Chapter 5.3- 5.8

INQUIRY SKILLS MENU
- ○ Questioning
- ○ Hypothesizing
- ○ Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ○ Evaluating
- ● Communicating

Testing Properties of Substances

How can you investigate a chemical substance in the laboratory? As you have seen, labels, WHMIS symbols, and the MSDS can provide some information about the physical and chemical properties of substances. You can also use chemical tests to investigate the properties of a substance.

Physical properties that can be tested for in the laboratory include solubility in water and the ability to conduct an electrical current. An **electrolyte** is a substance whose water solution can conduct electricity. A nonelectrolyte is a substance whose water solution does not conduct electricity.

Chemical properties can also be investigated in the laboratory. For example, the characteristic chemical reaction of a substance with an acid is a chemical property because it results in the production of a new substance, usually a gas. Often, the gas itself can be identified through observation of its properties. In this investigation, you will have the opportunity to review some basic lab skills as you investigate the properties of substances.

Question

How can the physical and chemical properties of substances be determined?

Design

In this investigation, you will test the solubility and electrical conductivity of several substances. You will also investigate the reactions of some substances with acid, and use chemical tests to determine the identity of gases formed as products.

(a) Read the Procedure and make a table to record (K7) your observations. For Parts 1 and 2, possible headings could be *Substance tested*, *Solubility in water*, and *Conductivity of solution*. For Part 3, possible headings could be *Starting materials*, *Observations during change*, and *Observations during gas test*.

Materials

- apron
- safety goggles
- sodium chloride (salt)
- sodium bicarbonate (baking soda)
- calcium carbonate powder (chalk)
- potassium bromide
- calcium chloride
- copper(II) sulfate
- glucose
- sucrose (table sugar)
- scoopula or toothpicks
- large-well "comboplate" microtray or 11 50-mL beakers
- distilled water
- tap water
- vegetable oil
- conductivity apparatus
- mossy zinc
- hydrochloric acid solution (10% or 1.0 mol/L)
- 3 small test tubes
- test tube holder
- wooden splints
- limewater (calcium hydroxide) solution (0.02 mol/L)
- rubber stopper or cork

Copper(II) sulfate and potassium bromide are poisonous and are irritants. Report any spills to your teacher.

Hydrochloric acid is corrosive. Any spills on the skin, in the eyes, or on clothing should be washed immediately with plenty of cold water. Report any spills to your teacher.

SKILLS HANDBOOK: (K7) Preparing Tables of Evidence

Procedure

Part 1: Solubility in Water

1. Put on your apron and safety goggles (**Figure 1**).

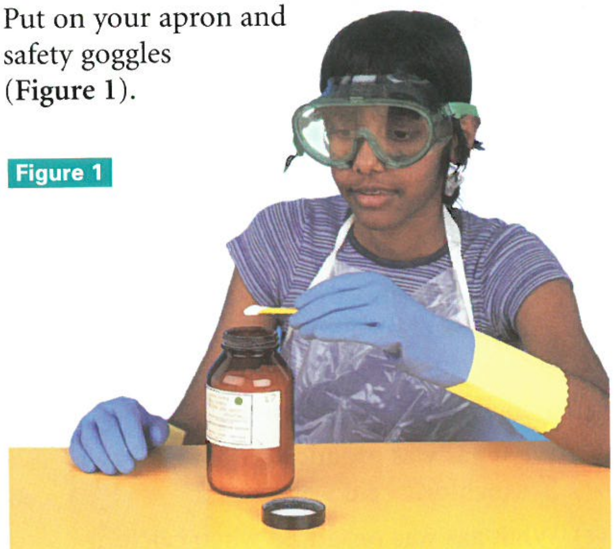


Figure 1

2. Obtain small samples of each of the following solids: sodium chloride, sodium bicarbonate, calcium carbonate, potassium bromide, calcium chloride, copper(II) sulfate, glucose, and sucrose.

3. Number eleven microtray wells or beakers. Each well or beaker will hold a different set of substances. Half-fill each of eight microtray wells with distilled water.

4. Add a small amount (enough to cover the tip of the scoopula) of sodium chloride to well 1. Stir the mixture to see whether the solid will dissolve. Save the mixture for Part 2. Record your observations.

5. Repeat step 4 with the seven other solids (one in each of wells 2 through 8). Record your observations.

Part 2: Conductivity

6. Half-fill three more microtray wells with distilled water (well 9), tap water (well 10), and vegetable oil (well 11).

7. Assemble the conductivity apparatus, as shown in **Figure 2**. Insert the two nails into the well containing distilled water (well 9). If the lamp glows, the liquid conducts electricity. If the lamp does not glow, the liquid does not conduct electricity. Rinse and dry the nails. Record your observations.

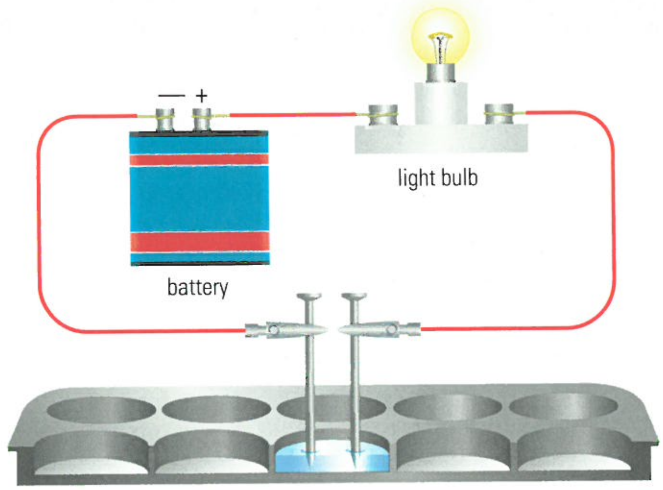


Figure 2

8. Insert the conductivity apparatus into the well containing tap water (well 10). After testing for conductivity, rinse and dry off the nails. Record your observations.

9. Insert the conductivity apparatus into the vegetable oil (well 11). After testing for conductivity, dry off the nails to remove any oil coating, rinse them with water, and dry them again. Record your observations.

10. Insert the conductivity apparatus into each of the mixtures in the remaining eight wells in turn (i.e., wells 1 through 8), cleaning the nails between trials. If the lamp glows, the solid is an electrolyte. If the lamp does not glow, the solid is a nonelectrolyte. Record your observations.

Part 3: Reaction with Acid

11. Obtain a small amount of zinc. Place hydrochloric acid solution to a depth of 2 cm in a small test tube.

12. Add the zinc to the hydrochloric acid. When the reaction has proceeded for about 30 s, light a wooden splint and bring it to the mouth of the test tube (**Figure 3**). Record your observations.

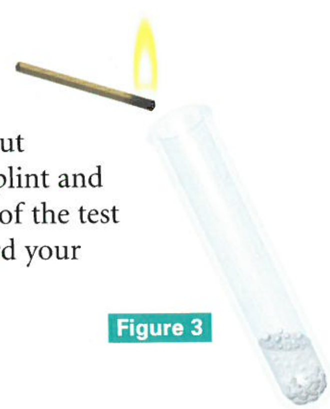


Figure 3

13 Place hydrochloric acid to a depth of about 0.5 cm in a test tube. Add about three times the volume of water to make a more dilute hydrochloric acid solution. In another test tube, place limewater to a depth of about 2 cm.

14 Obtain a small amount of calcium carbonate powder (enough to cover a fingernail). Add the calcium carbonate to the dilute hydrochloric acid. When the reaction has proceeded for about 30 s, carefully pour the product gas from the reaction into the limewater solution (**Figure 4**).

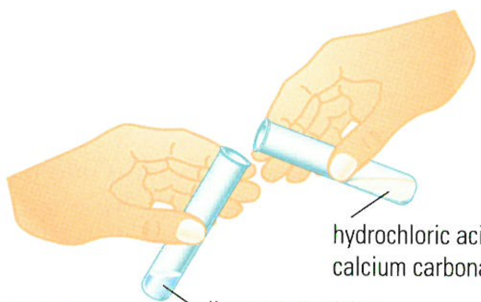


Figure 4

Do not allow any of the liquid to pour from the reaction tube. Insert a rubber stopper or cork into the limewater tube and shake the tube to dissolve the gas. Record your observations.

15 Dispose of the mixtures in your test tubes and microtrays as instructed by your teacher. Clean up your work station. Wash your hands.

Analysis

(b) Which substances were soluble in water? Which were insoluble?

(c) Which soluble substances were electrolytes? Which were nonelectrolytes?

(d) What gas was produced when zinc and hydrochloric acid were mixed?

(e) What gas was produced when calcium carbonate was added to hydrochloric acid solution?

(f) Write up your investigation as a formal (Q) lab report.

Understanding Concepts

1. Which properties in this investigation were physical and which were chemical? Explain.

2. What gases were tested for in this activity? What chemical test was used for each gas?

3. (a) What do the substances whose water solutions conduct electricity have in common? For example, what kinds of elements are they composed of?

(b) Sucrose and glucose contain the elements carbon, oxygen, and hydrogen. What kinds of elements are these?

(c) What conclusions can you make about substances that conduct or cannot conduct electricity when dissolved in water?

Making Connections

4. What safety precautions did you follow in this investigation?

Exploring

5. Carbon dioxide is naturally present in air and can be produced using common household materials.

(a) Plan a way to test air for the presence of carbon dioxide.

(b) Plan methods of testing whether carbon dioxide is (K) present when

(i) a seltzer tablet is placed in water

(ii) a can of pop is opened

(iii) vinegar is added to baking soda

Check all procedures with your teacher. Try the methods, observing all safety measures, and write a brief report on the ways in which carbon dioxide is produced.

Reflecting

6. Complete the following statement: "Something that captured my attention in this investigation was ... ."

SKILLS HANDBOOK: (Q) Lab Reports (K) Planning an Investigation

5.4 Career Profile

Lynn Walker

Chemical Engineer

Lynn Walker has always wanted to apply her science interests and training to challenging, real-world problems. She discovered that she could accomplish all this as a chemical engineer.

Lynn earned a degree in chemical engineering from the University of Waterloo in 1998. She took a five-year co-op program alternating four months of class study with four months of work in the field. During those co-op terms, she worked in the paint department of a car-manufacturing plant, for Environment Canada, and at Petro-Canada.

Lynn enjoyed her Petro-Canada experience and now is a process engineer in the company's Oakville refinery. She works in a team that solves problems arising in the refinery's day-to day operations and also makes sure that all oil-processing systems are operating at peak efficiency. A big focus of her work is ensuring that environmental regulations are met. To address these efficiency and environmental goals, chemical engineers have to be innovative.

"You need to be creative in your thinking. Part of being a process engineer is getting your coveralls on and going out into the plant to obtain physical measurements, which sometimes requires climbing tall distillation towers. You also must talk to a range of refinery personnel from tradespeople, to other engineers, and to senior management," Lynn says.

During high school, Lynn excelled at science and math, but was also strong in English. According to Lynn, good communication skills are a necessity in chemical engineering.

She became interested in engineering during her senior year of high school. Lynn admits that when choosing a career, she was influenced by her father's career choice (an electrical engineer). She was able to see firsthand that engineering is an applied science, mixing theory and practice.

While the academic training of Lynn's chemical engineering degree gave her the background needed in the petroleum industry, much of her learning has been acquired on the job. And there's a lot to know, given the different chemical distillation processes involved in creating the many products made from crude oil: gasoline, diesel, jet fuel, home heating oil, asphalt for roads, materials used to manufacture plastics, and sulfur, a by-product sold to make sulfuric acid.

Asked what she most enjoys about her work, Lynn replies, "It's hands-on and applied. You can see direct results of the work you do, and you're always learning. The field never stays still."

Making Connections

1. Lynn emphasizes the importance of good communication skills in her work. Interview an engineer to find out what communication tools or techniques are used.

Work the Web

Visit www.science.nelson.com and follow the links from Science 10, 5.4 to help you answer the questions below.

(a) How does an engineer qualify to have P. Eng. after his or her name?

(b) List industries and other places where a chemical engineer might work.

5.5

Elements and the Periodic Table

In Investigation 5.3, you discovered that some substances are electrolytes—their water solutions conduct electricity. Such substances as sodium chloride, potassium bromide, lithium fluoride, and calcium chloride all produce solutions that are electrical conductors. What makes these compounds electrolytes?

Substances such as vegetable oil and sugar are nonconductors, or insulators, when they are dissolved in water. They are nonelectrolytes. What makes these compounds different from electrolytes? We can answer these questions by looking at the types of elements that make up these compounds.

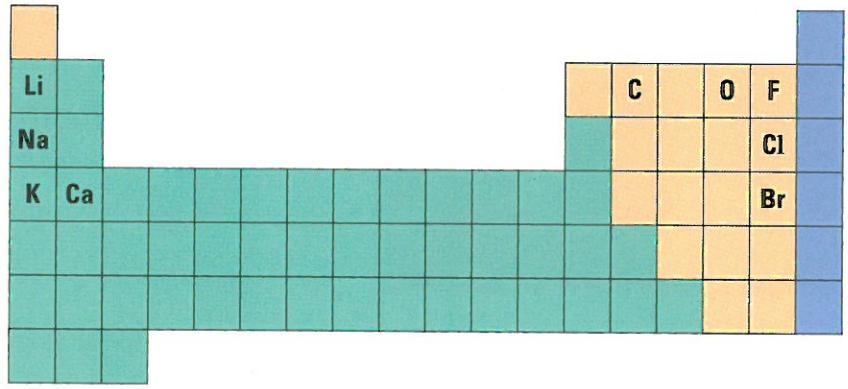


Figure 1
The position of elements in the periodic table provides hints about the types of compounds they form.

The Periodic Table

You have already learned that all the elements can be organized into a **periodic table** — a structured arrangement of elements that helps us to explain and predict physical and chemical properties. You will see a more detailed periodic table at the back of this text, but **Figure 1** shows a periodic table with only certain elements highlighted.

Elements such as sodium (Na) and potassium (K) were combined with other elements, such as chlorine (Cl) and bromine (Br) to form the compounds you encountered in Investigation 5.3. Note that sodium chloride, potassium bromide, lithium fluoride, and calcium chloride all involve pairs of elements that are on opposite sides of the periodic table. Something about the structure of these compounds results in the formation of conducting solutions.

Sugar and methyl alcohol contain carbon (C) and oxygen (O), which are both on the right side of the table. Even when these substances dissolve in water, they are nonelectrolytes. How does the arrangement of elements in the table reflect the types of compounds that elements form?

The periodic table is generally arranged with metals toward the left side of the table. Sodium, potassium, lithium (Li), and calcium (Ca) are all metals (**Figure 2**). Nonmetals are generally found on the right side of the

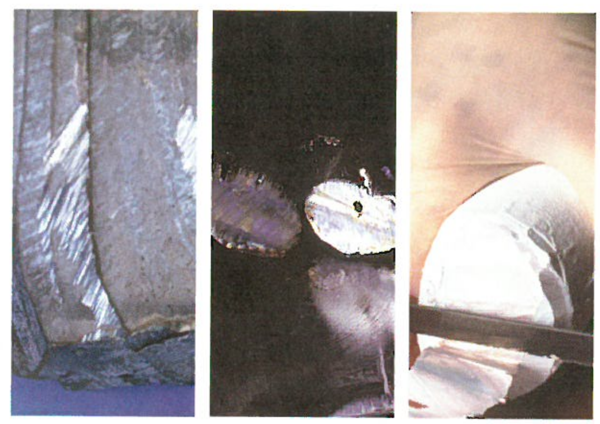


Figure 2
Metals are generally shiny solids.

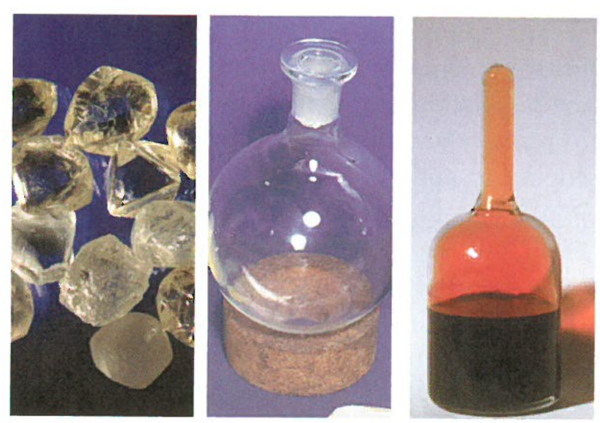


Figure 3
Nonmetals exist in all three states of matter at room temperature.

table. Carbon, oxygen, fluorine (F), and chlorine are all nonmetals (**Figure 3**). One exception is the lightest element, hydrogen (H). Although it is located in the top left corner of the periodic table, it behaves mostly as a nonmetal.

Metals and nonmetals have quite different physical and chemical properties, as **Table 1** shows. These properties can be explained by considering the structure of the atoms that make up these elements.

Table 1 **Properties of Metals and Nonmetals**

Property	Metals	Nonmetals
lustre	shiny	dull
malleability	malleable	brittle
conductivity	conductors	mostly insulators
reactivity with acid	mostly yes	no
state at room temperature	mostly solids	solids, liquids, and gases

Chemical Families

Elements in the periodic table can be grouped into families. **Chemical families** are groups of elements in the same vertical column of the periodic table. They tend to have similar physical and chemical properties. For example, the elements in the far left column of the periodic table are called **alkali metals.** These elements, also called Group 1 elements, include lithium, sodium, and potassium, and are all shiny, silvery metals. They form compounds that are mostly white solids and are very soluble in water. Group 2 elements, also known as **alkaline earth metals**, include magnesium (Mg), calcium, and barium (Ba). These elements are also shiny, silvery metals, but they form compounds that are often insoluble in water.

Did You Know?

The noble gases have been made to form some compounds. In 1962, Neil Bartlett, a chemist working at the University of British Columbia, synthesized the first noble gas compound—$XePtF_6$ or xenon hexafluoroplatinate.

The elements in the far right column of the periodic table are called the **noble gases.** Noble gases include such elements as helium (He) and neon (Ne). Generally, noble gases do not form compounds.

The elements in the second column from the right are called **halogens**. These nonmetallic elements, also called Group 17 elements, include fluorine, chlorine, and bromine. Halogens are all poisonous elements that react readily with sodium and other alkali metals.

Elements and Atomic Structure

What are atoms made of? The Bohr-Rutherford model of the atom (**Figure 4**) suggests that atoms are composed of three types of subatomic particles: protons, neutrons, and electrons. **Protons** are heavy positively charged particles that are found in a dense positive core of the atom called the nucleus. The number of protons in an atom is equal to the element's atomic number. **Neutrons** are neutral particles that have about the same mass as protons and are also found in the nucleus. **Electrons** are negatively charged particles with almost no mass that "circle" the nucleus at different energy levels, also called orbits or shells. Since atoms are electrically neutral, the number of electrons in an atom equals the number of protons.

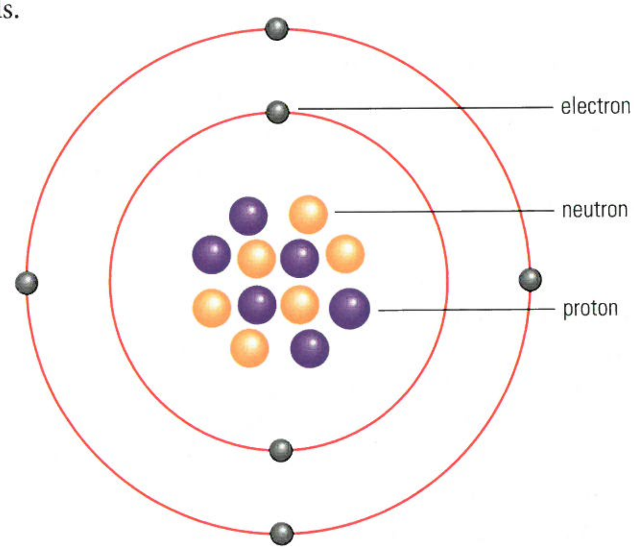


Figure 4
In the Bohr-Rutherford model of the atom, electrons travel in orbits about a positively charged nucleus. This is a model of a carbon atom (not to scale).

The key to understanding the formation of compounds is understanding the arrangement of the electrons about the nucleus.

The farther away an electron is from the nucleus, the greater is its energy and the more likely it is to be involved in a chemical change. Thus, the electrons in the outer orbit are involved in bonding. We can use **Bohr diagrams** to represent the arrangement of electrons in various orbits. Each orbit has a definite number of electrons. The first orbit can have a maximum of two electrons. The second orbit can have no more than eight electrons and, for elements with up to twenty electrons, the third orbit can also have no more than eight electrons. **Figure 5** shows Bohr diagrams for several elements.

Did You Know?

The outer electron shell of an atom is also called the **valence shell**, and the electrons in this shell are called valence electrons.

The noble gases do not easily form compounds because their arrangements of electrons are particularly stable. The electron arrangements for the first three noble gases are shown in **Figure 6**.

When elements form compounds, changes occur in the arrangement of electrons. In some compounds, electrons are transferred from one atom to another (or to several others) so that the atoms can have the stable electron arrangements of the closest noble gases.

Consider what might happen to the electrons in a metal such as lithium. As you can see in **Figure 5**, lithium has two electrons in the first orbit and one in the second orbit. If lithium loses the electron in its outer orbit, it has the same stable electron arrangement as helium: two electrons in the first orbit. But the lithium atom no longer has a neutral electric charge. It has formed an **ion**, a charged atom in which the number of electrons is different from the number of protons. The **ionic charge** is the numerical value of the electric charge with a plus or minus sign. For example, the lithium ion has an ionic charge of 1+, because it has three positive protons in the nucleus and only two negative electrons (see **Figure 7**). The lithium atom has become a positive lithium ion, Li^{1+} which is commonly written as Li^{+}.

A similar electron transfer happens to calcium when it forms compounds. Calcium, as shown in **Figure 5**, has two electrons in the first orbit, eight in the second orbit, eight in the third orbit, and two in the fourth orbit. If calcium loses two electrons, it has the same electron arrangement as the noble gas argon. The result is a Ca^{2+} ion (because it has twenty protons, but only eighteen electrons). Metals tend to have one, two, or three electrons in their outer orbits. They tend to lose these electrons when they combine with other elements to form positive ions.

What happens to the electrons in nonmetals such as fluorine or sulfur (S)? Consider the electron arrangement in fluorine as shown in **Figure 5**. Fluorine has two electrons in the first orbit and seven electrons in the second. If it gains one electron, it will have the stable electron arrangement of neon. The fluorine atom becomes a stable fluorine ion, F^{-}. When nonmetals gain electrons to form ions, the name of the ion changes its ending to "ide." Thus, a F^{-} ion is called a fluoride ion.

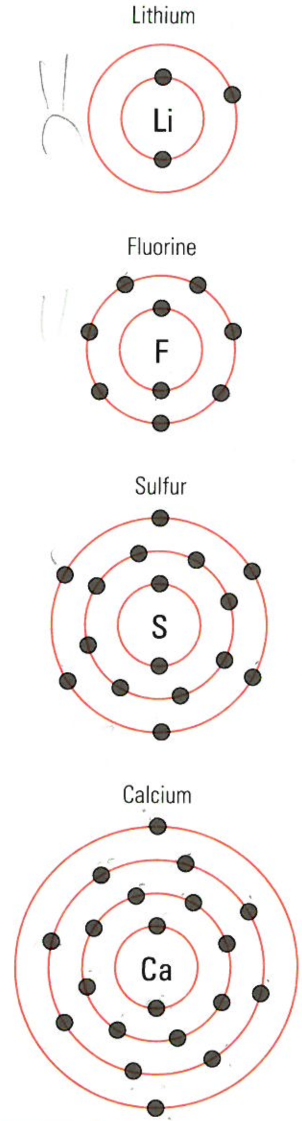


Figure 5
Bohr diagrams for lithium (element 3), fluorine (element 9), sulfur (element 16), and calcium (element 20).

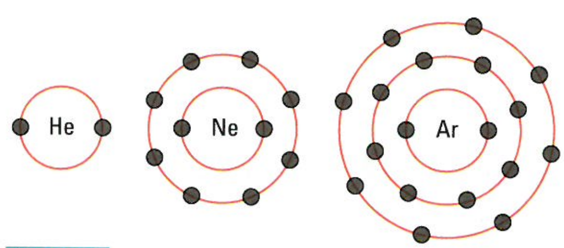


Figure 6
Helium (element 2), neon (element 10), and argon (element 18) have stable electron arrangements, and do not readily form compounds.

Similarly, sulfur has sixteen protons in its nucleus and sixteen electrons arranged in three orbits (**Figure 5**). If it gains two electrons to become an ion, it will have the stable electron arrangement of argon. The sulfur atom becomes a stable sulfide ion, S^{2-}. Nonmetals tend to have five, six, or seven electrons in their outer orbits. They all tend to gain electrons when they combine with metals to form compounds.

	Lithium	Calcium	Fluorine	Sulfur
protons	+ 3	+ 20	+ 9	+ 16
electrons	− 2	− 18	− 10	− 18
	+ 1	+ 2	− 1	− 2

Figure 7
Lithium, calcium, fluorine, and sulfur either gain or lose electrons to form stable ions. Protons are positive and electrons are negative.

Did You Know?

Positive ions are also called cations, and negative ions are also called anions. An easy way to remember these terms is that anions are **n**egative and ca**⁺**tions are **⁺**ve.

Understanding Concepts

1. Set up a chart to compare metals and nonmetals with respect to the following:

(a) lustre

(b) conductivity

(c) location in the periodic table

(d) state at room temperature

(e) numbers of electrons in the outer orbit

(f) tendency to gain or lose electrons

(g) charges of ions formed

(h) other properties

(i) examples

2. What element is located in the metallic area of the periodic table, but has mainly nonmetallic properties?

3. How many electrons are found in each of the first three orbits for the first twenty elements?

4. Draw Bohr diagrams for the following:

(a) a boron atom

(b) a chlorine atom

(c) a nitrogen atom

(d) a beryllium atom

5. What kind of arrangement of electrons in the outer orbit does a stable ion have?

6. **(a)** Draw Bohr diagrams for the stable ion formed by each of the atoms in question 4.

(b) State the number of electrons gained or lost to form each ion.

(c) State the ionic charge on each of the ions.

(d) Name the noble gas that has the same number of electrons as each ion.

7. A new element, ontarium (On), has been formed. We know that it is a halogen.

(a) How many electrons does it have in its outer orbit?

(b) What will be the name of the compound it forms with sodium?

(c) What will be the name of the compound it forms with calcium?

(d) Predict the formulas of the compounds named in (b) and (c).

8. Atoms and ions are described as isoelectronic if they have the same number of electrons. Name the noble gas that is isoelectronic with each of the following stable ions:

(a) Li^{+}

(b) F^{-}

(c) Ca^{2+}

(d) S^{2-}

(e) Br^{-}

(f) Rb^{+}

5.6

How Elements Form Compounds

The model you have just learned of, with atoms losing or gaining electrons to become stable, explains how some compounds are formed. For example, both sodium and chlorine are highly reactive. Atoms of these elements combine by transferring electrons from one to another as shown in **Figure 1**. Sodium chloride is a relatively harmless compound because the sodium and chlorine atoms have formed stable ions. The compound formed is called an **ionic compound** because it is made up of positive and negative ions that have resulted from the transfer of electrons from a metal to a nonmetal. The positive and negative ions are attracted to each other because they have opposite charges. **Figure 2** shows some common ionic compounds.

Consider a slightly more complicated example. Calcium and fluorine react to form calcium fluoride, an ionic compound. Each calcium atom has two electrons in its outer orbit that it tends to lose to become more stable. Each fluorine atom has seven electrons in its outer orbit and needs to gain only one more electron to become stable. How can this mismatch of electrons be solved? The solution is that one calcium atom requires two fluorine atoms to form the compound calcium fluoride (**Figure 3**).

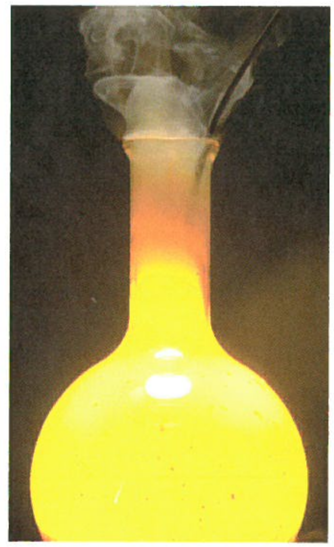


Figure 1

Sodium burns rapidly in chlorine gas to form the compound sodium chloride, a compound so harmless that you sprinkle it as salt onto your French fries. This reaction is too dangerous to carry out in a classroom. Each atom of sodium loses an electron to an atom of chlorine.

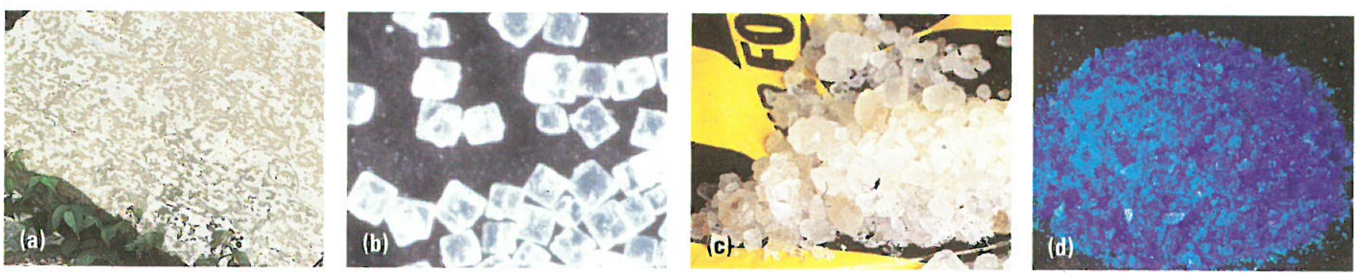


Figure 2

(a) Limestone ($CaCO_3$), **(b)** sodium chloride (table salt), **(c)** road salt (calcium chloride), and **(d)** copper(II) sulfate (algaecide) are all examples of ionic compounds.

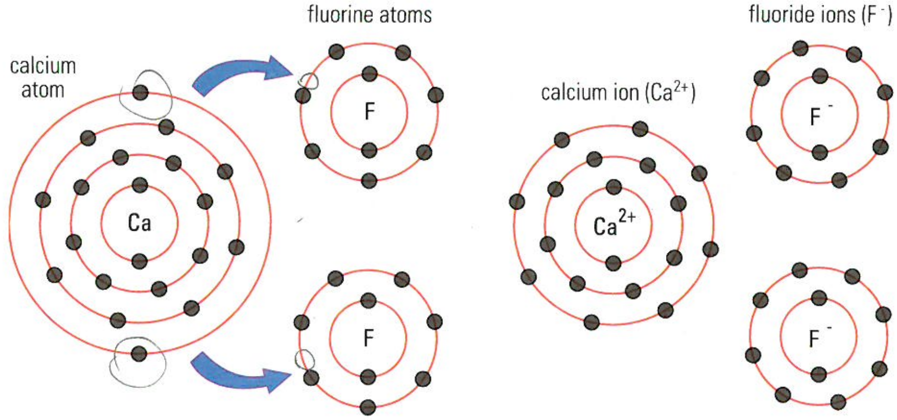


Figure 3

The calcium atom transfers one electron to each of the two fluorine atoms. The result is one calcium ion, Ca^{2+}, and two fluoride ions, F^-. The overall charge of the compound is zero because the positive charge on the calcium ion balances the negative charges on the two fluoride ions. The compound is calcium fluoride (CaF_2).

Chemical Formulas and Composition of Compounds

A chemical formula is a combination of symbols that represents a particular compound. As you have seen, ionic compounds can be represented by such formulas. The formula $MgCl_2$ (magnesium chloride) describes a compound in which the combining ratio of magnesium ions to chloride ions is one magnesium ion to two chloride ions. Similarly, the formula AlF_3 (aluminum fluoride) describes a compound in which the combining ratio of aluminum ions to fluoride ions is one aluminum ion to three fluoride ions.

Ionic compounds dissolve in water to form solutions that conduct electricity because they are made up of charged ions. When the substances are dissolved in water, the ions separate from one another and are now free to move and carry electric current (**Figure 4**).

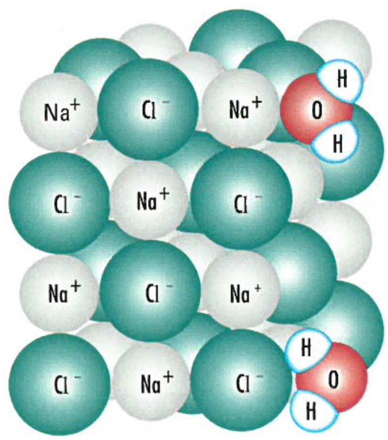
In Investigation 5.3, you found that compounds such as distilled water (H_2O), glucose ($C_6H_{12}O_6$), and sucrose ($C_{12}H_{22}O_{11}$) were non-electrolytes. Such compounds, called **molecular compounds**, are formed when nonmetals combine with other nonmetals. You will learn about molecular compounds in lesson 5.11.

Did You Know?

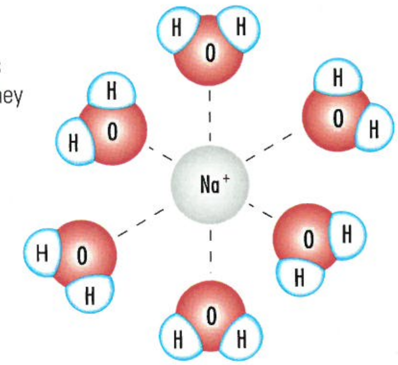
The concentrations of sodium, potassium, and chloride ions in the human body are vitally important. If the concentrations of these ions in the blood change drastically, death can result.

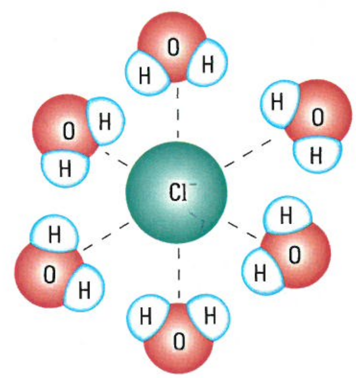
Figure 4

When ionic compounds are placed in water, the ions separate and are surrounded by water molecules. They are electrolytes.



$NaCl_{(s)} \longrightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$





Understanding Concepts

1. **(a)** How do metals form ionic compounds with nonmetals?
   (b) Describe the process with an example.
2. Beryllium and fluorine react to form an ionic compound.
   (a) Which element is the metal and which is the nonmetal?
   (b) Draw Bohr diagrams of beryllium and fluorine.
   (c) How many electrons must each element gain or lose to form stable ions?
   (d) Draw sketches to show how this compound forms by transfer of electrons.
   (e) Indicate the ionic charges on the ions.
   (f) What is the overall charge on the compound?
   (g) What is the chemical formula of the compound?
3. Repeat question 2 for the compound formed by aluminum and fluorine.
4. What part of the atom is involved in making chemical bonds?
5. Look at your observations from Investigation 5.3.
   (a) Which substances conducted electricity?
   (b) What ions did they form when they dissolved in water?

5.7 Activity

Ionic Charges and Chemical Families

In section 5.5 you reviewed the structure of the atom and learned how some atoms can form stable ions by gaining or losing electrons. You have also learned that the periodic table is a useful organizing tool for understanding and predicting the behaviour of substances. Elements in the same vertical column of the periodic table are described as members of the same chemical family or group. **Figure 1** shows some of these chemical families. For example, lithium, sodium, potassium, and other Group 1 metals are all members of a family called the alkali metals. Beryllium, magnesium, and other Group 2 metals are members of a family called the alkaline earth metals. And fluorine, chlorine, and other nonmetals are members of the halogen family.

How is an element's position in the periodic table related to the types and formulas of the compounds that it forms? In this activity, you will investigate and summarize the information that will enable you to write your own chemical formulas.

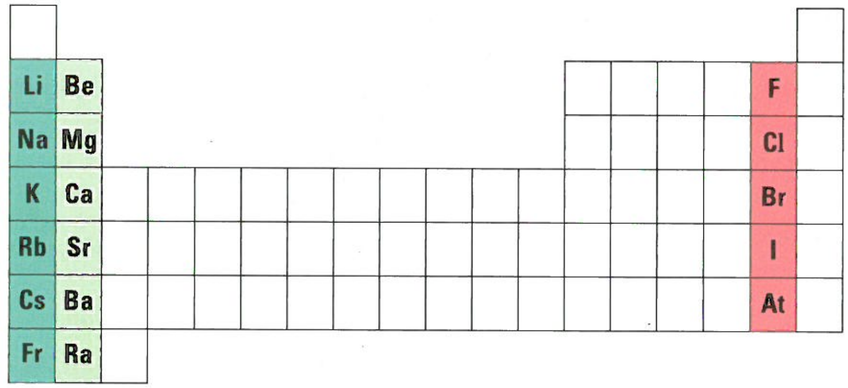


Figure 1

The location of the alkali metals (dark green), the alkaline earth metals (light green), and the halogens (red) in the periodic table.

Procedure

1 Construct a table titled "Alkali Metals" that includes the following information:

- the names of the alkali metals (remember that hydrogen is a special element with special properties and is not a member of this family);
- the symbols of the alkali metals;
- Bohr diagrams for the first three alkali metals;
- Bohr diagrams for the stable ions that the alkali metals will form;
- the ionic charge for the alkali metal ions.

2 Construct a table titled "Alkaline Earth Metals" that includes the following information:

- the names of the alkaline earth metals;
- the symbols of the alkaline earth metals;
- Bohr diagrams for the first three alkaline earth metals;
- Bohr diagrams for the stable ions that the alkaline earth metals will form;
- the ionic charge for the alkaline earth metal ions.

3 Construct a table titled "Halogens" that includes the following information:

- the names of the halogens;
- the symbols of the halogens;
- Bohr diagrams for the first three halogens;
- Bohr diagrams for the stable ions that the halogens will form;
- the ionic charge for the halogen ions;
- the name of each ion.

Analysis

(a) For the alkali metals (**Figure 2**), what connections can you draw from the data in your tables (names, symbols, ionic charges, symbols for the ions, and electrons in the outer orbit)?

(b) For the alkaline earth metals, what connections can you draw from the data in your tables (names, symbols, ionic charges, symbols for the ions, and electrons in the outer orbit)?

(c) For the halogens, what connections can you draw from the data in your tables (names, symbols, ionic charges, symbols for the ions, and electrons in the outer orbit)?

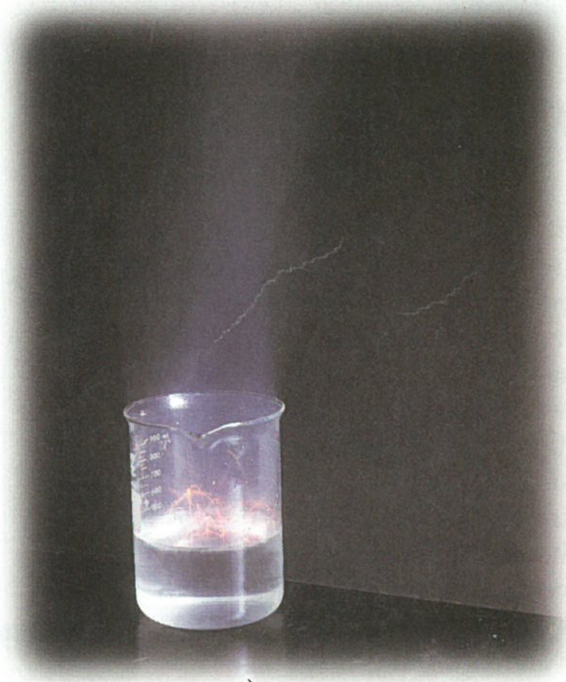


Figure 2
Sodium, like all alkali metals, reacts vigourously in water.

Understanding Concepts

1. For the metallic elements sodium, magnesium, and aluminum, answer the following questions:
   - **(a)** Draw a Bohr diagram for each element. How many electrons are in their outer orbits?
   - **(b)** Do these metallic elements tend to gain or lose electrons? Give reasons for your answer.
   - **(c)** What is the charge on each of the metal ions? (Include the ion symbol.)
2. For the nonmetallic elements nitrogen, oxygen, and fluorine, answer the following questions:
   - **(a)** Draw a Bohr diagram for each element. How many electrons are in their outer orbits?
   - **(b)** Do these nonmetallic elements tend to gain or lose electrons? Give reasons for your answer.
   - **(c)** What is the charge on each of the nonmetal ions? (Include the ion symbol.)

Exploring

3. Predict the names and charges of the ions that cesium, barium, and bromine might form.

Reflecting

4. This activity did not involve the family of elements on the far right side of the table. Why?
5. This activity omitted the family of elements that includes carbon (element 6) and silicon (element 14). The compounds that these elements form will be discussed in lesson 5.11.
   - **(a)** Draw Bohr diagrams for carbon and silicon.
   - **(b)** Do you think that these elements tend to gain or lose electrons? Give reasons for your answer.

Ionic Compounds

There are over one hundred elements in the periodic table, and thousands of different compounds are formed when these elements combine. How can we name these compounds? How can we write formulas to represent them?

In section 5.7, you saw that the periodic table and a knowledge of electronic structure could be used to predict the ionic charges of elements. Elements in the same families tend to form ions with similar ionic charges. Such an ionic charge may also be called the **valence**, or combining capacity, of an element. **Figure 1** shows the ionic charges of selected elements. Some elements with more than 20 electrons are included, although their electronic structure is more complicated than the model we have discussed so far.

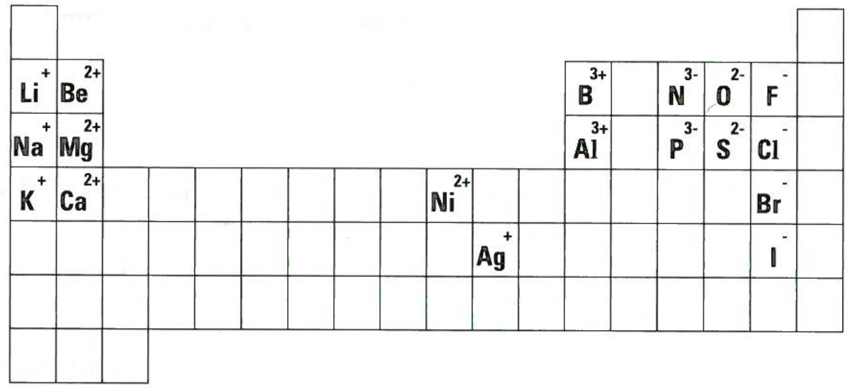


Figure 1
Ionic charges (or valences) of some elements in the periodic table.

Metals and nonmetals combine to form ionic compounds by transferring electrons. The metal atoms lose electrons to form positive ions, and the nonmetal atoms gain those electrons to form negative ions. The result is a compound that is electrically neutral. The sum of the charges on the positive ions equals the sum of the charges on the negative ions.

Consider the compound aluminum chloride ($AlCl_3$). As you can see in **Figure 1**, the ionic charge of the aluminum ion is 3+ and the ionic charge of each chloride ion is 1–. Since the compound contains a ratio of one Al^{3+} ion to three Cl^- ions, the total ionic charge is described by the following expression:

$$(3+) + 3(1-) = 0$$

The positive and negative ions attract each other to make a stable compound. Another way to look at the process is to think of the aluminum atom as losing three electrons, one to each of three chlorine atoms (**Figure 2**).

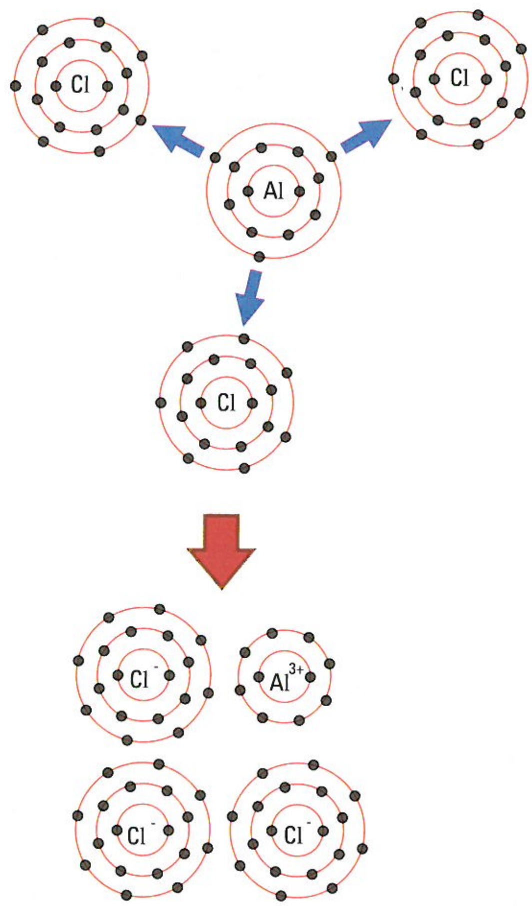


Figure 2
An aluminum atom transfers electrons to three chlorine atoms to form a stable compound of aluminum chloride.

Writing Formulas for Ionic Compounds

How can you write formulas for ionic compounds? You could randomly try different numbers of positive and negative ions until you obtained a neutral compound. However, a more logical approach involves a series of steps, as shown in the following example.

What is the formula for the ionic compound formed by calcium and iodine?

Step 1. Write the symbols, with the metal first.

Ca I

Step 2. Write the ionic charge above each symbol to indicate the stable ion that each element forms.

2+ 1–
Ca I

Step 3. Determine how many ions of each type you need so that the total ionic charge is zero.

One Ca^{2+} ion will balance the charge of two I^- ions.

Step 4. Write the formula using subscripts to indicate the number of ions of each type.

The formula is Ca_1I_2 or CaI_2. The subscript "1" is unnecessary because the symbol itself represents one atom or ion.
The total ionic charge is (2+) + 2(1–) = 0

Consider a second example in which the above steps are described as rules.

What is the formula for the ionic compound formed by aluminum and sulfur?

Rule 1: Write the symbols of the elements.

Al S

Rule 2: Write the ionic charges.

3+ 2–
Al S

Rule 3: Choose the number of ions to balance the charge.

The total ionic charge is (3+) + (2–) = 1+
Therefore, to balance the ionic charge,

2(3+) + 3(2–) = 0

Two Al^{3+} ions will balance the charge of three S^{2-} ions.

Rule 4: Write the formula using subscripts.

The formula is Al_2S_3.

There is another simple way to obtain the formula of a compound, called the “crisscross” rule, which replaces Rules 2, 3, and 4.

What is the formula for the ionic compound formed by aluminum and sulfur?

Crisscross Rule: Write the ionic charges above the symbols. Then crisscross the numbers, using them as subscripts.

3+ 2–

Al S

The formula is Al_2S_3.

The total ionic charge is $2(3+) + 3(2-) = 0$

Consider a final example, in which the “crisscross” rule is modified.

What is the formula for the ionic compound formed by nickel and oxygen?

Rule 1: Write the symbols of the elements.

Ni O

Crisscross Rule: Write the ionic charges above the symbols and crisscross them.

2+ 2-

Ni O

The formula is Ni_2O_2.

However, the formula must have the lowest number of ions that will produce an electrically neutral compound. Dividing by the common factor (in this case, 2), we find that the correct formula must be NiO.

The total ionic charge is $(2+) + (2-) = 0$

In the same way, the compound formed by tin ions (Sn^{4+}) and oxide ions (O^{2-}) would seem to have the formula Sn_2O_4. However, this formula can be reduced to SnO_2.

Naming Ionic Compounds

In many cases, the names of ionic compounds are quite straightforward. Just as in the chemical formula, the name of the metal is first, followed by the name of the nonmetal. However, the *ending* of the name of the nonmetal changes to “ide.” For example, the compound formed by calcium and iodine is called calcium iodide. The compound formed by aluminum and sulfur is called aluminum sulfide. **Table 1** gives the names of some nonmetals in ionic compounds.

Table 1 Names and Ionic Charges of Some Nonmetals

Name of element	Symbol	Ionic charge	Name in compound
fluorine	F	1–	fluoride
chlorine	Cl	1–	chloride
bromine	Br	1–	bromide
iodine	I	1–	iodide
oxygen	O	2–	oxide
sulfur	S	2–	sulfide
nitrogen	N	3–	nitride
phosphorus	P	3–	phosphide

Names and Formulas for Atoms with More Than One Ionic Charge

Some metals are able to form more than one kind of ion. For example, the element copper forms two completely different compounds when it reacts with chlorine. One of the compounds is white; the other is yellow. Chemists have found that the ionic charge on the copper in the white compound is 1+. Its chemical formula is CuCl, since the ionic charge of chlorine is always 1–. The ionic charge on the copper in the yellow compound is 2+. Its formula is therefore $CuCl_2$. **Table 2** shows the names and ionic charges of some metals that have more than one ionic charge.

These compounds are named in the same way as other ionic compounds, except that a Roman numeral (as shown in **Table 2**) is added in round brackets after the metal to indicate its ionic charge. For example, CuCl is called copper(I) chloride because the ionic charge on the copper is 1+. $CuCl_2$ is called copper(II) chloride because the ionic charge on the copper is 2+. Remember that you have to use the Roman numeral system only when naming the ions of metals that can have more than one ionic charge.

Table 2 **Names and Multiple Ionic Charges of Some Metals**

Name of element	Symbol	Ionic charges	Roman numeral
copper	Cu	1+, 2+	I, II
iron	Fe	2+, 3+	II, III
lead	Pb	2+, 4+	II, IV
tin	Sn	2+, 4+	II, IV

Challenge

1 Are there any ionic compounds in your product? What are their names?

Understanding Concepts

1. (a) How does the sum of the charges on the positive ions compare to the sum of the charges on the negative ions in ionic compounds?
   (b) Calculate the sum of the ionic charges in the compound Al_2O_3. Show your calculation.
2. Draw a Bohr diagram to show the electron transfer that occurs when magnesium and fluorine form the compound magnesium fluoride.
3. Write the formulas for the compounds formed by the following combinations of elements:
   (a) lithium and fluorine
   (b) calcium and bromine
   (c) sodium and nitrogen
   (d) aluminum and nitrogen
4. Name each of the compounds in question 3.
5. Write the formulas for the following compounds:
   (a) sodium iodide
   (b) beryllium fluoride
   (c) magnesium oxide
   (d) aluminum sulfide
6. Write the names for the following compounds:
   (a) KCl
   (b) Na_3P
   (c) CaF_2
7. Write the formulas for the following compounds:
   (a) copper(I) bromide
   (b) copper(II) bromide
   (c) iron(II) sulfide
8. Write the names for the following compounds:
   (a) $SnCl_2$
   (b) $SnCl_4$
   (c) $PbBr_2$
9. Write the formula and name of the compound formed by each of the following combinations of ions. (Note that some of these ions will require the use of Roman numerals in the names.)
   (a) Fe^{3+} and O^{2-}
   (b) Ca^{2+} and F^-
   (c) Cu^+ and S^{2-}
10. In mining, some minerals are referred to as ferrous. What metallic element is present in these compounds? (Hint: Look at the letters that begin the word.)