Putting Atoms Together

7.1

Most things are not made of individual atoms. Atoms can chemically join with other atoms to form small units called **molecules**. For example, our air contains many kinds of molecules. It is composed of roughly 80 % nitrogen molecules, 20 % oxygen molecules, and small amounts of water molecules and carbon dioxide molecules.

molecule two or more atoms of the same or different elements that are chemically joined together in a unit

Nitrogen molecules are composed of two nitrogen atoms joined together (Figure 1(a)). The chemical formula for a single nitrogen molecule is N_2. A **chemical formula** is the notation used to indicate the type and number of atoms in a pure substance. (Recall from Section 5.1 that a pure substance is made up of only one type of particle.) The subscript 2 indicates that there are two atoms of the element preceding it. The chemical formula for an oxygen molecule is O_2, indicating that there are two oxygen atoms joined together in this molecule (Figure 1(b)).

chemical formula notation that indicates the type and number of atoms in a pure substance

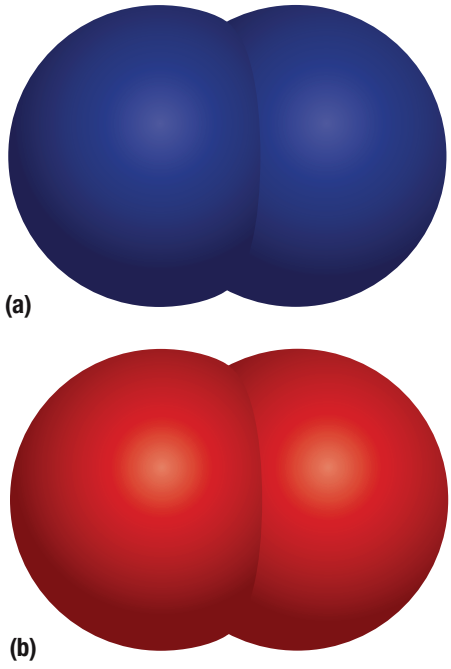

Figure 1 (a) A nitrogen molecule consists of two nitrogen atoms joined together. (b) An oxygen molecule consists of two oxygen atoms joined together.

WRITING TIP

Writing a Science Report

Before you begin writing a science report, say the purpose of the report aloud as clearly as possible in your own words. Turn this statement into a question to use at the beginning of the report.

Molecular Elements

Like a nitrogen atom, a nitrogen molecule, N_2, is an element. There is only one type of atom in this molecule—nitrogen—so N_2 is a **molecular element**, not a compound. (Recall from Section 6.1 that a compound is a pure substance composed of two or more *different* elements that are chemically joined.)

molecular element a molecule consisting of atoms of the same element

There are seven elements that form molecules consisting of two atoms. These molecular elements are commonly called diatomic molecules, where the prefix *di-* means two. The seven diatomic molecules are H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2.

LEARNING TIP

Remembering the Diatomic Molecules

To remember the seven diatomic molecules H_2, O_2, F_2, Br_2, I_2, N_2, Cl_2, use the nonsensical word HOF BrINCl, which rhymes with "Bullwinkle."

Molecular Compounds

molecular compound a molecule that consists of two or more different elements

Most molecules contain more than one type of element. These molecules are called **molecular compounds**. The chemical formula for the molecular compound water (H_2O) tells us that each water molecule contains two hydrogen atoms and one oxygen atom (Figure 2). If a letter in a chemical formula does not have a subscript, it means there is only one atom of that element. Carbon dioxide (CO_2) is a compound that contains one carbon atom and two oxygen atoms in each molecule. The chemical formula for table sugar that you stir into your coffee or tea is $C_{12}H_{22}O_{11}$ (Figure 3). Each molecule of sugar contains 12 carbon atoms, 22 hydrogen atoms, and 11 oxygen atoms. If that sounds like a large molecule, try counting the thousands of atoms in a molecule of protein or DNA!

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LEARNING TIP

Element or Compound?
A molecule can be an element or a compound. A molecule is an element when it is composed of only one type of atom. A molecule is a compound when it is composed of two or more different types of atoms.

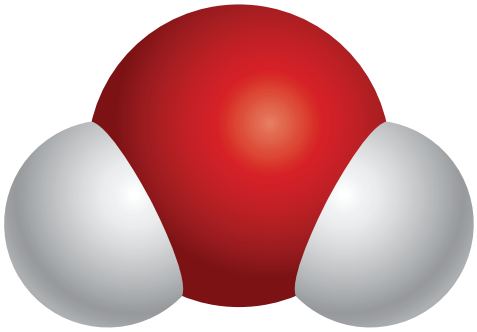


Figure 2 Water, H_2O, is an example of a molecular compound.

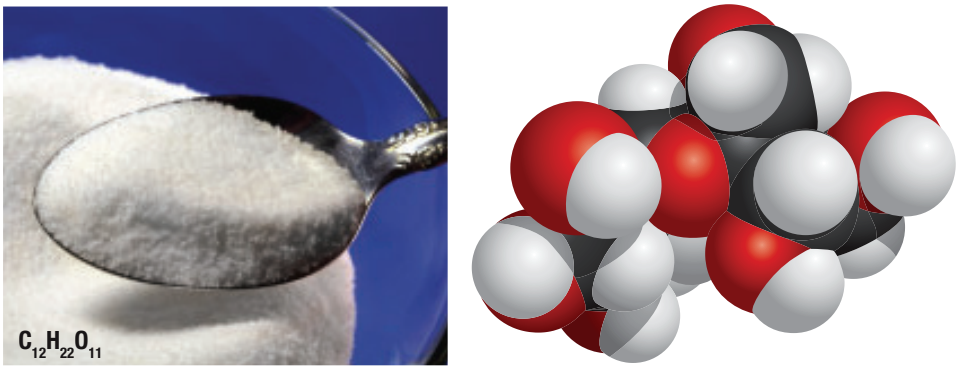
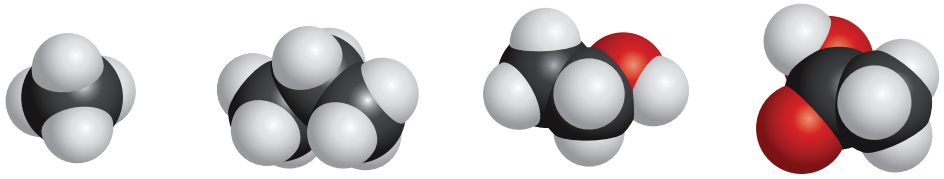


Figure 3 Molecules of sugar consist of atoms of carbon, hydrogen, and oxygen.

Only certain combinations of atoms are found in nature. Atoms of the same element combine in different ratios to form different substances. For example, oxygen atoms can combine in pairs to form oxygen molecules (O_2). They can also combine in triplets to form ozone molecules (O_3). Ozone is an entirely different substance from oxygen. We must breathe in O_2 molecules to keep our cells alive. Ozone is a highly reactive molecule, typically found 10 km to 50 km above the surface of Earth. It filters out harmful ultraviolet rays from the Sun. At ground level, ozone is a harmful air pollutant. It is added to ground-level air by vehicle exhaust and industrial activities.

Atoms of carbon and hydrogen join together in many combinations to form molecules with very different properties. The gas that you use at school in Bunsen burners consists mostly of methane (CH_4). Propane (C_3H_8) is used in barbecue tanks (Figure 4(a)). Octane, C_8H_{18}, is a component of gasoline. Many common substances are composed of three common types of atoms—carbon, hydrogen, and oxygen—combined in different ratios and with different structures. For example, C_2H_6O (alcohol) is found in wine, and $C_2H_4O_2$ (vinegar) can be put on French fries (Figure 4(b)). $C_9H_8O_4$ (Aspirin) can help prevent strokes.



methane propane alcohol vinegar

(a) (b)

Figure 4 Molecules made from different combinations of the same elements can have widely different properties.

LEARNING TIP

Understanding Molecular Models
In these molecular models, the white spheres represent hydrogen atoms, the black spheres represent carbon atoms, and the red spheres represent oxygen atoms.

TRY THIS RUSTING STEEL SLOWLY

SKILLS: Predicting, Controlling Variables, Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK 3.B.6., 3.B.7.

When iron reacts with oxygen and water, a new compound forms: iron oxide (Fe_2O_3) commonly known as rust. This reaction can happen at different speeds depending on the availability of the reactants. In this activity, you will use a low concentration of oxygen. You will obtain oxygen from the air, which contains about 20 % oxygen.

Equipment and Materials: 2 large test tubes; beaker; super-fine grade iron wool (sold in paint and hardware stores); water

1. Obtain two pieces of iron wool of equal size, each large enough to half-fill a test tube.
2. Keep one piece of iron wool dry. Moisten the other piece thoroughly with water.
3. Pack each piece of iron wool into the bottom of a dry test tube. Label the test tubes "wet iron" and "dry iron" to correspond with the contents.
4. Fill the beaker about half-full with cold water.
5. Invert each test tube into the beaker of water. Make sure that the water in the beaker does not touch the iron wool in either test tube (Figure 5). Allow the test tubes to sit in the beakers overnight.
6. Observe and compare the water levels in the two test tubes and the appearance of the iron wool in each tube.

A. What evidence is there that a new substance has formed? T/I

B. What evidence is there that oxygen is needed to form the new substance? T/I

Figure 5 Make sure that the iron wool does not come into contact with the water.

C. What substances are needed for iron to react with oxygen under these conditions? T/I

D. Predict how the results would be different if an iron nail were used instead of iron wool. Give reasons for your answer. T/I

E. Predict how the results would be different if pure oxygen were used instead of air. Give reasons for your answer. T/I

F. Describe one situation in your everyday life where you can apply what you have learned in this activity. A C

Ionic Compounds

ion a particle that has either a positive or a negative charge

cation a positively charged ion

anion a negatively charged ion

Some compounds are not molecules; that is, they are not composed of neutral atoms. Instead, these compounds are made up of charged particles called **ions**. An ion forms when an atom loses or gains one or more electrons without changing its number of protons. When this happens, one of two types of ions results—a positively charged ion, or **cation** (pronounced cat-ion), or a negatively charged ion, or **anion**. If an atom loses an electron, it has one more proton than electrons and therefore has a net positive charge. If an atom gains an electron, it has one more electron than protons and has a net negative charge.

Sodium atoms usually lose one electron when they react with other atoms. The resulting sodium ion contains 11 positive charges (protons) and only 10 negative charges (electrons). Since it has one more positive charge than negative charges, the sodium ion has an ionic charge of +1 (Table 1). Scientists use the symbol Na^{1+} or Na^{+} to represent this ion. (Note that the number 1 is usually omitted in chemical symbols.)

When chlorine reacts, it usually gains one electron to form an ion called chloride. Because the chloride ion has one extra negative charge, it has an ionic charge of –1 (Table 1). The chemical symbol of the chloride ion is Cl^{-}.

Table 1 Sodium and Chloride Ions

	Sodium, Na^{+}	Chloride, Cl^{-}
positive charge (protons)	+11	+17
negative charge (electrons)	–10	–18
ionic charge	+1	–1

DID YOU KNOW?

Iodized Salt

Check out your box of salt at home. It is probably iodized, meaning that sodium iodide (NaI) or potassium iodide (KI) has been added to the sodium chloride, NaCl. These iodine-containing compounds are added to supplement our intake of iodine, which our bodies need in very tiny amounts. A deficiency of iodine causes the thyroid gland to swell. This condition is called goitre.

To explain why sodium loses only one electron while chlorine gains one electron, look at the Bohr–Rutherford diagrams of sodium and chlorine (Figure 6). The electron that a sodium atom is most likely to lose is the one farthest from the nucleus: the single electron in its outermost orbit. This electron is the least attracted to the nucleus. A chlorine atom gains only one electron because it can only accommodate one more electron in its outermost orbit, for a maximum of 8 electrons.

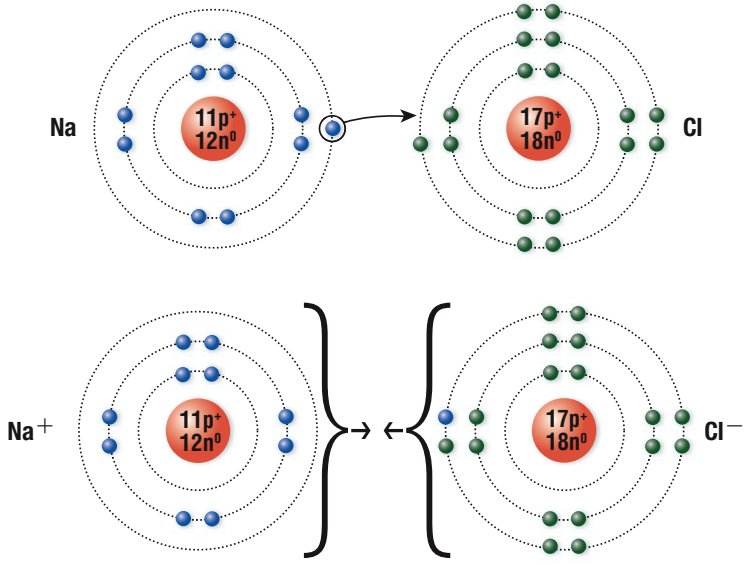


Figure 6 A sodium atom (left) loses the electron in its outermost orbit and becomes a positively charged sodium ion. A chlorine atom (right) gains an electron in its outermost orbit and becomes a negatively charged chloride ion.

Ions of sodium and chloride are oppositely charged, so they attract each other. They combine to form a compound called sodium chloride, commonly known as table salt. Compounds made up of oppositely charged ions are called **ionic compounds**. Aluminum chloride (the white solid in antiperspirants) and iron oxide (in rust) are other common examples of ionic compounds. In Try This: Rusting Steel Slowly, you observed the formation of rust. In Investigation 7.2, you will investigate the factors that determine how fast this reaction occurs.

ionic compound a compound that consists of positively and negatively charged ions

IN SUMMARY

- Atoms can join together with other atoms to form larger units called molecules.
- Molecules may contain atoms of different elements or atoms of the same element.
- Molecules that contain atoms of the same element are called molecular elements.
- Molecules that contain atoms of different elements are molecular compounds.
- A chemical formula indicates the type and number of atoms in a pure substance.
- Some compounds consist of charged atoms called ions. These compounds are called ionic compounds.

CHECK YOUR LEARNING

1. The chemical formula for baking soda is $NaHCO_3$. Answer the following questions about baking soda. K/U
   (a) How many elements does it contain?
   (b) How many atoms of each element are in this formula?
   (c) Does baking soda contain metallic and non-metallic elements? Which ones are which?
2. Consider the following substances: hydrogen gas (H_2), carbon dioxide (CO_2), sulfur (S_8), neon (Ne), and propane (C_3H_8). Which substance(s) are
   (a) elements?
   (b) compounds?
   (c) atoms?
   (d) molecules? K/U
3. What does the term "diatomic molecule" mean? K/U
4. List the seven diatomic molecules. K/U
5. Gasoline contains a mixture of compounds called hydrocarbons. They include molecules with the following formulas: pentane (C_5H_{12}), hexane (C_6H_{14}), heptane (C_7H_{16}), and octane (C_8H_{18}). Explain why "hydrocarbon" is a good name for this group of compounds. K/U
6. (a) Explain the difference between an atom and an ion.
   (b) Give an example of an atom and an ion, and draw a Bohr–Rutherford diagram of each. K/U
7. Write the chemical formula for each of the following compounds. Start the formula with the first element listed in each statement below and follow with the next element. The ratios in which the elements combine are given in each statement. K/U T/I
   (a) Ammonia, commonly found in window cleaning liquids, is formed when one nitrogen atom combines with three hydrogen atoms.
   (b) Carbon dioxide is formed when one carbon atom combines with two oxygen atoms.
   (c) When there is insufficient oxygen, one carbon atom combines with only one oxygen atom, forming the deadly gas carbon monoxide.
   (d) When hydrogen gas is burned, two atoms of hydrogen combine with one atom of oxygen to form a common substance.
   (e) Rubbing alcohol is formed when three atoms of carbon combine with eight atoms of hydrogen and one atom of oxygen.
8. An atom of calcium loses two electrons to become an ion. What kind of ion is a calcium ion? T/I
9. Write the chemical symbol for a calcium ion. K/U
10. Distinguish between molecular elements, molecular compounds, and ionic compounds. K/U
11. State whether each of the following is a molecular element, molecular compound, or ionic compound. K/U
    (a) iodine (I_2)
    (b) sodium chloride
    (c) vinegar
    (d) propane