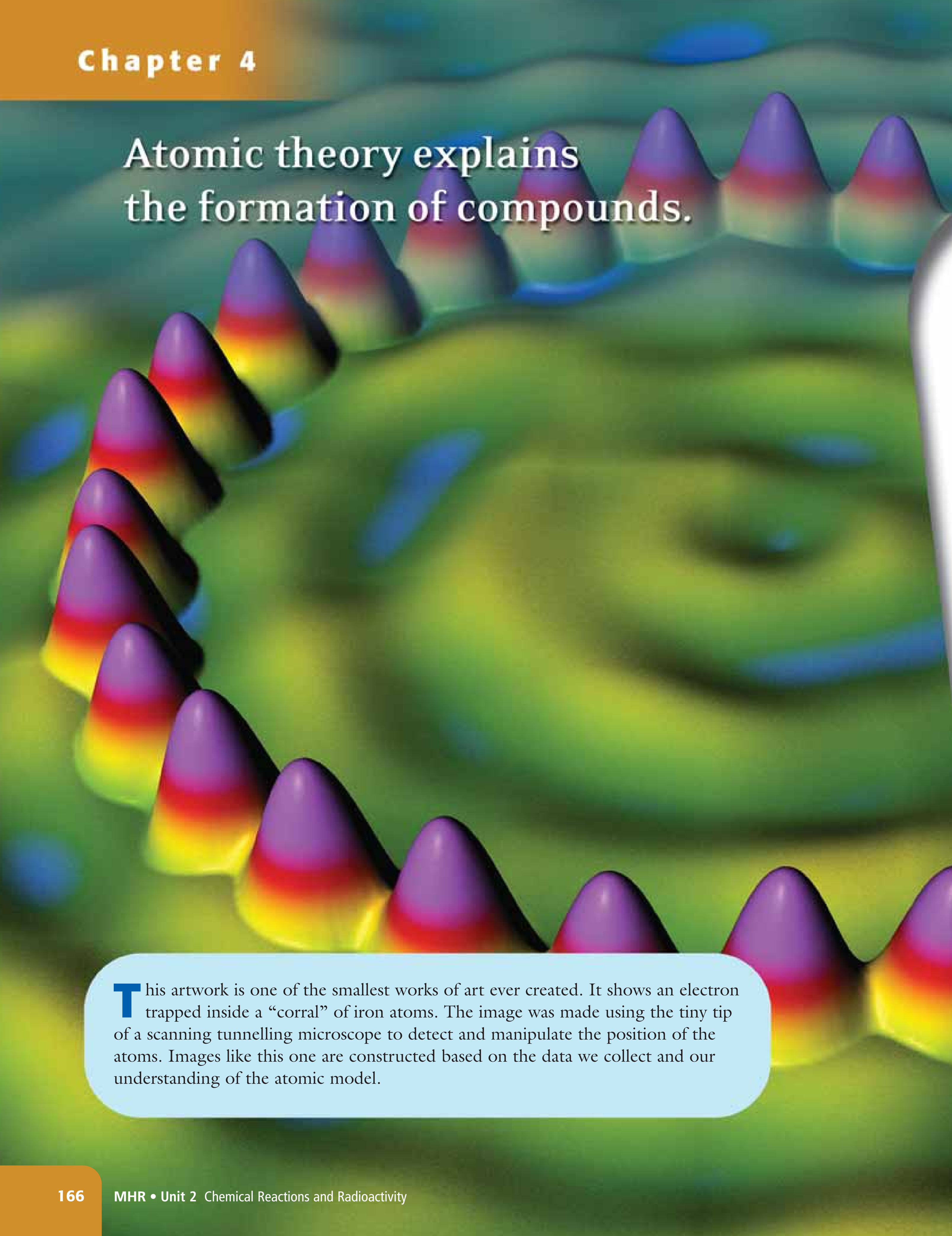
Chapter 4

Atomic theory explains the formation of compounds.



This artwork is one of the smallest works of art ever created. It shows an electron trapped inside a "corral" of iron atoms. The image was made using the tiny tip of a scanning tunnelling microscope to detect and manipulate the position of the atoms. Images like this one are constructed based on the data we collect and our understanding of the atomic model.

What You Will Learn

In this chapter, you will
- **distinguish** between atoms, ions, and molecules
- **describe** the arrangement of electrons in atoms, ions, and molecules
- **write** names and formulas for ionic and covalent compounds
- **balance** chemical equations
- **explain** the law of conservation of mass as it applies to chemical reactions

Why It Is Important

The atomic theory gives us a way to visualize matter that is too small to be viewed directly so we can understand and predict the changes we see in our everyday world. By learning more about how molecules and compounds form and break apart, we can use chemicals more effectively in industry and develop better medicines.

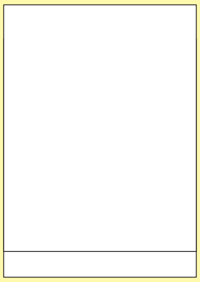
Skills You Will Use

In this chapter, you will
- **work co-operatively and safely** in a laboratory setting
- **observe** changes in properties of matter undergoing chemical change
- **classify** compounds as ionic or covalent
- **use models** to understand the structure of matter and the process of chemical changes

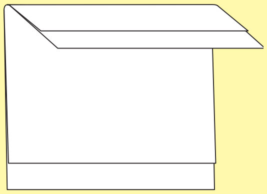
FOLDABLES™
Reading & Study Skills

Make the following Foldable and use it to take notes on what you learn in Chapter 4.

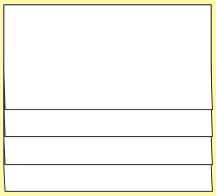
STEP 1 **Stack** two sheets of paper (22 cm by 28 cm) so that the back sheet is 2.5 cm lower than the front sheet.



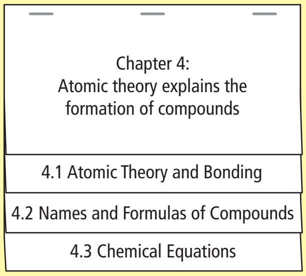
STEP 2 **Bring** the top of both sheets downward. **Align** the edges so that all of the layers or tabs are the same distance apart.



STEP 3 When all tabs are an equal distance apart, **fold** the papers and **crease** well.



STEP 4 **Open** the papers. **Glue** them together along the inner centre fold, or **staple** them along the mountain. **Label** as shown.



Organize As you progress through the chapter, summarize key points, record information, and define terms beneath the appropriate tabs. Use the back of the Foldable to practise drawing models of compounds, writing formulas, and writing and balancing equations.

4.1 Atomic Theory and Bonding

Atoms are composed of protons and neutrons, which make up the nucleus, and electrons, which surround the nucleus in patterns. Bohr diagrams show the arrangement of protons, neutrons, and electrons in atoms and also in ions. Ions are formed from atoms that have lost or gained electrons. Compounds can be ionic or covalent. Lewis diagrams show the arrangement of bonds within compounds.

Words to Know

atomic number
Bohr diagram
compound
covalent bonding
ionic bonding
ions
Lewis diagram
molecule
valence electrons

Did You Know?

Imagine dumping sand onto an area the size of a hockey arena until the ice rink is buried under 30 m of sand. Suppose that volume of sand represents 1 s. Half of the volume represents 0.5 s. How much sand would represent one femtosecond (10^{-15} s)? A femtosecond would be one single grain of sand.

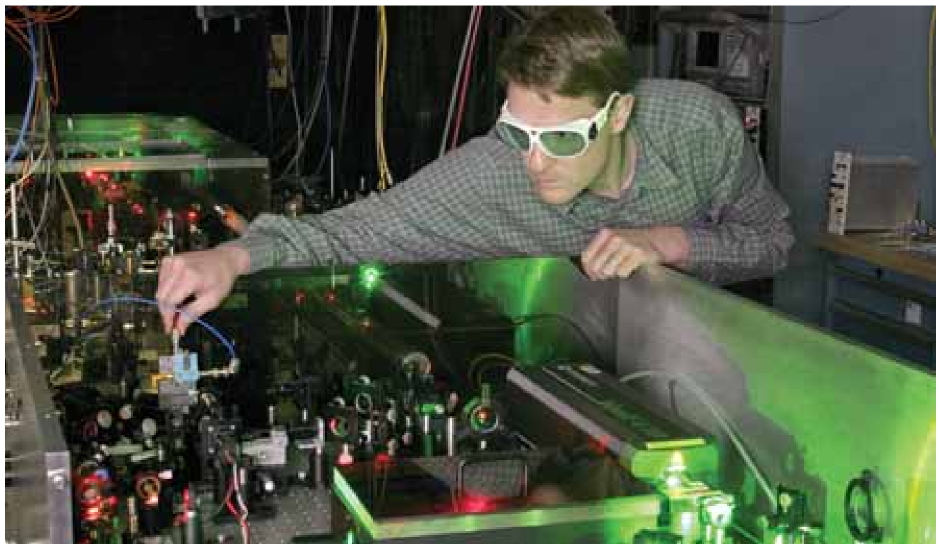


Figure 4.1A A researcher adjusts a component on a femtosecond laser at the National Institute of Standards and Technology. The apparatus is used for imaging chemical changes.

How could you capture the result of the collisions of atoms and molecules as they slam into each other during a chemical change? You could use the world's fastest camera and most powerful microscope—a femtosecond laser (Figure 4.1A).

In earlier science studies, you learned that a pure substance is made up of only one kind of matter. There are two categories of pure substances. An element is a pure substance that cannot be chemically broken down into simpler substances. A **compound** is a pure substance that is composed of two or more atoms combined in a specific way.

An **atom** is the smallest particle of any element that retains the properties of the element. How small is an atom? If you could line up 50 million atoms, the line would be about 1 cm long.

Because atoms are incredibly small, you cannot see an atom with regular light. With a femtosecond laser, the energy from an extremely fast pulse of laser light is used to position atoms and detect chemical changes. **Chemical changes** are changes in the ways the atoms and molecules in a pure substance are arranged and interconnected. To help get the clearest image, the chemicals are usually cooled as much as possible to slow down the particles.

People believed that atoms existed long before we were able to capture images of them. Two hundred years ago, John Dalton imagined that an atom could exist. With the invention of femtosecond laser technology, it is now possible to detect the movement of a single hydrogen atom (Figure 4.1B).

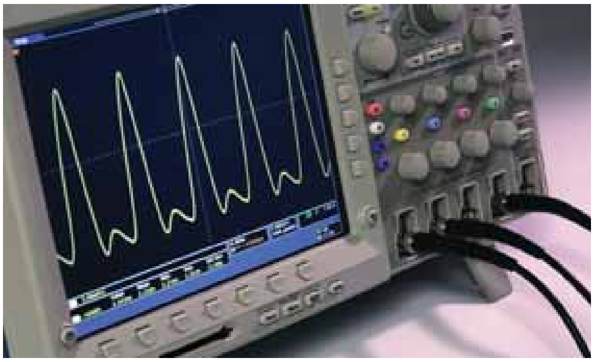


Figure 4.1B A digital oscilloscope measures the output and response time of the femtosecond laser.

4-1A Observing Chemical Changes

Find Out ACTIVITY

Teacher Demonstration

In this demonstration, you will observe chemical changes and reflect on some of the chemistry you learned in earlier science studies.

Safety

- Use a fume hood.
- Follow your teacher's directions regarding using open flames.
- The sparks from the burning steel wool are hot enough to cause burns.
- The light from burning magnesium is very bright and releases UV rays. Observe the light only from a distance and through glass, which absorbs UV.
- Persons with medical conditions that make them prone to seizure should not look directly at the light.
- Avoid touching all reactants and products.
- Wash your hands and equipment thoroughly after completing this activity.
- Do not remove any materials from the science room.

Materials

- fume hood
- steel wool
- 9.0 V dry cell
- magnesium ribbon
- large Pyrex® beaker
- tongs
- propane torch or Bunsen burner
- matches or flame striker
- hot pad

What to Do

1. Observe as your teacher uses the steel wool to make a short circuit between the terminals of the 9.0 V dry cell.
2. Record your observations.
3. Observe as your teacher ignites a small piece of magnesium ribbon inside a large Pyrex® beaker.
4. Record your observations.

What Did You Find Out?

1. Reflect on this activity in terms of laboratory safety. What safety issues are important to this activity?
2. Suggest which gas or gases in the air may have been responsible for the chemical changes that you saw.
3. New pure substances were formed in these chemical changes. Suggest what pure substance or substances formed in:
   (a) the first demonstration
   (b) the second demonstration

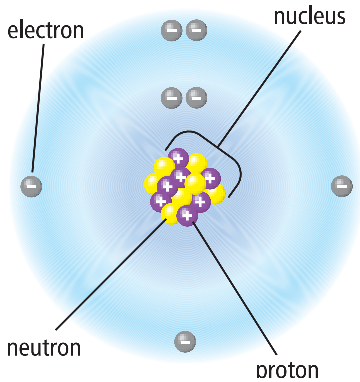


Figure 4.2 A model of the atom

Atomic Theory

Subatomic particles are the particles that make up an atom. Through many experiments, scientists have found that individual atoms are composed of three subatomic particles, which are called protons, neutrons, and electrons (Figure 4.2). You can compare the size and mass of subatomic particles in Table 4.1.

- **Protons** are subatomic particles that have a 1+ (positive) electric charge.
- **Neutrons** are subatomic particles that do not have an electric charge.
- **Electrons** are subatomic particles that have a 1− (negative) electric charge.
- Protons and neutrons are held tightly together at the centre of the atom in a tiny region called the nucleus.
- Electrons exist in the region around the nucleus in regular patterns called shells or energy levels.
- Most of the volume of an atom is the region occupied by its electrons.
- Every neutral atom of the same element contains an equal number of protons and electrons. Since a proton counts as a 1+ electric charge and an electron counts as a 1− electric charge, the charges add up to zero, making an atom uncharged or neutral.

Table 4.1 Subatomic Particles

Name	Symbol	Electric Charge	Location in the Atom	Relative Mass
Proton	p	1+	Nucleus	1836
Neutron	n	0	Nucleus	1837
Electron	e	1−	Surrounding the nucleus	1

The Nucleus

At the centre of each atom is a nucleus (Figure 4.2). The nucleus is tiny compared to the rest of the atom. Depending on the element, it would take between 10 000 and 100 000 nuclei lined up in a row to stretch across the diameter of one atom.

The simplest possible nucleus is found in the element hydrogen, which contains only one proton. A hydrogen atom may also have neutrons present in its nucleus. The nuclei of atoms of all other elements contain both protons and neutrons. For atoms with fewer than about 30 protons, the number of neutrons and the number of protons present in the nucleus are roughly equal. In heavier atoms, there are always more neutrons than protons. A stable nucleus is less likely to break apart from protons repulsing each other due to their positive charge. Extra neutrons help to make the nucleus stable by keeping the protons as far apart as possible. Very heavy atoms are unstable because the repulsion between the protons is so high.

Word Connect

The plural of nucleus is nuclei.

The electric charge on any nucleus is always positive, since the protons have a positive charge and the neutrons are not electrically charged. The **nuclear charge** is the term given to the electric charge on the nucleus, and it is simply found by counting the number of protons. For example, all carbon atoms possess six protons, so a carbon nucleus has a nuclear charge of 6+. The nuclear charge is the same as the **atomic number**. The number of protons and electrons in a neutral atom is equal.

$$\begin{array}{l}\text{atomic number}\\ \text{of a neutral atom}\end{array} = \text{number of protons} = \text{number of electrons}$$

The atomic number always identifies the element to which the atom belongs. For example, all atoms with an atomic number of 8 are oxygen atoms, and all oxygen atoms always have eight protons in the nucleus.

Did You Know?

If the nucleus of a carbon atom is represented by a loonie placed at centre ice, then the arena would represent the volume occupied by the electrons in their shells.

Reading Check

1. What is the electric charge on each of the three subatomic particles?
2. Which two subatomic particles have nearly equal mass?
3. Which particle determines the nuclear charge?
4. Which two subatomic particles are present in equal number in every atom of the same element?

Organization of the Periodic Table

Many facts about the elements are recorded in the periodic table of the elements (Figure 4.3). You may remember these points from earlier studies.

- Each element is listed according to its atomic number, left to right across each row and then row by row from top to bottom.
- Each row is also called a **period**. Each column (top to bottom) is called a **group** or **family**. For example, magnesium (Mg) is in group 2 of period 3.
- Metals are on the left side and in the middle of the table. Non-metals are in the upper right corner. The metalloids form a staircase toward the right side.
- Elements in the same chemical group or family have similar chemical properties. Four families you may have studied are:
  - the alkali metals (group 1 excluding hydrogen)—very reactive metals (e.g., sodium)
  - the alkaline earth metals (group 2)—somewhat reactive metals (e.g., calcium)
  - the halogens (group 17)—very reactive non-metals (e.g., chlorine)
  - the noble gases (group 18)—very unreactive gaseous non-metals (e.g., neon)
- The block of elements from group 3 through group 12 are collectively called the **transition metals**. They include familiar elements such as iron, nickel, copper, silver, and gold.

Periodic Table of the Elements

METALS ← | → NON-METALS

Atomic Number	Symbol	Name	Atomic Mass	Ion charge(s)
22	Ti	Titanium	47.9	4+ 3+

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.0 (+)																1 H Hydrogen 1.0 (–)	2 He Helium 4.0 (0)
3 Li Lithium 6.9 (+)	4 Be Beryllium 9.0 (2+)											5 B Boron 10.8	6 C Carbon 12.0	7 N Nitrogen 14.0 (3–)	8 O Oxygen 16.0 (2–)	9 F Fluorine 19.0 (–)	10 Ne Neon 20.2 (0)
11 Na Sodium 23.0 (+)	12 Mg Magnesium 24.3 (2+)											13 Al Aluminum 27.0 (3+)	14 Si Silicon 28.1	15 P Phosphorus 31.0 (3–)	16 S Sulfur 32.1 (2–)	17 Cl Chlorine 35.5 (–)	18 Ar Argon 39.9 (0)
19 K Potassium 39.1 (+)	20 Ca Calcium 40.1 (2+)	21 Sc Scandium 45.0 (3+)	22 Ti Titanium 47.9 (4+, 3+)	23 V Vanadium 50.9 (5+, 4+)	24 Cr Chromium 52.0 (3+, 2+)	25 Mn Manganese 54.9 (2+, 3+, 4+)	26 Fe Iron 55.8 (3+, 2+)	27 Co Cobalt 58.9 (2+, 3+)	28 Ni Nickel 58.7 (2+, 3+)	29 Cu Copper 63.5 (2+, 1+)	30 Zn Zinc 65.4 (2+)	31 Ga Gallium 69.7 (3+)	32 Ge Germanium 72.6 (4+)	33 As Arsenic 74.9 (3–)	34 Se Selenium 79.0 (2–)	35 Br Bromine 79.9 (–)	36 Kr Krypton 83.8 (0)
37 Rb Rubidium 85.5 (+)	38 Sr Strontium 87.6 (2+)	39 Y Yttrium 88.9 (3+)	40 Zr Zirconium 91.2 (4+)	41 Nb Niobium 92.9 (3+, 5+)	42 Mo Molybdenum 95.9 (2+, 3+)	43 Tc Technetium (98) (7+)	44 Ru Ruthenium 101.1 (3+, 4+)	45 Rh Rhodium 102.9 (3+, 4+)	46 Pd Palladium 106.4 (2+, 4+)	47 Ag Silver 107.9 (1+)	48 Cd Cadmium 112.4 (2+)	49 In Indium 114.8 (3+)	50 Sn Tin 118.7 (4+, 2+)	51 Sb Antimony 121.8 (3+, 5+)	52 Te Tellurium 127.6 (2–)	53 I Iodine 126.9 (–)	54 Xe Xenon 131.3 (0)
55 Cs Cesium 132.9 (+)	56 Ba Barium 137.3 (2+)	57 La Lanthanum 138.9 (3+)	72 Hf Hafnium 178.5 (4+)	73 Ta Tantalum 180.9 (5+)	74 W Tungsten 183.8 (6+)	75 Re Rhenium 186.2 (4+, 7+)	76 Os Osmium 190.2 (3+, 4+)	77 Ir Iridium 192.2 (3+, 4+)	78 Pt Platinum 195.1 (4+, 2+)	79 Au Gold 197.0 (3+, 1+)	80 Hg Mercury 200.6 (2+, 1+)	81 Tl Thallium 204.4 (1+, 3+)	82 Pb Lead 207.2 (2+, 4+)	83 Bi Bismuth 209.0 (3+, 5+)	84 Po Polonium (209) (2+, 4+)	85 At Astatine (210) (–)	86 Rn Radon (222) (0)
87 Fr Francium (223) (+)	88 Ra Radium (226) (2+)	89 Ac Actinium (227) (3+)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium (?)	118 Uuo Ununoctium (294)
Alkali Metals	Alkaline Earth Metals															Halogens	Noble Gases

58 Ce Cerium 140.1 (3+, 4+)	59 Pr Praseodymium 140.9 (3+, 4+)	60 Nd Neodymium 144.2 (3+)	61 Pm Promethium (145) (3+)	62 Sm Samarium 150.4 (3+, 4+)	63 Eu Europium 152.0 (3+, 2+)	64 Gd Gadolinium 157.3 (3+)	65 Tb Terbium 158.9 (3+, 4+)	66 Dy Dysprosium 162.5 (3+)	67 Ho Holmium 164.9 (3+)	68 Er Erbium 167.3 (3+)	69 Tm Thulium 168.9 (3+, 2+)	70 Yb Ytterbium 173.0 (3+, 2+)	71 Lu Lutetium 175.0 (3+)
90 Th Thorium 232.0 (4+)	91 Pa Protactinium 231.0 (5+, 4+)	92 U Uranium 238.0 (6+, 4+, 5+)	93 Np Neptunium (237) (5+, 3+, 4+, 6+)	94 Pu Plutonium (244) (4+, 6+, 3+, 5+)	95 Am Americium (243) (3+, 4+, 5+, 6+)	96 Cm Curium (247) (3+)	97 Bk Berkelium (247) (3+, 4+)	98 Cf Californium (251) (3+)	99 Es Einsteinium (252) (3+)	100 Fm Fermium (257) (3+)	101 Md Mendelevium (258) (2+, 3+)	102 No Nobelium (259) (2+, 3+)	103 Lr Lawrencium (262) (3+)

Based on mass of C-12 at 12.00.

Any value in parentheses is the mass of the most stable or best known isotope for elements that do not occur naturally.

Figure 4.3 The periodic table of the elements

The Periodic Table and Ion Formation

When atoms gain or lose electrons, they become electrically charged particles called **ions**. Metal atoms, for example, lose electrons to form positively charged ions called *cations*. Many metals can form a cation only in one way. For example, aluminum forms a cation by losing three electrons to become Al^{3+}. The common ions formed by the elements are sometimes shown in the upper right-hand corner of the element's box in the periodic table (Figure 4.4A).

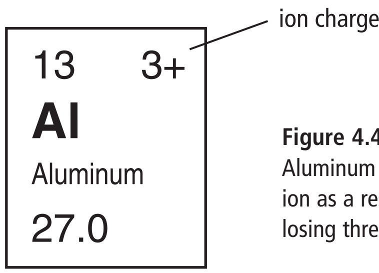


Figure 4.4A Aluminum forms a 3+ ion as a result of losing three electrons.

Some metals are **multivalent**, which means they can form ions in more than one way, depending on the chemical reaction they undergo. For example, iron is a multivalent element because it can lose two or three electrons to become Fe^{2+} ions and Fe^{3+} ions. Look at the periodic table to see which metals are multivalent. The most common charge is listed first at the top of the element's box in the periodic table (Figure 4.4B).

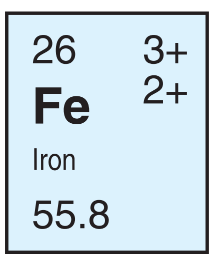


Figure 4.4B Iron is a multivalent element.

Many non-metals also form ions. However, since non-metal atoms, with very few exceptions, *gain* electrons, they form negative ions called *anions*. For example, the periodic table shows that chlorine will form a Cl^- ion (Figure 4.4C). This happens when a chlorine atom gains one electron.

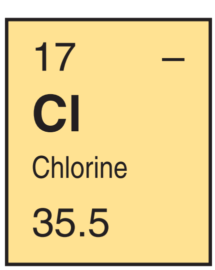


Figure 4.4C Chlorine forms a negative ion.

Reading Check

1. (a) What is another name for each row in the periodic table?
   (b) What is another name for each column or group in the periodic table?
2. Which group of metals is more reactive, the alkali metals or the alkaline earth metals?
3. List all five halogen elements.
4. Name the first and the last transition metal in period 4.

Bohr Diagrams

The periodic table represents patterns related to the arrangement of electrons in atoms. These patterns help explain how elements behave during a chemical change. For example, the periodic table can help you answer questions such as the following.

- What properties do elements in the same group (family) share?
- How can you predict the kinds of compounds that are likely to form?

The answer to both these questions comes from the electrons. Each shell can hold up to a certain number of electrons but no more. For example, the first shell can hold a maximum of two electrons. The second shell can hold a maximum of eight electrons. A **Bohr diagram** is a diagram that shows how many electrons are in each shell surrounding the nucleus. The Bohr diagram is named in honour of Niels Bohr (Figure 4.5), a Danish physicist who developed several models for showing the arrangement of electrons in atoms.

Figure 4.5 Niels Bohr (1885–1962) discovered that electrons were arranged in energy levels or shells in specific patterns. Bohr received a Nobel Prize in 1922 for his work on shells.

Figure 4.6 shows several types of Bohr diagrams, each representing an atom of potassium, which has 19 protons, 20 neutrons, and 19 electrons. Table 4.2 shows some examples of ion formations for lithium, aluminum, and chlorine.

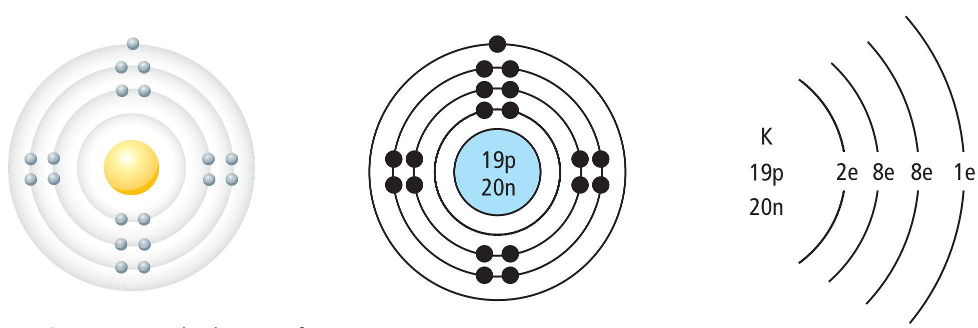


Figure 4.6 Bohr diagrams for potassium

Table 4.2 Ion Formations of Lithium, Aluminum, and Chlorine

	Lithium			Aluminum			Chlorine		
Atom	Li	3 p	2, 1	Al	13 p	2, 8, 3	Cl	17 p	2, 8, 7
Ion	Li^{+}	3 p	2	Al^{3+}	13 p	2, 8	Cl^{-}	17 p	2, 8, 8

Patterns of Electron Arrangement in Periods

The period number of an element equals the number of occupied shells of its atoms. Notice in Figure 4.7 that the two elements in period 1, hydrogen and helium, have a single occupied shell. The first shell of an atom can have a maximum of two electrons. Hydrogen has only one electron in its shell. Helium has a full set of two electrons in its shell.

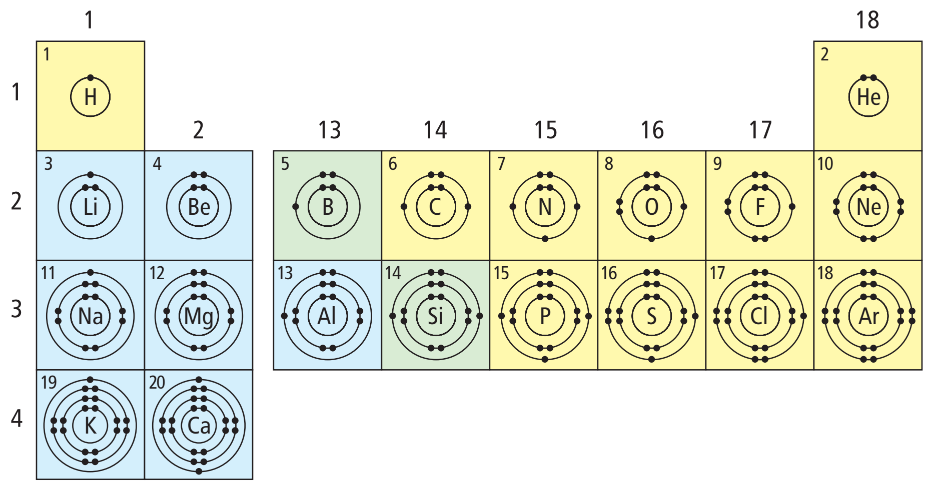


Figure 4.7 Occupied shells for individual atoms of the first 20 elements in the periodic table. Note that the diagrams do not represent the position or path of electrons.

The elements in period 2 all have two occupied shells. For each element in period 2, the first shell, which is closest to the nucleus, has a full set of two electrons. As you move from left to right across period 2, one more electron is added to the second shell of each atom. Notice that neon, the last element in period 2, has a full set of eight electrons in its second shell. The arrangement of eight electrons in the outermost shell is called a **stable octet**. "Octet" refers to a complete set of eight electrons.

Elements in period 3 have three occupied shells. The first two shells for each element in period 3 are full. As you move from left to right across period 3, one more electron is added to the third shell of each atom. Notice that argon has a stable octet in its outermost shell.

Patterns of Electron Arrangement in Groups

The outermost shell that contains electrons is called the **valence shell**. The electrons in the valence shell are called the **valence electrons**. Valence electrons are involved in chemical bonding. Examine the Group 1 elements in Figure 4.7 (lithium, sodium, and potassium). The atoms of each element in group 1, as well as hydrogen, have only one electron in their valence shell. Group 2 elements have two electrons in their valence shell. Group 13 elements have three electrons in their valence shell. Group 14 has four electrons, and so on through group 18. All group 18 elements have filled valence shells. Helium has two electrons filling its valence shell. Neon and argon each have eight electrons, or a stable octet, filling their valence shell. Figure 4.7 above shows that electrons can exist singly or in pairs. Electrons in completed shells (except for hydrogen) appear in pairs.

Did You Know?

Scientists were surprised to find that electrons could pair up inside atoms because all electrons have a negative charge and therefore should repel each other. The reason they can pair up is because of certain differences in the magnetic properties of each electron.

Practice Problems

Use the periodic table in Figure 4.3 on page 172 to help you answer the following questions.

1. Based on the patterns of the periodic table, identify the number of occupied shells for each of the following elements.
   (a) calcium, Ca
   (b) krypton, Kr
   (c) sulfur, S
   (d) iodine, I

2. Based on the patterns in the periodic table, identify the number of valence electrons for each of the following elements.
   (a) chlorine, Cl
   (b) magnesium, Mg
   (c) strontium, Sr
   (d) bromine, Br

Answers provided on page 591

Forming Compounds

When two atoms move close together, their valence electrons interact. A chemical bond forms between the atoms if the new arrangement of atoms and electrons is stable. The stability of an atom, ion, or compound is related to its energy; that is, lower energy states are more stable. The lowest energy is achieved when the atoms in the compound have the same arrangement of valence electrons as the arrangement for the noble gas to which they are closest in the periodic table.

When an atom forms a compound, it may acquire a valence shell like that of its closest noble gas in one of three ways.

- Atoms of metals may lose electrons to other atoms, forming **cations**.
- Atoms of non-metals may gain electrons from other atoms, forming **anions**.
- Atoms may share electrons.

Ionic bonding

Compounds are of two basic types, ionic and covalent. An ionic compound contains a positive ion (usually a metal) and a negative ion (usually a non-metal). In **ionic bonding**, one or more electrons transfers from each atom of the metal to each atom of the non-metal.

You can use Bohr diagrams to show ionic bonding for simple compounds. Calcium fluoride (CaF_2) has a ratio of ions of 1:2, as shown in Figure 4.8. In other words, each calcium fluoride has one calcium ion for every two fluoride ions.

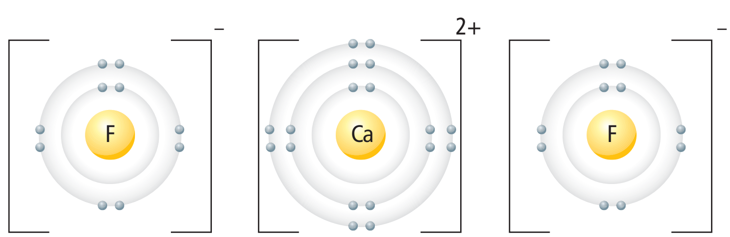


Figure 4.8 CaF_2 is represented using a Bohr diagram. Notice that each valence shell is full, making the element resemble the nearest noble gas.

The formation of the ionic compound sodium chloride is shown in Figure 4.9. Sodium chloride (NaCl) has a ratio of ions of 1:1. In other words, each sodium chloride is made up of one sodium ion and one chlorine ion. Notice that for sodium chloride, the valence shells are filled in both ions. Large square brackets are placed around the diagram with the ion charge shown just outside the end bracket.

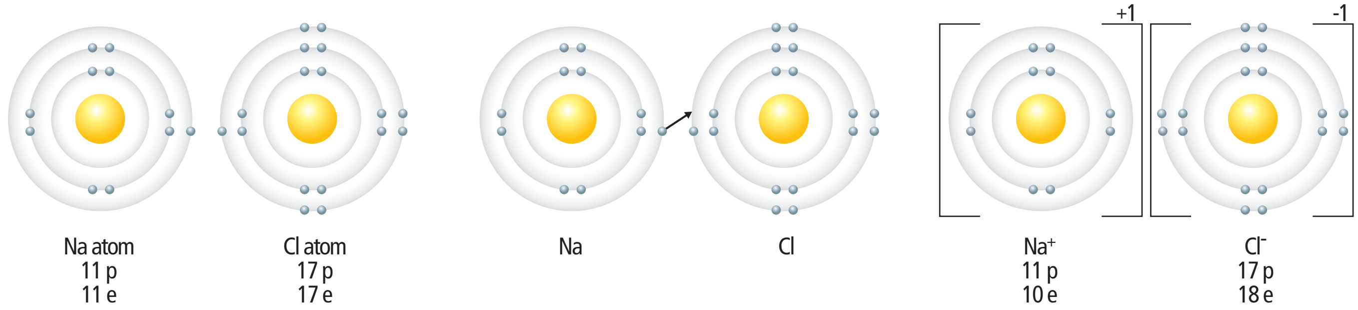


Figure 4.9 An ionic compound forms when an electron from a metal atom transfers to a non-metal atom, creating oppositely charged ions.

Covalent bonding

The atoms of many non-metals share electrons with other non-metal atoms. In **covalent bonding**, atoms overlap slightly, and one unpaired electron from each atom will pair together. Both atoms are attracted to the same pair of electrons, forming a covalent bond. A **covalent compound** is formed when non-metallic atoms share electrons to form covalent bonds. A covalent **molecule** is a group of atoms in which the atoms are bound together by sharing one or more pairs of electrons. The pair of electrons involved in a covalent bond are sometimes called the **bonding pair**. A pair of electrons in the valence shell that is not used in bonding is sometimes called a **lone pair**.

Bohr diagrams can be used to describe simple covalent compounds. Figure 4.10 shows the covalent compounds hydrogen fluoride (HF), water (H_2O), ammonia (NH_3), and methane (CH_4).

Word Connect

The prefix "co-" means sharing or together, and "–valent" refers to valence electrons. "Valence" is from a Latin word meaning strength or power.

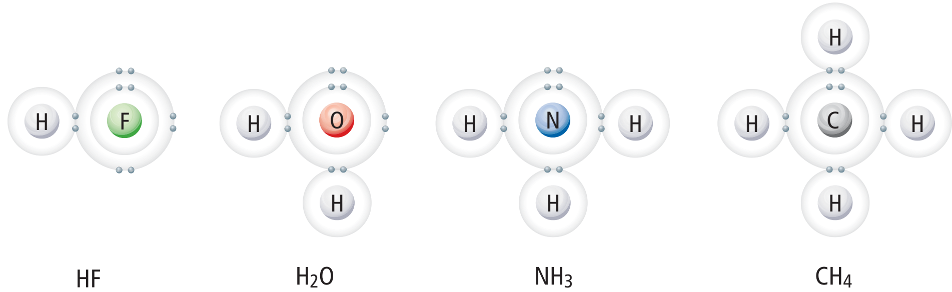


Figure 4.10 Bohr diagrams of HF, H_2O, NH_3, and CH_4

Reading Check

1. How many valence electrons are there in an atom of carbon?
2. (a) How many electrons in phosphorus are paired?
   (b) How many are single?
3. How many electrons are there in an ion of S^{2-}?
4. What ion has 36 electrons and a charge of 1−?

Lewis Diagrams

Gilbert Lewis (1875–1946) was a brilliant and influential American chemist who invented a concise method of showing bonding, particularly covalent bonding. A **Lewis diagram** is a diagram that illustrates chemical bonding by showing only an atom's valence electrons and the chemical symbol. Lewis diagrams are sometimes called Lewis structures or electron dot diagrams. Figure 4.11 compares Bohr diagrams and Lewis diagrams for the elements O, F, and Na.

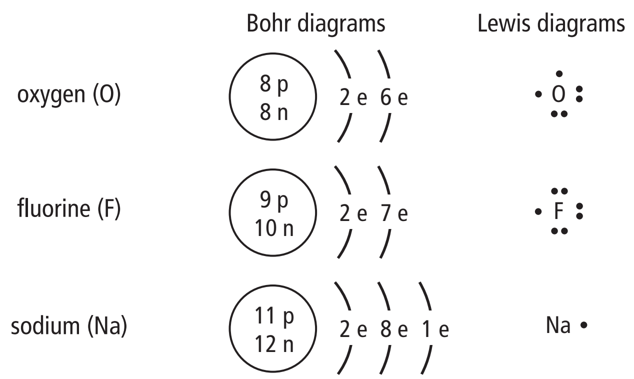


Figure 4.11 Comparison between Bohr diagrams and Lewis diagrams for atoms of oxygen, fluorine, and sodium

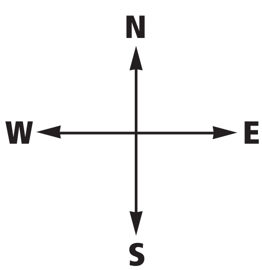


Figure 4.12A North, east, south and west are the four points of the compass.

You can follow these rules to draw a Lewis diagram:

- Dots representing electrons are placed around the element symbols at the points of the compass (Figure 4.12A).
- Electron dots are placed singly until the fifth electron is reached, then they are paired (Figure 4.12B).

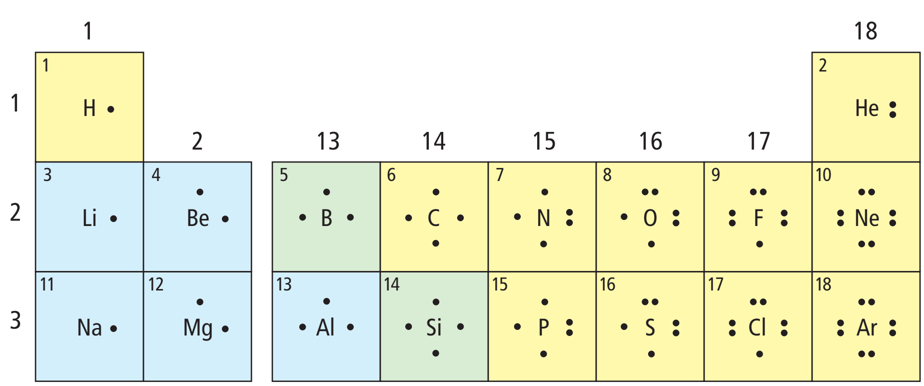


Figure 4.12B Lewis diagrams of the first 18 elements

Lewis diagrams of ions

You can follow these rules to draw ions in a Lewis diagram:

- For positive ions, one electron dot is removed from the valence shell for each positive charge of the ion. This usually means all the electron dots are removed. Only the element symbol remains encased in square brackets with a positive charge shown at the top right.
- For negative ions, one electron dot is added to each valence shell for each negative charge of the ion. This usually means the element's symbol is surrounded by eight electron dots (two electron dots for hydrogen). Square brackets are placed around this diagram with a negative charge shown at the top right (Figure 4.13).

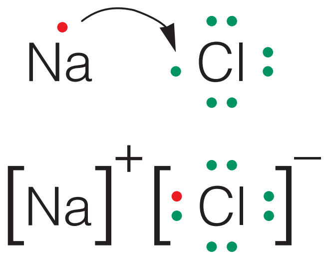
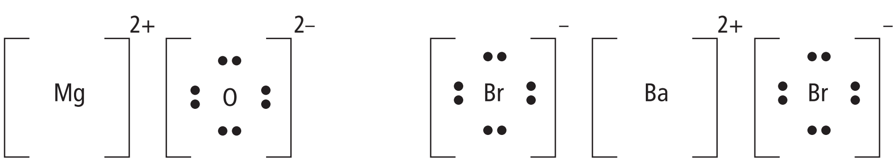


Figure 4.13 Lewis diagram for the formation of NaCl

Lewis diagrams of compounds

Lewis diagrams can be used to show ionic compounds, such as magnesium oxide and barium bromide (Figure 4.14).



MgO

$BaBr_2$

Figure 4.14 Lewis diagram for MgO and $BaBr_2$. The lack of electron dots around Mg and Ba means that the previous shell is full. Another way to write it would be with eight dots around Mg and Ba, but that is not done because those eight electrons are not in the valence shell.

Lewis diagrams are also useful for showing covalent bonds. Figure 4.15 shows the covalent compound HF.

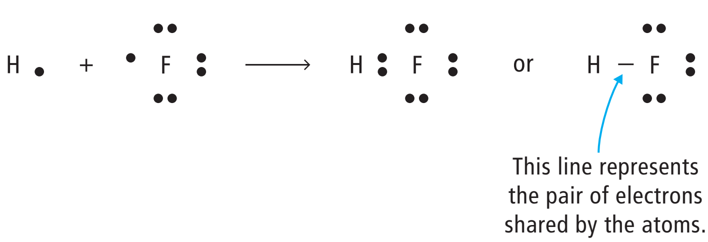


Figure 4.15 The electron from the hydrogen atom and the unpaired electron from the fluorine atom pair up in the HF molecule. Hydrogen has two paired electrons (in a full shell resembling the noble gas helium) and fluorine has four pairs of electrons (in a full shell resembling the noble gas neon).

Lewis diagrams of covalent molecules

The covalent molecules H_2O, NH_3, and CH_4 are shown below in Figure 4.16. Compare this illustration with the more complicated Bohr diagrams shown in Figure 4.10 on page 177.

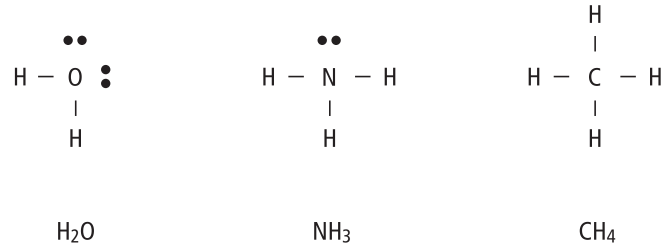


Figure 4.16 Lewis diagrams of H_2O, NH_3, and CH_4

Lewis diagrams of diatomic molecules

You can use Lewis diagrams to help explain why some of the non-metal elements exist as diatomic molecules. A **diatomic molecule** is a pair of atoms that are joined by covalent bonds. Diatomic elements form this way because the two-atom molecules are more stable than the individual atoms. For example, fluorine gas is diatomic. By joining together to form F_2, each fluorine atom can achieve a full valence shell of eight electrons (Figure 4.17). Other diatomic elements are hydrogen (H_2), nitrogen (N_2), oxygen (O_2), chlorine (Cl_2), bromine (Br_2), and iodine (I_2).

Suggested Activity

Think About It 4-1B on page 181

Explore More

Ozone, O_3, is a triatomic molecule that protects life on Earth from deadly ultraviolet radiation from the Sun. Try drawing a Lewis diagram for ozone. Then find out how it is produced in our atmosphere. Begin your search at **www.bcscience10.ca**.

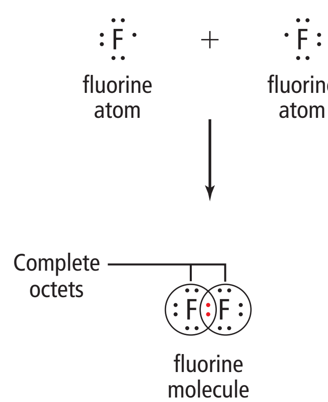


Figure 4.17 Two fluorine atoms share a pair of electrons to form a covalent bond. The shared electron pair gives each atom a complete octet.

4-1B Modelling Compounds

Bohr diagrams show all electrons present in an atom or ion, whereas Lewis diagrams show only valence electrons. In this activity, you will use Bohr diagrams and Lewis diagrams to describe bonding in compounds.

What to Do

Part 1 Bohr Diagrams

1. Copy and complete the following chart in your notebook. Refer to the periodic table in Figure 4.7 on page 172 to help you draw the Bohr diagrams.

Bohr Diagrams

Hydrogen	Lithium	Magnesium	Oxygen	Chlorine	Fluorine

2. Draw a Bohr model of Li_2O following these instructions.
   - Use a pencil to draw a Bohr diagram for an oxygen atom.
   - Draw two diagrams of lithium atoms, one to the left and one to the right of the oxygen atom. Notice that each lithium atom has one valence electron, and that the outer shell of the oxygen atom has room for two more valence electrons.
   - Erase the valence electrons from each of the lithium atoms and redraw them in the oxygen atom's valence shell.
   - Place a square box around each of the element symbols, and write 1^+ beside each lithium atom and 2^- beside the oxygen atom.
3. Follow the steps above to draw Bohr diagrams for these ionic compounds.
   (a) LiCl
   (b) MgO
   (c) $MgCl_2$
4. Follow the steps above to draw Bohr diagrams for these covalent compounds.
   (a) HF
   (b) H_2O
   (c) OF_2

Part 2 Lewis Diagrams

5. Copy and complete the following chart in your notebook. Refer to the periodic table in Figure 4.12B on page 178 to help you draw the Lewis diagrams. Find the number of valence electrons in each atom and arrange them as follows.
   - Dots representing electrons are placed around the element symbols at the points of the compass (north, east, south, and west)
   - Electron dots are placed singly until the fifth electron is reached, then they are paired. For example, oxygen has six electrons in its valence shell, so the fifth and sixth dots are each paired with one of the other four dots.

Lewis Diagrams

Hydrogen	Lithium	Magnesium	Oxygen	Chlorine	Fluorine

6. Draw Lewis diagrams for these ionic compounds.
   (a) Li_2O
   (b) LiCl
   (c) MgO
   (d) $MgCl_2$
7. Draw Lewis diagrams for these covalent compounds.
   (a) HF
   (b) H_2O
   (c) OF_2

What Did You Find Out?

1. Describe the information contained in a Bohr diagram compared with the information contained in a Lewis diagram.
2. (a) Which diagram do you find easier to use, a Bohr diagram or a Lewis diagram?
   (b) Why?

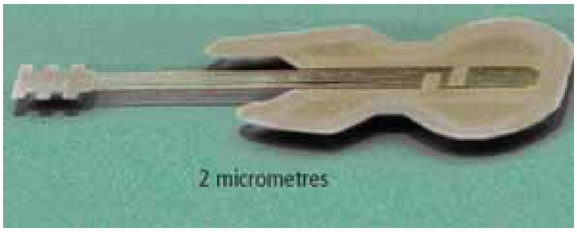
Wild, Weird, Wonderful

www Science

The Art of Science

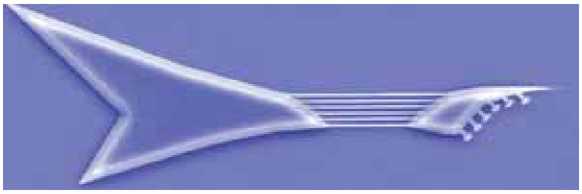
When you imagine a scientist at work, do you also picture an artist? Creativity is an essential part of both art and science. New technologies often open the door for new kinds of artistic experimentation and expression. For example, advances in electronics have changed the way we make and listen to music. Now, developments in nanotechnology are blending science, technology, and art at the microscopic scale. Nanotechnology takes its name from the nanometre, which is an extremely small unit of measurement equalling one billionth of a metre.

The tiny guitar shown below is a replica of a Fender Stratocaster and was made in a university laboratory in 1997. It was cut from a single crystal of silicon dioxide, a major component of glass and concrete. With a length of 10 micrometres, it is the world's smallest guitar. To get an idea of how small it is, picture this: five of these guitars could fit across the width of one human hair. Although it cannot be used to make music, it pushes the boundaries in the production of tiny devices.



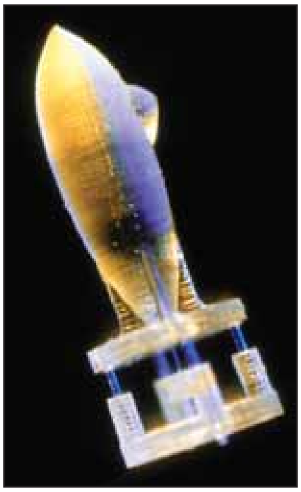
Nano guitar

In 2003, a slightly larger version of the guitar was produced, this time with working "strings." Although it is too small to be played by any mechanical device, the strings can be vibrated using lasers. The frequency of the sound is too high to be heard by humans. However, the same technology may be used to help construct timing devices used in cellphones.



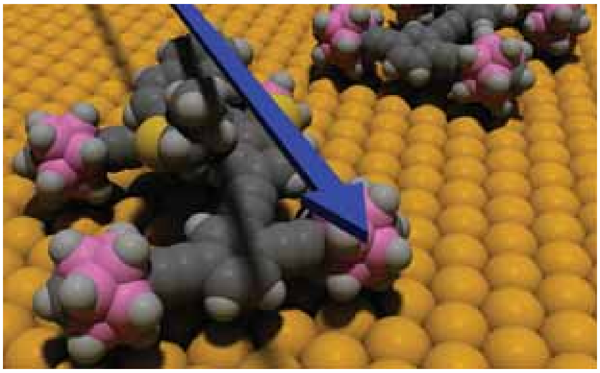
Nano guitar with strings

A tiny functioning submarine was recently produced by shining lasers through a liquid material containing acrylic, a kind of plastic. Computer-controlled lasers caused certain parts of the material to become solid while the surrounding parts remained liquid. At 4 mm in length, this submarine is large enough to be seen by the human eye. This kind of technology might one day lead to developing devices small enough to be used inside the body to deliver medicines or repair damaged tissues.



Nano submarine

There are plans to build machines made from individual atoms, including motors, wheels, and axles. Recently a "nano car" was designed and built from carbon atoms and driven on a "road" made of gold atoms, but it had no engine. It was pushed around using a tiny needle, which was only a few atoms wide at its tip.



Nano car

What will the future bring? Possible applications of nanotechnology in medicine and research seem endless. What issues do we need to consider in applying nano-technology?

Check Your Understanding

Checking Concepts

1. (a) What is one property that protons and neutrons have in common?
(b) What is one property that is different for protons and neutrons?

2. Which two subatomic particles are nearly equal in mass?

3. Which subatomic particle is nearly equal to the masses of the other two subatomic particles added together?

4. A bucket full of water has both mass and volume. Referring to the subatomic particles, explain what accounts for most of the:
(a) mass of the water
(b) volume of the water

5. Explain how an atom is composed of charged particles yet can have an overall charge of zero.

6. (a) What is the value of the nuclear charge on a neon atom?
(b) How is the nuclear charge determined?

7. Copy and complete the following chart in your notebook.

	Element	Atomic Number	Number of Protons	Number of Electrons
(a)	Pb	82		
(b)			8	
(c)				30
(d)	Fe			
(e)		47		
(f)				17

8. For each of Cs, S, Kr, C, Fe, and Hg, name its:
(a) period
(b) group

9. List four chemical family names, working from left to right across the periodic table.

Understanding Key Ideas

10. Name the subatomic particle(s) that best fit each of the following descriptions.
(a) has a negative charge
(b) has an electric charge
(c) surrounds the nucleus in a regular pattern
(d) has an electric charge of zero
(e) is present in the nucleus
(f) The number of this particle is always the same as the atomic number.

11. How is a covalent compound different from an ionic compound?

12. Compare a Bohr diagram and a Lewis diagram. Explain how they are:
(a) similar
(b) different

13. Draw Bohr diagrams for:
(a) diatomic molecules H_2 and F_2
(b) covalent compounds H_2O and HCl
(c) ionic compounds KF and Li_2O

14. Draw Lewis diagrams for:
(a) diatomic molecules H_2 and F_2
(b) covalent compounds H_2O and HCl
(c) ionic compounds NaF, $BeCl_2$ and Li_2O

Pause and Reflect

Think back over the information you have learned about atoms in this section. Illustrate and explain your understanding of the current model for the atom. How have your ideas changed from your earlier understanding of the atom?

4.2 Names and Formulas of Compounds

Compounds can be represented with both a name and a chemical formula. In an ionic compound, the first part of the name indicates the positive ion and the second part indicates the negative ion. In the formula of an ionic compound, the subscripts indicate the ratio in which the positive ions and negative ions are present together in the compound. In a binary covalent compound, both the name and the formula indicate the number of each type of atom present in the compound.

Words to Know

binary covalent compound
ionic compounds
polyatomic
subscript

Figure 4.18 A single crystal of salt (sodium chloride) embedded in a rock formation

If you were asked to take a chisel and carve a cube out of a large crystal of table salt, would you be able to make one as perfect as the one shown in Figure 4.18? Or would you need to be a master carver? In fact, the crystal shown here formed naturally in this shape. How can this happen?

Table salt (sodium chloride) is an ionic compound, meaning that it is made of positive and negative ions that are held together by ionic bonds. Instead of being shaped from the outside, as a sculptor would do, the crystal is highly organized and formed piece by piece (ion by ion) from the inside out.

This crystal of salt formed from a solution that contained sodium and chloride ions. Slowly, the solution dried up, leaving this cube embedded in other rocks. The regular shape reveals the order of the ions at the atomic level.

Did You Know?

Before chemical names were standardized, a single compound might have more than one name. For example, sulfur dioxide (SO_2) was known as both vitriolic acid air and sulfurous gas.

The ions in the sodium chloride crystal line up this way because of the forces acting between the ions. The oppositely charged ions are attracted to each other, and the similarly charged ions repulse each other. The combination of charges forms the arrangement of ions shown in Figure 4.19.

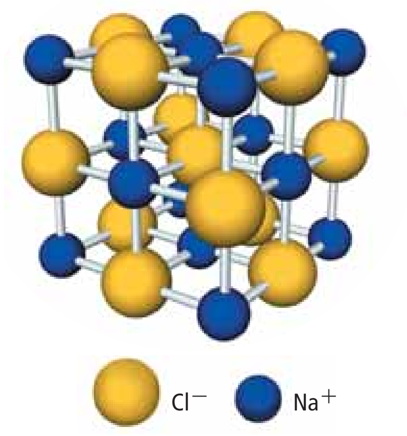


Figure 4.19 The arrangement of ions in sodium chloride

4-2A Chemical Names

Think About It

In this activity, you will work with a partner to discover what information can be collected from the names of ionic compounds and covalent compounds.

What to Do

1. With a partner, use the periodic table in Figure 4.3 on page 172 to determine the elements in the ionic compounds listed below. Notice where each element in the compound is located on the periodic table. List three patterns that you can find in how these names are written.
   (a) sodium bromide
   (b) magnesium sulfide
   (c) iron(III) oxide
   (d) lead(IV) nitride
   (e) aluminum fluoride
2. Review the covalent compounds listed below. Notice where each element in the compound is located on the periodic table. List three patterns that you can find in how these names are written.
   (a) dinitrogen trioxide
   (b) nitrogen trichloride
   (c) carbon disulfide
   (d) tetraphosphorus decaoxide
   (e) phosphorus pentabromide
3. Write the chemical formula for each covalent compound listed in step 2. Use the following hint to suggest how the formulas are written from the name. **Hint:** disulfur decachloride is S_2Cl_{10}.
4. Share your findings with the class.

What Did You Find Out?

1. Which parts of the periodic table do elements come from when they combine to form ionic compounds?
2. Which part of the periodic table do elements come from when they combine to form covalent compounds?
3. What are two ways to distinguish ionic compounds from covalent compounds by looking only at a compound's name?
4. What information is included in the name of a covalent compound that is not included in the name of an ionic compound?

The Chemical Name of an Ionic Compound

Ionic compounds are compounds that are composed of positive ions and negative ions. You can describe ionic compounds using a name or a formula. A chemical formula indicates the elements present in the compound.

The International Union of Pure and Applied Chemistry (IUPAC) is the organization that represents chemists around the world and develops the rules for naming compounds. One rule is that the chemical name of an ionic compound always has two parts, one for each type of ion in it. An example of a compound made of only two elements is potassium iodide, which is a component of sea salt (Figure 4.20).

Figure 4.20 Potassium metal (A) and iodine gas (B) can combine to form potassium iodide crystals (C).

- The first part of "potassium iodide" names the positive ion, potassium. The positive ion is *always* a metal in a compound containing two elements. The positive, metal ion is *always* written first.
- The second part of "potassium iodide" names the negative ion, iodide, an ion of iodine. The negative ion is *always* a non-metal in a compound containing two elements. The negative, non-metal ion is *always* written second.
- The non-metal's name always ends with the suffix "-ide." In this example, "iodine" changed to "iodide."

The names and symbols of the non-metal ions are shown in Table 4.3. You may recall from earlier in this chapter that the charge of each ion refers to the electrons present (for metals) or missing (for non-metals) in the valence shell. Some examples of ionic compounds are listed in Table 4.4.

Table 4.3 Examples of Names and Symbols of Non-Metal Ions

Name	Symbol
fluoride	F^-
chloride	Cl^-
bromide	Br^-
iodide	I^-
oxide	O^{2-}
sulfide	S^{2-}
selenide	Se^{2-}
nitride	N^{3-}
phosphide	P^{3-}

Table 4.4 Examples of Names of Ionic Compounds

Elements Forming the Ionic Compound	Name of the Ionic Compound
magnesium and phosphorus	magnesium phosphide
calcium and bromine	calcium bromide
aluminum and oxygen	aluminum oxide
lithium and nitrogen	lithium nitride
zinc and sulfur	zinc sulfide

The Chemical Formula of an Ionic Compound

The chemical formula of an ionic compound contains a symbol to identify each ion. The formula also shows the number of ions of each element in the compound. The small number written to the right of the symbol of an element, such as the 3 in Na_3P, is called a **subscript**. A subscript gives the ratio of each type of ion in the compound. If no subscript is shown after an element, such as after the P in Na_3P, you can assume the number to be 1. In Na_3P, there are three sodium ions for every one phosphorus ion. Figure 4.21 shows three examples of chemical formulas of ionic compounds.

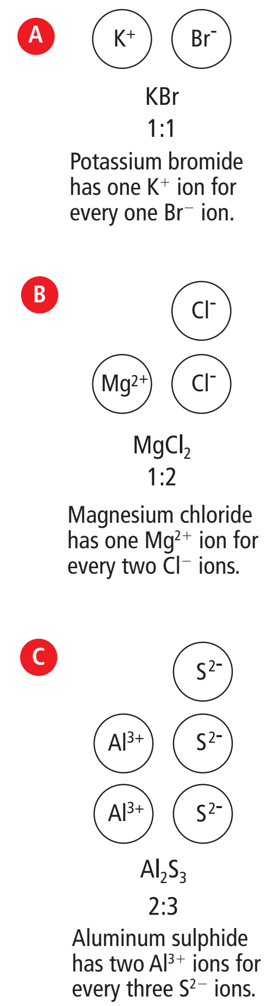


Figure 4.21 Chemical formulas for three ionic compounds

Naming Ionic Compounds

You can determine the name of an ionic compound containing two elements by analyzing its formula (Table 4.5).

Table 4.5 Naming Ionic Compounds Containing Two Elements

Steps	Examples	
	CaI_2	Na_3P
1. Name the metal ion.	• The metal ion is Ca^{2+}. • The ion's name is given in the periodic table as calcium.	• The metal ion is Na^+. • The ion's name is given in the periodic table as sodium.
2. Name the non-metal ion by ending the element name with the suffix "ide."	• The non-metal ion is I^-. The element's name is iodine. • Changing the name to end with the suffix "-ide" gives iodide.	• The non-metal ion is P^{3-}. The element's name is phosphorus. • Changing the name to end with the suffix "-ide" gives phosphide.
3. Write the name of the compound.	calcium iodide	sodium phosphide

Practice Problems

Write the names of the following ionic compounds.

1. (a) Li_3N
(b) $MgBr_2$
(c) Ag_2O
(d) RbF
(e) AgI
(f) $AlBr_3$
(g) CaI_2
(h) GaI_3
(i) Ag_3N
(j) MgSe
(k) Ca_3P_2
(l) Na_2O
(m) CdS
(n) Sr_3P_2
(o) CsF

Answers provided on page 591

Writing the Formulas of Ionic Compounds

In an ionic compound, the positive charges balance the negative charges. You can use this balance to find the ratio of positive ions to negative ions. Then you can use the ratio to write subscripts in the formula. Table 4.6 shows the steps for writing the formula of an ionic compound if you know the names of the elements it contains.

Notice that the final formula represents the smallest whole number ratio. For example, Pb^{4+} combining with S^{2-} is written as PbS_2, and not as Pb_2S_4.

Table 4.6 Writing Formulas of Ionic Compounds Containing Two Elements

Steps	Examples	
	aluminum fluoride	magnesium nitride
1. Identify each ion and its charge.	aluminum: Al^{3+} fluoride: F^{-}	magnesium: Mg^{2+} nitride: N^{3-}
2. Determine the total charges needed to balance positive with negative.	Al^{3+}: $= +3$ F^{-}: $-1\ -1\ -1 = -3$	Mg^{2+}: $+2 + 2 + 2 = +6$ N^{3-}: $-3\ -3 = -6$
3. Note the ratio of positive ions to negative ions.	1 Al^{3+} ion for every 3 F^{-} ions	3 Mg^{2+} ions for every 2 N^{3-} ions
4. Use subscripts to write the formula. A "1" is not shown in the subscripts.	AlF_3	Mg_3N_2

Practice Problems

1. Write the formulas of the compounds containing the following ions.

(a) Na^{+} with Br^{-}
(b) Zn^{2+} with I^{-}
(c) K^{+} with S^{2-}
(d) Al^{3+} with S^{2-}
(e) Ca^{2+} with O^{2-}
(f) Al^{3+} with P^{3-}

2. Write the formulas of the following ionic compounds.

(a) strontium nitride
(b) lithium oxide
(c) silver sulfide
(d) barium phosphide
(e) sodium nitride
(f) potassium selenide
(g) cesium sulfide
(h) aluminum nitride
(i) zinc oxide
(j) aluminum iodide
(k) lithium fluoride
(l) sodium sulfide
(m) zinc phosphide
(n) magnesium chloride
(o) rubidium bromide

Answers provided on page 591

Compounds Containing a Multivalent Metal

You may recall from section 4.1 that some metals are multivalent, which means they can form ions in more than one way, depending on the situation. Multivalent metals can form two or more different positive ions with different ion charges. For example, find nickel (Ni) in the periodic table. The periodic table lists two ion charges, 2+ and 3+. This means that nickel is multivalent. In some compounds, the nickel ion is Ni^{2+}; in other compounds, the nickel ion is Ni^{3+}. The periodic table always lists the most common ion charge first. So for nickel, Ni^{2+} is more common than Ni^{3+}. An example of an ionic compound containing nickel is $NiCl_2$, used in some kinds of batteries (Figure 4.22).

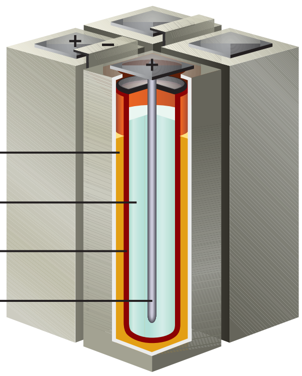


Figure 4.22 A Na-$NiCl_2$ battery, also called a zebra battery, operates at temperatures above 250°C and can be used to power vehicles.

To distinguish between two ions formed from multivalent metals, you need to name each ion. The name must contain the ion's charge. To indicate the charge, you use the Roman numerals from I to VII that correspond to ion charges from 1+ to 7+, as shown in Table 4.7. Examples of how to show the charge on ions include the following.

- Ni^{2+} or nickel(II) is called "nickel two" and shows the nickel ion has an ion charge of 2+.
- Ni^{3+} or nickel(III) is called "nickel three" and shows the nickel ion has an ion charge of 3+.
- V^{4+} or vanadium(IV) is called "vanadium four" and shows the vanadium ion has an ion charge of 4+. (The other valence for vanadium is 5+.)
- Au^{+} or gold(I) is called "gold one" and shows the gold ion has an ion charge of 1+. (The other valence for gold is 3+.)

What does a Roman numeral reveal about an ion of a metal? First, it tells you that there is more than one type of ion for that metal—the metal is multivalent. Second, it tells you the charge of the metal ion. Table 4.8 gives examples of names and formulas for some compounds containing a multivalent ion. Remember that the positive and negative charges on the ions must balance so that the overall charge on the compound is zero.

Table 4.7
Roman Numerals

Metal Ion Charge	Roman Numeral
1+	I
2+	II
3+	III
4+	IV
5+	V
6+	VI
7+	VII

Table 4.8
Some Compounds with Multivalent Metal Ions

Name	Formula
nickel(II) chloride	$NiCl_2$
nickel(III) chloride	$NiCl_3$
titanium(IV) oxide	TiO_2
lead(IV) sulfide	PbS_2
chromium(II) fluoride	CrF_2
chromium(III) fluoride	CrF_3
copper(I) nitride	Cu_3N
copper(I) phosphide	Cu_3P

Formulas of Compounds Containing a Multivalent Metal

Table 4.9 shows how to write the formula when you are given the name of a compound containing a multivalent metal. Figure 4.23 shows two examples of compounds containing a multivalent metal.

Figure 4.23 Although they are both made of copper and chlorine, copper(I) chloride has a greenish colour, whereas copper(II) chloride has a bluish colour.

Did You Know?

Roman numerals are numerals used by the ancient Romans for trade and commerce. The Romans did not have a numeral to represent zero.

Table 4.9 Writing Formulas of Compounds Containing a Multivalent Metal

Steps	Examples	
	manganese(IV) sulfide	cobalt(III) oxide
1. Identify each ion and its charge.	manganese(IV): Mn^{4+} sulfide: S^{2-}	cobalt(III): Co^{3+} oxide: O^{2-}
2. Determine the total charges needed to balance positive with negative.	Mn^{4+}: $= +4$ S^{2-} : $-2 -2 = -4$	Co^{3+}: $+3+3 = +6$ O^{2-}: $-2 -2 -2 = -6$
3. Note the ratio of positive ions to negative ions.	1 Mn^{4+} ion for every 3 S^{2-} ions	2 Co^{3+} ions for every 3 O^{2-} ions
4. Use subscripts to write the formula. A "1" is not shown in the subscripts.	MnS_2	Co_2O_3

Practice Problems

1. Write the formulas of the following compounds containing multivalent metals.

(a) copper(I) nitride
(b) iron(II) phosphide
(c) manganese(II) oxide
(d) manganese(IV) oxide
(e) chromium(II) bromide
(f) chromium(III) bromide
(g) lead(IV) chloride
(h) iron(III) phosphide
(i) tin(II) sulfide
(j) tin(II) nitride
(k) tin(IV) nitride
(l) mercury(II) fluoride
(m) copper(I) iodide
(n) copper(II) iodide
(o) copper(II) selenide

Answers provided on page 591

Naming Compounds that Contain a Multivalent Metal

When you are writing the name of an ionic compound containing a multivalent metal, you need a Roman numeral to indicate the ion charge. Table 4.10 shows how to determine the correct Roman numeral.

Table 4.10 Naming Ionic Compounds Containing a Multivalent Metal

Steps	Examples	
	Au_3N	PdS_2
1. Identify the metal.	gold (Au)	palladium (Pd)
2. Verify that it can form more than one kind of ion by checking the periodic table.	Au^+ and Au^{3+}	Pd^{2+} and Pd^{4+}
3. Determine the ratio of the ions in the formula.	Au_3N means 3 gold ions for every 1 nitride ion.	PdS_2 means 1 palladium ion for every 2 sulfide ions.
4. Note the charge of the negative ion from the periodic table.	The charge on the N^{3-} ion is 3−.	The charge on the S^{2-} ion is 2−.
5. The positive and negative charges must balance out. Determine what the charge needs to be on the metal ion to balance the negative ion.	Each of the 3 gold ions must have a charge of 1+ to balance the 1 nitride ion with a charge of 3−. Therefore the name of the gold ion is gold(I).	The 1 palladium ion must have a charge of 4+ to balance the 2 sulfide ions that each have a charge of 2−. Therefore, the name of the palladium ion is palladium(IV).
6. Write the name of the compound.	gold(I) nitride	palladium(IV) sulfide

Practice Problems

Each of these compounds contains a multivalent metal ion. That means that the name of the metal ion will contain a Roman numeral, which you will need to determine. Write the names of the following compounds.

1. (a) Fe_2O_3
(b) PbF_4
(c) FeI_2
(d) HgI_2
(e) Hg_3N_2
(f) Sn_3P_4
(g) MnS
(h) MnS_2
(i) VCl_5
(j) Ni_2S_3
(k) NiS
(l) Mo_2O_3
(m) UCl_6
(n) ReF_7
(o) TiS_2

Answers provided on page 591

Did You Know?

Iron(III) oxide forms nanoparticles that change colour depending on the magnetic field they are exposed to. Research is being conducted to see whether this form of iron(III) oxide could be used in computer displays. Iron(III) oxide is cheap, abundant, and non-toxic.

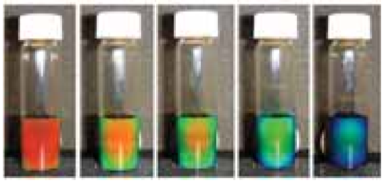


Figure 4.24 Shellfish, such as clams, use carbonate ions to make their shells.

Polyatomic Ions

A **polyatomic** ion is an ion composed of more than one type of atom joined by covalent bonds. Because polyatomic ions carry an electric charge, they cannot exist on their own. An example of a polyatomic ion is carbonate, CO_3^{2-} (Figure 4.24).

Table 4.11 lists some common polyatomic ions. The names of these ions were assigned by the IUPAC. You do not have to memorize them. Simply refer to the ion table to find a name and formula. Table 4.12 explains the steps for writing the formula of a compound with polyatomic ions.

Table 4.11 Names, Formulas, and Charges of Some Polyatomic Ions

Positive Ions	Negative Ions		
NH_4^+ ammonium	CH_3COO^- acetate	HCO_3^- hydrogen carbonate, bicarbonate	NO_2^- nitrite
	CO_3^{2-} carbonate	HSO_4^- hydrogen sulfate, bisulfate	ClO_4^- perchlorate
	ClO_3^- chlorate	HS^- hydrogen sulfide, bisulfide	MnO_4^- permanganate
	ClO_2^- chlorite	HSO_3^- hydrogen sulfite, bisulfite	PO_4^{3-} phosphate
	CrO_4^{2-} chromate	OH^- hydroxide	PO_3^{3-} phosphite
	CN^- cyanide	ClO^- hypochlorite	SO_4^{2-} sulfate
	$Cr_2O_7^{2-}$ dichromate	NO_3^- nitrate	SO_3^{2-} sulfite

Word Connect

"Poly-" means many. Per-, hypo-, -ate, and -ite are prefixes and suffixes that help indicate the number of oxygen atoms present in some polyatomic ions.

Table 4.12 Writing the Formula of a Compound with Polyatomic Ions

Steps	Examples	
	manganese(III) chlorate	**ammonium sulfate**
1. Identify each ion and its charge.	manganese(III): Mn^{3+} chlorate: ClO_3^-	ammonium: NH_4^+ sulfate: SO_4^{2-}
2. Determine the total charges needed to balance positive with negative.	Mn^{3+}: $= +3$ ClO_3^-: $-1\ -1\ -1 = -3$	NH_4^+: $+1\ +1 = +2$ SO_4^{2-}: $= -2$
3. Note the ratio of positive ions to negative ions.	1 Mn^{3+} ion for every 3 ClO_3^- ions	2 NH_4^+ ions for every 1 SO_4^{2-} ion
4. Use brackets around ions to correctly show the ratio of ions.	$(Mn)(ClO_3)_3$	$(NH_4)_2(SO_4)$
5. Use subscripts and brackets to write the formula. Omit brackets if only one ion is needed.	$Mn(ClO_3)_3$	$(NH_4)_2SO_4$

Notice the use of brackets in the formula to allow the ratio of ions to be shown correctly. Brackets are dropped if the ion is not polyatomic or if the ratio number outside the brackets is 1. However, when you read the formula, you should always remember that the ratio numbers and brackets are implied. For example, you would read Na_2CO_3 as sodium carbonate with two Na^+ ions for every one CO_3^{2-} ion.

Practice Problems

Refer to Table 4.11, Names, Formulas, and Charges of Some Polyatomic Ions, as you do these problems.

1. Write the names of the following compounds with polyatomic ions.

(a) KCH_3COO
(b) $Ca(CH_3COO)_2$
(c) $(NH_4)_3P$
(d) $(NH_4)_3PO_4$
(e) $Al(OH)_3$
(f) $Fe(OH)_3$
(g) K_2CrO_4
(h) $K_2Cr_2O_7$
(i) $Ca(HCO_3)_2$
(j) $Mg_3(PO_4)_2$

2. Write the formulas of the following compounds with polyatomic ions.

(a) potassium permanganate
(b) sodium chromate
(c) ammonium nitrate
(d) lithium hydroxide
(e) aluminum hydroxide
(f) lead(II) perchlorate
(g) iron(III) hydrogen sulfide
(h) vanadium(V) nitrate
(i) magnesium acetate
(j) tin(II) cyanide

Answers provided on page 591

Names and Formulas of Covalent Compounds

In a covalent compound, the precise number of atoms of each element in the molecule is shown by the chemical formula. For example, H_2O_2 is a covalent compound that may be familiar to you as a disinfectant. Its name is hydrogen peroxide. Each molecule of hydrogen peroxide has two hydrogen atoms and two oxygen atoms, for a total of four atoms in each molecule (Figure 4.25). Notice that the formula is not reduced to HO, as would be the case for an ionic compound. This is because the subscripts in a covalent compound have a different meaning than those in an ionic compound. In an ionic compound, subscripts are used to show the smallest whole-number ratio of the ions. In a covalent compound, the subscripts show the actual number of atoms of each element in the molecule.

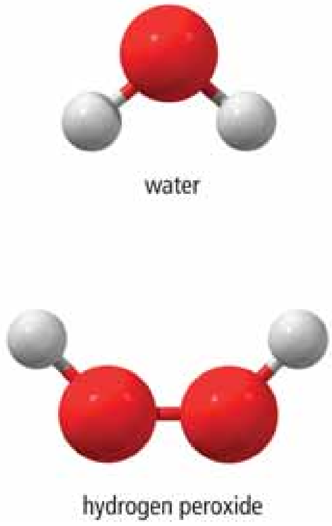


Figure 4.25 Water and hydrogen peroxide are both molecules.

Word Connect

"Binary" means involving two. For example, binary digits in computer technology are 0 and 1. Binary fission in biology involves reproduction by splitting into two parts.

Naming Binary Covalent Compounds

A **binary covalent compound** contains two non-metal elements joined together by one or more covalent bonds. Atoms in covalent compounds do not connect by forming ions. Instead, they combine chemically by sharing electrons in a covalent bond. A binary covalent compound can have many atoms, such as in $C_{25}H_{52}$, a main component of candle wax, or it can be diatomic (having only two atoms) as in ClF.

Prefixes indicate the numbers of atoms of each element that appear in the formula of binary covalent compounds. These prefixes are used for naming only covalent compounds. See Table 4.13 for a list of prefixes. Table 4.14 shows how to use these prefixes for naming binary covalent compounds that do *not* contain hydrogen.

Table 4.13 Prefixes Used in Naming Binary Covalent Compounds

Prefix	Number
mono-	1
di-	2
tri-	3
tetra-	4
penta-	5
hexa-	6
hepta-	7
octa-	8
nona-	9
deca-	10

Table 4.14 Writing the Names of Binary Covalent Compounds

Steps	Examples	
	CO	N_2O_3
1. Name the left most element in the formula first.	• The first element is C (carbon).	• The first element is N (nitrogen).
2. Name the second element, making sure the element name ends with the suffix "ide."	• The second element is O (oxygen). • It becomes oxide.	• The second element is O (oxygen). • It becomes oxide.
3. Add a prefix to each element's name to indicate the number of atoms of each element in the compound. Exceptions to rule 3: • If the first element has only one atom, do *not* add a prefix. • The prefix "mono-" is shortened to "mon-" if it is placed before "oxide."	• Do not use a prefix when there is only one atom of the first element. • The compound's name is carbon monoxide.	• There are two (di-) nitrogen atoms and three (tri-) oxygen atoms. • The compound's name is dinitrogen trioxide.

Steps for naming most compounds containing hydrogen are given in Chapter 5; however, three common binary compounds of hydrogen are listed in Table 4.15. These compounds were known before any standard naming system came into use.

Table 4.16 give some examples of hints you can use when you write the names of covalent compounds from their formulas. Remember, you do not use a subscript when there is only one atom.

Table 4.15 Common Binary Compounds of Hydrogen

Formula	Name
CH_4	methane
NH_3	ammonia
H_2O	water

Table 4.16 Hints for Writing Names of Binary Covalent Compounds

Formula	Name	Hints for Writing Names
CS_2	carbon disulfide	Do not use a prefix when there is only one atom of the first element.
CCl_4	carbon tetrachloride	Do not use a prefix when there is only one atom of the first element.
P_4O_{10}	tetraphosphorus decaoxide	Do not reduce the name to diphosphorus pentoxide.

Figure 4.26 Sulfur, shown here in Vancouver harbour, forms many useful industrial compounds. For example, carbon disulfide is produced commercially for use in making viscose material, cellophane film, insecticide, and rubber products.

Practice Problems

1. Write the names of the following compounds.

(a) N_2O
(b) CO_2
(c) PI_3
(d) PCl_5
(e) SO_2
(f) N_2O_4
(g) P_4S_{10}
(h) S_2F_{10}
(i) NI_3
(j) NO

2. Write the formulas of the following compounds.

(a) nitrogen tribromide
(b) sulfur hexafluoride
(c) dinitrogen tetrasulfide
(d) oxygen difluoride
(e) carbon tetraiodide
(f) sulfur trioxide
(g) phosphorus pentabromide
(h) diiodine hexachloride
(i) dichlorine monoxide
(j) xenon hexafluoride

Answers provided on page 591

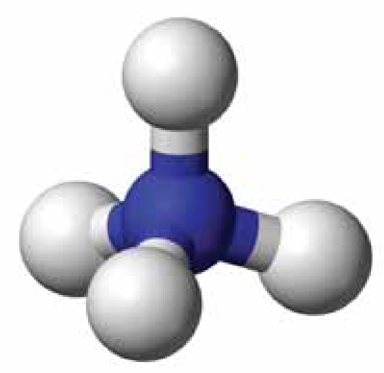


Figure 4.27 The positively charged ammonium ion forms four covalent bonds connecting the nitrogen to each hydrogen.

Comparing Ionic and Covalent Compounds

The formulas of ionic compounds and covalent compounds can look very similar. This makes naming them difficult if you are not sure which naming rules to use. The following tips are helpful for naming compounds.

1. **Examine the formula**
   - Ionic compounds begin with a metal or the ammonium ion (NH_4^+) as shown in Figure 4.27.
   - If the formula starts with a non-metal, it is likely that it is a covalent compound. There are special rules for compounds with hydrogen.
2. **If the compound is covalent**
   - If the covalent compound is binary (and does not begin with hydrogen), then use the prefix naming system. For example, P_2F_4 is binary because it has only two elements, and it is covalent because it begins with a non-metal. Using the prefix naming system, its name is diphosphorus tetrafluoride.
3. **If the compound is ionic**
   - If the positive ion is a metal, the periodic table will show whether it has one or more than one ion charge.
     - For a metal with only one form of ion, the ion simply takes the name of the element. For example, the name of Ba^{2+} is the barium ion.
     - For a metal with more than one form of ion (multivalent), a Roman numeral is added to the name of the first element (the metal). The Roman numeral indicates the ion's charge. For example, nickel has two common ion charges, so the name of Ni^{2+} is nickel(II), and the name of Ni^{3+} is nickel(III).
   - If the negative ion comes from a single non-metal atom (such as P^{3-}) then the name of the ion ends with the suffix "-ide." For example, K_3P is called potassium phosphide, and Fe_2O_3 is called iron(III) oxide.
   - If the negative ion is a polyatomic ion, look up the formula in Table 4.11, Names, Formulas, and Charges of Some Polyatomic Ions, on page 192. Use that name in the compound's name. Pay close attention to the endings (suffixes). Some examples include the following.
     $(NH_4)_2S$ is ammonium sulf**ide**
     $(NH_4)_2SO_4$ is ammonium sulf**ate**
     Na_2SO_4 is sodium sulf**ate**
     Na_2SO_3 is sodium sulf**ite**

Sodium sulfate and sodium sulfite are shown in Figure 4.28 on the next page.

Figure 4.28 Sodium sulfite (Na_2SO_3) is used to reduce chlorine levels in swimming pools and to prevent dried fruit from discolouring (A). Sodium sulfate (Na_2SO_4) shown in (B) as crystals, is used as a filler in laundry detergents, to remove air bubbles from molten glass, and to reduce negative charges on fabrics so dyes can penetrate evenly.

Practice Problems

1. Identify each of the following compounds as either ionic or covalent.

(a) $(NH_4)_2S$
(b) OCl_2
(c) $SnCl_2$
(d) $NaNO_3$
(e) N_2O_3
(f) SCl_2
(g) NBr_3
(h) FeF_2

2. The compounds in each group below have similar–looking formulas. However, they may have very different names. Some in each group are ionic, while others are covalent. Classify and name each compound.

(a) VO_2
NO_2
(b) $CrBr_2$
$CdBr_2$
SBr_2
(c) $Na_2Cr_2O_7$
Na_2CrO_4
Cr_2O_3
N_2O_3
(d) SO_3
Li_2SO_3
Li_2SO_4
SO_2
(e) OCl_2
BeF_2
FeF_2
(f) CO_2
$NaHCO_3$
$PbCO_3$

Answers provided on page 591

Suggested Activity

Conduct an Investigation 4-2B on page 198

Explore More

Most of the compounds you have been writing names and formulas for have some practical use. Discover the uses for $FeCl_3$, $CuSO_4$, and ZnO. Find out more at **www.bcscience10.ca**.

4-2B Combining Solutions of Ionic Compounds

Skill Check

- Observing
- Predicting
- Communicating
- Working co-operatively

Safety

- Wear safety goggles and protective clothing.
- Handle chemicals safely.
- Follow your teacher's directions regarding using open flames.
- Avoid touching the chemical solutions and solids.
- Wash your hands and equipment thoroughly after completing this activity.
- Do not remove any materials from the science room.

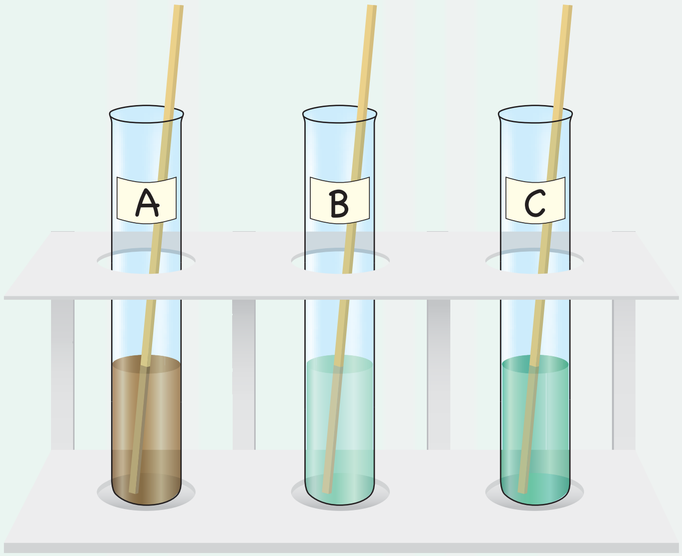
Materials

- masking tape
- marker
- 6 medium test tubes
- test tube rack
- iron(III) chloride solution ($FeCl_3$)
- nickel(II) chloride solution ($NiCl_2$)
- copper(II) chloride solution ($CaCl_2$)
- 4 long wooden splints
- sodium hydroxide solution ($NaOH$)
- glass stirring rod
- paper towel
- Bunsen burner
- ceramic pad
- brass test tube holder

You have been studying chemical names and formulas. Soon, you will study chemical equations, which show how elements and compounds combine to form new compounds. In this activity, you will combine solutions of ionic compounds and observe the results.

Question

What are some of the chemical and physical properties of some common ionic compounds?



Allow the wooden splints to soak for about 5 min.

Procedure

1. Create a table for your observations. Give your table a title.
2. Label three test tubes A, B, and C, and place in test tube rack. In test tube A, place iron(III) chloride solution to a depth of about 2 cm. In test tube B, place nickel(II) chloride solution to a depth of about 2 cm. In test tube C, place copper(II) chloride solution to a depth of about 2 cm.
3. Place a wooden splint into each of the three test tubes containing the solutions you have just poured. Allow them to soak for about 5 min. Label your wooden splints using the metal ion name. Set the wooden splints aside.
4. In each of three new test tubes, pour sodium hydroxide to a depth of about 2 cm. Place a wooden splint into one of these three new test tubes. Label the wooden splint as Na^+, and let it soak for about 5 min. Set the wooden splints aside.

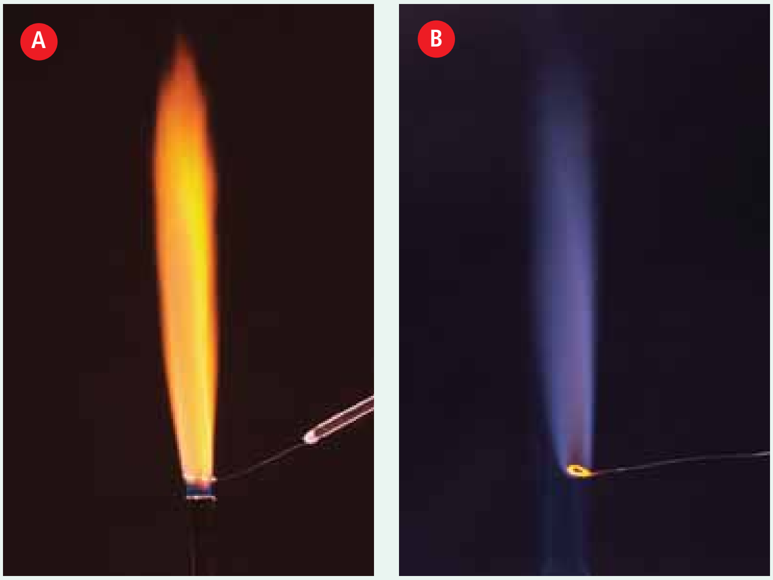
5. Take the three test tubes containing sodium hydroxide and pour their contents into each of the other three test tubes containing the chloride solutions and observe. Record your observations.
6. Mix each solution using a glass stirring rod, and allow to settle for several minutes. Then decant (pour off) the liquid into the designated waste container.
7. Using the glass stirring rod, scrape some of the solid from each test tube out onto a piece of paper towel. Examine the solid. Record your observations.
8. Set up a Bunsen burner. Place the soaked tip of each wooden splint into the flame of the Bunsen burner briefly until the flame takes on a colour due to the solution it soaked in. Note the colour in each case. Then make sure the wooden splints have stopped burning. Place the burned splints onto the ceramic pad.
9. Using the brass test tube holder, test each of the solids in the flame as well. Note the colour.
10. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

Analyze

1. Refer to your table of observations to help you describe the appearance of the solids when they first formed. Include the texture and colour in your answer.
2. How did the flame colours of the solutions compare with the flame colours of the solids?

Conclude and Apply

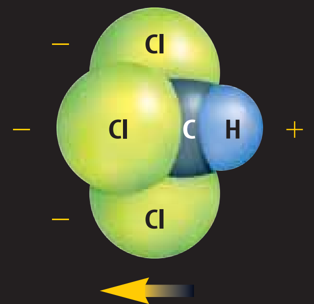
1. Each ionic compound name comes in two parts, the positive ion name and the negative ion name. When the solutions were combined, the ions involved in the two compounds also combined. Try predicting the names of the newly produced pure substances by recombining the names of the starting materials. List the possible names of the new compounds.
2. The flame test is a method that can identify the presence of certain ions, particularly metal ions. Using the results from the flame test, try to predict the name and formula of the solid in each of the three test tubes.



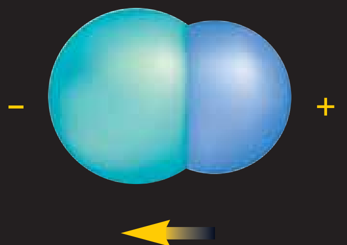
The colour of the flame is different for different elements and can be used to identify unknown substances. Calcium burns with an orange flame (A). Potassium has a lilac flame (B).

Visualizing Polar Molecules

When playing tug-of-war, if there are more—or stronger—team members on one end of the rope than the other, there is an unequal balance of power. The stronger team can pull harder on the rope and has the advantage. A similar situation exists in polar molecules, in which electrons are attracted more strongly by one type of atom in the molecule than another. Because of this unequal sharing of electrons, polar molecules have a slightly negative end and a slightly positive end, as shown below.



In a molecule of chloroform ($CHCl_3$), or trichloromethane (tri klor oh ME thayn), the three chlorine atoms attract electrons more strongly than the hydrogen atom does. This creates a partial negative charge on the chlorine end of the molecule and a partial positive charge on the hydrogen end. Chloroform is a clear, sweet-smelling liquid once widely used as an anesthetic in human and veterinary surgery.



Hydrogen and fluorine react to form hydrogen fluoride (HF). In an HF molecule, the two atoms are bound together by a pair of electrons, one contributed by each atom. The electrons are not shared equally because the fluorine atom attracts them more strongly than the hydrogen atom does. The result is a polar molecule with a slightly positive charge near the hydrogen end and a slightly negative charge near the fluorine end.

Check Your Understanding

Checking Concepts

1. List the information about a compound given by the name of:
   (a) an ionic compound
   (b) a covalent compound
2. Explain the following terms related to chemical naming.
   (a) multivalent
   (b) polyatomic
   (c) ratio of ions
3. List the prefixes used in covalent naming that represent the numbers 1 through 10.
4. Name each of the ions in the list below.
   (a) Na^+
   (b) SO_4^{2-}
   (c) V^{4+}
   (d) CN^-
   (e) NH_4^+
   (f) O^{2-}
5. List which of the following words describes each ion in question 4: polyatomic ion, multivalent metal, negative ion, positive ion.
6. Copy and complete the following chart about polyatomic ions in your notebook.

	Formula	Name	Number of Each Kind of Atom	Total Number of Atoms	Electric Charge on the Ion
(a)	CH_3COO^-				
(b)	HSO_3^-				
(c)	PO_4^{3-}				
(d)	CrO_4^{2-}				
(e)	$Cr_2O_7^{2-}$				
(f)	MnO_4^-				

Understanding Key Ideas

7. Write the formula of each of the following ionic compounds.
   (a) sodium bromide
   (b) calcium fluoride
   (c) iron(III) bromide
   (d) gold(I) iodide
   (e) vanadium(V) oxide
   (f) molybdenum(III) nitride
   (g) ammonium phosphate
   (h) potassium nitrate
   (i) manganese(II) perchlorate
8. Write the name of each of the following ionic compounds.
   (a) LiF
   (b) MgI_2
   (c) Fe_2O_3
   (d) Ag_3N
   (e) Au_3N
   (f) $Pt(SO_4)_2$
   (g) $(NH_4)_2CO_3$
   (h) $CsNO_3$
9. Write the formula of each of the following covalent compounds.
   (a) sulfur dioxide
   (b) chlorine monofluoride
   (c) nitrogen triiodide
   (d) dinitrogen monoxide
   (e) dinitrogen tetraoxide
   (f) selenium difluoride
10. Write the name of each of the following covalent compounds.
    (a) PF_5
    (b) P_4O_{10}
    (c) CO
    (d) SF_6
    (e) XeO_3
    (f) NO_2
    (g) OF_2
11. Copy and complete the following chart in your notebook.

	Formula	Ionic or Covalent?	Name of Compound
(a)	Cl_2O		
(b)	CO_2		
(c)	CoO		
(d)	CO		
(e)	PbO_2		
(f)	$MgCl_2$		
(g)	$PtCl_2$		
(h)	SCl_2		
(i)	$NaCH_3COO$		
(j)	NH_4CH_3COO		

Pause and Reflect

Reflect on the similarities and differences between ionic compounds and covalent compounds. Draw a mind map that shows both types of compounds and the steps for writing their chemical formulas. Include examples of compounds in your mind map.

4.3 Chemical Equations

A chemical change is a change in the arrangements and connections between ions and atoms. One or more chemical changes that occur at the same time are called a chemical reaction. Chemical reactions can be represented using a chemical equation. A chemical equation may be written in words or in chemical symbols. In a chemical reaction, the reactants are written to the left of an arrow and the products are written to the right. The symbols for states of matter may be used to show whether each reactant or product is solid, liquid, gas, or aqueous. Chemical reactions obey the law of conservation of mass, and atoms are neither destroyed nor produced in a chemical reaction. Chemical equations are balanced using the lowest whole number coefficients, which are numbers written in front of the pure substances in the reaction.

Words to Know

balanced chemical equation
chemical equation
chemical reaction
conservation of mass
products
reactants
skeleton equation
symbolic equation

A chemical change can be very spectacular (Figure 4.29A). Bubbling liquids, fumes, and new colours may appear. Light and heat may be produced, or energy may be consumed. However, many chemical changes happen very quietly and are not visible. Thousands of kinds of chemical changes happen in your body every day to help you digest your food and supply the nutrients needed by your body to grow and be active.

Figure 4.29A Copper reacting in nitric acid

Chemical change always involves the conversion of pure substances (elements and compounds) called **reactants** into other pure substances called **products** with different properties from the reactants. One or more chemical changes that occur at the same time are called a **chemical reaction**. A chemical reaction may be represented using a **chemical equation**. A chemical equation may be written in words or symbols. A **symbolic equation** is a set of chemical symbols and formulas that identify the reactants and products in a chemical reaction. For example, a reaction happening in the beaker in Figure 4.29A produces nitrogen dioxide, an air pollutant, which is a major component of smog in many cities (Figure 4.29B).

word equation: nitrogen monoxide + oxygen → nitrogen dioxide
symbolic equation: $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

Figure 4.29B Smog over Vancouver

A chemical equation may also show the following.

Coefficients: Integers are placed in front of the formula or a chemical symbol for an element. These coefficients can be used to determine the ratios between the various compounds in a chemical reaction. For example, in the reaction above, the coefficients show that two molecules of NO react with one molecule of O_2 to form two molecules of NO_2. In other words, NO and O_2 react in a 2:1 ratio.

State of matter: Letters indicate the compound's state: (g) for gas; (ℓ) for liquid; (s) for solid; (aq) for aqueous (dissolved in water).

Did You Know?

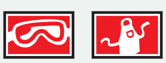
Some chemical changes produce electricity, as in a battery; some produce heat, as in a fire; and some produce light, as in a glow stick. Other chemical changes consume energy, as in cooking food.

4-3A Investigating Mass Changes in a Reaction

Find Out ACTIVITY

How do the masses of reactants compare to the masses of products? In this activity, you will seal the reactants of a chemical reaction in a closed container and then combine them, keeping the seal in place. You will measure and record the total mass before and after the reaction.

Safety



- Avoid touching all reactants and products.
- Wash your hands and equipment thoroughly after completing this activity.
- Do not remove any materials from the science room.

Materials

- small test tube that will fit inside sealed flask
- small Erlenmeyer flask
- solid rubber stopper to seal flask
- calcium chloride solution
- sodium carbonate solution
- small graduated cylinder (10–50 mL)
- paper towel
- balance

What to Do

1. Place the empty test tube into the Erlenmeyer flask and fit the rubber stopper into the flask. Make sure that the flask will seal properly with the test tube inside it. Open the flask, and take the test tube out.
2. Choose one of the solutions. Measure about 10 mL of the solution into a graduated cylinder and pour this into the Erlenmeyer flask. Wipe the outside of the flask with the paper towel to ensure it is dry.
3. Fill the test tube $\frac{2}{3}$ full with the second solution. Wipe the outside of the test tube to ensure it is dry.
4. Carefully slide the test tube filled with the second solution into the Erlenmeyer flask. Do not allow the solutions to combine. Seal the flask.
5. Check closely for any leaks, but do not allow the liquids to combine yet. If any leaking occurs, dispose of the chemicals as directed by your teacher, wash and dry your equipment thoroughly, and start again from the beginning.
6. Find and record the total mass of the flask and contents.
7. Tip the apparatus to allow the two solutions to combine. Observe what happens.
8. Predict whether the mass after combining is greater than, equal to, or less than the mass before combining.
9. Record the total mass of the flask and contents.
10. Compare your results with all students in your class.
11. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

What Did You Find Out?

1. As a general trend, did the chemical reaction cause the mass to increase, decrease, or stay the same?
2. It is unlikely that all the results were the same. Explain why results varied from one group to another.

Conservation of Mass in Chemical Change

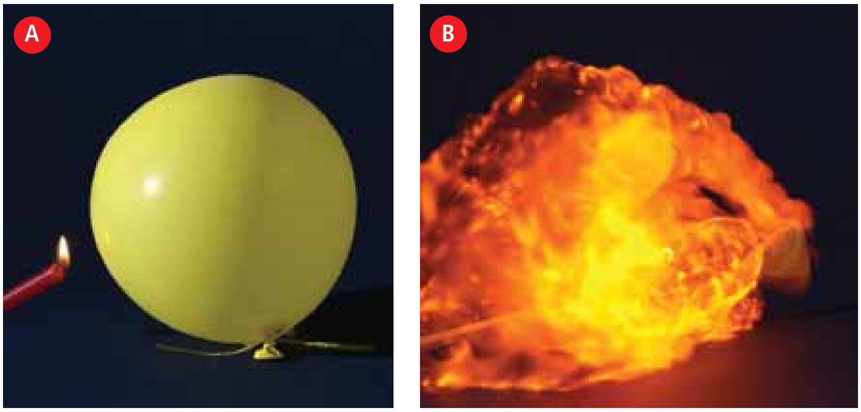


Figure 4.30 The hydrogen and oxygen in the balloon do not react until the balloon is touched by a flame (A). Then, an explosive chemical reaction occurs (B).

What happens to atoms of hydrogen and atoms of oxygen when the two gases are brought together and ignited (Figure 4.30)? Are new atoms created in the flash? Are some destroyed?

These are questions that the English chemist John Dalton (1766–1844) thought about 200 years ago (Figure 4.31). He imagined that tiny particles called atoms rearranged themselves in new ways during chemical reactions (Figure 4.32). He also imagined that during chemical reactions no atoms were ever created or destroyed. The total number of each kind of atom present at the start of the reaction equalled the total number of each kind of atom after the reaction. Dalton used these ideas to draw symbols for compounds as combinations of the atoms of different elements (Figure 4.33).

Figure 4.31 Dalton thought of atoms as combining when compounds form.

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

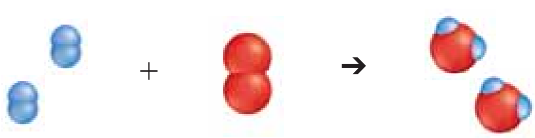


Figure 4.32 The reaction of oxygen molecules with hydrogen molecules involves rearranging atoms in new ways.

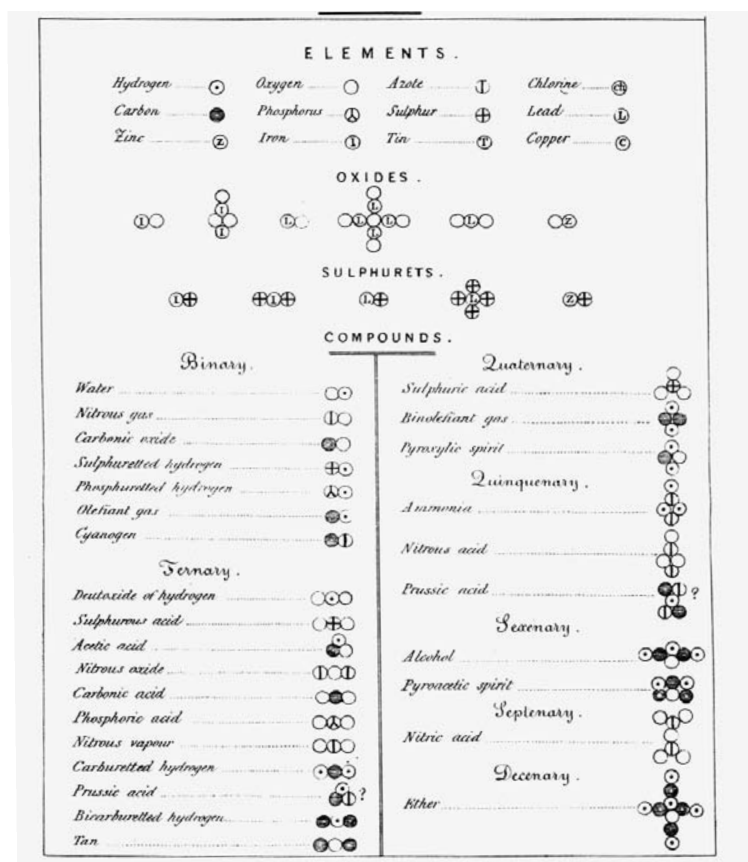


Figure 4.33 Once Dalton had visualized the way atoms can join to make compounds, he could picture how these atoms might rearrang in a chemical reaction.

The law of conservation of mass

Other researchers, such as Antoine Lavoisier (Figure 4.34) (1743–1794), who was a French chemist, and his wife, Marie-Anne, made careful measurements of the masses of reactants and products in many chemical reactions (Figure 4.34). They found that the total mass of the system never changed during a chemical change. Antoine Lavoisier identified and named oxygen in 1778 and hydrogen in 1783. He is credited with determining that water results from the combination of the elements oxygen and hydrogen. Lavoisier also devised a system of naming the elements.

Building on the work of other scientists and on the results of his own carefully controlled experiments, Lavoisier formulated the law of conservation of mass. The law of **conservation of mass** states that mass is conserved in a chemical reaction; the total mass of the products is always equal to the total mass of the reactants in a chemical reaction. The idea that atoms are conserved (neither made nor destroyed) is believed to be true for all chemical reactions (Figure 4.35).

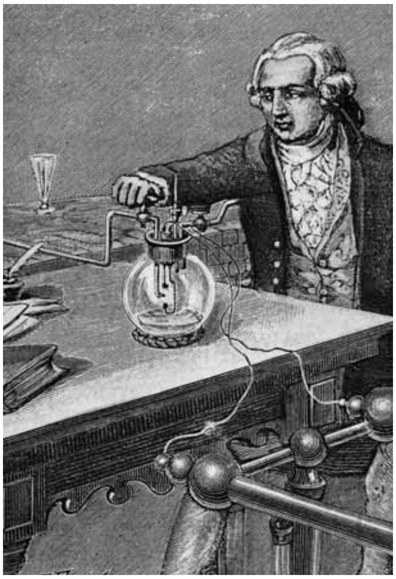
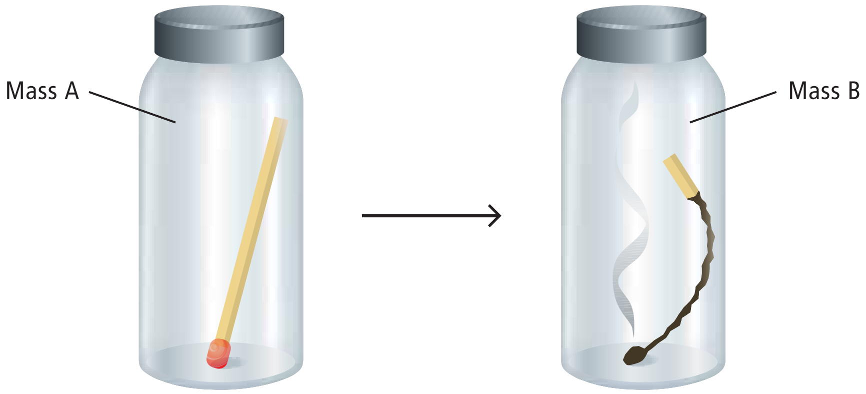


Figure 4.34 Antoine Lavoisier and his apparatus for a hydrogen combustion experiment

Conservation of Mass



Mass A [wood + air] = Mass B [carbon + CO_2 + H_2O]

Figure 4.35 Mass is conserved in a chemical reaction.

Reading Check

1. What is the definition of a chemical reaction?
2. What are two ways a chemical equation may be written?
3. What ratio can you determine using the coefficient in a chemical formula?
4. What are the four abbreviations for a compound's state of matter?
5. According to the law of conservation of mass, what does the total mass of the products in a chemical reaction equal?

Word Connect

"Conservation" means keeping or protecting. In science, there are many conservation laws. In each conservation law, some quantity, such as mass or energy, remains unchanged under all conditions.

Writing and Balancing Chemical Equations

The simplest form of a chemical equation is a word equation. For example, potassium metal reacts with oxygen gas to produce potassium oxide.

Arrow means "produces."

Reactants appear on left side of arrow.

potassium metal + oxygen gas ➔ potassium oxide

Products appear on right side of arrow.

Plus sign on left side means "reacts with."

Plus sign on right side means "plus."

A word equation provides only limited information about a chemical reaction. You can write a more useful equation by replacing words with chemical symbols and formulas. A **skeleton equation** simply shows the formulas of the reactants and products. The skeleton equation for the reaction of potassium metal with oxygen gas to form potassium oxide is:

skeleton equation: $K + O_2 \rightarrow K_2O$

Notice that the formula of potassium oxide is K_2O because it is an ionic compound made from K^+ ions and O^{2-} ions. The ions combine in a ratio of 2:1.

A skeleton equation does not show the correct proportions in which the reactants will actually combine and the products will be produced. So your next step would be to balance the skeleton equation. A **balanced chemical equation** shows the identities of each pure substance involved as well as the matching number of atoms of each element on both sides of a chemical equation. According to the law of conservation of mass, the mass of each element present is conserved during a chemical reaction. In other words, the number of atoms of an element is the same after a chemical reaction as it was before a chemical reaction. You can use this information to determine the coefficients that balance the equation. The balanced chemical equation for the above reaction is:

balanced chemical equation: $4K + O_2 \rightarrow 2K_2O$

The coefficient in front of the K is 4. The O_2 has a coefficient of 1, but it is not shown. The coefficient of 1 means that only one molecule of oxygen is required.

You can read this equation as "Four atoms of potassium (K) will combine with one molecule of oxygen (O_2) to produce two potassium oxides (K_2O)." This is much like a recipe used in cooking. For example, it is possible to "double" a recipe, which for this reaction means that eight atoms of K will react with two molecules of O_2 to produce four K_2O. Keep in mind that, in a balanced chemical equation, the smallest whole number ratio is always used, which for the above reaction is 4:1:2.

Reading Check

Refer to the following balanced chemical equation to answer these questions: $3H_2 + N_2 \rightarrow 2NH_3$

1. List the names of the reactants.
2. Give the formula of the product.
3. How many molecules of hydrogen (H_2) will combine exactly with one molecule of nitrogen (N_2)?
4. How many molecules of nitrogen are required to produce 10 molecules of ammonia (NH_3)?
5. What is the symbol that means "produces" in a chemical reaction?

Counting Atoms to Balance an Equation

You can use the law of conservation of mass to help you balance equations that contain compounds. Consider the combustion of methane (CH_4) in air (Figure 4.36).

word equation: methane + oxygen ➔ water + carbon dioxide
skeleton equation: $CH_4 + O_2 \rightarrow H_2O + CO_2$
balanced chemical equation: $CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$

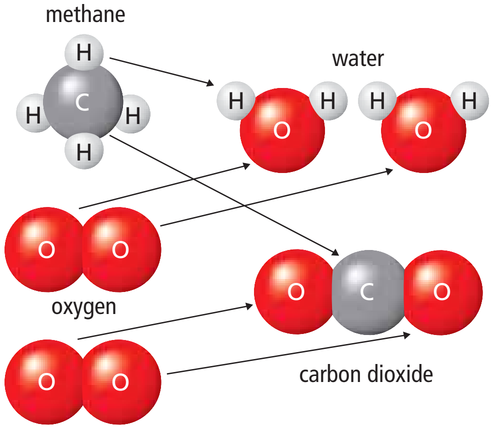


Figure 4.36 For an equation to be balanced, the same number of atoms of each element must be present on both sides of the equation.

We count the atoms in the balanced chemical equation as follows:
Reactants
CH_4 means 1 molecule of CH_4 (1 C atom and 4 H atoms).
$2O_2$ means 2 molecules of O_2 ($2 \times 2 = 4$ atoms of O).
Reactants total: 1 C, 4 H, 4 O

Products
$2H_2O$ means 2 molecules of H_2O ($2 \times 2 = 4$ H atoms and $2 \times 1 = 2$ O atoms)
CO_2 means 1 molecule of CO_2 (1 C atom and $1 \times 2 = 2$ O atoms)
Products total: 4 H, 1 C, 4 O
Since the numbers of atoms of carbon, hydrogen, and oxygen are equal in both the reactants and in the products, the equation is correctly balanced.

Practice Problems

List the total number of each type of atoms in the following reactants.

1. $2H_2O + 2NaF$
2. $3Br_2 + 2FeI_3$
3. $Pb(NO_3)_2 + 2NaI$
4. $2K_3PO_4 + 3(NH_4)_2SO_4$

Answers provided on page 591

Figure 4.37 During photosynthesis in a leaf, carbon dioxide and water react to produce glucose and oxygen.

	1			18
	1 + H Hydrogen 1.0			2 0 He Helium 4.0
14	15	16	17	
6 C Carbon 12.0	7 3– N Nitrogen 14.0	8 2– O Oxygen 16.0	9 – F Fluorine 19.0	10 0 Ne Neon 20.2
14 Si Silicon 28.1	15 3– P Phosphorus 31.0	16 2– S Sulfur 32.1	17 – Cl Chlorine 35.5	18 0 Ar Argon 39.9
32 4+ Ge Germanium 72.6	33 3– As Arsenic 74.9	34 2– Se Selenium 79.0	35 – Br Bromine 79.9	36 0 Kr Krypton 83.8
50 4+ 2+ Sn Tin 118.7	51 3+ 5+ Sb Antimony 121.8	52 2– Te Tellurium 127.6	53 – I Iodine 126.9	54 0 Xe Xenon 131.3
82 2+ 4+ Pb Lead 207.2	83 3+ 5+ Bi Bismuth 209.0	84 2+ 4+ Po Polonium (209)	85 – At Astatine (210)	86 0 Rn Radon (222)

Figure 4.38 Diatomic elements are shown in pink.

Did You Know?

Astatine is predicted to form diatomic molecules, but it is extremely rare, making it difficult to study. It is estimated that in the entire Earth's crust there is less than 30 g of astatine.

Hints for Writing Word Equations

Chemical equations can be written using chemical names instead of formulas. For example, a chemical reaction in plants consumes light energy and converts it into chemical energy in the form of sugar (Figure 4.37).

word equation: carbon dioxide + water ➔ glucose + oxygen

Translating this word equation into a skeleton equation presents several problems. It is likely that you know the formula for water is H_2O. But if you did not know, the formula would not be obvious from the name. Similarly, glucose is the correct chemical name for the sugar produced in photosynthesis, but the formula $C_6H_{12}O_6$ cannot be deduced from it. Finally, you would need to know that oxygen is a diatomic molecule.

skeleton equation: $CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$
balanced chemical equation: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

When you translate a word equation into a skeleton equation, remember these points.

- We use the chemical symbol for nearly all elements when they are not in a compound. For example, we use Cu to symbolize pure copper.
- Three common compounds containing hydrogen that you can memorize are methane (CH_4), ammonia (NH_3), and water (H_2O).
- There are seven common diatomic elements, all of which are non-metals. When these elements occur on their own (not in a compound), they are written as H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2. They are sometimes remembered as the "-gens": hydro*gen*, nitro*gen*, oxy*gen*, and the halo*gens*. A second nickname for the diatomic elements is "the special seven." If you look carefully at their location on the periodic table, you will see they form a "7" with the exception of hydrogen, as shown in Figure 4.38.

You can translate the following word equation into a skeleton equation and balance it.

hydrogen + nitrogen ➔ ammonia

Both reactants are diatomic.
The chemical formula for ammonia is NH_3.

$H_2 + N_2 \rightarrow NH_3$

Balancing gives:
$3H_2 + N_2 \rightarrow 2NH_3$

Strategies for Balancing Equations

Some strategies you can use to help you balance a skeleton equation include the following.

- Use trial and error. If you are not sure where to place the first coefficient, just start anywhere. For simple equations, this is often the fastest method.
- Balance compounds first and single elements last.
- Finish balancing all atoms in one formula after you have placed a coefficient in front. Do not jump from one pure substance to another before balancing the first formula.
- Add coefficients only in front of formulas. Do not change subscripts.
- Sometimes, oxygen or hydrogen will appear in more than one place on the reactants side or on the products side of the chemical equation. This is your signal to balance oxygen and hydrogen last. Once you have finished balancing the other elements, you may find that the oxygen and hydrogen are already balanced.
- You can sometimes treat polyatomic ions as a unit. For example, if SO_4^{2-} appears on both sides of the equation, count the number of SO_4^{2-} groups on both sides. This is often faster than counting S and O separately.
- Perform a final check once you are finished to be sure that all elements are balanced.

Hints for Balancing Equations

Some helpful hints for balancing equations are shown in the following examples. The goal is to determine the correct coefficient for each chemical symbol or formula in order to balance the equation. Read the examples, but do not write in your textbook.

Example 1

iron + bromine ➔ iron(III) bromide

___ Fe + ___ Br_2 ➔ ___ $FeBr_3$

- The subscripts in the formulas of Br_2 and $FeBr_3$ cannot be changed. There are two Br atoms on the left and three Br atoms on the right.

___ Fe + $3Br_2$ ➔ $2FeBr_3$

- You can balance the Br atoms by placing a 3 in front of the Br_2 while at the same time placing a 2 in front of the $FeBr_3$. This gives a total of six Br atoms on each side.

2Fe + $3Br_2$ ➔ $2FeBr_3$ (balanced)

- The Fe atoms are no longer in balance. Finish by placing a 2 in front of the Fe on the reactant side.

Did You Know?

Most diatomic elements are gases at room temperature. However, bromine is a liquid at room temperature, and iodine is a solid at room temperature.

Example 2

tin(IV) nitrite + potassium phosphate ➔ potassium nitrite + tin(IV) phosphate

$\_\_\_\ Sn(NO_2)_4 + \_\_\_\ K_3PO_4 \rightarrow \_\_\_\ KNO_2 + \_\_\_\ Sn_3(PO_4)_4$

- Oxygen is present in all four chemical formulas. Balance all the other elements first. By the time you get to oxygen, it may already be balanced.
- One Sn atom appears on the left, and three Sn atoms appear on the right. Balance Sn by putting a 3 in front of $Sn(NO_2)_4$. A 1 is implied in front of $Sn_3(PO_4)_2$.

$3Sn(NO_2)_4 + \_\_\_\ K_3PO_4 \rightarrow \_\_\_\ KNO_2 + Sn_3(PO_4)_4$

- Now that a coefficient has been placed in front of $Sn(NO_2)_4$, finish balancing the compound by considering the NO_2^- group.
- The NO_2^- group appears on both sides, so balance it as a unit. Since there are $3 \times 4 = 12$ NO_2^- groups on the left, place a 12 in front of KNO_2 on the right.

$3Sn(NO_2)_4 + \_\_\_\ K_3PO_4 \rightarrow 12KNO_2 + Sn_3(PO_4)_4$

- The coefficient 12 in front of KNO_2 should lead you to balance K next.
- Balance the K by placing a 4 in front of K_3PO_4.

$3Sn(NO_2)_4 + 4K_3PO_4 \rightarrow 12KNO_2 + Sn_3(PO_4)_4$ (balanced)

- Notice the phosphate group is balanced with $4PO_4^-$ on each side.
- A final check of individual oxygen atoms shows 4O on each side.

Example 3

ethane (C_2H_6) + oxygen ➔ carbon dioxide + water

Figure 4.39 Ethane is a by-product of petroleum refining.

$\_\_\_\ C_2H_6 + \_\_\_\ O_2 \rightarrow \_\_\_\ CO_2 + \_\_\_\ H_2O$

- Bring C into balance by placing a 2 in front of CO_2.

$C_2H_6 + \_\_\_\ O_2 \rightarrow 2CO_2 + \_\_\_\ H_2O$

- Because O appears in three of the four formulas and it is in elemental form, leave it for last.
- Balance H by placing a 3 in front of H_2O to give 6 H on each side.

$C_2H_6 + \_\_\_\ O_2 \rightarrow 2\ CO_2 + 3H_2O$

- The oxygen is now a problem because on the right there are $(2 \times 2) + (3 \times 1) = 7$ oxygen atoms. Since we wish to place an integer in front of O_2, there is a problem. For now, do not use an integer. Instead, balance O using a fraction. A coefficient of $3\frac{1}{2}$ will work.

$C_2H_6 + 3\frac{1}{2}\ O_2 \rightarrow 2\ CO_2 + 3H_2O$

- Now the equation is balanced, but the idea of having half a molecule of O_2 may seem odd, though it is correct. To make all coefficients integers, simply seems a problem. The solution is to double all the coefficients at once, giving the following set of integers.

$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$ (balanced)

Practice Problems

1. Balance each of the following skeleton equations.

(a) $NaI + AlCl_3 \rightarrow NaCl + AlI_3$
(b) $Li + Br_2 \rightarrow LiBr$
(c) $CH_4 + O_2 \rightarrow CO_2 + H_2O$
(d) $PbO \rightarrow Pb + O_2$
(e) $Na_4C + Ca \rightarrow Na + Ca_2C$
(f) $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$
(g) $Ca(NO_3)_2 + Cu_2SO_4 \rightarrow CaSO_4 + CuNO_3$
(h) $NaN_3 \rightarrow Na + N_2$
(i) $Mg(ClO_4)_2 + Na \rightarrow NaClO_4 + Mg$
(j) $AlCl_3 \rightarrow Al + Cl_2$

2. Write the skeleton equation for each of the following reactions. Then balance each of the equations.

(a) nitrogen monoxide + oxygen ➔ nitrogen dioxide
(b) iron(III) bromide + sodium hydroxide ➔ sodium bromide + iron(III) hydroxide
(c) methane + oxygen ➔ carbon dioxide + water
(d) calcium nitrate + potassium carbonate ➔ potassium nitrate + calcium carbonate
(e) phosphorus trichloride + chlorine ➔ phosphorus pentachloride
(f) potassium permanganate + nickel(II) nitrate ➔ potassium nitrate + nickel(II) permanganate
(g) iron + copper(II) chloride ➔ iron(II) chloride + copper
(h) sodium phosphate + barium hydroxide ➔ sodium hydroxide + barium phosphate

Answers provided on page 591

Suggested Activity

Conduct an Investigation 4-3B on page 212

Explore More

John Dalton thought that atoms had some kind of hooks that attached when they formed compounds. Find out more about early models of chemical compounds. Start your research at **www.bcscience10.ca**.

4-3B Observing Chemical Change

Skill Check

- Observing
- Predicting
- Communicating
- Working co-operatively

Safety

- Follow your teacher's directions regarding using open flames.
- Tie back long hair.
- Be sure to wear eye protection.
- Avoid touching all reactants and products.
- Wash your hands and equipment thoroughly after completing this activity.
- Do not remove any materials from the science room.

Materials

- hydrochloric acid solution (HCl)
- 50 mL graduated cylinder
- small Erlenmeyer flask
- rubber stopper with glass tube insert and rubber tube attachment
- 400 mL beaker
- water
- 3 medium test tubes
- sodium carbonate powder
- paper towel
- flame striker or matches
- Bunsen burner or candle
- wooden splints
- test tube tongs
- magnesium metal ribbon
- zinc metal (mossy)

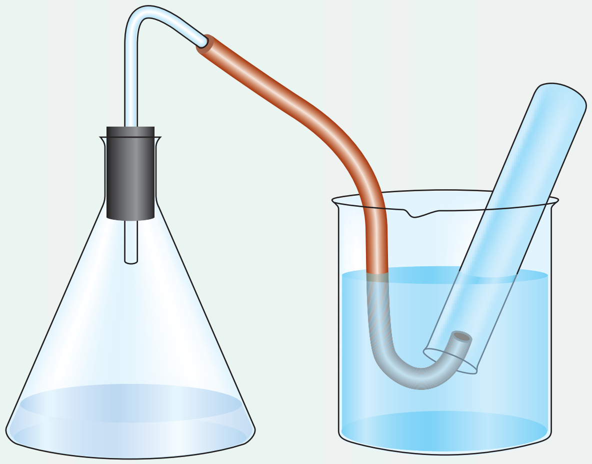
In this activity, you will observe three similar chemical reactions, all of which happen in solution (dissolved in water). You will write chemical equations representing these reactions.

Question

How can you observe, capture, and test the products of a chemical reaction?

Procedure

1. Measure 50 mL of HCl solution using a graduated cylinder, and pour it into the Erlenmeyer flask. Place the rubber stopper with the glass tube insert into the mouth of the Erlenmeyer flask to make sure it fits correctly. Attach a rubber tube to the outside of the glass tube.
2. Fill a 400 mL beaker $\frac{2}{3}$ with water. Fill a medium test tube with water, and invert it into the beaker without letting any air back into the test tube. Try not to spill any water. You may have to get your hands wet for this part of the procedure.
3. Place the end of the rubber tube inside the inverted test tube. Dry your hands.



Step 3

Adding sodium carbonate to the HCl solution:

4. Obtain about 3 g of sodium carbonate powder on a paper towel. Lift the rubber stopper out of the Erlenmeyer flask, and add the powder to the acid. Reseal the flask so no gas can get out. Observe as gas enters the inverted test tube.
5. Light the candle or Bunsen burner. Light a wooden splint. Lift the gas-filled inverted test tube out of the water, holding it in your hand or with test tube tongs. Bring the lit splint close to the mouth of the test tube, and attempt to ignite the gas that was collected. Record your observations.
6. Dispose of the HCl solution from the Erlenmeyer flask as directed by your teacher. Clean and dry the flask.

Adding magnesium metal ribbon to the HCl solution:

7. Repeat procedure steps 1 to 3.
8. Obtain a piece of magnesium ribbon on a paper towel from your teacher. Lift the rubber stopper out of the Erlenmeyer flask, and add the magnesium ribbon to the acid. Reseal the flask so no gas can get out. Observe as gas enters the inverted test tube.
9. Light a wooden splint. Lift the gas-filled inverted test tube out of the water, holding it in your hand or with test tube tongs. Bring the lit splint close to the mouth of the test tube, and attempt to ignite the gas that was collected. Record your observations.
10. Dispose of the HCl solution from the Erlenmeyer flask as directed by your teacher. Clean and dry the flask.

Adding zinc metal (mossy) to the HCl solution:

11. Repeat procedure steps 1 to 3.
12. Obtain a piece of mossy zinc metal on a paper towel from your teacher. Lift the rubber stopper out of the Erlenmeyer flask, and add the zinc metal to the acid. Reseal the flask so no gas can get out. Observe as gas enters the inverted test tube.
13. Light a wooden splint. Lift the gas-filled inverted test tube out of the water, holding it in your hand or with test tube tongs. Bring the lit splint close to the mouth of the test tube, and attempt to ignite the gas that was collected. Record your observations.
14. Dispose of the HCl solution from the Erlenmeyer flask as directed by your teacher.
15. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

Analyze

1. In step 4, a chemical reaction occurred between hydrochloric acid (HCl) and sodium carbonate. The products were sodium chloride, carbon dioxide gas, and water. For this reaction, write:
   (a) the word equation
   (b) the skeleton equation
   (c) the balanced chemical equation
2. In step 8, a chemical reaction occurred between hydrochloric acid (HCl) and magnesium metal. The products were magnesium chloride and hydrogen gas (H_2). For this reaction, write:
   (a) the word equation
   (b) the skeleton equation
   (c) the balanced chemical equation
3. In step 12, a chemical reaction occurred between hydrochloric acid (HCl) and zinc metal. The products were zinc chloride and hydrogen gas (H_2). For this reaction, write:
   (a) the word equation
   (b) the skeleton equation
   (c) the balanced chemical equation

Conclude and Apply

1. (a) In what ways were the three chemical reactions similar?
   (b) In what ways were the three chemical reactions different?
2. The hydrogen in the test tube reacted with the oxygen in the air.
   (a) What do you think is the product of this reaction?
   (b) What is the balanced equation for this reaction?

Science Watch

Antoine and Marie-Anne Lavoisier

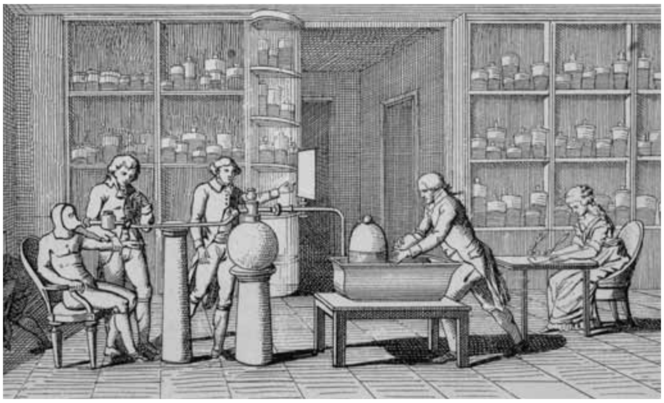
In 1783, the brilliant chemist Antoine Lavoisier presented an experiment to the French Academy of Sciences that shocked the scientific world. Lavoisier showed how he had been able to separate water into two gases, which he called hydrogen and oxygen. He then recombined the two gases and ignited them with a spark. The result was the formation of water. In recombining the two gases, he had shown that water is not an element, something not known at the time.

Although this was not the first time these chemical reactions had been studied, Lavoisier was the first person to correctly explain what was happening during the reactions. His understanding revolutionized scientists' knowledge of everyday processes such as combustion, by showing that it is the reaction of substances with oxygen.

Lavoisier was guided towards his discoveries through an idea that he had pursued since early in his scientific career. His idea became the most important concept in chemistry since Dalton's suggestion that matter was made of atoms. The idea was that all chemical reactions occur in such a way that the total mass of the chemicals involved never changes. For example, consider a campfire. The burning wood changes into gases, which, if captured and weighed, would equal the mass of the original wood and oxygen that burned it. Such a hypothesis is very difficult to prove, especially with gases, which tend to escape and are difficult to contain and weigh.

Lavoisier had help in his endeavours. His wife, Marie-Anne was interested in chemistry, which she studied along with English and art. She became Lavoisier's assistant and colleague. They worked together in their laboratory. Antoine spoke only French, and Marie translated many of his writings into English. She also translated the writings of English scientists into French. Together, the Lavoisiers laboured for 20 years to gather data that showed that the masses of the reactants always equalled the masses of the products. Their data provided evidence of the law of conservation of mass.

Modern chemistry has its basis in the law of conservation of mass. For example, when 4 g of hydrogen gas react to produce 36 g of water, the law tells us that some other substance must have reacted with the hydrogen to make the water. The law even tells how much of the other substance was used: 32 g. Through understanding the law of conservation of mass, Antoine and Marie-Anne Lavoisier were able to discover the role of oxygen in combustion.



Marie-Anne Lavoisier is shown taking notes as Antoine presents an experiment.

Questions

1. How did the Lavoisiers demonstrate that water is not an element?
2. What idea about the behaviour of chemical reactions guided Antoine Lavoisier for most of his career?
3. In what ways were Marie-Anne and Antoine Lavoisier colleagues?

Check Your Understanding

Checking Concepts

1. Most commercial trucks use diesel fuel. Consider the following reaction that occurs during the combustion of diesel fuel.

heptane + oxygen ➔ carbon dioxide + water

$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$

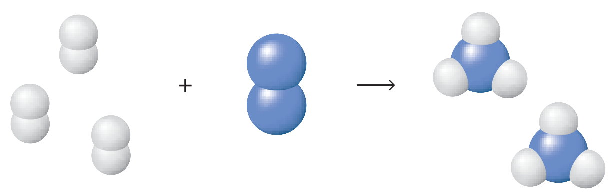
(a) List the names of the reactants.

(b) Give the formulas of the products.

(c) What is the coefficient of the carbon dioxide?

(d) What is the meaning of the + symbol on the left side of the equation?

2. Study the following diagram, and then write a skeleton equation for the reaction it represents. A white circle represents an H atom. A blue circle represents an N atom.



$3\,H_2 + N_2 \longrightarrow 2\,NH_3$

Understanding Key Ideas

3. Copy and balance the following skeleton equations.

(a) $Al + F_2 \rightarrow AlF_3$

(b) $PbCl_4 + K_3PO_4 \rightarrow KCl + Pb_3(PO_4)_4$

(c) $Br_2 + FeI_3 \rightarrow I_2 + FeBr_3$

(d) $Na_2CO_3 + Cr(NO_3)_3 \rightarrow NaNO_3 + Cr_2(CO_3)_3$

(e) $Mn + I_2 \rightarrow MnI_4$

(f) $C_2H_6 + O_2 \rightarrow CO_2 + H_2O$

(g) $K_2SO_4 + AgNO_3 \rightarrow Ag_2SO_4 + KNO_3$

(h) $Ca(OH)_2 + HCl \rightarrow CaCl_2 + H_2O$

(i) $Mg_3N_2 \rightarrow Mg + N_2$

(j) $Fe + CuCl_2 \rightarrow FeCl_3 + Cu$

4. Write skeleton equations for the following chemical reactions and then balance them. Be sure to check your formulas carefully before you begin to balance.

(a) lithium phosphate + magnesium sulfate ➔ lithium sulfate + magnesium phosphate

(b) zinc iodide + copper(I) nitrate ➔ zinc nitrate + copper(I) iodide

(c) mercury(II) nitrate + sodium hydrogen carbonate ➔ sodium nitrate + mercury(II) hydrogen carbonate

(d) nickel(III) iodide and iron(II) sulfide ➔ nickel(III) sulfide + iron(II) iodide

(e) aluminum hydroxide + hydrogen fluoride ➔ aluminum fluoride + water

(f) hydrogen chloride + barium hydroxide ➔ barium chloride + water

(g) calcium bromide + potassium carbonate ➔ calcium carbonate + potassium bromide

(h) titanium(III) fluoride + cesium sulfite ➔ cesium fluoride + titanium(III) sulfite

(i) barium sulfate + sodium hydroxide ➔ sodium sulfate + barium hydroxide

(j) calcium chloride + potassium ➔ potassium chloride + calcium

(k) hydrogen nitrate + strontium carbonate ➔ strontium nitrate + water + carbon dioxide

Pause and Reflect

The law of conservation of mass was developed after many experiments consistently showed that mass is neither gained nor lost during a chemical reaction. How does our understanding of atoms help explain why mass does not change during chemical reactions?

Chapter 4

Chapter Review

Prepare Your Own Summary

In this chapter, you investigated atomic theory, chemical bonding, compounds, and balancing chemical equations. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 11 for help with graphic organizers.) Use the following headings to organize your notes:

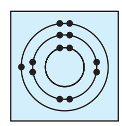
1. Atomic Theory and the Periodic Table
2. Bohr Diagrams and Lewis Diagrams of Compounds
3. Names and Chemical Formulas of Ionic Compounds
4. Names and Chemical Formulas of Covalent Compounds
5. Balancing Chemical Equations

Checking Concepts

1. Copy and complete the following chart in your notebook.

Property	Proton	Electron	Neutron
Relative mass		1	
Charge	+		
Location in the atom			

2. (a) List the names of four chemical families in the periodic table.
(b) State the group number of each family.
(c) Describe a special property of each family.
3. (a) Explain how metal atoms become ions.
(b) Explain how non-metal atoms become ions.
4. Define "stable octet."
5. (a) Define "multivalent."
(b) Name one metal ion that is multivalent.
(c) Name one metal ion that is not multivalent.
6. Name and give the symbol for each of the following.
(a) the element in period 3 and group 2
(b) the halogen in period 4
(c) the element in period 6 and group 11
(d) the alkali metal in period 2
(e) the noble gas in period 1
7. Draw a Bohr diagram of the protons and electrons in each of the following.
(a) an atom of magnesium
(b) a chloride ion, Cl^-
(c) a calcium ion, Ca^{2+}
(d) an atom of argon
(e) the ionic compounds lithium fluoride, LiF, and beryllium chloride, $BeCl_2$
(f) the covalent compounds ammonia, NH_3, and methane, CH_4
8. Draw a Lewis diagram for each of the following.
(a) one atom of each of the elements in the second period
(b) one atom of each of the elements in the halogen family (group 17)
(c) the molecules H_2 and F_2
(d) the covalent compounds HF, H_2O, and OBr_2
9. Identify the following atoms from their Bohr diagram.

(a)


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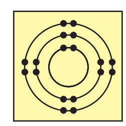

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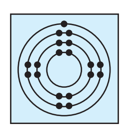

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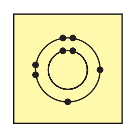
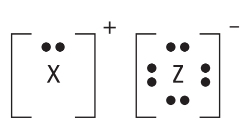


10. (a) Identify the following compounds as ionic or covalent from their Lewis diagram.
(b) Write a formula for a compound that they might represent using elements with an atomic number less than 21.

(a)


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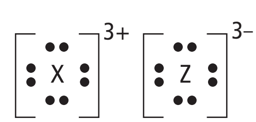

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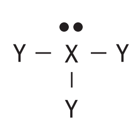

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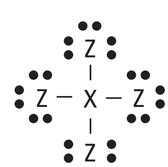

11. Copy and complete the following chart in your notebook.

	Reactants	Name	Formula
(a)	sodium and nitrogen		
(b)	magnesium and oxygen		
(c)	aluminum and sulfur		
(d)	gallium and fluorine		
(e)	silver and selenium		
(f)	zinc and chlorine		

12. Write the formula for each of the following compounds involving a multivalent metal ion.
(a) gold(III) fluoride
(b) lead(IV) nitride
(c) copper(I) iodide
(d) nickel(III) sulfide
(e) chromium(II) oxide

13. Write the name for each of the following compounds involving a multivalent metal ion. Remember to include the Roman numeral in the metal ion's name.
(a) $SnCl_4$
(b) Au_3N
(c) PbS_2
(d) Bi_2O_5
(e) FeI_3
(f) UF_6

14. Write the formula for each of the following ionic compounds, which may contain a multivalent metal ion or a polyatomic ion.
(a) sodium carbonate
(b) ammonium phosphate
(c) ammonium nitrate
(d) iron(III) nitrite
(e) calcium perchlorate

15. Write the name for each ionic compound.
(a) $Al_2(SO_4)_3$
(b) NH_4CH_3COO
(c) $Fe_2(CrO_4)_3$
(d) $Na_2Cr_2O_7$
(e) KCN
(f) $Pb(HS)_2$

16. Write the formula for each covalent compound.
(a) phosphorus pentachloride
(b) nitrogen trichloride
(c) sulfur hexaiodide
(d) tetraphosphorus decaoxide
(e) dinitrogen trioxide

17. Write the name of each covalent compound.
(a) N_2F_4
(b) PBr_3
(c) NBr_3
(d) CO_2

18. Copy and complete the following chart in your notebook.

	Formula	Ionic or Covalent?	Name of Compound
(a)	$CaCl_2$		
(b)	$CuCl_2$		
(c)	SCl_2		
(d)	CoS		

19. List the total number of each type of atoms in the following reactants.
(a) $2HCl + Ca(OH)_2$
(b) $2Na_3PO_3 + 3Ca(NO_3)_2$

20. Balance each of the following skeleton equations.
(a) $KCl + Pb(NO_3)_2 \rightarrow PbCl_2 + KNO_3$
(b) $Na + F_2 \rightarrow NaF$
(c) $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$
(d) $C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$

Applying Your Understanding

21. Antoine and Marie-Anne Lavoisier did many chemical experiments involving the metal mercury. In one type of experiment, they put liquid mercury in a jar and sealed it in with oxygen gas. Suppose that, in one of these experiments, they observed that 10.0 g of silver-coloured mercury changed into 10.8 g of a red solid. As the solid formed, the pressure of the oxygen gas decreased.
(a) Why did the pressure drop in the sealed jar?
(b) What mass of gas was consumed in the reaction?
(c) What might be the identity of the new substance?

Pause and Reflect

How did reading this chapter change your understanding of the formation of chemical compounds? Create a graphic organizer showing what you knew (or predicted) before you read this chapter and what you know now.