Key Terms
molecular compound
molecule
binary molecular compound

4.2 Representing Molecular Compounds

The chemical shown in **Figure 4.12**, named dihydrogen monoxide, is a molecular compound with many uses. For example, it is a key ingredient in most pesticides, it contributes to environmental hazards (such as acid rain, the greenhouse effect, and soil erosion), and it causes severe illness or death in either very low or very high concentrations in the body. Knowing these facts, a group of students voted in favour of banning dihydrogen monoxide. The students were missing a key piece of information, however. Dihydrogen monoxide is just another name for water!

This example illustrates how important it is to know the names and chemical formulas for compounds, so that you can make well-informed decisions about the chemicals you encounter every day at home, at school, at work, and in the environment.

Study Toolkit

Base Words What is the base of *molecular*? Use this word to predict the meaning of *molecular*. Use a dictionary or the Glossary at the end of this textbook to check your prediction.

Figure 4.12 What's in a name? Everything, when it comes to chemicals. You are continually exposed to this molecular compound, dihydrogen monoxide. Should you be worried?

Forming Molecular Compounds

Molecular compounds, also known as *covalent compounds,* are usually composed of two or more different non-metals. A molecular compound forms when atoms share a pair of electrons to form a covalent bond. In a covalent bond, the shared electrons are attracted to the nuclei of both atoms. This attraction holds the atoms together. Therefore, unlike electrons in an ionic compound, electrons in a molecular compound are not transferred between atoms, so the atoms remain uncharged. Nevertheless, the formation of a molecular compound is based on the same principle as the formation of an ionic compound: the stability that is associated with a full outer energy level of electrons. The Bohr-Rutherford model for water is shown in **Figure 4.13**. It demonstrates how the covalent bonding of each hydrogen atom to the oxygen atom produces filled outer energy levels for all three atoms.

molecular compound a compound formed when atoms of two or more different elements share electrons

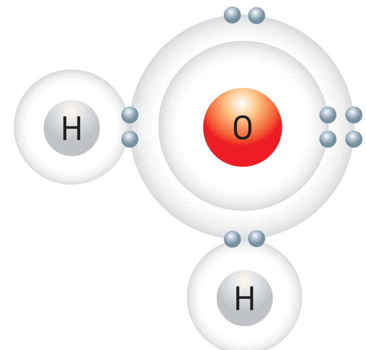


Figure 4.13 This Bohr-Rutherford model for water demonstrates how the atoms share electrons so that each atom has a full set of electrons in its outer energy level.

Molecules

In the last section, you saw that an ionic solid is composed of a repeating pattern of ions. In contrast, molecular compounds are composed of individual **molecules**. Each molecule, like the one shown in **Figure 4.14**, is composed of a set number of atoms of each element.

The term *molecule* is also used to describe two or more atoms of the same element that are joined by a covalent bond. Elements that exist in this form include H_2, N_2, O_2, Cl_2, Br_2, I_2, and F_2. Remember, however, that these molecules are not compounds because they contain only one kind of atom.

The following activity will give you a chance to model molecule formation.

molecule a neutral particle composed of two or more atoms joined together by covalent bonds

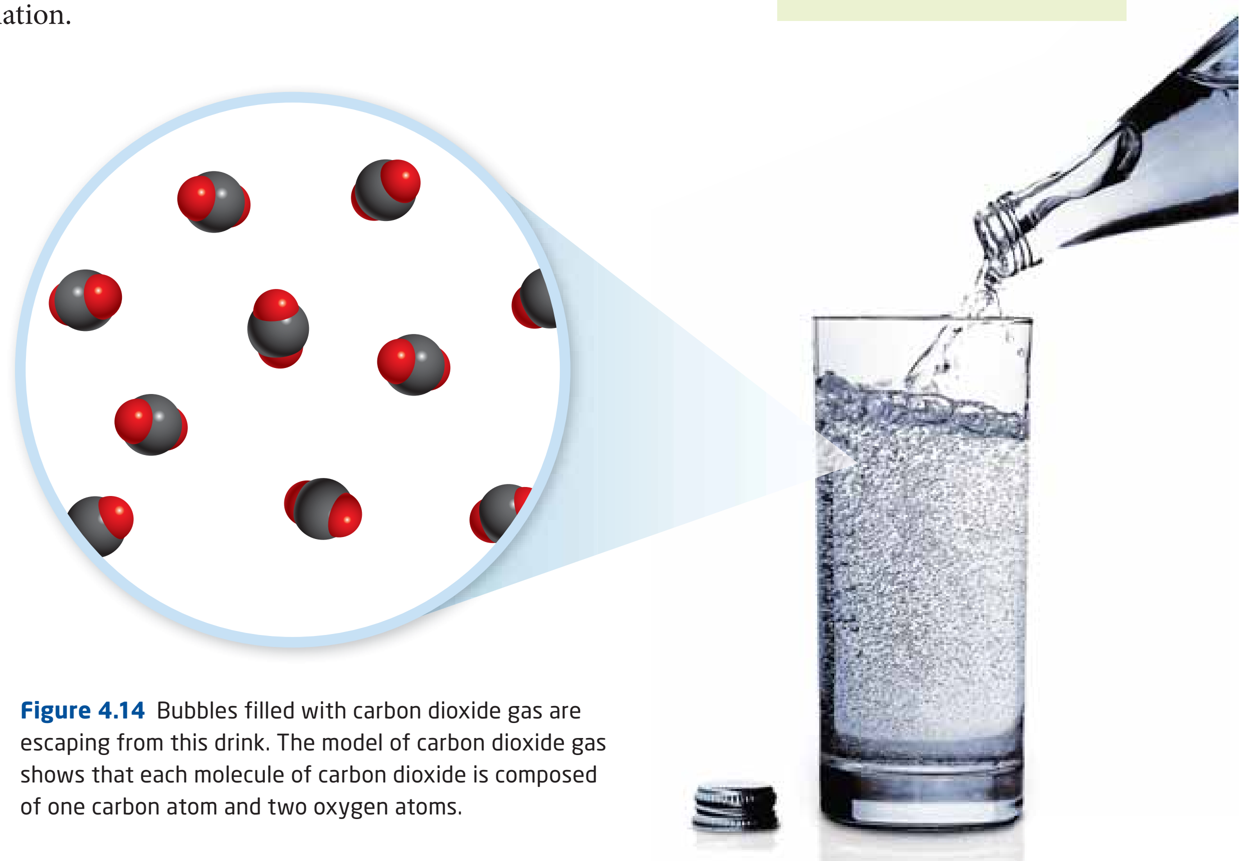


Figure 4.14 Bubbles filled with carbon dioxide gas are escaping from this drink. The model of carbon dioxide gas shows that each molecule of carbon dioxide is composed of one carbon atom and two oxygen atoms.

Activity 4-3

Electron, Anyone?

In this activity, you will use circular objects to represent electrons and model the formation of three molecular compounds: water (H_2O), ammonia (NH_3), and methane (CH_4). Based on what you know about molecular compounds, what must happen to the electrons between two atoms?

Materials

- bag that contains small rings (such as washers or coloured paper reinforcements)
- sheets of blank paper
- molecular modelling kit

Procedure

1. At the top of a sheet of paper, write the symbol for an atom of oxygen. Use the objects to represent electrons in a Bohr-Rutherford model of the atom. Write the symbol for the element as a representation of the nucleus. Examine your model, and determine how many electrons the oxygen atom would need to have a full set of eight electrons in its outer energy level.
2. For each electron that the oxygen atom needs, write one symbol for an atom of hydrogen. Use the objects to show the electrons in the hydrogen atoms. Draw arrows to connect the electrons that will be shared by the oxygen atom and each hydrogen atom.
3. Using the objects, show how electrons between the oxygen atom and each hydrogen atom are shared to form covalent bonds and full outer energy levels of electrons.
4. Use the molecular modelling kit to build a three-dimensional model of the molecule. Draw a sketch of your model, and label your sketch.
5. Repeat steps 1 to 4, using nitrogen instead of oxygen.
6. Repeat steps 1 to 4, using carbon instead of oxygen.

Questions

1. How many electrons are surrounding each hydrogen atom after each compound forms?
2. What is the total number of electrons in the outer level of the central atom in each molecule you modelled? How is this number related to the number of covalent bonds that can form?
3. Water, methane, and ammonia are older conventional names of the compounds modelled in this activity. Why do you think chemists sometimes continue to use an old name for a compound, rather than switching to a name that follows the official rules for naming compounds?

binary molecular compound a compound that is composed of two non-metals joined by one or more covalent bonds

Naming Binary Molecular Compounds

The rules for naming **binary molecular compounds** ensure that the identity of each compound is absolutely clear. For example, the chemical name of the molecular compound *carbon dioxide* reveals two pieces of information. First, it tells you that the compound is composed of the elements carbon and oxygen. Second, it tells you that the ratio of carbon atoms to oxygen atoms is 1:2. The prefixes in the name show the number of atoms of each element in a molecule of the compound. **Table 4.9** lists the common prefixes and their meanings.

Table 4.9 Prefixes Used in the Names of Binary Molecular Compounds

Prefix	Number	Prefix	Number
mono-	1	penta-	5
di-	2	hexa-	6
tri-	3	hepta-	7
tetra-	4	octa-	8

Using the Prefixes

The dark hazy smog in **Figure 4.15** is a common sight in some large cities. Many molecular compounds are present in smog, including several compounds that are composed of nitrogen and oxygen. The molecular compound nitrogen dioxide (NO_2) is one of these compounds. Its name reflects the fact that each molecule of the compound is composed of a single nitrogen atom bonded to two oxygen atoms. Two NO_2 molecules can join together to form a completely different compound, N_2O_4. This compound, dinitrogen tetroxide, has different properties and is used in rocket fuels. Notice that the subscripts are not reduced to the simplest whole number ratio because, unlike ionic compounds, a simplified ratio can result in a different molecular compound (for example, NO_2 and N_2O_4).

Table 4.10 shows the steps to follow when writing the name of a binary molecular compound based on its chemical formula. Two examples are given to illustrate the steps.

Sense of place

It is estimated that over 6000 Toronto residents visit hospitals each year due to health problems associated with exposure to air pollution or smog. In addition, exposure to air pollution costs the Toronto economy more than $150 million in health-care costs each year.

Table 4.10 **Naming a Binary Molecular Compound**

Steps	Examples	
	N_2O_4 (used as a rocket fuel)	**BrCl (used to detect mercury in water)**
1. Count the number of atoms of the first element in the chemical formula.	Number of nitrogen atoms: 2	Number of bromine atoms: 1
2. Write the appropriate prefix followed by the name of the element. Note that the prefix *mono-* is never used for the first element.	First part of name: dinitrogen	First part of name: bromine
3. Count the number of atoms of the second element in the chemical formula.	Number of oxygen atoms: 4	Number of chlorine atoms: 1
4. Write the appropriate prefix followed by the name of the element using the suffix *-ide*. If the prefix ends with *a* or *o*, this letter is dropped before *oxide*.	Second part of name: tetroxide Full name: dinitrogen tetroxide	Second part of name: monochloride Full name: bromine monochloride

Figure 4.15 Smog like this, which hangs over Toronto, contains the molecular compound NO_2, or nitrogen dioxide.

Figure 4.16 This herbicide is produced using the molecular compound phosphorus trichloride.

Learning Check

1. What does a prefix in the name of a molecular compound tell you?
2. Write the name of each molecular compound.
   a. CS_2
   b. N_2O_3
   c. CO
   d. CCl_4
   e. PF_5
   f. Si_2Br_6
3. Use a diagram to illustrate the meaning of each part of the name *diphosphorus pentoxide*.
4. Show how the prefixes that are used in the names of molecular compounds are also used in everyday language.

Writing Chemical Formulas for Binary Molecular Compounds

The prefixes that are used to name molecular compounds make it easy to infer their chemical formulas. To write the chemical formula for a binary molecular compound, simply write the symbols of the elements with the subscripts indicated by the prefixes, as outlined in **Table 4.11**. One of the examples in the table is phosphorus trichloride, a very toxic chemical that is used to make insecticides and herbicides, such as the one in **Figure 4.16**.

Table 4.11 Writing the Chemical Formula for a Binary Molecular Compound

Steps	Examples	
	Phosphorus Trichloride (used to make insecticide)	**Disulfur Dinitride (used to synthesize other chemicals)**
1. Write the chemical symbol of the first element.	First element in formula: P	First element in formula: S
2. Determine the number of atoms of the first element, based on the prefix. This number will appear in the final chemical formula. If there is no prefix for the first element, there is only one atom.	Number of phosphorus atoms: 1	Number of sulfur atoms: 2
3. Write the chemical symbol of the second element. Keep in mind that the ending *-ide* is not part of the element's name.	Second element in formula: Cl	Second element in formula: N
4. Determine the number of atoms of the second element, based on the prefix. This number will appear in the final chemical formula.	Number of chlorine atoms: 3	Number of nitrogen atoms: 2
5. Write the chemical formula for the compound, using the appropriate subscripts.	Formula: PCl_3	Formula: S_2N_2

Sample Problem: Writing the Chemical Formula for a Binary Molecular Compound

Problem

Write the chemical formula for dinitrogen pentoxide.

Solution

Step 1: Determine the chemical symbol for the first element.

- The symbol for nitrogen is N.

Step 2: Determine the number of atoms of the first element, based on its prefix in the name of the compound. This is the subscript for the first element in the chemical formula.

- The prefix used with nitrogen is *di-*, which means two. The subscript for nitrogen in the chemical formula is 2.

Step 3: Determine the chemical symbol for the second element.

- *Oxide* refers to the element oxygen, O.

Step 4: Determine the number of atoms of the second element, based on its prefix in the name of the compound. This is the subscript for the second element in the chemical formula.

- The prefix used with oxide is *pent-*, which means five. The subscript for oxygen in the chemical formula is 5.

Therefore, the chemical formula is N_2O_5.

Check Your Solution

Check that the correct elements are represented in the chemical formula. Then, check the subscripts. The prefix *di-* is used with nitrogen. Therefore, a 2 should be a subscript to the symbol for nitrogen. The prefix *penta-* is used with oxygen. Therefore, a 5 should be a subscript to the symbol for oxygen.

GRASP
Go to **Science Skills Toolkit 11** to learn about an alternative problem solving method.

Practice Problem

1. Write the chemical formula for each binary molecular compound.

a. nitrogen trifluoride
b. phosphorus tribromide
c. nitrogen trihydride
d. sulfur difluoride
e. diphosphorus hexoxide
f. carbon tetrachloride

Other Molecular Compounds

Binary molecular compounds make up only a small fraction of all molecular compounds. For example, octane, shown in **Figure 4.17**, is a compound that is a component of gasoline. There are special rules for naming such complex molecular compounds, and for writing their chemical formulas. You will learn these rules in later chemistry courses.

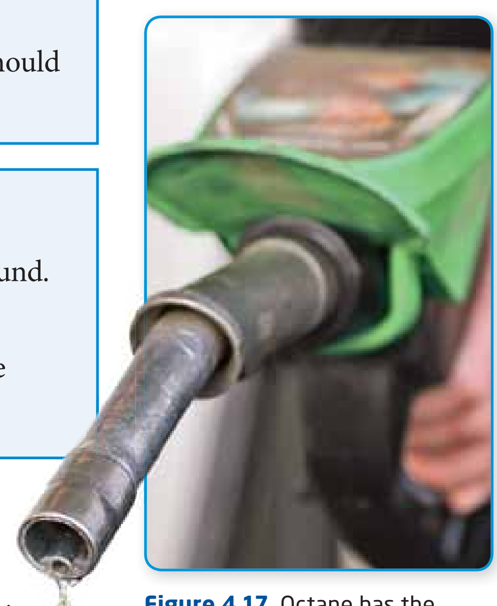


Figure 4.17 Octane has the chemical formula C_8H_{18}. Notice the prefix *oct-*. This prefix indicates that this compound contains eight carbon atoms.

Section 4.2 Review

Section Summary

- Molecular compounds form when atoms share electrons in covalent bonds.
- Prefixes are used in the name of a binary molecular compound to indicate the number of atoms of each element in a molecule of the compound.
- The chemical formula for a binary molecular compound shows the number of each atom in a molecule of the compound. The subscripts correspond to the prefixes in the name of the compound.
- Molecular compounds have important functions in energy generation and in the production of chemicals used by agricultural industries. Many molecular compounds, however, are environmental pollutants. Other molecular compounds can have negative consequences if they are not handled correctly.

Review Questions

C **1.** Draw a Bohr-Rutherford model of a water molecule to show how the electrons in the outer energy level of the atoms are arranged.

K/U **2.** When writing the name of a molecular compound, which part of the name ends in the suffix *-ide*?

K/U **3.** Name each molecular compound.

a. CO

b. PCl_5

c. N_2O_5

A **4.** Suppose that you see the compounds carbon tetrahydride and nitrogen trihydride on an MSDS. What are these compounds more commonly known as?

C **5.** Using a flowchart, write a set of rules for naming binary molecular compounds.

K/U **6.** Write the chemical formula for each binary molecular compound.

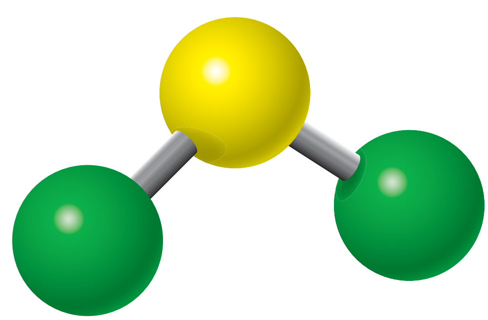
a. sulfur hexafluoride

b. oxygen difluoride

c. carbon tetrabromide

K/U **7.** Examine the model on the right. Write the name and chemical formula for the compound represented.

T/I **8.** "The subscripts in the chemical formula for a molecular compound are not always in the lowest ratio." Using what you have learned about naming binary molecular compounds, provide evidence that supports this statement.



This model shows a molecule composed of one sulfur atom and two chlorine atoms.