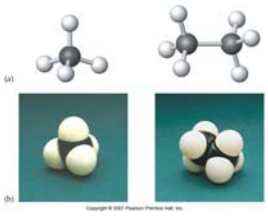
Alkanes are hydrocarbons that contain only single bonds. Because all carbon-to-carbon bonds are single bonds, alkanes are often called **saturated** hydrocarbons.

The simplest hydrocarbon is methane (CH_4).



Alkanes

The general formula of alkanes is C_nH_{2n+2}.



Alkanes

The names of alkanes begin with a prefix denoting the number of carbon atoms followed by the suffix –ane.

TABLE 9.1 Word Stems Indicating the Number of Carbon Atoms in Organic Molecules

Stem	Number
Meth-	One
Eth-	Two
Prop-	Three
But-	Four
Pent-	Five
Hex-	Six
Hept-	Seven
Oct-	Eight
Non-	Nine
Dec-	Ten

Alkanes

Ball-and-stick and space-filling models can be used to represent organic compounds.

(a)

(b)

Alkanes

Condensed structural formulas are often used to represent organic compounds. In condensed structural formulas, C to H bond lines are omitted and the formulas are written in this manner:

propane: $CH_3CH_2CH_3$

Alkanes

The alkanes represent a **homologous series** that differ by the number of $–CH_2-$ groups. Members of a homologous series exhibit properties that differ in a regular and predictable manner.

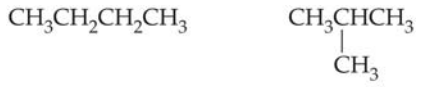
TABLE 9.2 The First Ten Continuous-Chain Alkanes

Name	Molecular Formula	Condensed Structural Formula	Number of Possible Isomers
Methane	CH_4	CH_4	—
Ethane	C_2H_6	CH_3CH_3	—
Propane	C_3H_8	$CH_3CH_2CH_3$	—
Butane	C_4H_{10}	$CH_3CH_2CH_2CH_3$	2
Pentane	C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$	3
Hexane	C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$	5
Heptane	C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	9
Octane	C_8H_{18}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	18
Nonane	C_9H_{20}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	35
Decane	$C_{10}H_{22}$	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	75

Alkanes

Isomerism:

Isomers are compounds with the same molecular formula but different structural formulas.



Butane Isobutane

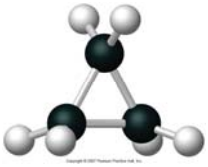
Alkanes

TABLE 9.3 Physical Properties and Uses/Occurrences of Selected Alkanes

Name	Molecular Formula	Melting Point (°C)	Boiling Point (°C)	Density at 20 °C (g/mL)	Use/Occurrence
Methane	CH_4	−183	−162	(Gas)	Natural gas (main component); fuel
Ethane	C_2H_6	−172	−89	(Gas)	Natural gas (minor component); production of chemicals
Propane	C_3H_8	−188	−42	(Gas)	LPG (bottled gas; fuel)
Butane	C_4H_{10}	−138	0	(Gas)	LPG (fuel; lighter fuel)
Pentane	C_5H_{12}	−130	36	0.626	Gasoline component (fuel)
Hexane	C_6H_{14}	−95	69	0.659	Gasoline component (fuel); extraction solvent (food oils)
Heptane	C_7H_{16}	−91	98	0.684	Gasoline component (fuel)
Octane	C_8H_{18}	−57	126	0.703	Gasoline component (fuel)
Decane	$C_{10}H_{22}$	−30	174	0.730	Gasoline component (fuel)
Dodecane	$C_{12}H_{26}$	−10	216	0.749	Gasoline component (fuel)
Tetradecane	$C_{14}H_{30}$	6	254	0.763	Diesel fuel component
Hexadecane	$C_{16}H_{34}$	18	280	0.775	Diesel fuel component
Octadecane	$C_{18}H_{38}$	28	316	(Solid)	Paraffin wax component
Eicosane	$C_{20}H_{42}$	37	343	(Solid)	Paraffin wax component

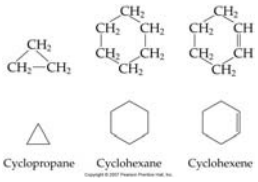
Cyclic Hydrocarbons

Cyclic hydrocarbons are ring compounds. The simplest cyclic hydrocarbon is cyclopropane.



Cyclic Hydrocarbons

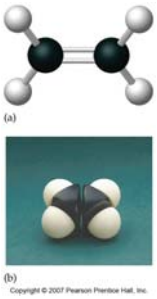
The names of cyclic hydrocarbons begin with the prefix **cyclo-** followed by the name of the alkane with the same number of carbon atoms.



Unsaturated Hydrocarbons

Alkenes are hydrocarbons which contain a carbon-to-carbon double bond. Their general formulas are C_nH_{2n}. Their names begin with a prefix denoting the number of carbon atoms followed by the suffix –ene.

Ethylene is the simplest alkene.



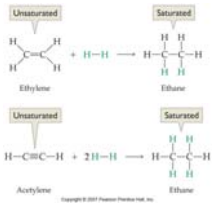
Unsaturated Hydrocarbons

Alkynes are hydrocarbons which contain a carbon-to-carbon triple bond. Their general formulas are C_nH_{2n-2}. Their names begin with a prefix denoting the number of carbon atoms followed by the suffix –yne.

Ethyne (acetylene) is the simplest alkyne.

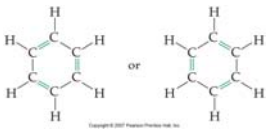
Unsaturated Hydrocarbons

Both alkenes and alkynes are **unsaturated hydrocarbons**. A saturated hydrocarbon has the maximum number of hydrogen atoms attached to each carbon and no double or triple bonds. Unsaturated hydrocarbons can undergo an **addition reaction**:

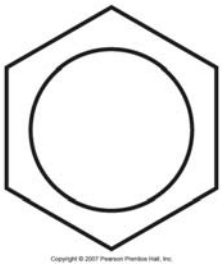


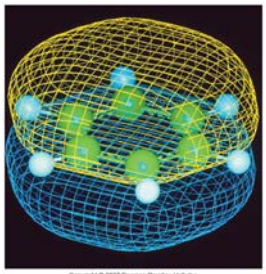
Aromatic Hydrocarbons: Benzene and Relatives

Benzene is a unique organic compound in that it is a very stable six-sided ring. **Aromatic** hydrocarbons contain a benzene ring or have properties similar to those of benzene.

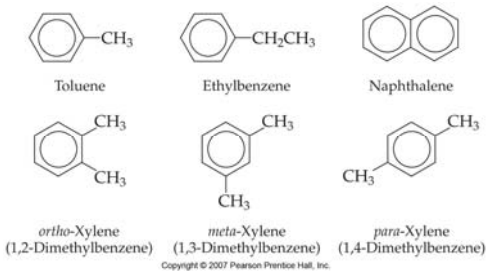


Aromatic Hydrocarbons: Benzene and Relatives





Aromatic Hydrocarbons: Benzene and Relatives



Chlorinated Hydrocarbons

When hydrogen atom or atoms of a hydrocarbon are substituted by chlorine, a **chlorinated hydrocarbon** is formed. Chlorinated hydrocarbons have many useful properties.

Dichloromethane is used as a solvent and paint remover.

Trichloromethane (chloroform) is also a solvent and at one time was used as an anesthetic. It is now considered hazardous.

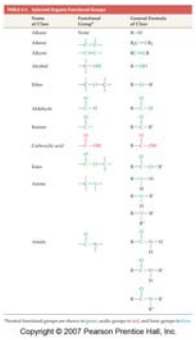
Chlorofluorocarbons and Fluorocarbons

Carbon compounds with both chlorine and fluorine are known as **chlorofluorocarbons (CFCs).**

Functional Groups

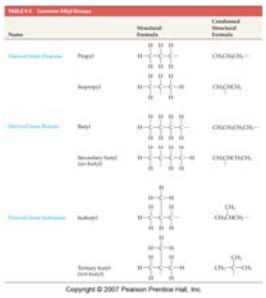
Atoms or groups of atoms attached to hydrocarbon skeletons give the compounds characteristic chemical and physical properties and are known as **functional groups**. Double and triple bonds as well as halogen substituents are examples of functional groups.

Functional Groups



Alkyl Groups

Alkyl groups are derived from the alkanes.



Alcohols

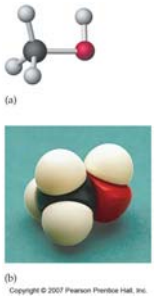
Alcohols contain the hydroxyl (-OH) functional group.

Examples include:

methanol	CH_3OH
ethanol	CH_3CH_2OH
1-propanol	$CH_3CH_2CH_2OH$

Methanol

Methanol or **methyl alcohol** is sometimes called wood alcohol. It is an important solvent and automotive fuel additive and possible fuel replacement.



Ethanol

Ethanol or **ethyl alcohol** is also known as grain alcohol. It is the alcohol of alcoholic beverages. It is also an additive to automotive fuel and is being considered as a gasoline replacement.

(a)

(b)

Toxicity of Alcohols

All alcohols are toxic. **Methanol** for instance is oxidized to formaldehyde by liver enzymes. It can lead to blindness and death.

Even **ethanol** is toxic. The effects of drinking ethanol are due to its toxicity. Drunk driving, alcoholism, and fetal alcohol syndrome are all effects due to the toxicity of ethanol.

Ethanol

TABLE 9.6 Approximate Relationship Among Drinks Consumed, Blood-Alcohol Level, and Behavior*

Number of Drinks†	Blood-Alcohol Level (percent by volume)	Behavior‡
2	0.05	Mild sedation; tranquility
4	0.10	Lack of coordination
6	0.15	Obvious intoxication
10	0.30	Unconsciousness
20	0.50	Possible death

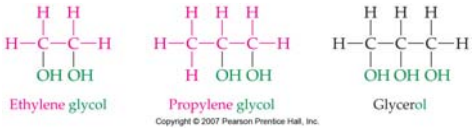
*Data are for a 70-kg (154-lb) moderate drinker.

†Rapidly consumed 30-mL (1-oz) "shots" of 90-proof whiskey, 360-mL (12-oz) bottles of beer, or 150-mL (5-oz) glasses of wine.

‡An inexperienced drinker would be affected more strongly, or more quickly, than one who is ordinarily a moderate drinker. Conversely, an experienced heavy drinker would be affected less.

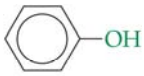
Multifunctional Alcohols

Some alcohols contain more than one hydroxyl group.



Phenols

Phenols are aromatic compounds with the hydroxyl group attached to the aromatic ring. The presence of the aromatic ring alters the properties of the hydroxyl group. Phenols do not act as alcohols but as acids. Phenols are an effective antiseptic.



Phenol

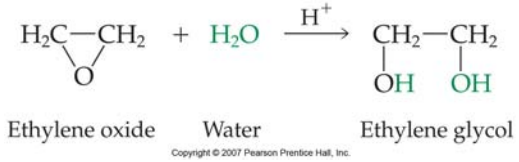
Ethers

Ethers are compounds with two alkyl groups bonded to the same oxygen.

General formula: ROR or ROR'

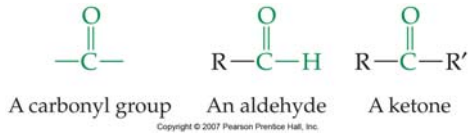
$CH_3CH_2OCH_2CH_3$ is diethyl ether

Ethers

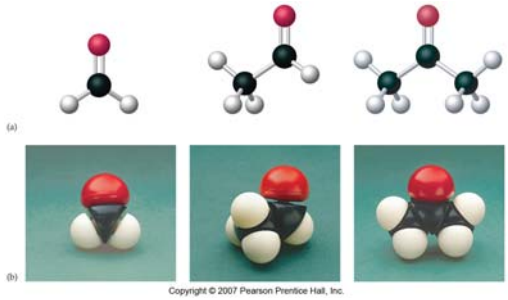


Aldehydes and Ketones

Aldehydes and **ketones** are two families of organic compounds that contain the **carbonyl** (C=O) functional group.



Aldehydes and Ketones

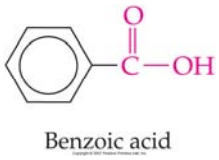


Carboxylic Acids

Organic acids contain the **carboxyl** (COOH) functional group.

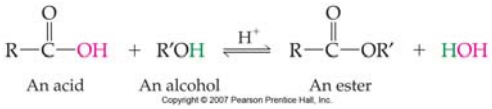
Carboxylic Acids

When the carboxyl group is attached directly to the benzene ring, it is called benzoic acid.



Esters

Esters are derived from carboxylic acids and alcohols or phenols.



Esters

Esters generally have a pleasant odor.

TABLE 9.7 Ester Flavors and Fragrances

Ester	Formula	Flavor/Fragrance
Methyl butyrate	$CH_3CH_2CH_2COOCH_3$	Apple
Ethyl butyrate	$CH_3CH_2CH_2COOCH_2CH_3$	Pineapple
Propyl acetate	$CH_3COOCH_2CH_2CH_3$	Pear
Pentyl acetate	$CH_3COOCH_2CH_2CH_2CH_2CH_3$	Banana
Pentyl butyrate	$CH_3CH_2CH_2COOCH_2CH_2CH_2CH_2CH_3$	Apricot
Octyl acetate	$CH_3COOCH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Orange
Methyl benzoate	$C_6H_5COOCH_3$	Ripe kiwifruit
Ethyl formate	$HCOOCH_2CH_3$	Rum
Methyl salicylate	$o\text{-}HOC_6H_4COOCH_3$	Wintergreen
Benzyl acetate	$CH_3COOCH_2C_6H_5$	Jasmine

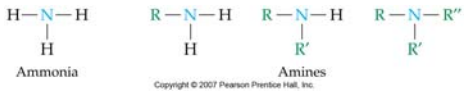
Esters

Esters are named by stating the name of the alcohol part first followed by the name of the acid part with the suffix –ate.

For example: Methyl butyrate

Amines and Amides

Amines are derivatives of ammonia. When one or more hydrogen of ammonia is replaced by an alkyl group, an amine is the result. Like ammonia, amines tend to be basic and have similar odors.

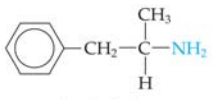


Amines and Amides

Aniline has an amine functional group attached to a benzene ring.

Aniline

Amines and Amides



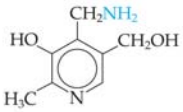
Amphetamine

$H_2NCH_2CH_2CH_2CH_2CH_2CH_2NH_2$

1,6-Hexanediamine

$H_2NCH_2CH_2CH_2CH_2CH_2NH_2$

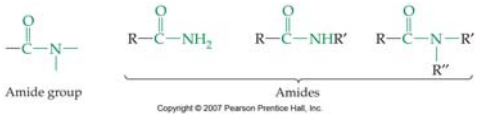
Cadaverine



Pyridoxamine

Amines and Amides

Amides have the nitrogen bonded to a carbonyl carbon.



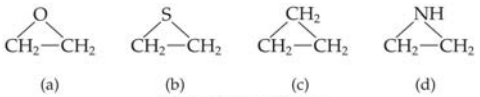
Amide group

Amides

The amino acids of proteins are linked by amide linkages.

Heterocyclic Compounds

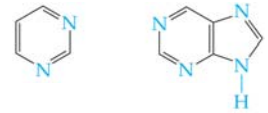
Heterocyclic compounds are rings that contain atoms other than carbon as part of the ring. Most organic heterocyclic compounds contain nitrogen, oxygen, or sulfur.



(a) (b) (c) (d)

Alkaloids

Alkaloids are amines that occur naturally in plants. Many have physiological effects. Morphine, caffeine, nicotine, and cocaine are alkaloids. So are the bases pyrimidine and purine.



Pyrimidine Purine