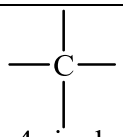
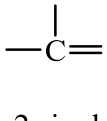
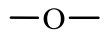
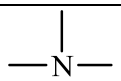
UNIT (7) ORGANIC COMPOUNDS: HYDROCARBONS

Organic chemistry is the study **carbon** containing compounds.

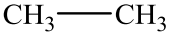
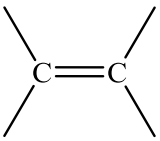
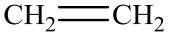
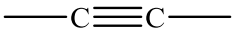
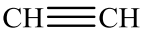
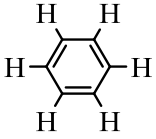
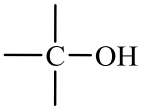
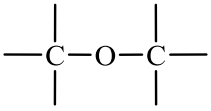
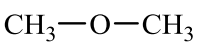
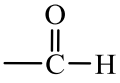
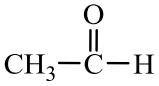
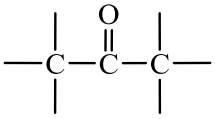
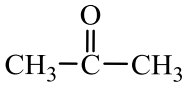
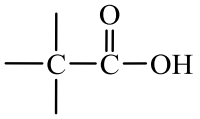
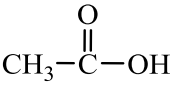
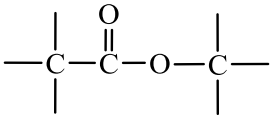
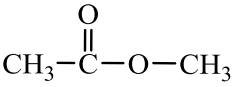
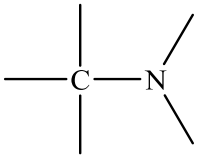
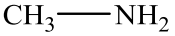
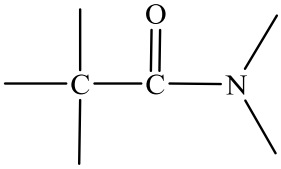
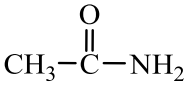
7.1 Bonding in Organic Compounds

Organic compounds are made up of only a few elements and the bonding is almost entirely covalent. The following table gives the "bonding requirements" of the elements commonly present in organic compounds.

Element	Number of bonds	Bonding representation
C	4	 4 single bonds or  2 single and 1 double bonds or  1 single and 1 triple bonds
H	1	
O	2	 2 single bonds or  1 double bond
N	3	 3 single bonds
F, Cl, Br, I	1	

7.2 The Organization of Organic Compounds: Functional Groups

Millions of organic compounds have been discovered or made by chemists.
This enormous number of compounds can be divided into relatively small number of classes according to the functional groups they contain.
A **functional group** is *an atom, group of atoms, or bond* that is present in each molecule of a class of compounds.
Table 7.1 summarizes some of the major classes of organic compounds.
Table 7.1 Some important classes of organic compounds.

Class Name	Functional group	Example	Name ending
Alkane	None		-ane
Alkene			-ene
Alkyne			-yne
Aromatics			None
Alcohol			-ol
Ether			None
Aldehyde			-al
Ketone			-one
Carboxylic acid			-ic acid
Ester			-ate
Amine			-amine
Amide			-amide

7.3 Hydrocarbons

The first four classes of organic compounds in Table 7.1 are known as hydrocarbons. A **hydrocarbon** is a compound composed of entirely carbon and hydrogen atoms. Hydrocarbons are classified as aromatic compounds (containing benzene rings) and aliphatics (all other hydrocarbons).

Hydrocarbons	Aliphatics	Alkanes	contain only **single** bonds
		Alkenes	contain at least one **double** bond
		Alkynes	contain at least one **triple** bond
	Aromatics		

Alkanes: The Simplest Organic Compounds

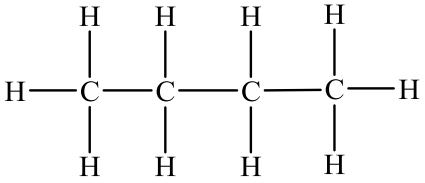
Alkanes are called *saturated* hydrocarbons because only *single bonds* connect carbons to each other and to other hydrogen atoms. The molecular formula of all alkanes fit the general formula $\mathbf{C_nH_{2n+2}}$, where **n** equals the number of carbon atoms.

There are several methods used to represent organic molecules.
The **molecular formula** tells the kind and number of each type of atom in a molecule but does not show the bonding pattern,
The **expanded structural formula** shows each atom and bond in a molecule.
The **condensed structural formula** shows all the atoms in a molecule and place them in a sequential order that indicates which atoms are bonded to which.
The **line formula**, a carbon atom is understood to be at every intersection of lines and hydrogen atoms are filled mentally.

Consider butane (C_4H_{10}) as an example.

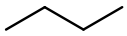
molecular formula C_4H_{10}

expanded structural formula



condensed structural formula $CH_3-CH_2-CH_2-CH_3$ or $CH_3CH_2CH_2CH_3$

line formula



Practice 7-1

Draw the expanded structural formula, condensed structural formula, and line formula for hexane (C_6H_{14}).

Answer

Names and Structures of the first ten Continuous-Chain Alkanes

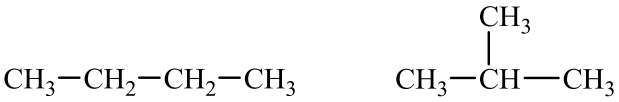
*Name	molecular formula	condensed structural formula
Methane	CH_4	CH_4
Ethane	C_2H_6	CH_3CH_3
Propane	C_3H_8	$CH_3(CH_2)CH_3$
Butane	C_4H_{10}	$CH_3(CH_2)_2CH_3$
Pentane	C_5H_{12}	$CH_3(CH_2)_3CH_3$
Hexane	C_6H_{14}	$CH_3(CH_2)_4CH_3$
Heptane	C_7H_{16}	$CH_3(CH_2)_5CH_3$
Octane	C_8H_{18}	$CH_3(CH_2)_6CH_3$
Nonane	C_9H_{20}	$CH_3(CH_2)_7CH_3$
Decane	$C_{10}H_{22}$	$CH_3(CH_2)_8CH_3$

*The IUPAC system (International Union of Pure and Applied Chemistry) determines the protocol for naming organic compounds.

Isomers

Molecules that have the same molecular formula but different structural formulas are called **structural isomers**.
Structural isomers are possible in all alkanes containing four or more carbon atoms.

For example, we can write two different structural isomers for butane, C_4H_{10}, a straight chain and a branched chain isomer:



Straight-chain Branched-chain

Worked Example 7-1

Draw all structural isomers having the molecular formula C_5H_{12}.

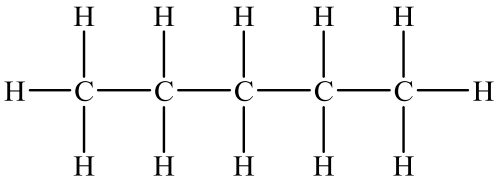
Solution

continuous chain

Write five carbon atoms linked together to form a chain:

C — C — C — C — C —

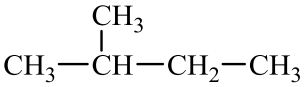
Attach hydrogen atoms to the carbon atoms so each carbon atom forms four bonds.



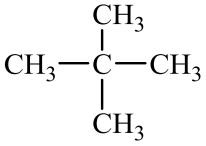
condensed form: $CH_3—CH_2—CH_2—CH_2—CH_3$

branched chains

Now try a four-carbon chain structure with a methyl group attached to one of the internal carbon atoms of the chain.



Next consider the possibilities of three-carbon structure to which two methyl groups may be attached.



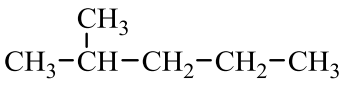
Worked Example 7-2

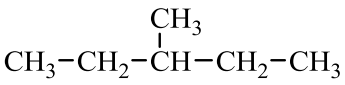
Draw all structural isomers of C_6H_{14}.

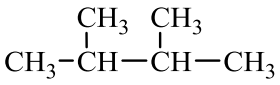
Solution

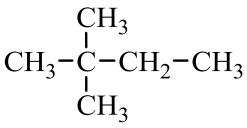
continuous chain

branched chains









7.4 IUPAC Naming of Branched-Chain Alkanes

When naming branched-chain alkanes, we must name the branch(s) that are attached to the main-chain. If the branches (substituted groups) are smaller chain hydrocarbons they are called *alkyl groups.*

An **alkyl group** is a group derived by removing a single hydrogen atom from an alkane molecule, thus creating a point of attachment. The letter "R" is used as a general symbol for alkyl groups.

Alkane		Alkyl	-R
methane	(CH_4)	methyl	$-CH_3$
ethane	(CH_3CH_3)	ethyl	$-CH_2CH_3$
propane	($CH_3CH_2CH_3$)	propyl	$-CH_2CH_2CH_3$
		isopropyl	CH_3CHCH_3

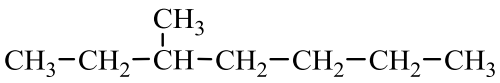
IUPAC Rules for Naming Branched-Chain Alkanes

I) An Alkane With Only One Branch

1. Determine the name of the *parent chain*, the longest continuous carbon chain in the alkane.
2. The parent chain is numbered from the end nearest to the alkyl group. Give the alkyl group (the branch) a *name* and a *number*. Use a hyphen to connect the number to the name.
3. Write the name as single word.

Worked Example 7-3

Name the following alkane:



Solution

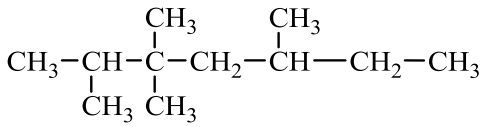
1. The longest continuous chain contains seven carbon atoms (heptane).
2. There is one methyl group on the chain on carbon 3: "3-methyl" (the numbering must be from the left to give the lowest number to the branch).
3. The correct name is **3-methylheptane**.

II) An Alkane With More Than One Branch Where Branches Are Identical

1. Determine the name of the *parent chain*, the longest continuous carbon chain in the alkane.
2. The parent chain is numbered from the end nearer the first alkyl group. Give each alkyl group a *name* and a *number*. Use hyphens to separate the numbers from the different prefixes and commas to separate numbers. If two or more identical alkyls are present, use one of the prefixes *di*-, *tri*-, *tetra*-, and so forth, to the name of the alkyl.
3. Write the name as single word.

Worked Example 7-4

Name the following alkane:



Solution

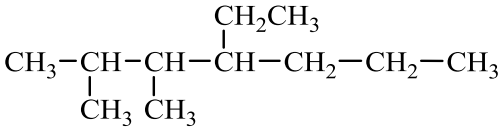
1. The longest continuous chain contains seven carbon atoms (heptane).
2. There are four methyl groups on the chain: two methyl groups are on carbon 3, one CH_3 on carbon 2, and one CH_3 on carbon 5.
3. The correct name is **2,3,3,5-tetramethylheptane**.

III) An Alkane With More Than One Branch Where Branches Are Different

1. Determine the name of the *parent chain*, the longest continuous carbon chain in the alkane.
2. The parent chain is numbered from the end nearer the first alkyl group. Give each alkyl group a *name* and a *number*. Use hyphens to separate numbers from words; use commas to separate numbers. If different alkyl groups are present, write them in alphabetical order. If necessary, use one of the prefixes di-, tri-, tetra-, and so forth, but don't use them for alphabetizing purposes.
3. Write the name as single word.

Worked Example 7-5

Name the following alkane:

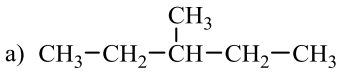


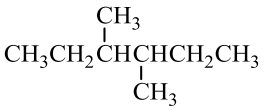
Solution

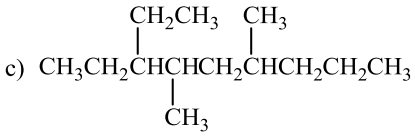
1. The longest continuous chain contains seven carbon atoms (heptane).
2. There are three branches: two *methyl* groups on carbon 2 and 3; one ethyl group on carbon 4. Write the alkyl groups in alphabetical order (**e**thyl before **m**ethyl).
3. The correct name is **4-ethyl-2,3-dimethylheptane**.

Practice 7-2

Name each the following compounds:

a) 

b) 

c) 

Answer

Practice 7-3

Draw structure for each of the following compounds:

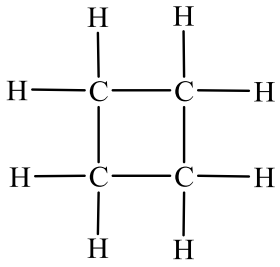
a) 3-ethyl-2-methylhexane
b) 2,2,5-trimethylheptane
c) 4,6-diethyl-6-methylnonane
d) 4-ethyl-4-isopropyloctane

Answer

7.5 Cycloalkanes

A **cycloalkane** is an alkane in which carbon atoms are connected to one another in a cyclic (ring) arrangement. Cycloalkanes have two fewer hydrogen atoms than the corresponding alkanes.

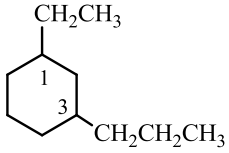
Cycloalkanes are commonly represented using geometric formulas in which each corner of the figure represents a carbon atom and its attached hydrogen atoms.



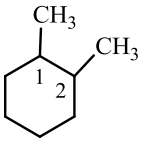
condensed formula

geometric formula

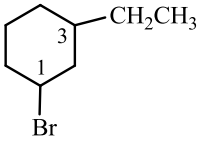
Substituted cycloalkanes are named by identifying and numbering the position of groups on the ring, followed by the name of the parent cycloalkane.
The ring numbering begins with the carbon attached the first carbon alphabetically and proceeds around the ring in the direction that will give the lowest numbers for the positions of the other attached groups.



1-ethyl-3-propylcyclohexane

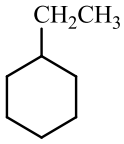


1,2-dimethylcyclohexane

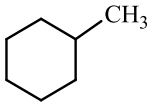


1-bromo-3-ethylcyclohexane

The position of single attached group does not need to be specified in the name because all positions in the ring are equivalent.



ethylcyclohexane



methylcyclohexane

Worked Example 7-6

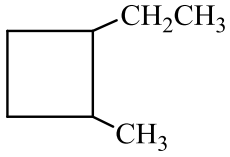
Draw the geometric formula for each of the following:

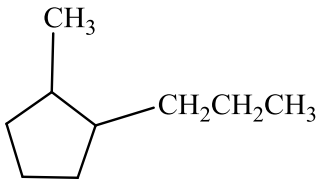
a) 1-ethyl-2-methylcyclobutane

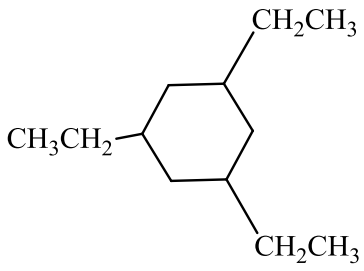
b) 1-methyl-2-propylcyclopentane

c) 1,3,5-triethylcyclohexane

Solution

a) 

b) 

c) 

7.6 Reactions of Alkanes

1. Combustion is a reaction between a substance and oxygen (usually from air) that proceeds with the evolution of heat and light.

alkane + oxygen → carbon dioxide + water + energy

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{energy}$$

Worked Example 7-7

Write a balanced equation for the combustion of pentane.

Solution

$$C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O + \text{energy}$$

2. Halogenation is a reaction between a substance and a halogen (group VIIA) in which one or more halogens are incorporated into molecules of a substance.

alkane + halogen → halogenated alkane + hydrogen halide

$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ (Light or heat is needed for the reaction.)

Nomenclature of Halogenated Alkanes

Halogen atoms are called fluoro- (F), chloro- (Cl), bromo- (Br), or iodo- (I).

Practice 7-4

Draw structural formula for each of the following:

a) 2,3-dichloropentane
b) 2-bromo-3,4-difluorohexane
c) 1,1-diiodocyclobutane
d) 1,2-dibromo-3-methylcyclohexane

Answer

7.7 Alkenes and Alkynes

Alkenes and alkynes are *unsaturated hydrocarbon*s because their molecules do not contain the maximum possible number of hydrogen atoms.

Alkenes are hydrocarbons that have at least one carbon-carbon double bond (>C=C<).

General formula for alkenes: C_nH_{2n}

Alkynes are hydrocarbons that have at least one carbon-carbon triple bond (–C≡C–).

General formula for alkynes: C_nH_{2n-2}

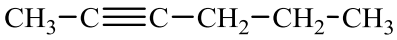
7.8 Naming Alkenes and Alkynes

Alkenes and alkynes are named similar to the IUPAC rules used for naming alkanes.

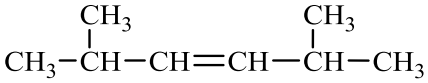
Guideline:

- The parent name is the longest chain that has a carbon-carbon multiple bond.
- Number from the end closest to the multiple bond.
- Names of alkenes end with "ene" and alkynes end with "yne".

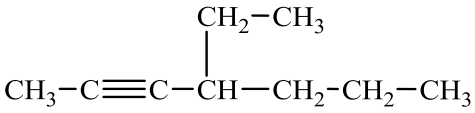
2-pentene



2-hexyne

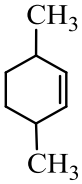


2,5-dimethyl-3-hexene



4-ethyl-2-heptyne

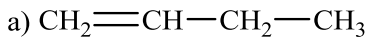
cyclopentene

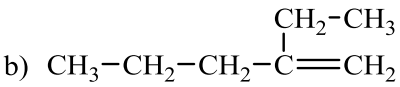


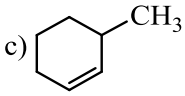
3,6-dimethylcyclohexene

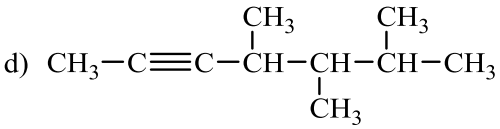
Practice 7-5

Give the IUPAC name for each of the following:

a) 

b) 

c) 

d) 

Answer

Common Names (non-IUPAC Names)

A small number of organic compounds have common names (non-IUPAC) that are used almost exclusively to identify them. These compounds are usually the smallest members of a particular class often containing only a few carbons. You need to be familiar to these names.

	$CH_2 = CH_2$	$CH \equiv CH$
IUPAC name	ethene	ethyne
Common name	ethylene	acetylene

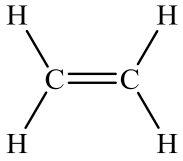
7.9 Geometric Isomers

Unlike alkanes, there is no free rotation around a carbon-carbon double bond in alkenes. If both carbons of the double bond have *two different groups* attached, *cis* and *trans* isomers exist.

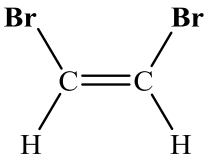
Cis isomer: two substituted groups are on the same side of double bond.

Trans isomer: two substituted groups are on opposite sides of double bond.

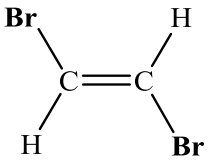
Consider ethene:



If one of the hydrogen atoms attached to each of the carbon atoms in ethene is replaced by a bromine atom, two distinct compounds are formed:



cis-1,2-dibromoethene
(bromines on same side)

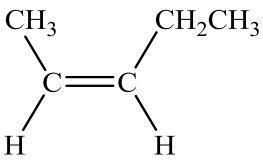


trans-1,2-dibromoethene
(bromines on different sides)

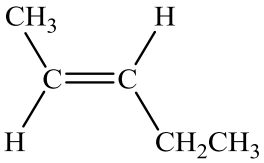
This type of isomerism is called ***cis-trans* isomerism**. The prefix *cis*- and *trans*- are derived from the Latin; cis- "on this side" and trans- "across."

Worked Example 7-8

Give the name of the following alkenes, using *cis* or *trans*.



(a)



(b)

Solution

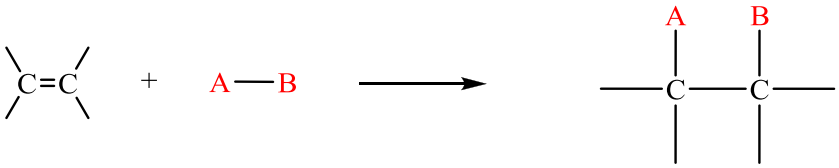
a) The longest chain has 5 carbons with the double bond starts at carbon 2.
The name is 2-pentene. The two identical groups (the hydrogen atoms) are on the same side of the double, so we use the prefix "*cis*".
The full name is ***cis*-2-pentene**.

b) The longest chain has 5 carbons with the double bond starts at carbon 2.
The name is 2-pentene. The two identical groups (the hydrogen atoms) are on the opposite side of the double bond, so we use the prefix "*trans*".
The full name is ***trans*-2-pentene**.

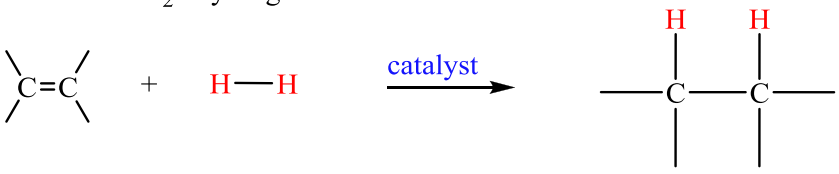
7.10 Reactions of Alkenes

The most common reactions of alkenes are addition reactions. In an **addition reaction**, the double bond is broken and a single bond is formed at each carbon to new atoms or groups of atoms.

A generalized addition reaction is shown here:

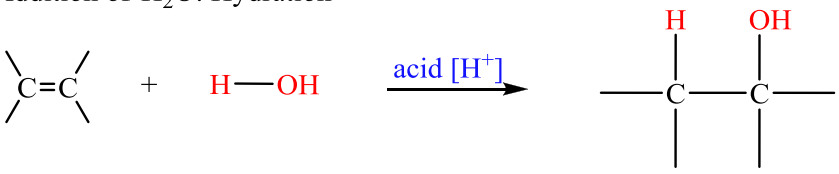


1) Addition of H_2: Hydrogenation



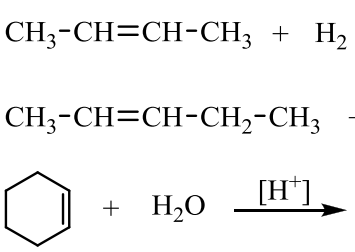
2) Addition of Cl_2 or Br_2: Halogenation

3) Addition of H_2O: Hydration

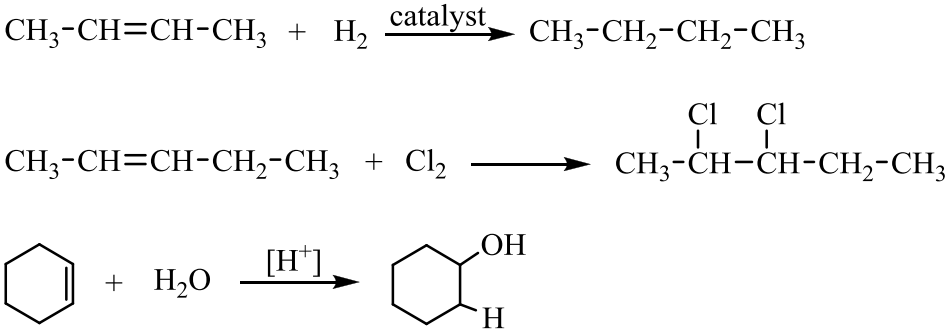


Worked Example 7-9

Give the organic product formed in each of the following reactions:

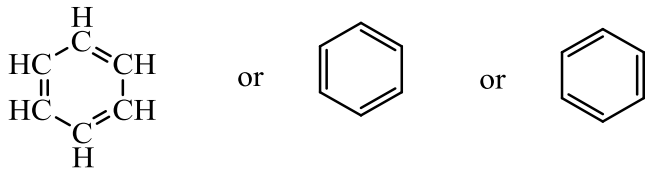


Solution



7.11 Aromatic Compounds

The simplest aromatic compound is called **benzene**, molecular formula C_6H_6. A benzene molecule is a ring containing six carbon atoms with a single hydrogen atom attached to each carbon. Each carbon has one single bond and one double bond to neighboring carbon atoms.

Benzene: 

For convenience, we write the structure of benzene in the following abbreviated form:

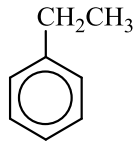
The circle in the center of the ring represents the six shared electrons (three double bonds.)

The word *aromatic* originally referred to the unpleasant odor characteristic to many of these substances, but this meaning is not in use anymore.

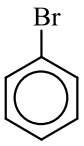
Naming Benzene Derivatives

When one or more hydrogen atoms of the benzene ring are replaced with other groups, the compound is named as a derivative of benzene.

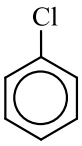
Examples:



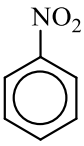
ethylbenzene



bromobenzene

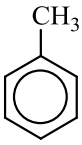


chlorobenzene

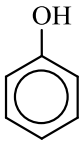


nitrobenzene

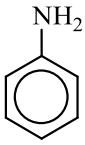
The IUPAC system retains the common names for the following:



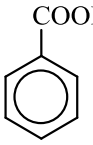
toluene



phenol



aniline



benzoic acid

Worked Example 7-10

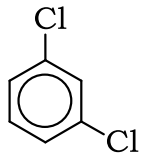
Draw the structural formula for each of the following:

a) 1,3-dichlorobenzene

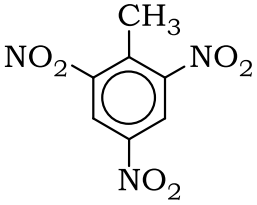
b) 2,4,6-trinitrotoluene (TNT)

c) 2-bromo-3,4-dichlorophenol

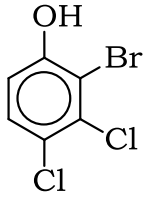
Solution



a)



b)

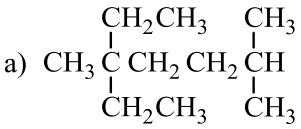


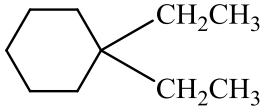
c)

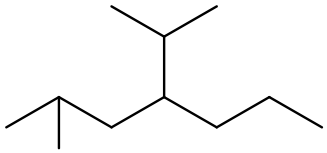
Homework Problems

7.1 Write condensed structures for each of the following compounds:
a. 2,2,4-trimethylpentane
b. 5-isopropyl-2-methyloctane
c. 1,1,3,3-tetrabromopropane
d. 1,1-dichlorocyclopentane
e. 1,4-diethylcyclohexane
f. 1-bromo-2-methylcyclobutane

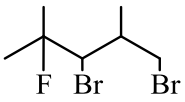
7.2 What are the IUPAC names of the following compounds?

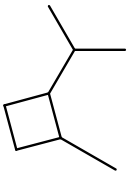
a) 

b) 

c) 

d) $(CH_3)_3CCH_2CH_3$

e) 

f) 

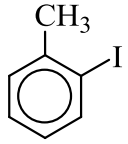
7.3 Write the structural formulas and names for FOUR isomers of cycloalkane, C_5H_{10}.

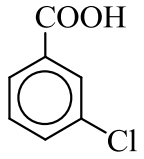
7.4 Propose structures for molecules that fit the following descriptions:
a. an alkene with three carbons
b. an alcohol with two carbons
c. an ether with three carbons
d. an amine with four carbons
e. a three-carbon ester
f. a ketone with four carbons
g. a four-carbon carboxylic acid
h. a cycloalkene with six carbons

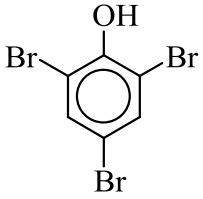
7.5 Write equations for the reaction of cyclopentene with each of the following:
a. H_2 and Pd catalyst
b. Br_2
c. H_2O and H_2SO_4 catalyst

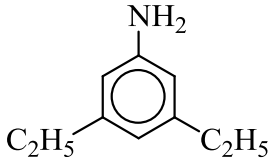
7.6 Write a structural formula for each of the following:
a. *cis*-3-heptene
b. *trans*-3-heptene
c. 1,1-dibromo-2,2-dichloroethene
d. 1,2-dibromo-1,2-dichloroethene
e. 4-methyl-2-hexyne
f. 3-ethyl-1-heptyne
g. 1,2-dimethylcyclopentene
h. *trans*-2,5-dimethyl-3-hexene
i. diisopropylacetylene

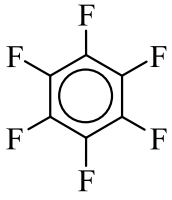
7.7 Name the following compounds:

a) 

b) 

c) 

d) 

e) 

f)