TOPIC 6 Chemical Compounds

Table 2.4 Some Properties of Ionic and Molecular Compounds

Ionic	Molecular
• formed from metallic and non-metallic elements	• usually formed from only non-metallic elements
• forms ions in solution	• does not form ions in solution
• conducts electricity	• usually does not conduct electricity
• solid at room temperature	• solid, liquid, or gas at room temperature

There are over 112 elements. These elements can combine in groups of two, three, or more to form compounds. Imagine how many combinations are possible!

What holds elements together when they form compounds? Elements are held together by chemical bonds. Chemical bonds are formed when elements gain, lose, or share electrons. If atoms transfer electrons to other atoms, an **ionic compound** is formed. If atoms share electrons, a **molecular compound** is formed.

In Topic 6 you will learn about what makes molecular and ionic compounds different, and how compounds are named. Some properties of these two types of compounds are summarized in Table 2.4.

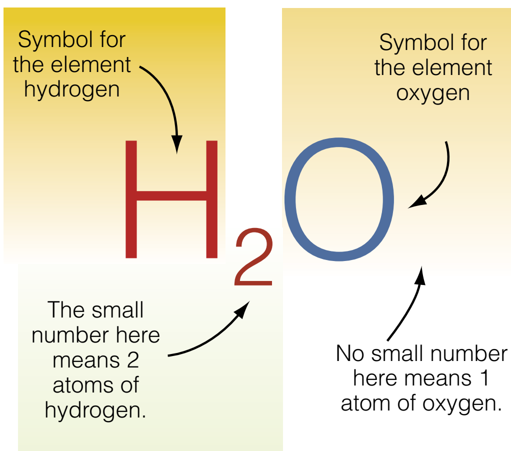


Figure 2.39 Anatomy of a chemical formula

Understanding Formulas for Compounds

At room temperature both hydrogen (H) and oxygen (O) are gases. If hydrogen is burned in oxygen, however, the product is water. You may already know that H_2O represents the formula for water (see Figure 2.39).

A **chemical formula** uses symbols and numerals to represent the composition of a pure substance. Each symbol in a chemical formula represents an atom of an element. If there is more than one atom of an element, a small number written below the line (a subscript) follows the element's symbol. The subscript shows the number of atoms.

The law of definite composition tells us that every pure substance has a fixed and definite composition. For example, the chemical formula for water represents the composition of pure water wherever it is found. According to the chemical formula H_2O, water must always contain two atoms of hydrogen for each atom of oxygen, whether the water is in a glass or a lake (see Figure 2.40).

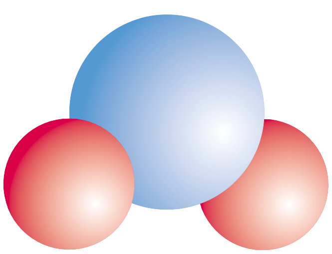


Figure 2.40 Each water molecule contains two hydrogen atoms and one oxygen atom. How does this model of water compare with Dalton's model in Figure 2.17, on page 111?

Molecular Compounds

A **molecule** is the smallest independent unit of a pure substance and is generally a cluster of atoms joined together. These atoms stay linked together regardless of how many times the substance is melted, boiled, or frozen. **Diatomic molecules** are molecules made of two atoms of the same element. Oxygen, nitrogen, and hydrogen are examples of diatomic molecules.

Most molecular compounds do not form large structures. Although the *bonding* between *atoms* is strong, the *attraction* between *molecules* is weak.

When you melt or vaporize a molecular compound, you must supply enough energy to overcome the attraction between the molecules. Because this attraction is weak, most molecular compounds have relatively low melting and boiling points. Because molecular compounds have no free electrons, they are poor electrical conductors, even when in a liquid state.

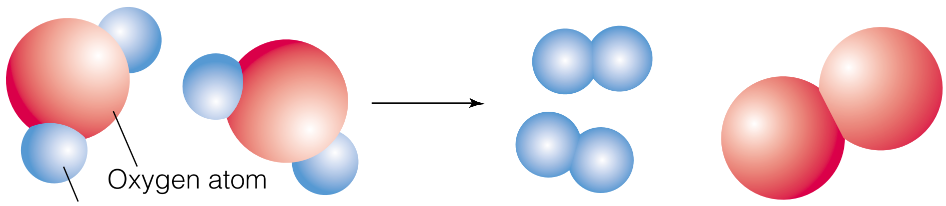


Figure 2.41 During electrolysis the added energy breaks the H_2O molecules apart. Unless there is added energy, the atoms remain fixed or locked in their own independent molecules.

How Are Molecular Compounds Named?

Chemists in all parts of the world work with elements and compounds. They share their knowledge with colleagues in other countries who speak other languages. How is this communication made possible? You already know that elements have universal symbols that are recognized worldwide. Compounds are also named according to global guidelines. The International Union of Pure and Applied Chemistry (IUPAC) is an organization of scientists responsible for setting standards in chemistry. IUPAC committees make recommendations on how compounds should be named.

There are several rules you can learn to help you communicate using the language of chemistry. For example, a compound made from two elements is called a **binary compound**. The names of *molecular* binary compounds follow these rules:

1. Write the entire name of the first element.
2. Change the ending on the name of the second element to *-ide*.
3. Use a prefix to indicate the number of each type of atom in the formula: *mono-* for one, *di-* for two, *tri-* for three, and *tetra-* for four. The prefix *mono-* is used only for the second element.

Suppose you wanted to write the name of the molecular compound, CO_2.

1. First write carbon.
2. Change the name of the second element (oxygen) to end with *-ide* (oxide).
3. There is only one carbon atom, so there is no change. There are two oxygen atoms, so add the prefix *di-*.

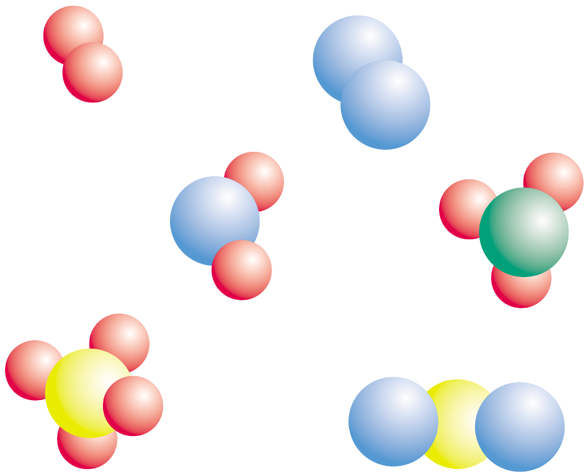


Figure 2.42 Pictured above are some examples of common molecular compounds and diatomic molecules. Red spheres are hydrogen, blue spheres are oxygen, green spheres are nitrogen, and yellow spheres are carbon. Name the compounds and diatomic molecules.

If you are changing from the written name to the symbol:

1. Write the symbols for the elements in the same order as they appear in the name.
2. Use subscripts to indicate the numbers of each type of atom.

Some molecular compounds are known by common names as well as by chemical names. For example, what is the formula for water? Use the formula and the steps above to determine the chemical name for water. Then read Table 2.5, Common Molecular Compounds. Notice the small symbols in parentheses after each compound. These symbols indicate the state of matter: (s) for solid, (l) for liquid, (g) for gas and (aq) for aqueous (a solid dissolved in water).

You can build your own model molecular compounds in the next activity. Then learn more about the formulas for molecular compounds in Think & Link Investigation 2-E: Interpreting Chemical Formulas.

Table 2.5 Common molecular compounds

Name	Formula	Description
Carbon monoxide	$CO_{(g)}$	poisonous gas
Carbon tetrachloride	$CCl_{4(l)}$	organic solvent
Silicon dioxide	$SiO_{2(s)}$	major component of sand and glass
Sulfur dioxide	$SO_{2(g)}$	result of burning sulfur, a component of acid rain

Find Out ACTIVITY

Building Model Molecules

Scientists often build models to help them understand the components of matter. How will a model help you understand molecules?

Procedure

Build your own models of each of the following molecules: hydrogen, water, ammonia, and methane. You will find the chemical formula for each of these substances in Appendix C. You may use the model components provided by your teacher, or you may create your own model kit. Use materials such as coloured mini-marshmallows and toothpicks. A computer drawing program could also be used.

What Did You Find Out?

1. How are molecules of hydrogen and oxygen similar?
2. How are molecules of ammonia and methane similar?

Extend Your Skills

3. Make a model of ethanol.
4. Find examples of molecule models on the Internet. How are they similar to your models?

INVESTIGATION 2-E

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Interpreting Chemical Formulas

Chemists have described many groups and types of compounds. What do the chemical formulas indicate about molecular compounds?

Part 1

Think About It

Most compounds are made of molecules. Examples include water, carbon dioxide, propane, and glucose (sugar). Interpret the formulas for these compounds by using the example of water in this table as a guide.

The Composition of Four Compounds

Name of compound	Formula of molecule	Elements present	How many atoms of each?
water	H_2O	hydrogen, oxygen	2 atoms H, 1 atom O
carbon dioxide	CO_2		
propane	C_3H_8		
glucose	$C_6H_{12}O_6$		

What to Do

1. Based on the table above, how many atoms, in total, are present in the following molecules?
   (a) one water molecule
   (b) one carbon dioxide molecule
   (c) one propane molecule
   (d) one glucose molecule

Word CONNECT

Dalton and others of his time used the terms "compound particles" and "compound atoms" when theorizing about what happens to atoms when elements combine. The Italian physicist Amedeo Avogadro (1776–1856) introduced the term "molecule." What did "molecule" originally mean? Check print or electronic sources to find out.

Part 2

Think About It

Many elements exist as molecules under ordinary conditions. For example, the air you inhale with every breath is mostly a mixture of two compounds and two elements, as shown in the following table.

Some Components of Air

Name of gas	Compound or element?	Made of molecules?	Formula	Number of atoms per molecule
water vapour	compound	yes	H_2O	3
carbon dioxide				
oxygen				
nitrogen				

What to Do

1. The first line in the table is complete. Copy the table and fill in the missing information in the other three lines.

Looking Ahead

Have you had your plan approved by your teacher for your End of Unit Investigation: Tough as Nails? Depending on your design, it may be time to start your investigation in the next few days so it will be finished by the end of the unit.

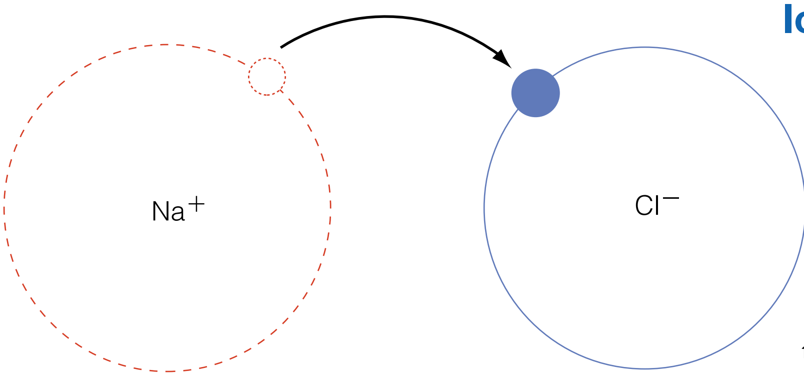


Figure 2.43 One electron has been transferred from sodium to chlorine. Both atoms now have a stable electron arrangement.

Ionic Compounds

When an atom gains or loses electrons, the atom is no longer neutral. It has become an **ion**, which is a particle or group of particles with a positive or negative charge. Atoms are neutral because they contain equal numbers of positive and negative charges. A sodium atom contains 11 protons and 11 electrons. If sodium loses one electron (as shown in Figure 2.43), it has 11 protons but only ten electrons, so the ion is positive.

The electron rearrangement leaves the chlorine atom with a slight negative charge and the sodium atom with a slight positive charge. There is no longer an equal number of electrons and protons in each atom. The sodium will no longer have its original properties, however, and neither will the chlorine. Instead of two elements, the atoms now form a compound — sodium chloride, or NaCl, which is common table salt.

Conductivity is the ability of a substance to carry an electric current. Ionic compounds separate into positive or negative particles (ions) when they dissolve in water. Both negative and positive ions are formed in the water. Charged particles can carry an electric current through the water (see Figure 2.46). How can conductivity be used to determine whether a compound is ionic or molecular?

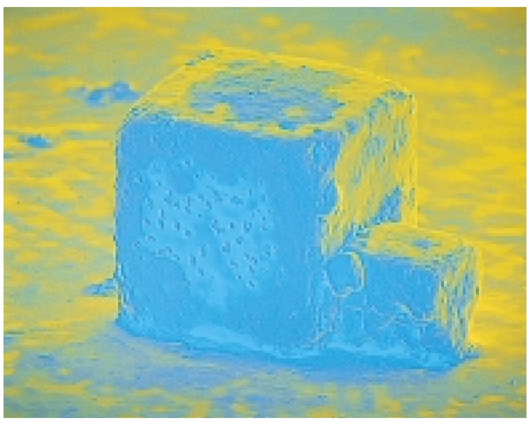


Figure 2.44 Salt is made of positively charged sodium ions and negatively charged chloride ions. The positive and negative ions form a cube-shaped arrangement. This photograph shows the electron microscope view of the tiny crystals.

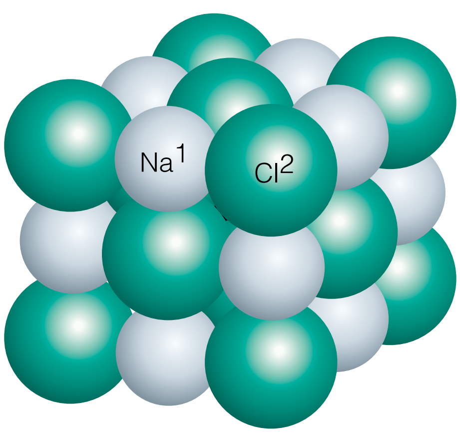


Figure 2.45 Positive sodium ions attract negative chloride ions to form a cube-shaped arrangement in sodium chloride. In this arrangement, six chloride ions surround every sodium ion, and six sodium ions surround every chloride ion. The forces holding each ion in place are ionic bonds.

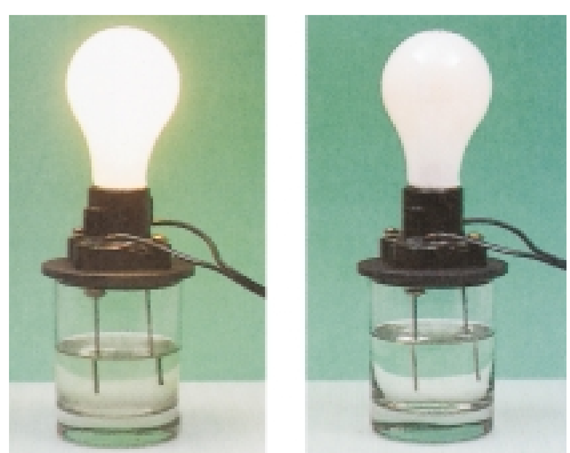


Figure 2.46 A simple conductivity tester can be used to determine if a solution conducts electricity. How do you know the solution conducted the electricity?

How Are Ionic Compounds Named?

The rules for naming binary ionic compounds are similar to those for binary molecular compounds. However, the name of the compound does not indicate the number of ions of each element.

1. The name includes both elements in the compound, with the name of the metallic element first.
2. The non-metallic element is second. Its ending is changed to *-ide*.
3. Subscripts indicate the ratio of ions in the compound. For example, in $CaCl_2$ the ratio of calcium to chloride ions is 1:2.

Name these ionic compounds: NaCl, NaF, LiCl, and ZnS.

Some ionic compounds are known by their common names, such as $CaCO_3$ (limestone) and NaOH (lye). In the next activity, you will work with the formula for a familiar ionic compound.

Find Out ACTIVITY

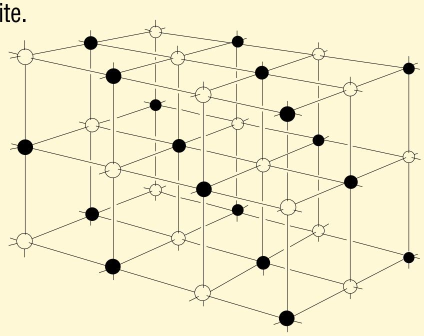
Formulas for Ionic Compounds

Some compounds consist of large collections of ions. For example, sodium chloride (table salt) is made of sodium ions and chloride ions. The following representative model shows part of a salt crystal. It shows the position of the ions in the salt crystal, but it does not show what the crystal actually looks like.

Procedure Analyzing and Interpreting

Examine the model carefully to see how the two elements are arranged.

The symbol for sodium is Na. The sodium ions are black in this model. The symbol for chlorine is Cl. The chloride ions are white.



What Did You Find Out?

1. Count the total number of ions of each element that are represented in the model.
   (a) How many sodium ions are represented?
   (b) How many chloride ions are represented?
2. The formula for sodium chloride is normally written as NaCl. Should the formula for the part of the salt crystal shown here be Na_{18} Cl_{18}? Why or why not?
3. Ionic compounds are made of oppositely charged ions held together strongly in well-organized units. How could you use a pair of magnets to make a model of the attractive forces in ionic compounds?

Extension

4. Try to match each of the following ionic compounds with its common use. Then check your work by using the Internet or library resources.

Compounds: potassium chloride, potassium iodide, sodium fluoride

Uses: A toothpaste additive to strengthen tooth enamel

A salt substitute used by people avoiding sodium for health reasons

A table salt additive to prevent iodine deficiency

INQUIRY

INVESTIGATION 2-F

SKILLCHECK

- Initiating and Planning
- ✹ Performing and Recording
- ✹ Analyzing and Interpreting
- Communication and Teamwork

Comparing Ionic and Molecular Properties

In this investigation, you will examine a number of substances to find out which are ionic and which are molecular. You will then conduct some further tests to compare the properties of ionic and molecular compounds.

Safety Precautions

- If you are using an older model conductivity tester that is not battery operated, be extremely careful to keep the ends well separated while you perform your tests.
- Be careful not to touch hot surfaces.

Question

How do the properties of ionic and molecular substances compare?

Apparatus

conductivity tester
wire gauze
ceramic evaporating dish
8 small beakers (100 mL)
hot plate
scoopula
magnifying lens
stirring rod
ring clamp and stand
8 labels

Materials

400 mL distilled water
sodium iodide, NaI
copper (II) nitrate, $Cu(NO_3)_2$
magnesium chloride, $MgCl_2$
graphite (C)
paraffin wax, $C_{25}H_{52}$
sucrose, $C_{12}H_{22}O_{11}$
starch (chains of CH_2OH)

Substance	Ionic (yes/no)	Solubility in water	Conductivity test	Appearance	Odour	Texture	Relative melting point
sodium iodide							
copper (II) nitrate							
magnesium chloride							
graphite							
paraffin wax							
sucrose							
starch							

Procedure

1. Make a table like the one above. Give your table a title.

2. **Prediction** Based on information from the periodic table and what you already know, **predict** which substances are ionic. Write yes or no in the Ionic column.

3. **Solubility**
(a) Label each beaker with the name of one of the substances to be tested. Pour about 50 mL distilled water into each beaker.

(b) Use the scoopula to add a small quantity of sodium iodide (about the size of a peanut) to the beaker with the appropriate label. Use a stirring rod to dissolve the solid. Note whether the solid dissolves completely. **Record**. Repeat for each of the other substances.

4. **Conductivity**

(a) Add 50 mL distilled water to a beaker. Label it "Control." Test the "Control" beaker with the conductivity tester. **Record** your results.

(b) Test the solution from step 3 with the conductivity tester. **Record** your results.

5. **Appearance** Examine a small sample of each substance using a magnifying lens. Briefly describe the shape of the grains.

6. **Odour** Carefully smell each compound. In your table, describe any odour.

7. **Texture** **CAUTION:** You must wear protective gloves for this test.

(a) Test the texture of each substance by rubbing a small sample between your thumb and forefinger. Use words like "soft," "waxy," "brittle," and "granular" to **record** your observations.

(b) Wash your hands thoroughly when you have completed this step.

8. **Relative Melting Point** Choose one solid that you think is ionic and one solid that you think is molecular.

(a) Place a small sample of each solid into an evaporating dish. Put the samples on opposite sides of the dish.

(b) Heat the evaporating dish evenly with a hot plate until one of the substances melts. In your table, **record** the relative melting point for this substance as "low" and for the other substance as "high."

(c) After the evaporating dish has cooled down, clean it and put it away.

Analyze

1. (a) Which compounds used in this investigation are ionic?
   (b) In which part of the periodic table do the elements in ionic compounds occur?
2. (a) Which compounds are molecular?
   (b) In which part of the periodic table do their elements occur?
3. (a) In general, are ionic compounds soluble in water?
   (b) In general, are molecular compounds soluble in water?
   (c) Did you find any compounds that were exceptions to your answers for parts (a) and (b)?

Conclude and Apply

4. In general, which type of substance seems to be harder, ionic or molecular?
5. Share your results on relative melting points with other groups in your class.
   (a) Which type of compound seems to have the higher melting point?
   (b) What might explain the differences in data among groups?
6. Summarize some general properties of ionic and molecular compounds. Explain how the evidence you gathered supports your summary.

Find Out ACTIVITY

Multimedia Models

You have been learning about atomic structure, elements, and compounds. Now it's your turn to be the teacher. How much information can you pack into 5 min of presentation time?

Procedure — Performing and Recording

1. Work with a partner or in a small group. Select (or be assigned) a classification system for your presentation, such as a the periodic table; a comparison of atomic theories; metals and non-metals; or ionic and molecular compounds.

2. Your presentation can only last 5 min. Decide what information you want to include in the presentation and which formats to use. Be sure to describe the work of scientists. Part of your presentation will include a model that you have made of your subject. The model could be made of clay or other materials, or it could be made with computer software. Consider using tape recorders, video cameras, songs, dances, skits, posters, and so on as part of your presentation. Have your teacher approve your choice of formats.

3. Prepare and practise the presentation with your group. Ask for feedback from classmates, parents, or friends.

4. Make your presentation. Enjoy!

What Did You Find Out? — Analyzing and Interpreting

1. In what ways is your model an accurate portrayal of your subject? In what ways is it different from your actual subject?

2. How did having a model help your audience in understanding what you were presenting?

3. If you had unlimited access to tools and equipment, how would you design your model to be more accurate?

4. How could you improve your ability to work with a group?

DidYouKnow?

Carbon is one of the most plentiful and important elements on Earth. It is found in foods, plastics, plants, and animals. Carbon atoms can form small groups with other atoms, such as hydrogen. These groups can string together like beads to form chain-like molecules.

TOPIC 6 Review

1. Name four properties of molecular compounds.
2. Name four properties of ionic compounds.
3. In terms of electrons, what is the difference between a molecular compound and an ionic compound?
4. Define molecule. Define diatomic molecule.
5. What is an ion?
6. Write the names of these compounds. Is each compound molecular or ionic?
   LiCl ZnS SO_2 CO HCl NaF
7. The formula for hydrogen peroxide is H_2O_2. Which elements are present in hydrogen peroxide? How many atoms are in each molecule?
8. **Thinking Critically** When salt (sodium chloride) dissolves in water, the salt particles break apart and form positive sodium and negative chlorine ions. If the salt particles break apart, why does the water still taste salty?

Wrap-up TOPICS 4-6

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

element symbols	atomic number	molecular compound	diatomic molecules
chemical family	mass number	chemical formula	binary compounds
atomic mass	ionic compound	molecule	conductivity

Reviewing Key Terms

1. Write the words from column A in your notebook. Select the terms from column B that match column A words. (4–6)

A
- halogen
- alkali metal
- atomic number
- noble gas
- alkaline earth metal
- diatomic molecule

B
- hydrogen
- gold
- argon
- sodium
- number of neutrons
- number of protons
- beryllium
- chlorine

Understanding Key Concepts

2. Name three examples of highly corrosive elements. (4)

3. Name three highly reactive metals. (4)

4. Explain why some elements must be stored in oil. Give an example (4).

5. State two differences and two similarities between the noble gases and the alkali metals. (4)

6. State the element symbol, atomic number, and atomic mass of lithium, beryllium, phosphorus, and sulfur. (4–5)

7. The _____________ table is a collection of elements. Vertical columns in the table are called _____________ . Horizontal rows in the table are called ____________. (5)

8. State whether each compound is ionic or molecular: hydrogen peroxide, carbon tetrachloride, aluminum oxide, and nitrogen dioxide. (6)

9. For which organization is IUPAC the abbreviation? (6)

10. Why can ionic compounds conduct electricity, but molecular compounds usually can not? (6)