# 25 Hydrocarbon Compounds

## Chapter Preview



Sections 25·6 and 25·7 are appropriate for honors students.

The element carbon comprises only two-tenths of 1% of the elements found in the earth's crust. Oxygen, silicon, aluminum, and iron are much more abundant, but carbon is the basis of life on earth.

Scientists of 150 years ago believed the ability to produce carbon compounds rested exclusively with living things. The creation of carbon compounds was thought to be directed by a mysterious "vital force." Vitalism was rudely shattered in 1828 by a German chemist named Friedrich Wöhler (1800–1882). Wöhler discovered one way to make urea in the absence of any living agent. Urea is a carbon-containing compound found in urine.

Since Wöhler's day the definition of organic chemistry has been extended to include the study of all carbon compounds, regardless of their origin. Organic chemists have discovered how carbon compounds can be synthesized, or built, from simpler materials by ordinary chemical reactions. *Organic compounds that contain only carbon and hydrogen are called* **hydrocarbons.** They provide a logical introduction to organic chemistry.

## 25·1 Hydrocarbon Bonds

The simplest organic molecules are the **alkanes** *which are hydrocarbons that contain only single covalent bonds*. Methane is the simplest alkane. It is a gas at standard temperature and pressure. Methane is the major component of natural gas. It is sometimes called "marsh gas" because it is formed by the action of bacteria on decaying vegetation in swamps and other marshy areas. The methane molecule, which contains four hydrogens and one carbon, is a good example of carbon–hydrogen bonding.

**Figure 25·1**
In a petroleum refinery, useful hydrocarbons such as gasoline, kerosene, and heating oil are distilled from crude oil.

**Figure 25·2**
In this painting by Ford Madox Brown, John Dalton is collecting "marsh gas" (methane), which he used in many of his experiments. Methane is one product of the decomposition of plant materials by decay bacteria.

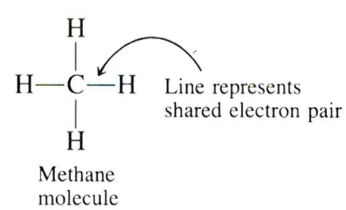
■ The covalent bonding in alkanes involves the sharing of valence electrons between carbon and hydrogen or between two carbons.

A carbon atom has four valence electrons. Four hydrogen atoms, each with one valence electron, form four covalent carbon–hydrogen bonds. This combination is a molecule of methane.

$$\underset{\text{Carbon atom}}{\cdot\dot{\underset{\cdot}{C}}\cdot} \;+\; \underset{\text{Hydrogen atoms}}{4H\cdot} \longrightarrow \underset{\text{Methane molecule}}{H:\overset{H}{\underset{H}{\overset{\cdot\cdot}{\underset{\cdot\cdot}{C}}}}:H}$$

This illustrates an important principle. *Because a carbon atom contains four valence electrons, it always forms four covalent bonds.* Remembering this principle will help you write complete and correct structures for organic molecules.

For simplicity, organic chemists often abbreviate bonding electron pairs as short lines. The line between the atomic symbols represents two bonding electrons.



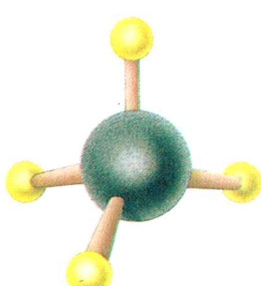



**Figure 25·3**
This three dimensional model shows the tetrahedral shape of the methane molecule.

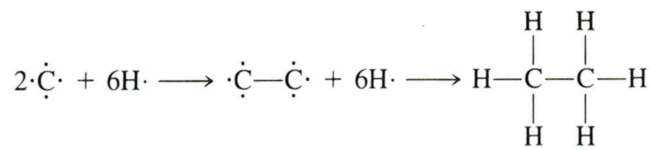
Structural formulas are convenient to write on a page. Keep in mind though that they are only two-dimensional representations of three-dimensional molecules. Molecular models represent the shapes of molecules more accurately. These shapes are predicted by VSEPR theory and hybrid orbital theory (Sections 14·8 and 14·9). For example, methane has a tetrahedral shape (Figure 25·3).

Carbon has the unique ability to make stable carbon–carbon bonds and to form chains. This is the major reason for the vast number of organic molecules. Silicon also forms short chains, but they are unstable in an oxygen environment.

**Safety**

Alkanes are highly flammable. Mixtures of air and hydrocarbons can be explosive.

Ethane, $C_2H_6$, is the simplest alkane containing a carbon–carbon bond. Like methane, ethane is a gas at standard temperature and pressure. When ethane is formed from carbon and hydrogen, two carbon atoms share a pair of electrons. A carbon-carbon covalent bond is formed. The remaining six valence-shell electrons form bond pairs with the electrons from six hydrogen atoms.



Ethane

## 25·2 Continuous-Chain Alkanes

Continuous-chain alkanes are hydrocarbons with the general formula $C_nH_{2n+2}$.

**Continuous-chain alkanes** *contain any number of carbon atoms in a straight chain*. They are similar to ethane. To draw a structural formula, just write the symbol for carbon as many times as necessary to get the proper chain length. Then fill in with hydrogens and lines representing covalent bonds. Remember that carbon has four covalent bonds. Table 25·1 shows the continuous-chain alkanes containing up to ten carbons. Note that the names of alkanes always end with *-ane*.

The continuous-chain alkanes are an example of a homologous series. *A group of compounds forms a* **homologous series** *if there is a constant increment of change in molecular structure from one compound in the series to the next*. The increment of change in the continuous-chain alkanes is the —$CH_2$— group. For example, propane and butane are *homologs* of each other. Note that as the number of carbons in this series increases, so does the boiling point. This is also true of the melting point.

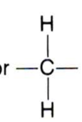
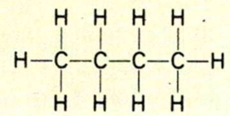
—$CH_2$— is shorthand notation for 

**Table 25·1 Structural Formulas of the First Ten Continuous-Chain Alkanes**

| Name | Molecular formula | Structural formula | Boiling point (°C) |
|---|---|---|---|
| Methane | $CH_4$ | $CH_4$ | −161.0 |
| Ethane | $C_2H_6$ | $CH_3CH_3$ | −88.5 |
| Propane | $C_3H_8$ | $CH_3CH_2CH_3$ | −42.0 |
| Butane | $C_4H_{10}$ | $CH_3CH_2CH_2CH_3$ | 0.5 |
| Pentane | $C_5H_{12}$ | $CH_3CH_2CH_2CH_2CH_3$ | 36.0 |
| Hexane | $C_6H_{14}$ | $CH_3CH_2CH_2CH_2CH_2CH_3$ | 68.7 |
| Heptane | $C_7H_{16}$ | $CH_3CH_2CH_2CH_2CH_2CH_2CH_3$ | 98.5 |
| Octane | $C_8H_{18}$ | $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$ | 125.6 |
| Nonane | $C_9H_{20}$ | $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$ | 150.7 |
| Decane | $C_{10}H_{22}$ | $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$ | 174.1 |

**Figure 25·4**
The structure of butane can be represented in a variety of ways.

| | |
|---|---|
| $C_4H_{10}$ | Molecular formula. |
|  | Complete structural formula. |
| $CH_3—CH_2—CH_2—CH_3$ | Condensed structural formula; C—H bonds understood |
| $CH_3CH_2CH_2CH_3$ | Condensed structural formula; C—H and C—C bonds understood. |
| $CH_3(CH_2)_2CH_3$ (Methylene units; Subscript) | Condensed structural formula: all bonds understood; parentheses indicate $CH_2$ units are linked together in a continuous chain (the $—CH_2—$ unit is called a methylene group); subscript 2 to the right of parenthesis indicates there are two methylene units linked together. |
| C—C—C—C | Carbon skeleton; all hydrogens and C—H bonds understood. |

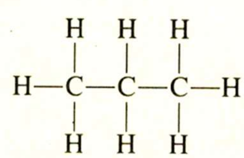
By custom we draw the structural formulas of continuous chain alkanes so that the carbon atoms form a straight line. In reality, the atoms are connected in a zig-zag manner because of the tetrahedral bonding of carbon. Since rotation can occur about the carbon–carbon single bond, a long chain will take a random shape. It may even curve back upon itself.

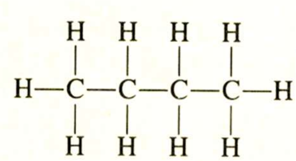
Complete structural formulas show all the atoms and bonds in a molecule. Sometimes, however, shorthand or condensed structural formulas work just as well. **Condensed structural formulas** *leave out some bonds and/or atoms from the structural formula*. The reader must understand that these bonds and atoms are there. Figure 25·4 shows several ways to draw condensed structural formulas for butane.

## Example 1

Draw complete structural formulas for the continuous-chain alkanes that have three and four carbons.

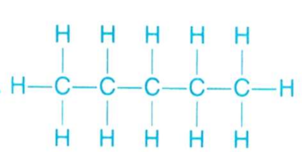
### Solution

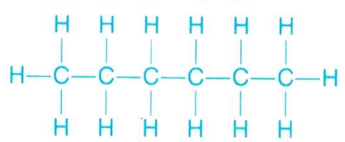




## Problems

1. Draw complete structural formulas for the continuous-chain alkanes with five and six carbons.
2. Draw condensed structural formulas for pentane and hexane. Assume that the C—H and C—C bonds are understood.

1. 



2. $CH_3CH_2CH_2CH_2CH_3$
$CH_3CH_2CH_2CH_2CH_2CH_3$

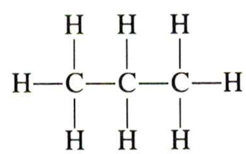
**Figure 25·5**
Pressurized tanks of propane and butane are used as heating and cooking fuels for campers. They are also used in rural areas where gas pipelines are not available.

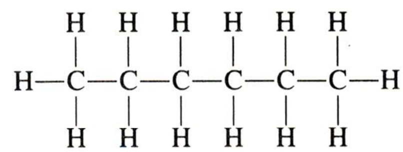
The names listed in Table 25·1 are recommended by the International Union of Pure and Applied Chemistry (IUPAC). You should memorize these names. They are the basis of *a precise, internationally accepted system of naming organic compounds called the* **IUPAC system.** Note, however, that organic chemists still rely on a mixture of systematic, semisystematic, and common names. This is in spite of the precision of the IUPAC system.

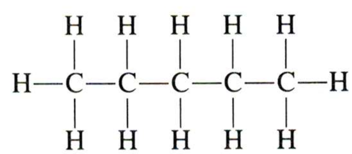
## Problem

**3. a.** propane **b.** pentane **c.** hexane

**3.** Name the following alkanes.

**a.** 

**c.** 

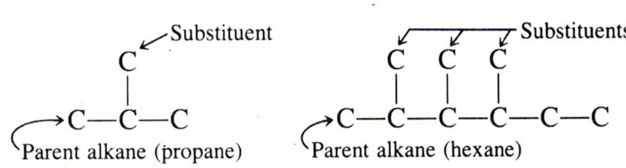
**b.** 

Many organic compounds are best known by their common names. These names bear no relation to the IUPAC name or to the molecular structure of the compounds. Nevertheless, these names have been used for a long time. Many organic compounds isolated from nature have common names that reflect their origin. For example, penicillin is named from the mold *Penicillium notatum*. In most instances, common names are simpler than IUPAC names, which can become long and cumbersome. Scientists also use semisystematic names which mix IUPAC and common names. This is similar to the way that immigrants lapse into their native tongue when they have an important idea to express. Like any living language, the language of science is constantly changing. IUPAC, semisystematic, and common names are used in this book.

## 25·3 Branched-Chain Alkanes

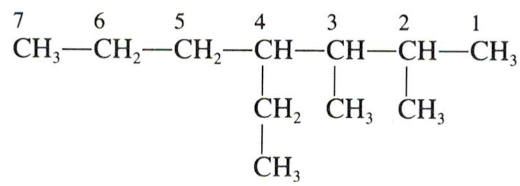
One or more hydrogens on a continuous-chain alkane can be substituted by other hydrocarbon groups to form branched-chain hydrocarbons.

*An atom or group of atoms, called a* **substituent,** *can take the place of a hydrogen atom on a parent hydrocarbon molecule.* Common substituents are the halogens and groups of atoms including carbon, hydrogen, oxygen, nitrogen, sulfur, or phosphorus.



*A hydrocarbon substituent is called an* **alkyl group.** It can be one or several carbons long. Three common alkyl groups are the methyl group ($CH_3$—), the ethyl group ($CH_3CH_2$—), and the propyl group ($CH_3CH_2CH_2$—). As you can see, an alkyl group consists of an alkane with one terminal hydrogen removed. Alkyl groups are sometimes referred to as radicals. They are named by removing the *-ane* ending from the parent hydrocarbon name and adding *-yl*.

*An alkane with one or more alkyl groups is a* **branched-chain alkane.** The IUPAC rules for naming branched-chain alkanes are quite straightforward. The following compound can be used as an example.



1. *Find the longest continuous chain of carbons in the molecule.* This chain is used as the parent structure. In the example, the longest continuous chain contains seven carbons. Therefore the parent hydrocarbon structure is heptane.

2. *Number the carbons in the main chain in sequence.* In doing this start at the end that will give the groups attached to the chain the *smallest numbers*. This has already been done in the preceding example. In this instance the numbers go from right to left, which places the substituent groups at carbon atoms 2, 3, and 4. If the chain were numbered from left to right, the groups would be at positions 4, 5, and 6. These are higher numbers and therefore violate the rule.

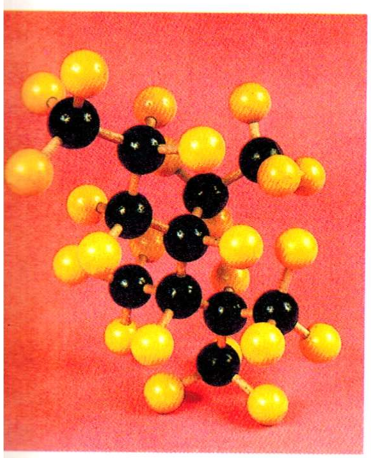
3. *Add numbers to the names of the substituent groups to identify their positions on the chain.* These numbers become prefixes to the name of the parent alkane. In this example the substituents and positions are 2-methyl, 3-methyl, and 4-ethyl.

4. *Use prefixes to indicate the appearance of a group more than once in the structure.* Common prefixes are *di* (twice), *tri* (three times), *tetra* (four), and *penta* (five). This example has two methyl substituents. Thus the word *dimethyl* will be part of the complete name.

5. *List the names of alkyl substituents in alphabetical order.* For purposes of alphabetizing, the prefixes *di, tri,* and so on are ignored. In this example, the 4-ethyl group is listed before the 2-methyl and 3-methyl groups (which are combined as 2, 3-dimethyl in the name).

6. *Use proper punctuation.* This is very important in writing the names of organic compounds in the IUPAC system. Commas are used to separate numbers. Hyphens are used to separate numbers and words. *The name of the alkane is written as one word.* The demonstration compound, then, would be written as dimethylheptane, *not* dimethyl heptane.

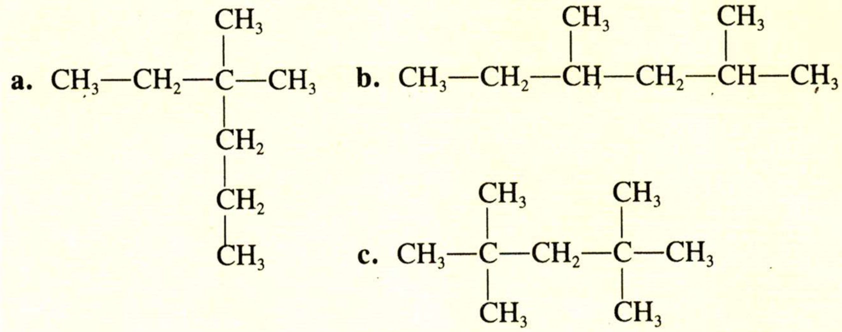
According to the IUPAC rules, the name of this compound is 4-ethyl-2,3-dimethylheptane.



**ure 25·6**
is is a ball and stick model of thyl-2,3, dimethylheptane. The rent structure forms a diagonal -zag chain from the lower right to upper left.

## Example 2

Name these compounds using the IUPAC system. (Note: The longest continuous chain is *not* written in a straight line in molecule **a.**)



### Solution

**a.** 3,3-dimethylhexane **b.** 2,4-dimethylhexane
**c.** 2,2,4,4-tetramethylpentane

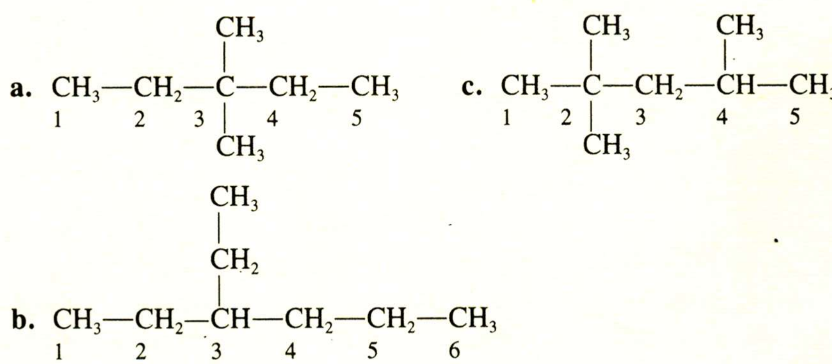
With an alkane name and knowledge of the IUPAC rules, it is easy to reconstruct the structural formula.

1. *Find the root word* (ending in *-ane*) *in the hydrocarbon name.* Then write the longest carbon chain to create the parent structure.
2. *Number the carbons on this parent carbon chain.*
3. *Identify the substituent groups.* Attach the substituents to the numbered parent chain at the proper positions.
4. *Add hydrogens as needed.*

## Example 3

Draw complete structural formulas for the following compounds.
**a.** 3,3-dimethyl-pentane **c.** 2,2,4-trimethylpentane
**b.** 3-ethylhexane

### Solution



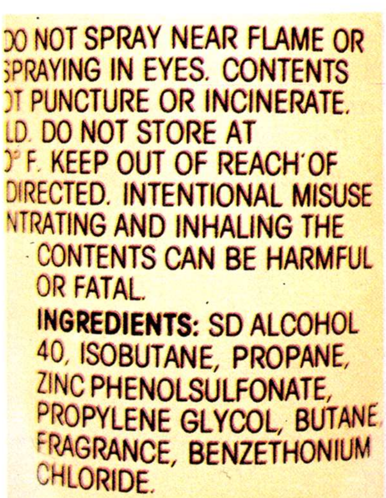
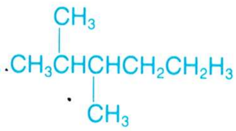
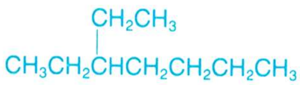
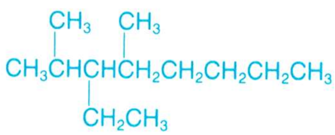



**Figure 25·7**
Alkanes such as isobutane, propane, and butane are commonly used as propellants in aerosol sprays.

4. **a.** 2-methylbutane
**b.** 3-methylpentane
**c.** 3-ethyhexane

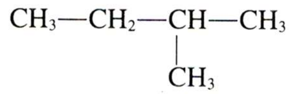
5. **a.** 
2,3-dimethylhexane

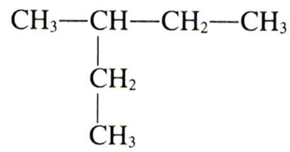
**b.** 
3-ethylheptane

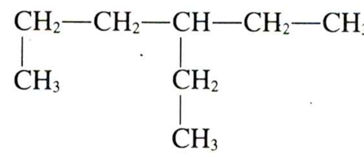
**c.** 
3-ethyl-2,4-dimethyloctane

## Problems

4. Name the following compounds according to the IUPAC system.

**a.** 

**b.** 

**c.** 

5. Draw a structural formula for each of the following compounds.
**a.** 2,3-dimethylhexane
**b.** 3-ethylheptane
**c.** 3-ethyl-2,4-dimethyloctane

## 25·4 Properties of Alkanes

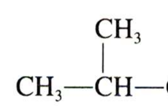
The alkanes are gases or low-boiling, greasy liquids which are insoluble in water.

The electron pair in a carbon–hydrogen or a carbon–carbon bond is about equally shared by the nuclei of the elements involved. Therefore hydrocarbon molecules such as the alkanes are nonpolar. The nonpolar attractions that hold hydrocarbon molecules together are the very weak van der Waals forces. Thus hydrocarbons of low formula weight tend to be gases or low-boiling liquids.

Nonpolar organic molecules such as the hydrocarbons are not attracted to water. For example, oil and water do not mix. A good rule of thumb is that "like dissolves like." That is, two nonpolar compounds will form a solution as will two polar compounds. By contrast, a nonpolar compound and a polar compound will not form a solution.

It is possible to draw the structures of two or more alkanes that have the same molecular formula but different molecular structures. *Compounds that have the same molecular formula but different molecular structures are called* **structural isomers.** For example, two different molecules have the formula $C_4H_{10}$: butane and 2-methylpropane. They are isomers of each other.

$CH_3—CH_2—CH_2—CH_3$
Butane ($C_4H_{10}$)
(bp 0°C)

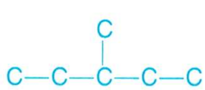

2-Methylpropane ($C_4H_{10}$)
(bp −10.2°C)

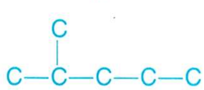
## Problem

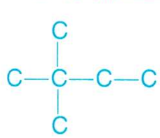
6. Draw all the structural isomers with the molecular formula $C_6H_{14}$. Name each one. (For convenience, you may wish to draw only the carbon skeleton for each structure.)

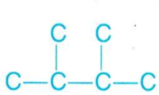
6. Five structural isomers of molecular formula $C_6H_{14}$ exist.

C—C—C—C—C—C
hexane


3-methylpentane


2-methylpentane


2,2-dimethylbutane


2,3-dimethylbutane

The physical properties of structural isomers are different.

Structural isomers differ in their physical properties such as boiling points and melting points. They also have different chemical reactivities. In general, the more highly branched the hydrocarbon structure, the lower its boiling point compared with its other structural isomers. For example, 2-methylpropane has a lower boiling point than butane.

## 25·5 Alkenes and Alkynes

The alkenes have the general formula $C_nH_n$, and they contain carbon–carbon double bonds.

The carbon–carbon bonds in alkanes are examples of single bonds. Multiple bonds between carbons also exist. *Organic compounds containing carbon–carbon double bonds are called* **alkenes.** This is the carbon–carbon double bond found in alkenes.

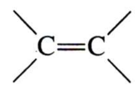
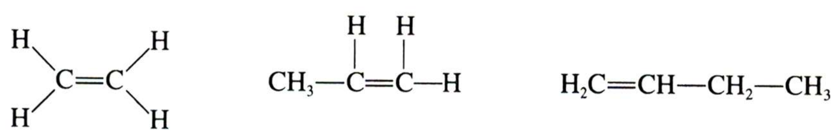


**Figure 25·8**
Plants produce ethene, which plays a vital role in their growth and development. Farmers treat tomato plants with a compound that breaks down into ethene inside the plants. This makes the tomatoes ripen at the same time so they can be harvested more efficiently.

*Organic compounds that contain double and triple carbon–carbon bonds are called* **unsaturated compounds.** This is because they contain fewer than the maximum number of hydrogens in their structure. *The alkanes (which contain the maximum number of hydrogens) are called* **saturated compounds.**

To name an alkene by the IUPAC system, find the longest continuous chain in the molecule that contains the double bond. This chain is the parent alkene. It gets the root name of the alkane with the same number of carbons plus the ending *-ene*. The chain is numbered so that the carbon atoms of the double bond get the lowest possible numbers. Substituents on the chain are named and numbered the same way as for the alkanes. Ethene and propene are the simplest alkenes. They are often called by the common names ethylene and propylene. Here are some examples of the structures and IUPAC names of simple alkenes.



Ethene (ethylene, the simplest alkene) | Propene (propylene) | 1-Butene

2-Butene (1-butene and 2-butene are structural isomers of $C_4H_8$) | 4-Methyl-2-pentene

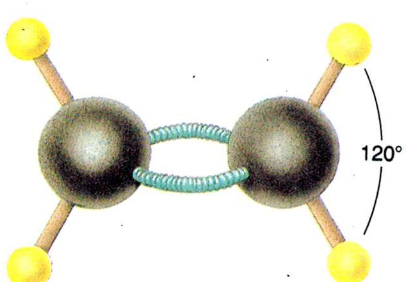



**Figure 25·9**
The six atoms of ethene lie in one plane. Rotation does not occur about the double bond.

No rotation occurs about a carbon–carbon double bond. The four hydrogens that project from the double-bonded carbons in ethene lie in a plane and are 120° apart (Figure 25·9). This is the maximum separation of atoms that can be attained without breaking bonds.

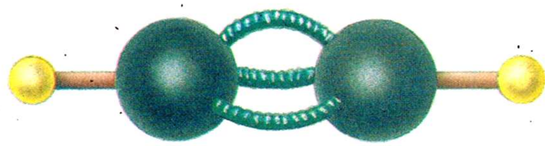


**Figure 25·10**
This is a ball-and-stick model of ethyne, the simplest alkyne. Rotation about the triple bond does not occur.

**Safety**

Alkenes and alkynes are very reactive because of the presence of double and triple bonds.

*Organic compounds containing carbon–carbon triple bonds are called* **alkynes.** Like alkenes, alkynes are unsaturated compounds. This is the carbon–carbon triple bond found in alkynes.

$$—C\equiv C—$$

Alkynes are not plentiful in nature. The simplest alkyne is the gas ethyne, $C_2H_2$. The common name for ethyne is acetylene. It is the fuel burned in oxyacetylene torches used in welding. In open flame lamps that were used for mining, acetylene was produced by reacting calcium carbide with water.

$$CaC_2(s) + 2H_2O(l) \longrightarrow C_2H_2(g) + Ca(OH)_2(aq)$$

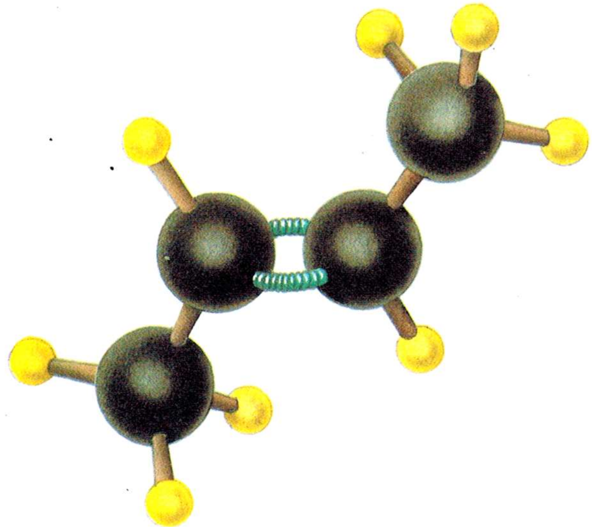
The single bonds that extend from the carbons involved in the carbon–carbon triple bond of ethyne are separated by the maximum angle of 180° (Figure 25·10). Thus ethyne is a linear molecule.

The physical properties of alkanes and alkenes of similar molecular mass are similar.

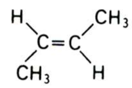
The major attractions between alkanes, alkenes, or alkynes are weak van der Waals forces. As a result, the introduction of a double or triple bond into a hydrocarbon does not have a dramatic effect on physical properties such as the boiling point (Table 25·2).

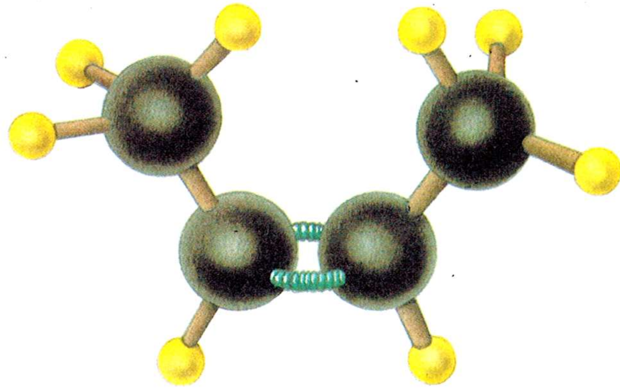
**Table 25·2 Boiling Points of Homologous Alkanes, Alkenes, and Alkynes**

| Name | Molecular structure | Boiling Point(°C) |
|---|---|---|
| $C_2$ | | |
| Ethane | $CH_3—CH_3$ | −88.5 |
| Ethene | $CH_2{=}CH_2$ | −103.9 |
| Ethyne | $CH\equiv CH$ | −81.8 |
| $C_3$ | | |
| Propane | $CH_3CH_2CH_3$ | −42.0 |
| Propene | $CH_3CH{=}CH_2$ | −47.0 |
| Propyne | $CH_3C\equiv CH$ | −23.3 |
| $C_4$ | | |
| Butane | $CH_3CH_2CH_2CH_3$ | 0.5 |
| 1-Butene | $CH_3CH_2CH{=}CH_2$ | −6.3 |
| 1-Butyne | $CH_3CH_2C\equiv CH$ | 8.6 |
| $C_5$ | | |
| Pentane | $CH_3CH_2CH_2CH_2CH_3$ | 36.0 |
| 1-Pentene | $CH_3CH_2CH_2CH{=}CH_2$ | 30.0 |
| 1-Pentyne | $CH_3CH_2CH_2C\equiv CH$ | 40.0 |



**a** *trans*-2-Butene
(bp 1°C)





**b** cis-2-Butene
(bp 4°C)

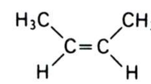


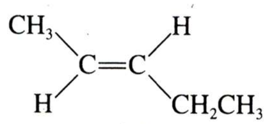
**Figure 25·13**
These are the two geometric isomers of 2-butene. How does the *trans* configuration differ from the *cis* configuration?
The methyl groups are on opposite sides of the double bond in the *trans* configuration. They are on the same side of the double bond in the *cis* configuration.

## 25·6 Geometric Isomers

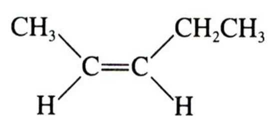
Appropriate for honors students.

The lack of rotation around carbon–carbon double bonds has an important structural implication. Look at the structure of 2-butene in Figure 25·13. Two arrangements are possible for the methyl groups with respect to the rigid double bond. *In the* **trans configuration** *the substituted groups are on opposite sides of the double bond. In the* **cis configuration** *the substituted groups are on the same side of the double bond. Trans*-2-butene and *cis*-2-butene are geometric isomers. **Geometric isomers** *differ only in the geometry of their substituted groups*. Like other structural isomers, isomeric 2-butenes are distinguishable by their different physical and chemical properties. The groups on the carbons of the double bond need not be the same. Geometric isomerism is possible whenever each carbon of the double bond has at least one substituent.

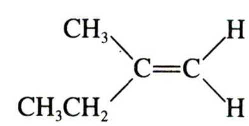
Stable geometric isomers exist because there is no rotation about carbon–carbon double bonds.



*trans*-2-Pentene

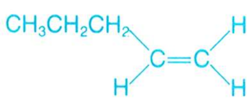


*cis*-2-Pentene



2-Methyl-1-butene
(no *cis*, *trans* isomers)

Note that a *fourth* isomer possible is: 1-pentene



However, there are only two *geometric* isomers, the *cis*- and *trans*- forms.

### Problem

7. Draw structural formulas for the following alkenes. If a compound has geometric isomers, draw both the *cis* and *trans* forms.
   **a.** 1-pentene
   **b.** 2-hexene
   **c.** 2-methyl-2-hexene
   **d.** 2,3-dimethyl-2-butene

Answers are shown in Appendix C.

## 25·8 Cyclic and Aromatic Hydrocarbons

Carbon forms rings as well as open-chain molecules.

In some hydrocarbon compounds, the two ends of a carbon chain are attached to form a ring. *Compounds that contain a hydrocarbon ring are* **cyclic hydrocarbons.** The structures of some cyclic hydrocarbons are shown in Figure 25·16. Rings containing from 3 to 20 carbons are found in nature. Five- and six-membered rings are the most abundant. *All hydrocarbon compounds which do not contain rings are known as* **aliphatic compounds.** They include compounds with both short and long carbon chains.

Cyclopropane (bp −34.4°C)

Cyclobutane (bp −13°C)

Cyclopentane (bp 49.5°C)

Cyclohexane (bp 81.4°C)

Cycloheptane (bp 118°C)

Cyclooctane (bp 149°C)

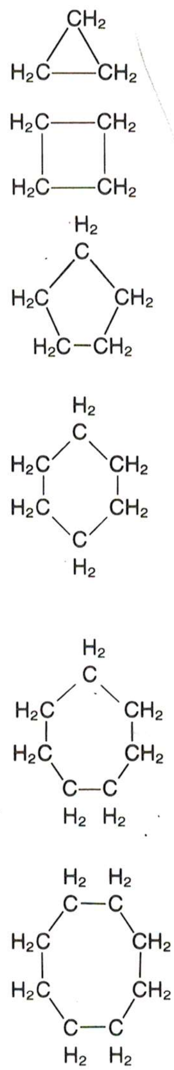
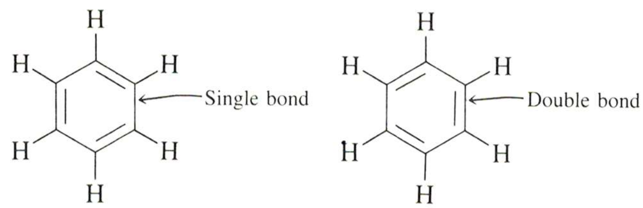


**Figure 25·16**
Cycloalkanes are named after the parent alkane. Cycloalkenes are similar but are not shown here.

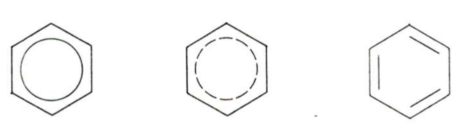
*A special group of unsaturated cyclic hydrocarbons are known as* **arenes.** These compounds contain single rings or groups of rings. The arenes were originally called aromatic compounds because many of them have pleasant odors. Benzene, $C_6H_6$, is the simplest arene. *Today the term* **aromatic compound** *is applied to any substance in which the bonding is like that of benzene.*

The benzene molecule has a six-membered carbon ring with a hydrogen attached to each carbon. This leaves one electron from each carbon free to participate in a double bond. Two different structures with double bonds can be written for benzene.




These structural formulas show only the extremes in electron sharing between any two adjacent carbons in benzene. One extreme is a normal single bond. The other extreme is a normal double bond. *Resonance occurs when two or more equally valid structures can be drawn for a molecule.* The benzene molecule exhibits resonance. Benzene and other molecules that exhibit resonance are more stable than similar molecules that do not exhibit resonance. Thus benzene is not as reactive as six-carbon alkenes.

Because of resonance, the bonding in benzene and related arenes is unique. The benzene molecule is perfectly flat. Bending or twisting would disrupt the electron sharing and the molecule's stability. Some chemists use a circle to show the presence of resonance in a benzene ring.



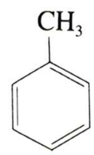
The inscribed circle is a good way to represent the nature of resonance bonding. However, it does not show the number of electrons involved. For this reason, the traditional structure (shown on the right) will be used.

A more satisfactory model is provided by modern bonding theory. It is thought that each carbon atom forms three sigma bonds, one to a hydrogen atom and two to neighboring carbon atoms. The remaining six electrons are spread evenly over the entire molecule to form pi bonds.

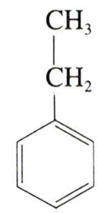
**Safety**

Benzene is a known carcinogen and is not recommended for use in schools. Several of its derivatives are also suspected carcinogens or are highly toxic.

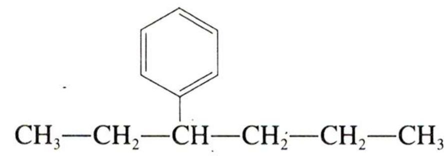
Compounds containing substituents attached to the benzene ring are named as derivatives of benzene. Sometimes the benzene ring is named as a substituent on an alkane. In such instances the $C_6H_5$— group is called a phenyl group.



Methylbenzene (toluene)



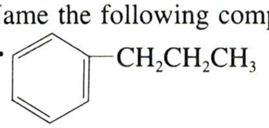
Ethylbenzene

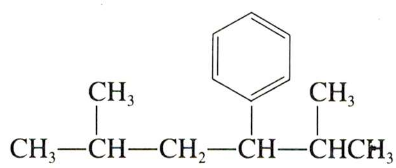


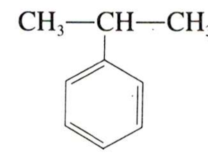
3-Phenylhexane

## Problem

10. Name the following compounds.

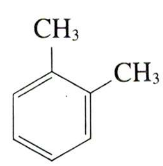
a. 

b. 

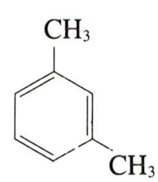
c. 

10. a. 1-phenylpropane
b. 2, 5-dimethyl-3-phenylhexane
c. 2-phenylpropane

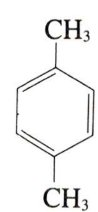
Some derivatives of benzene have two substituents. Such derivatives are called *disubstituted* benzenes. Three different structural isomers occur for the liquid aromatic compound dimethylbenzene, $C_6H_4(CH_3)_2$. Once again, the physical properties of structural isomers are different, as indicated by their boiling points.



1,2-Dimethylbenzene (*o*-dimethylbenzene, *o*-xylene) (bp 144°C)



1,3-Dimethylbenzene (*m*-dimethylbenzene, *m*-xylene) (bp 139°C)



1,4-Dimethylbenzene (*p*-dimethylbenzene, *p*-xylene) (bp 138°C)

In the IUPAC naming system, the possible positions of two substituents in disubstituted benzene are designated as 1,2; 1,3; or 1,4. Common names for disubstituted benzenes use the terms *ortho, meta,* and *para* (abbreviated *o, m,* and *p*) in place of numbers. The dimethylbenzenes are also called xylenes.

# 25 Hydrocarbon Compounds

## Chapter Review

### Key Terms

- aliphatic compound *25·8*
- alkane *25·1*
- alkene *25·5*
- alkyl group *25·3*
- alkyne *25·5*
- arene *25·8*
- aromatic compound *25·8*
- asymmetric carbon *25·7*
- branched-chain alkane *25·3*
- *cis* configuration *25·6*
- condensed structural formula *25·2*
- continuous-chain alkane *25·2*
- cracking *25·9*
- cyclic hydrocarbon *25·8*
- geometric isomer *25·6*
- hydrocarbon *25·0*
- homologous series *25·2*
- IUPAC system *25·2*
- saturated compound *25·5*
- stereoisomer *25·7*
- structural isomer *25·4*
- substituent *25·3*
- *trans* configuration *25·6*
- unsaturated compound *25·5*

### Chapter Summary

The branch of chemistry that deals with carbon compounds is called organic chemistry. Carbon makes stable covalent bonds with other carbons to form chain and ring compounds. Hydrocarbons are compounds containing only carbon and hydrogen. Many hydrocarbons exhibit structural isomerism. Structural isomers have the same molecular formula but different molecular structures.

Alkanes contain only carbon–carbon single bonds. The groups attached to single bonds in continuous-chain alkanes rotate freely about the bonds at room temperature. Alkenes are unsaturated hydrocarbons. That is, they contain one or more carbon–carbon double bonds. Alkenes may exhibit geometric isomerism. Geometric isomers are *cis* or *trans* according to whether substituent groups are on the same side or on opposite sides of the double bond. Alkynes are also unsaturated compounds. They contain one or more carbon–carbon triple bonds. Rotation about the multiple bonds of alkenes and alkynes does not occur at ordinary conditions. Some organic molecules exhibit stereoisomerism. Stereoisomers are related in much the same way that the right hand is related to the left. Stereoisomerism can occur if four different groups are attached to carbon.

Aromatic hydrocarbons or arenes are related to the hydrocarbon benzene. Benzene is rather unusual among hydrocarbons. As a result of resonance, the interior bonds of the benzene ring are somewhere between ordinary single bonds and double bonds. Benzene is less reactive than ordinary alkenes because of this unusual bonding.

Aliphatic, or open-chain, hydrocarbons come mainly from petroleum. Aromatic hydrocarbons come mainly from coal. Many hydrocarbons are obtained directly from crude petroleum by distillation. The molecular structures of the hydrocarbons present in natural petroleum can be reorganized into other useful products by the cracking process.

### Practice Questions and Problems

**11.** What is the number of covalent bonds formed by carbon? *25·1*

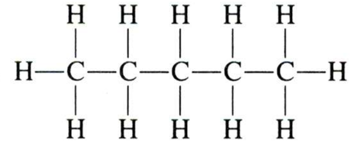
**12.** Draw complete and condensed structural formulas, and give the correct names for the first ten continuous-chain alkanes. (Do not look at Table 25·1!) *25·2*

**13.** Name the alkanes that have the following formulas. *25·2*

**a.** $CH_3CH_2CH_3$

**b.** $CH_3(CH_2)_6CH_3$

**c.**




**d.** $C_3H_8$

**e.** $CH_3CH_2CH_2CH_2CH_3$

**14.** Write structures for the alkyl groups derived from methane, ethane, and propane. *25·3*

15. What system is used for naming branched-chain alkanes? Briefly state the rules. *25·3*

16. Why are the following names incorrect? What are the correct names? *25·3*

**a.** 2-dimethylpentane
**b.** 1,3-dimethylpropane
**c.** 3-methylbutane
**d.** 3,4-dimethylbutane

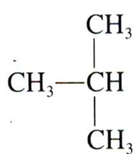
17. Draw structural formulas for the following branched-chain alkanes. *25·3*

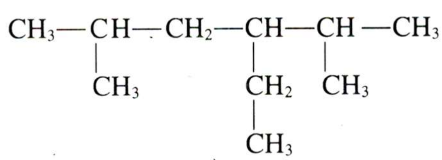
**a.** 2,3-dimethylbutane
**b.** 2,2-dimethylbutane
**c.** 2,2,3-trimethylbutane
**d.** 3,4-diethyl-4,5-dimethyloctane

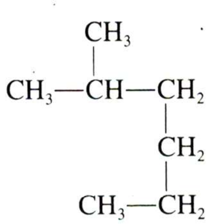
18. Draw structural formulas for these compounds. *25·3*

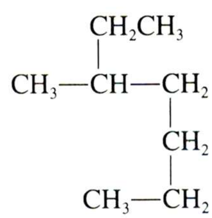
**a.** pentane
**b.** 3-ethylpentane
**c.** 4-ethyl-2,3,4,-trimethylnonane
**d.** 3,5-diethyl-2,3-dimethyl-5-propyldecane

19. Give the IUPAC name for each compound. *25·3*

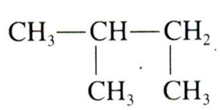
**a.** 

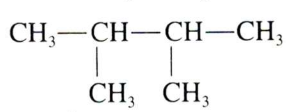
**b.** 

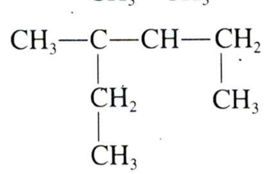
**c.** 

**d.** 

20. Give the IUPAC name for each compound. *25·3*

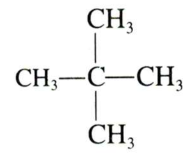
**a.** 

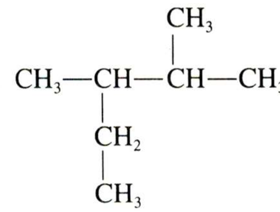
**b.** 

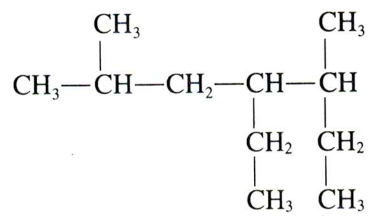
**c.** 

21. What are structural isomers? *25·4*

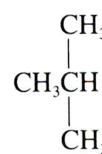
22. Draw one structural isomer of each of the following compounds. *25·4*

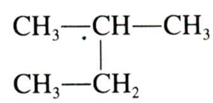
**a.** 

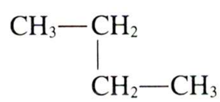
**b.** 

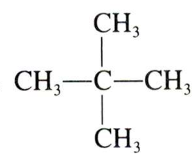
**c.** 

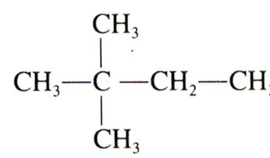
23. Which of these are structural isomers? *25·4*

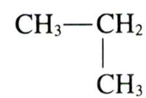
**a.** 

**b.** 

**c.** 

**d.** 

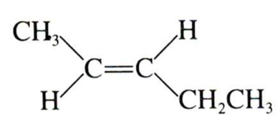
**e.** 

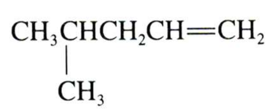
**f.** 

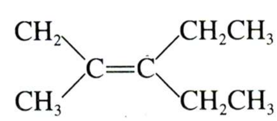
24. Explain the difference between saturated and unsaturated hydrocarbons. *25·5*

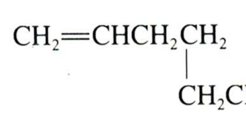
25. Give a systematic name for these alkenes. *25·5*

**a.** $CH_3CH{=}CH_2$

**b.** 

**c.** 

**d.** 

**e.** 

**26.** Draw a structural formula for each alkene with the molecular formula $C_5H_{10}$. Name each of these compounds. *25·5*

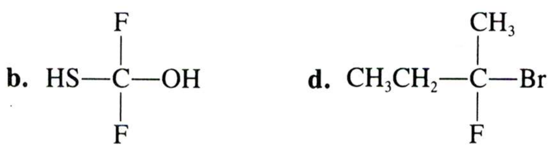
**27.** Draw all the alkenes with the molecular formula $C_4H_8$. Name each compound. *25·5*

**28.** Show how lack of rotation about a carbon–carbon double bond leads to geometric isomerism. Use the isomers of 2-pentene to illustrate your answer. *25·6*

**29.** Draw a structural formula or carbon skeleton for each of the following alkenes. Include both *cis* and *trans* forms if the compound has geometric isomers. **a.** 2-pentene **b.** 2-methyl-2-pentene **c.** 3-methyl-2-pentene *25·6*

**30.** For which of the following structural formulas can mirror image molecules be drawn? Why? *25·7*

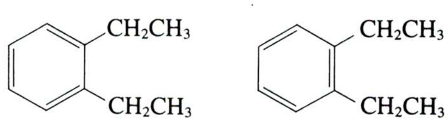
**a.** $CH_2Cl_2$ **c.** $CH_3CF_2CH_3$



**31.** Draw a structure for each compound. *25·8*

**a.** *p*-diethylbenzene **c.** *p*-xylene
**b.** 2-methyl-3-phenylpentane **d.** toluene

**32.** Explain why both of these structures represent 1,2-diethylbenzene. *25·8*



**33.** Does crude oil contain mostly aliphatic or aromatic hydrocarbons? *25·9*

**34.** Define *petroleum refining* and *cracking*. *25·9*

**35.** Write a balanced equation for the complete combustion of pentane. *25·9*

## Mastery Questions and Problems

**36.** Briefly describe. *25·8*

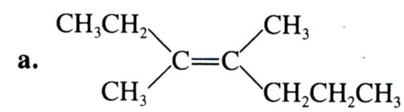
**a.** hydrocarbon **d.** alkyne
**b.** alkane **e.** alkene
**c.** arene **f.** aromatic compound

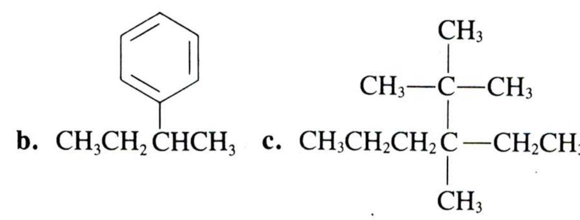
**37.** Draw electron dot structures for each of these compounds. **a.** ethene **b.** propane **c.** ethyne **d.** cyclobutane *25·8*

**38.** Write structural formulas for each of the following compounds. *25·8*

**a.** propyne **d.** 2,2,4-trimethylpentane
**b.** cyclohexane **e.** 2,3-dimethylpentane
**c.** 2-phenylpropane **f.** 1,1-diphenylhexane

**39.** Give the IUPAC name for each compound. *25·8*





**40.** Name the next three higher homologs of ethane. *25·2*

**41.** Compare these three molecular structures. Which would you expect to be most stable? Why? *25·8*

## Review Questions and Problems

**42.** What are the pH values for aqueous solutions containing each of the following hydroxide ion concentrations?

**a.** $1.00 \times 10^{-4}M$ **c.** $0.01M$
**b.** $3.92 \times 10^{-7}M$ **d.** $0.005M$

**43.** Give the oxidation number of each element in the following compounds.

**a.** $CaCO_3$ **c.** $LiIO_3$
**b.** $Cl_2$ **d.** $Na_2SO_3$

**44.** Write equilibrium constant expressions for the following reactions.

**a.** $Cl_2(g) + I_2(g) \rightleftharpoons 2ICl(g)$
**b.** $2HBr(g) \rightleftharpoons H_2(g) + Br_2(g)$
**c.** $2S_2Cl_2(g) + 2H_2O(g) \rightleftharpoons 4HCl(g) + 3S(g) + SO_2(g)$
**d.** $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$