3

CHAPTER OUTLINE

CHAPTER GOALS

In this chapter you will learn how to:

1. Describe the basic features of ionic and covalent bonds
2. Use the periodic table to determine whether an atom forms a cation or an anion, and determine its charge using the group number
3. Describe the octet rule
4. Write the formula for an ionic compound
5. Name ionic compounds
6. Describe the properties of ionic compounds
7. Recognize the structures of common polyatomic ions and name compounds that contain them
8. List useful consumer products and drugs that are composed of ionic compounds

Zinc oxide is an ionic compound widely used in sunblocks to protect the skin from harmful ultraviolet radiation.

IONIC COMPOUNDS

ALTHOUGH much of the discussion in Chapter 2 focused on atoms, individual atoms are rarely encountered in nature. Instead, atoms are far more commonly joined together to form compounds. There are two types of chemical compounds, **ionic** and **covalent. Ionic compounds** are composed of positively and negatively charged ions held together by strong electrostatic forces—the electrical attraction between oppositely charged ions. Examples of ionic compounds include the sodium chloride (NaCl) in table salt and the calcium carbonate ($CaCO_3$) in snail shells. **Covalent compounds** are composed of individual molecules, discrete groups of atoms that share electrons. Covalent compounds include water (H_2O) and methane (CH_4), the main component of natural gas. Chapters 3 and 4 focus on the structure and properties of ionic and covalent compounds, respectively.

3.1 INTRODUCTION TO BONDING

It is rare in nature to encounter individual atoms. Instead, anywhere from two to hundreds or thousands of atoms tend to join together to form compounds. The oxygen we breathe, for instance, consists of two oxygen atoms joined together, whereas the hemoglobin that transports it to our tissues consists of thousands of carbon, hydrogen, oxygen, nitrogen, and sulfur atoms joined together. We say **two atoms are *bonded* together.**

- ***Bonding* is the joining of two atoms in a stable arrangement.**

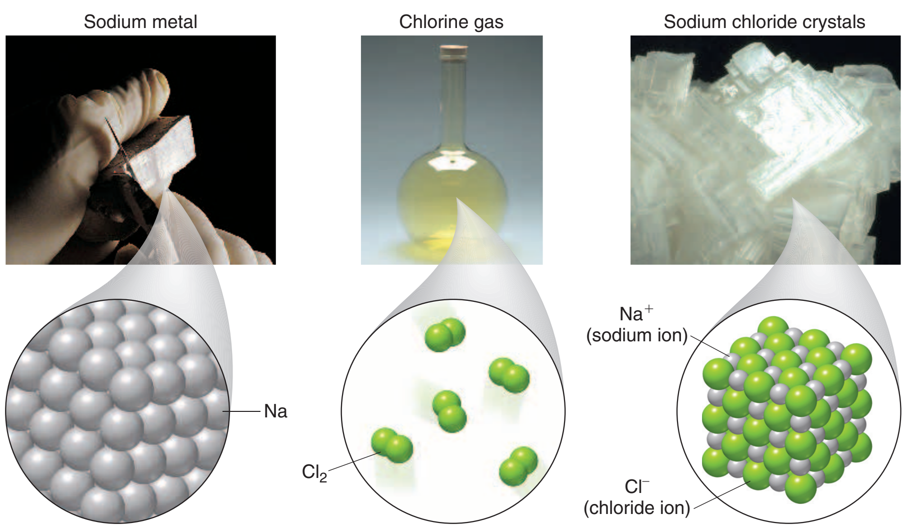
Bonding is a favorable process because it always forms a compound that is more stable than the atoms from which it is made. Only the noble gases in group 8A of the periodic table are particularly stable as individual atoms; that is, the **noble gases do *not* readily react to form bonds.** Since chemical reactivity is based on electronic configuration, the electronic configuration of the noble gases must be especially stable to begin with. As a result, one overriding principle explains the process of bonding.

- **In bonding, elements gain, lose, or share electrons to attain the electronic configuration of the noble gas closest to them in the periodic table.**

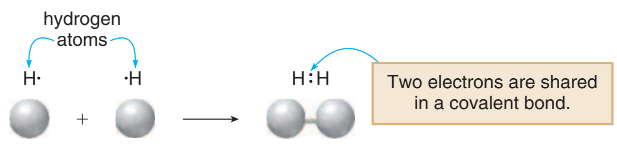
Bonding involves only the valence electrons of an atom. There are two different kinds of bonding: **ionic** and **covalent.**

- ***Ionic bonds* result from the transfer of electrons from one element to another.**
- ***Covalent bonds* result from the sharing of electrons between two atoms.**

The position of an element in the periodic table determines the type of bonds it makes. **Ionic bonds form between a metal on the left side of the periodic table and a nonmetal on the right side.** For example, when the metal sodium (Na) bonds to the nonmetal chlorine (Cl_2), the ionic compound sodium chloride (NaCl) forms. Since ionic compounds are composed of ***ions*—charged species in which the number of protons and electrons in an atom is *not* equal**—we begin our discussion of ionic compounds with how ions are formed in Section 3.2.



Covalent bonds are formed when two nonmetals combine, or when a metalloid bonds to a nonmetal. **A *molecule* is a discrete group of atoms that share electrons.** For example, when two hydrogen atoms bond they form the molecule H_2, and two electrons are shared. Covalent bonds and molecules are discussed in Chapter 4.



SAMPLE PROBLEM 3.1

Predict whether the bonds in the following compounds are ionic or covalent: (a) NaI (sodium iodide); (b) H_2O_2 (hydrogen peroxide).

ANALYSIS The position of the elements in the periodic table determines the type of bonds they form. When a metal and nonmetal combine, the bond is ionic. When two nonmetals combine, or a metalloid bonds to a nonmetal, the bond is covalent.

SOLUTION

a. Since Na is a metal on the left side and I is a nonmetal on the right side of the periodic table, the bonds in NaI are ionic.

b. Since H_2O_2 contains only the nonmetals hydrogen and oxygen, the bonds must be covalent.

PROBLEM 3.1

Predict whether the bonds in the following species are ionic or covalent.

a. CO b. CaF_2 c. MgO d. Cl_2 e. HF f. C_2H_6

PROBLEM 3.2

Label each of the following as a compound, element, or molecule. In some cases, more than one term applies.

a. CO_2 b. H_2O c. NaF d. $MgBr_2$ e. F_2 f. CaO

PROBLEM 3.3

Vitamin C is important in the formation of collagen, a protein that holds together the connective tissue of skin, muscle, and blood vessels. Vitamin C has the chemical formula $C_6H_8O_6$. Even if you know nothing about how the atoms in vitamin C are arranged, what type of bonds are likely to be present in vitamin C?

3.2 IONS

Ionic compounds consist of oppositely charged **ions** that have a strong electrostatic attraction for each other.

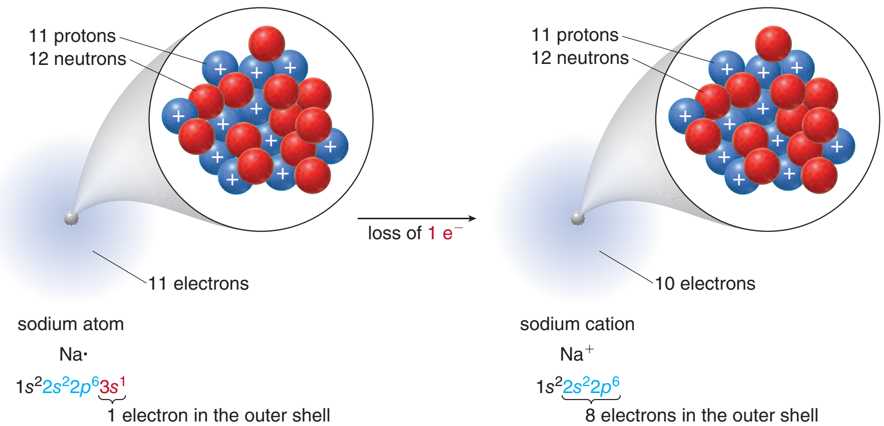
3.2A CATIONS AND ANIONS

There are two types of ions called **cations** and **anions.**

- *Cations* are positively charged ions. A cation has fewer electrons than protons.
- *Anions* are negatively charged ions. An anion has more electrons than protons.

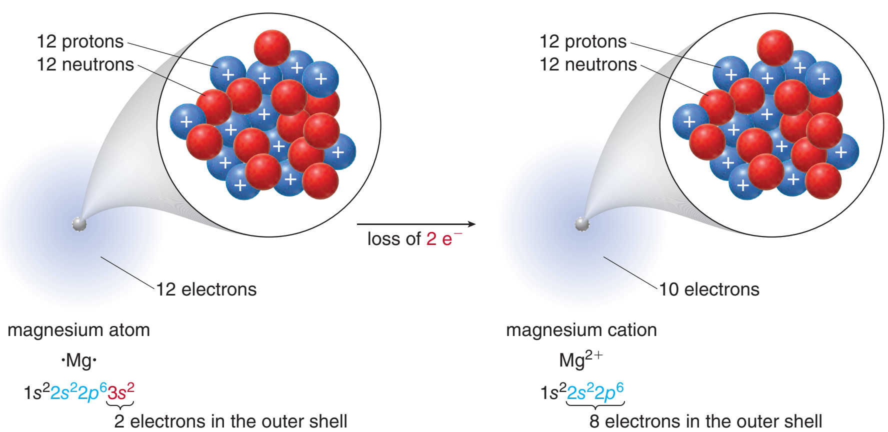
The nature and magnitude of the charge on an ion depend on the position of an element in the periodic table. In forming an ion, an atom of a main group element loses or gains electrons to obtain the electronic configuration of the noble gas closest to it in the periodic table. This gives the ion an especially stable electronic arrangement with a **completely filled shell of electrons;** that is, the electrons completely fill the shell farthest from the nucleus.

For example, sodium (group 1A) has an atomic number of 11, giving it 11 protons and 11 electrons in the neutral atom. This gives sodium one *more* electron than neon, the noble gas closest to it in the periodic table. In losing one electron, sodium forms a cation with a +1 charge, which still has 11 protons, but now has only 10 electrons in its electron cloud.



What does this mean in terms of valence electrons? A neutral sodium atom, with an electronic configuration of $1s^22s^22p^63s^1$, has a single valence electron. Loss of this valence electron forms a **sodium cation,** symbolized as **Na^+,** which has the especially stable electronic configuration of the noble gas neon, $1s^22s^22p^6$. The sodium cation now has eight electrons that fill the 2*s* and three 2*p* orbitals.

Magnesium (group 2A) has 12 protons and 12 electrons in the neutral atom. This gives magnesium two *more* electrons than neon, the noble gas closest to it in the periodic table. In losing two electrons, magnesium forms a cation with a +2 charge, which still has 12 protons, but now has only 10 electrons in its electron cloud.



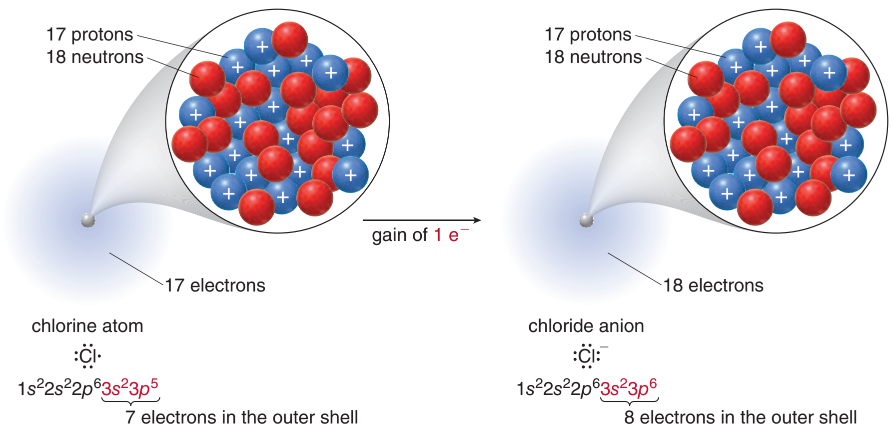
In terms of valence electrons, a neutral magnesium atom, with an electronic configuration of $1s^22s^22p^63s^2$, has two valence electrons. Loss of these valence electrons forms a **magnesium cation,** symbolized as **Mg^{2+},** which has the especially stable electronic configuration of the noble gas neon, $1s^22s^22p^6$. The magnesium cation now has eight electrons that fill the 2*s* and three 2*p* orbitals.

Sodium and magnesium are examples of metals.

- **Metals are found on the left side of the periodic table.**
- **Metals form *cations.***
- **By losing one, two, or three electrons, an atom forms a cation with a completely filled outer shell of electrons.**

Some metals—notably tin and lead—can lose *four* electrons to form cations.

A neutral chlorine atom (group 7A), on the other hand, has 17 protons and 17 electrons. This gives it one *fewer* electron than argon, the noble gas closest to it in the periodic table. By gaining one electron, chlorine forms an anion with a –1 charge because it still has 17 protons, but now has 18 electrons in its electron cloud.



In terms of valence electrons, a neutral chlorine atom, with an electronic configuration of $1s^22s^22p^63s^23p^5$, has seven valence electrons. Gain of one electron forms a **chloride anion,** symbolized as **Cl^-,** which has the especially stable electronic configuration of the noble gas argon, $1s^22s^22p^63s^23p^6$. The chloride anion now has eight valence electrons that fill the 3*s* and three 3*p* orbitals.

Chlorine is an example of a nonmetal.

- **Nonmetals are found on the right side of the periodic table.**
- **Nonmetals form *anions.***
- **By gaining one, two, or sometimes three electrons, an atom forms an anion with a completely filled outer shell of electrons.**

Ions are written with the element symbol followed by a superscript to indicate the charge. The number "1" is omitted in ions that have a +1 or –1 charge, as in Na^+ or Cl^-. When the charge is "2" or greater, it is written as 2+ or 2–, as in Mg^{2+} or O^{2-}.

Each of these ions formed from a main group element has the *s* and three *p* orbitals filled with **eight electrons.** This results in the **octet rule.**

- **A main group element is especially stable when it possesses an *octet* of electrons in its outer shell.**

SAMPLE PROBLEM 3.2

Write the ion symbol for an atom with: (a) nine protons and 10 electrons; (b) three protons and two electrons.

ANALYSIS Since the number of protons equals the atomic number (Section 2.2), this quantity identifies the element. The charge is determined by comparing the number of protons and electrons. If the number of electrons is greater than the number of protons, the charge is negative (an anion). If the number of protons is greater than the number of electrons, the charge is positive (a cation).

SOLUTION

a. An element with nine protons has an atomic number of nine, identifying it as fluorine (F). Since there is one more electron than proton (10 vs. 9), the charge is –1. **Answer:** F^-

b. An element with three protons has an atomic number of three, identifying it as lithium (Li). Since there is one more proton than electron (3 vs. 2), the charge is +1. **Answer:** Li^+

PROBLEM 3.4

Write the ion symbol for an atom with the given number of protons and electrons.

a. 19 protons and 18 electrons
b. seven protons and 10 electrons
c. 35 protons and 36 electrons
d. 23 protons and 21 electrons

SAMPLE PROBLEM 3.3

How many protons and electrons are present in each ion: (a) Ca^{2+}; (b) O^{2-}?

ANALYSIS Use the identity of the element to determine the number of protons. The charge tells how many more or fewer electrons there are compared to the number of protons. A positive charge means more protons than electrons, while a negative charge means more electrons than protons.

SOLUTION

a. Ca^{2+}: The element calcium (Ca) has an atomic number of 20, so it has 20 protons. Since the charge is +2, there are two more protons than electrons, giving the ion 18 electrons.

b. O^{2-}: The element oxygen (O) has an atomic number of eight, so it has eight protons. Since the charge is –2, there are two more electrons than protons, giving the ion 10 electrons.

PROBLEM 3.5

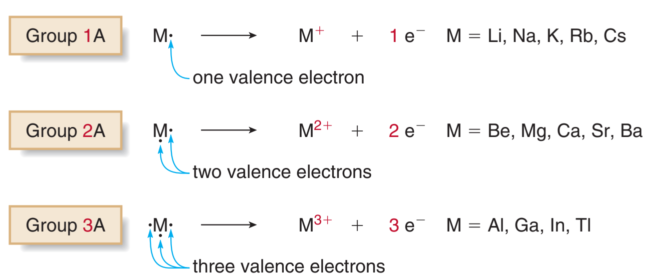
How many protons and electrons are present in each ion?

a. Ni^{2+} b. Se^{2-} c. Zn^{2+} d. Fe^{3+}

3.2B RELATING GROUP NUMBER TO IONIC CHARGE FOR MAIN GROUP ELEMENTS

Because elements with similar electronic configurations are grouped together in the periodic table, **elements in the same group form ions of similar charge.** The group number of a main group element can be used to determine the charge on an ion derived from that element.

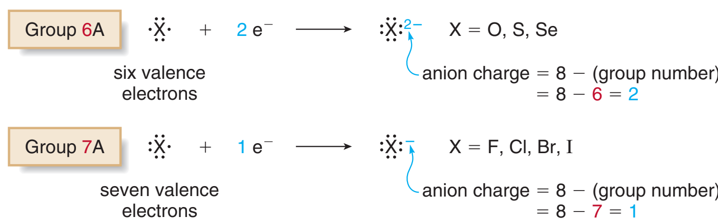
- **Metals form cations. For metals in groups 1A, 2A, and 3A, the group number = the charge on the cation.**



Group **1**A elements (Li, Na, K, Rb, and Cs) have **one** valence electron. Loss of this electron forms a cation with a **+1** charge. Group **2**A elements (Be, Mg, Ca, Sr, and Ba) have **two** valence electrons. Loss of both electrons forms a cation with a **+2** charge. Group **3**A elements (Al, Ga, In, and Tl) form cations, too, but only aluminum is commonly found in ionic compounds. It has **three** valence electrons, so loss of three electrons from aluminum forms a cation with a **+3** charge.

All of the cations derived from group 1A–3A elements have an octet of outer shell electrons except for Li^{+} and Be^{2+}. Li^{+} and Be^{2+} have a $1s^2$ electronic configuration like helium, the noble gas to which they are closest in the periodic table. Thus, these cations are especially stable because they have a filled outer shell of electrons but they do *not* have an octet of electrons.

- **Nonmetals form anions. For nonmetals in groups 6A and 7A, the anion charge = 8 – (the group number).**



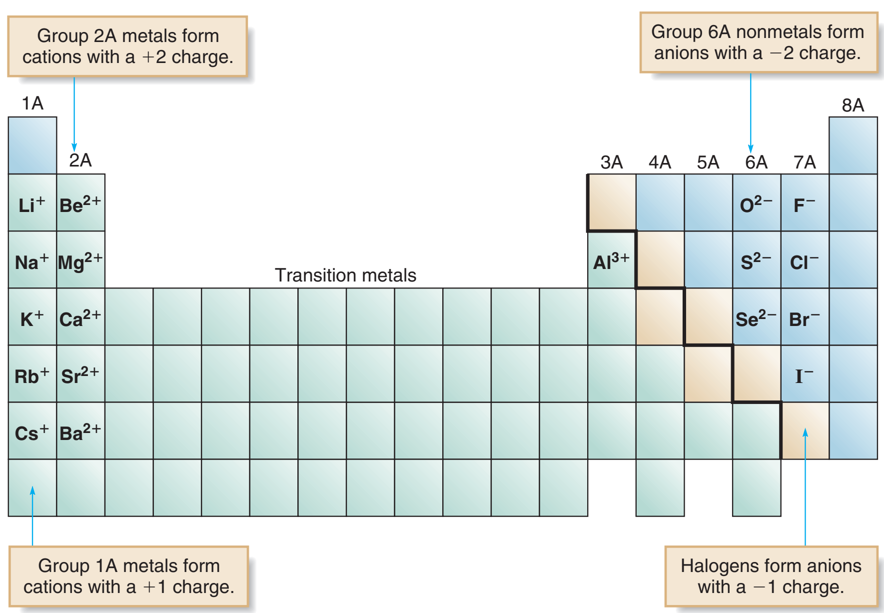
Group **6**A elements have **six** valence electrons. Gain of **two** electrons forms an anion with a **–2** charge (anion charge = 8 – 6). Group **7**A elements have **seven** valence electrons. Gain of one electron forms an anion with a **–1** charge (anion charge = 8 – 7).

Table 3.1 summarizes the ionic charges of the main group elements. The periodic table in Figure 3.1 gives the common ions formed by the main group elements.

TABLE 3.1 Ionic Charges of the Main Group Elements

Group Number	Number of Valence Electrons	Number of Electrons Gained or Lost	General Structure of the Ion
1A (1)	1	1 e^- lost	M^+
2A (2)	2	2 e^- lost	M^{2+}
3A (3)	3	3 e^- lost	M^{3+}
6A (16)	6	2 e^- gained	M^{2-}
7A (17)	7	1 e^- gained	M^-

FIGURE 3.1 Common Ions Formed by Main Group Elements



SAMPLE PROBLEM 3.4 Use the group number to determine the charge on an ion derived from each element: (a) barium; (b) sulfur.

ANALYSIS Locate the element in the periodic table. A metal in groups 1A, 2A, or 3A forms a cation equal in charge to the group number. A nonmetal in groups 6A and 7A forms an anion whose charge equals 8 – (the group number).

SOLUTION

a. Barium (Ba) is located in group 2A, so it forms a cation with a +2 charge; Ba^{2+}.

b. Sulfur (S) is located in group 6A, so it forms an anion with a negative charge of 8 – 6 = 2; S^{2-}.

PROBLEM 3.6 Use the group number to determine the charge on an ion derived from each element.

a. magnesium b. iodine c. selenium d. rubidium

PROBLEM 3.7 Nitrogen rarely forms ionic compounds. How many electrons would nitrogen have to gain to form an anion with an electronic configuration of its nearest noble gas?

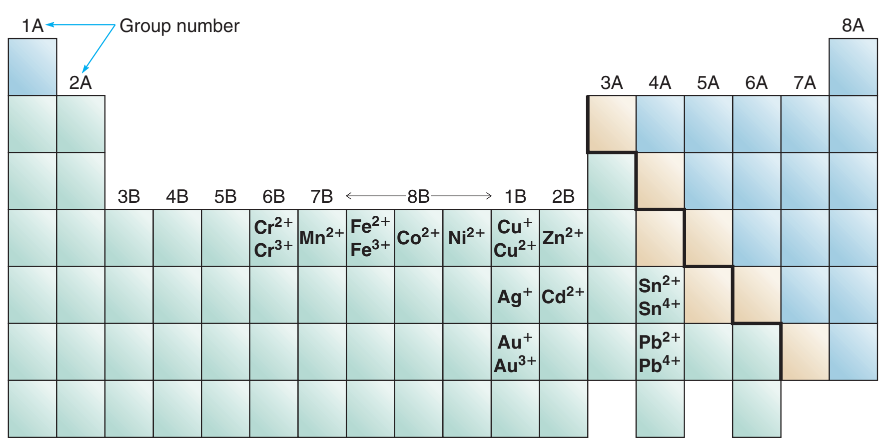
PROBLEM 3.8 What noble gas has the same electronic configuration as each ion derived from the elements in Problem 3.6?

3.2C METALS WITH VARIABLE CHARGE

The transition metals form cations like other metals, but the magnitude of the charge on the cation is harder to predict. Some transition metals, and a few main group metals as well, form more than one type of cation. For example, iron forms two different cations, Fe^{2+} and Fe^{3+}. Fe^{2+} is formed by losing two valence electrons from the 4*s* orbital. Fe^{3+} is formed by loss of three electrons, two from a 4*s* orbital and one from a 3*d* orbital.

Because transition metal cations generally have additional *d* electrons that the nearest noble gas does not, the octet rule is not usually followed. Figure 3.2 illustrates the common cations formed from transition metals, as well as some main group elements that form more than one cation.

FIGURE 3.2 Common Cations Derived from Transition Metals and Main Group Elements, Some of Which Have Variable Charge



PROBLEM 3.9 How many electrons and protons are contained in each cation?

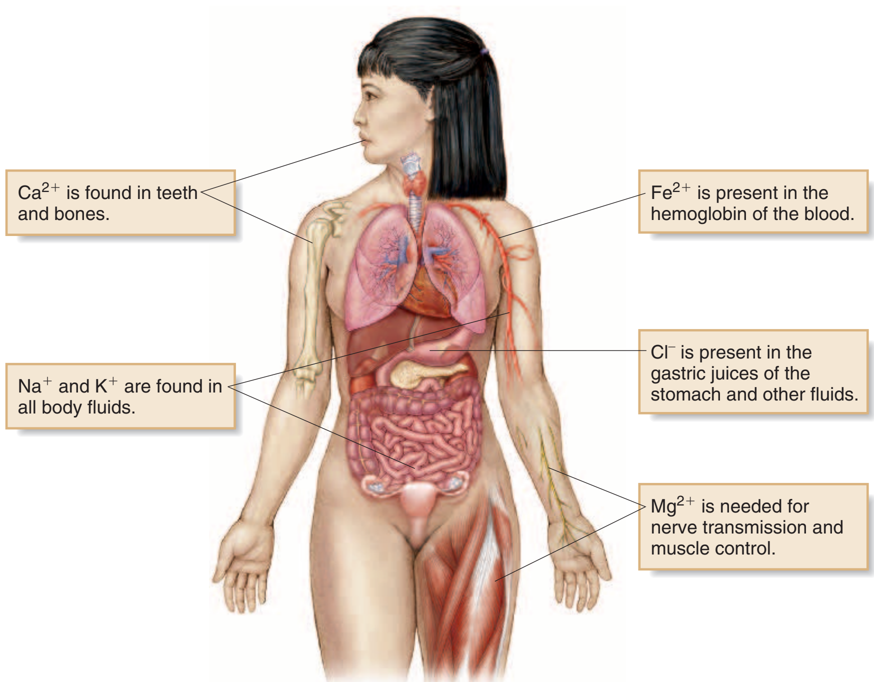
a. Au^+ b. Au^{3+} c. Sn^{2+} d. Sn^{4+}

3.2D FOCUS ON THE HUMAN BODY IMPORTANT IONS IN THE BODY

Many different ions are required for proper cellular and organ function (Figure 3.3). The major cations in the body are Na^+, K^+, Ca^{2+}, and Mg^{2+}. K^+ and Mg^{2+} are present in high concentrations inside cells, while Na^+ and Ca^{2+} are present in a higher concentration outside of cells, in the extracellular fluids. Na^+ is the major cation present in blood and extracellular bodily fluids and its concentration is carefully regulated through a number of mechanisms to maintain blood volume and blood pressure within acceptable ranges that permit organ function. Ca^{2+} is found mainly in solid body parts such as teeth and bones, but it is also needed for proper nerve conduction and muscle contraction, as is Mg^{2+}.

In addition to these four cations, Fe^{2+} and Cl^- are also important ions. Fe^{2+} is essential for oxygen transport by red blood cells. Cl^- is present in red blood cells, gastric juices, and other body fluids. Along with Na^+, it plays a major role in regulating the fluid balance in the body.

FIGURE 3.3 Common Ions in the Human Body



Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, and Cl^- are all common ions present throughout the organs of the human body.

HEALTH NOTE

All of these foods are high in sodium.

TABLE 3.2 Na^+ Content in Common Foods

Foods High in Na^+		Foods Low in Na^+	
Food	**Na^+ (mg)**	**Food**	**Na^+ (mg)**
Potato chips (30)	276	Banana (1)	1
Hot dog (1)	504	Orange juice (1 cup)	2
Ham, smoked (3 oz)	908	Oatmeal, cooked (1 cup)	2
Chicken soup, canned (1 cup)	1,106	Cereal, shredded wheat (3.5 oz)	3
Tomato sauce, canned (1 cup)	1,402	Raisins, dried (3.5 oz)	27
Parmesan cheese (1 cup)	1,861	Salmon (3 oz)	55

Although Na^+ is an essential mineral needed in the daily diet, the average American consumes three to five times the recommended daily allowance (RDA) of 2,400 mg. Excess sodium intake is linked to high blood pressure and heart disease. Dietary Na^+ comes from salt, NaCl, added during cooking or at the table. Na^+ is also added during the preparation of processed foods and canned products. For example, one 3.5-oz serving of fresh asparagus has only 1 mg of Na^+, but the same serving size of canned asparagus contains 236 mg of Na^+. Potato chips, snack foods, ketchup, processed meats, and many cheeses are particularly high in Na^+. Table 3.2 lists the Na^+ content of some common foods.

PROBLEM 3.10 Horseshoe crabs utilize a copper-containing protein called hemocyanin to transport oxygen. When oxygen binds to the protein it converts Cu^+ to Cu^{2+}, and the blood becomes blue in color. How many protons and electrons do each of these copper cations contain?

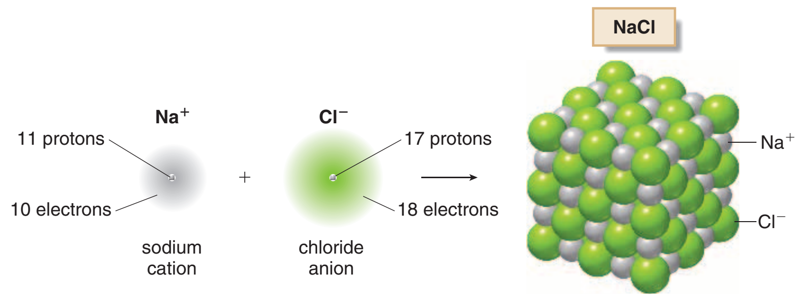
PROBLEM 3.11 Mn^{2+} is an essential nutrient needed for blood clotting and the formation of the protein collagen. (a) How many protons and electrons are found in a neutral manganese atom? (b) How many electrons and protons are found in the cation Mn^{2+}? (c) Write the electronic configuration of the element manganese and suggest which electrons are lost to form the Mn^{2+} cation.

3.3 IONIC COMPOUNDS

When a metal on the left side of the periodic table transfers one or more electrons to a nonmetal on the right side, **ionic bonds** are formed.

- **Ionic compounds are composed of cations and anions.**

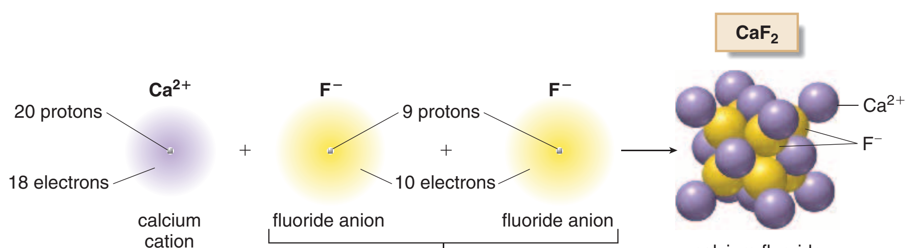
The ions in an ionic compound are arranged to maximize the attractive force between the oppositely charged species. For example, sodium chloride, NaCl, is composed of sodium cations (Na^+) and chloride anions (Cl^-), packed together in a regular arrangement in a crystal lattice. Each Na^+ cation is surrounded by six Cl^- anions, and each Cl^- anion is surrounded by six Na^+ cations. In this way, the positively charged cations are located closer to the charged particles to which they are attracted—anions—and farther from the particles from which they are repelled—cations.



- **The sum of the charges in an ionic compound must always be zero overall.**

The formula for an ionic compound shows the ratio of ions that combine to give zero charge. Since the sodium cation has a +1 charge and the chloride anion has a –1 charge, there must be one Na^+ cation for each Cl^- anion; thus, the formula is **NaCl.**

When cations and anions having charges of different magnitude combine, the number of cations per anion is not equal. Consider an ionic compound formed from calcium (Ca) and fluorine (F). Since calcium is located in group 2A, it loses two valence electrons to form Ca^{2+}. Since fluorine is located in group 7A, it gains one electron to form F^- like other halogens. When Ca^{2+} combines with the fluorine anion F^-, there must be two F^- anions for each Ca^{2+} cation to have an overall charge of zero.



In writing a formula for an ionic compound, we use subscripts when the number of ions needed to achieve zero charge is greater than one. Since two F^- anions are needed for each calcium cation, the formula is $\mathbf{CaF_2}$.

PROBLEM 3.12

Which pairs of elements will form ionic compounds?

a. lithium and bromine
b. chlorine and oxygen
c. calcium and magnesium
d. barium and chlorine

3.3A FORMULAS FOR IONIC COMPOUNDS

Writing a formula for an ionic compound from two elements is a useful skill that can be practiced by following a series of steps.

HOW TO Write a Formula for an Ionic Compound

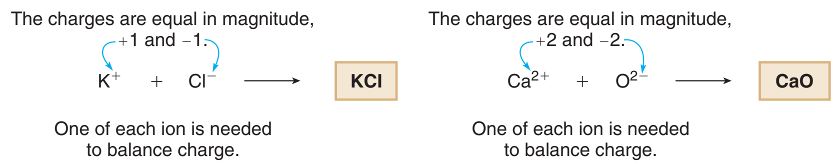
Step [1] **Identify which element is the cation and which is the anion.**

- **Metals form *cations* and nonmetals form *anions*.**
- Use the group number of a main group element to determine the charge.

An ionic compound derived from calcium and oxygen has the metal calcium as the cation and the nonmetal oxygen as the anion. Calcium (group 2A) loses two electrons to form Ca^{2+}. Oxygen (group 6A) gains two electrons to form O^{2-}.

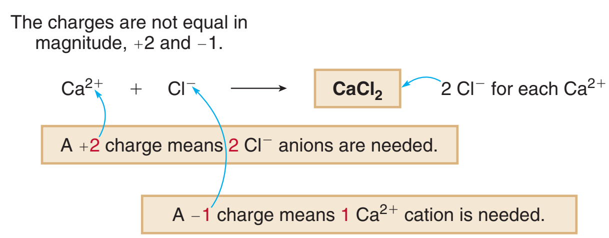
Step [2] **Determine how many of each ion type is needed for an overall charge of zero.**

- When the cation and anion have the *same* charge only *one* of each is needed.



- When the cation and anion have different charges, use the ion charges to determine the number of ions of each needed.

An ionic compound from calcium and chlorine has two ions of unequal charges, Ca^{2+} and Cl^-. **The charges on the ions tell us how many of the *oppositely* charged ions are needed to balance charge.**



Step [3] **To write the formula, place the cation first and then the anion, and omit charges.**

- Use subscripts to show the number of each ion needed to have zero overall charge. When no subscript is written it is assumed to be "1."

As shown in step [2], the formula for the ionic compound formed from one calcium cation (Ca^{2+}) and one oxygen anion (O^{2-}) is CaO. The formula for the ionic compound formed from one calcium cation (Ca^{2+}) and two chlorine anions (Cl^-) is $CaCl_2$.

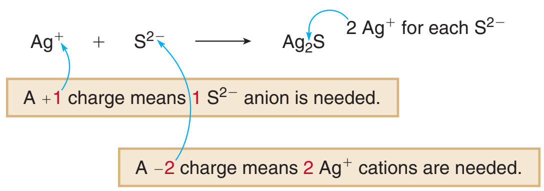
SAMPLE PROBLEM 3.5

When sterling silver tarnishes it forms an ionic compound derived from silver and sulfur. Write the formula for this ionic compound.

ANALYSIS

- Identify the cation and the anion, and use the periodic table to determine the charges.
- When ions of equal charge combine, one of each ion is needed. When ions of unequal charge combine, use the ionic charges to determine the relative number of each ion.
- Write the formula with the cation first and then the anion, omitting charges, and using subscripts to indicate the number of each ion.

SOLUTION Silver is a metal, so it forms the cation. Sulfur is a nonmetal, so it forms the anion. The charge on silver is +1 (Ag^+), as shown in Figure 3.2. Sulfur (group 6A) is a main group element with a −2 charge (S^{2-}). Since the charges are unequal, use their magnitudes to determine the relative number of each ion to give an overall charge of zero.



Answer: Since two Ag^+ cations are needed for each S^{2-} anion, the formula is $\mathbf{Ag_2S}$.

PROBLEM 3.13

Write the formula for the ionic compound formed from each pair of elements.

a. sodium and bromine
b. barium and oxygen
c. magnesium and iodine
d. lithium and oxygen

The tarnish on sterling silver is composed of an ionic compound formed from silver and sulfur (Sample Problem 3.5).

3.3B FOCUS ON HEALTH & MEDICINE IONIC COMPOUNDS IN CONSUMER PRODUCTS

Simple ionic compounds are added to food or consumer products to prevent disease or maintain good health. For example, **potassium iodide** (KI) is an essential nutrient added to table salt. Iodine is needed to synthesize thyroid hormones. A deficiency of iodine in the diet can lead to insufficient thyroid hormone production. In an attempt to compensate, the thyroid gland may become enlarged, producing a swollen thyroid referred to as a goiter. **Sodium fluoride** (NaF) is added to toothpaste to strengthen tooth enamel and help prevent tooth decay.

HEALTH NOTE

Potassium is a critical cation for normal heart and skeletal muscle function and nerve impulse conduction. Drinking electrolyte replacement beverages like Gatorade or Powerade can replenish K^+ lost in sweat.

Potassium chloride (KCl), sold under trade names such as K–Dur, Klor–Con, and Micro–K, is an ionic compound used for patients whose potassium levels are low. Potassium chloride can be given as tablets, an oral suspension, or intravenously. Adequate potassium levels are needed for proper fluid balance and organ function. Although potassium is readily obtained from many different food sources (e.g., potatoes, beans, melon, bananas, and spinach), levels can become low when too much potassium is lost in sweat and urine or through the use of certain medications.

PROBLEM 3.14

Zinc oxide, an ionic compound formed from zinc and oxygen, is a common component of sunblocks, as mentioned in the chapter opener. The zinc oxide crystals reflect sunlight away from the skin, and in this way, protect it from sun exposure. What is the ionic formula for zinc oxide?

3.4 NAMING IONIC COMPOUNDS

Now that we have learned how to write the formulas of some simple ionic compounds, we must learn how to name them. Assigning an unambiguous name to each compound is called chemical **nomenclature.** To name ionic compounds, we must first learn how to name the cations and anions that compose them.

3.4A NAMING CATIONS

Cations of main group metals are given the name of the element from which they are formed.

Na^+	K^+	Ca^{2+}	Mg^{2+}
sodium	potassium	calcium	magnesium

It is common to add the word "ion" after the name of the metal cation to distinguish it from the neutral metal itself. For example, when the concentration of sodium in a blood sample is determined, what is really measured is the concentration of sodium *ions* (Na^+).

When a metal is able to form two different cations, a method is needed to distinguish these cations. Two systems are used, the systematic method and the common method. The systematic method (Method [1]) will largely be followed in this text. Since many ions are still identified by older names, however, the common method (Method [2]) is also given.

- **Method [1]: Follow the name of the cation by a Roman numeral in parentheses to indicate its charge.**
- **Method [2]: Use the suffix *-ous* for the cation with the smaller charge, and the suffix *-ic* for the cation with the higher charge. These suffixes are often added to the Latin names of the elements.**

For example, the element iron (Fe) forms two cations, Fe^{2+} and Fe^{3+}, which are named in the following way:

	Systematic Name	Common Name
Fe^{2+}	iron(II)	ferr***ous***
Fe^{3+}	iron(III)	ferr***ic***

Table 3.3 lists the systematic and common names for several cations.

TABLE 3.3 Systematic and Common Names for Some Metal Ions

Element	Ion Symbol	Systematic Name	Common Name
Copper	Cu^+	Copper(I)	Cuprous
	Cu^{2+}	Copper(II)	Cupric
Chromium	Cr^{2+}	Chromium(II)	Chromous
	Cr^{3+}	Chromium(III)	Chromic
Iron	Fe^{2+}	Iron(II)	Ferrous
	Fe^{3+}	Iron(III)	Ferric
Tin	Sn^{2+}	Tin(II)	Stannous
	Sn^{4+}	Tin(IV)	Stannic

3.4B NAMING ANIONS

Anions are named by replacing the ending of the element name by the suffix *-ide*. For example:

Cl chlor*ine*	- - - →	Cl^- chlor***ide***	[Change *-ine* to ***-ide.***]
O *oxygen*	- - - →	O^{2-} ox***ide***	[Change *-ygen* to ***-ide.***]

Table 3.4 lists the names of common anions derived from nonmetal elements.

TABLE 3.4 Names of Common Anions

Element	Ion Symbol	Name
Bromine	Br^-	Bromide
Chlorine	Cl^-	Chloride
Fluorine	F^-	Fluoride
Iodine	I^-	Iodide
Oxygen	O^{2-}	Oxide
Sulfur	S^{2-}	Sulfide

PROBLEM 3.15 Give the name of each ion.

a. S^{2-} b. Cu^+ c. Cs^+ d. Al^{3+} e. Sn^{4+}

PROBLEM 3.16 Give the symbol for each ion.

a. stannic b. iodide c. manganese ion d. lead(II) e. selenide

PROBLEM 3.17 Under certain reaction conditions, an anion (H^-) can be formed from the hydrogen atom. Given the general way that anions are named, suggest a name for this anion.

3.4C NAMING IONIC COMPOUNDS WITH CATIONS FROM MAIN GROUP METALS

To name an ionic compound with a main group metal cation whose charge never varies, **name the cation and then the anion.** Do *not* specify the charge on the cation. Do *not* specify how many ions of each type are needed to balance charge.

Na^+ sodium	F^- fluoride	- - - →	NaF sodium fluoride
Mg^{2+} magnesium	Cl^- chloride	- - - →	$MgCl_2$ magnesium chloride

Thus, $BaCl_2$ is named barium chloride (*not* barium *di*chloride). The number of ions of each type is inferred in the name because the net charge must be zero.

SAMPLE PROBLEM 3.6 Name each ionic compound: (a) Na_2S; (b) $AlBr_3$.

ANALYSIS Name the cation and then the anion.

SOLUTION

a. Na_2S: The cation is sodium and the anion is sulfide (derived from sulfur); thus, the name is sodium sulfide.

b. $AlBr_3$: The cation is aluminum and the anion is bromide (derived from bromine); thus, the name is aluminum bromide.

PROBLEM 3.18 Name each ionic compound.

a. NaF	c. $SrBr_2$	e. TiO_2	g. CaI_2
b. MgO	d. Li_2O	f. $AlCl_3$	h. $CoCl_2$

3.4D NAMING IONIC COMPOUNDS CONTAINING METALS WITH VARIABLE CHARGE

To name an ionic compound that contains a metal with variable charge, we must specify the charge on the cation. The formula of the ionic compound—that is, how many cations there are per anion—allows us to determine the charge on the cation.

HOW TO Name an Ionic Compound That Contains a Metal with Variable Charge

EXAMPLE **Give the name for $CuCl_2$.**

Step [1] **Determine the charge on the cation.**

- Since there are two Cl^- anions, each of which has a –1 charge, the copper cation must have a +2 charge to make the overall charge zero.

$CuCl_2$ → 2 Cl^- anions ---→ The total negative charge is −2.

Cu must have a +2 charge to balance the −2 charge of the anions. → Cu^{2+}

Step [2] **Name the cation and anion.**

- Name the cation using its element name followed by a Roman numeral to indicate its charge. In the common system, use the suffix *-ous* or *-ic* to indicate charge.
- Name the anion by changing the ending of the element name to the suffix *-ide.*

Cu^{2+} ---→ copper(II) or cupric

Cl^- ---→ chloride

Step [3] **Write the name of the cation first, then the anion.**

- **Answer:** Copper(II) chloride or cupric chloride.

Sample Problem 3.7 illustrates the difference in naming ionic compounds derived from metals that have fixed or variable charge.

SAMPLE PROBLEM 3.7

SnF_2 and Al_2O_3 are both ingredients in commercial toothpastes. SnF_2 contains fluoride, which strengthens tooth enamel. Al_2O_3 is an abrasive that helps to scrub the teeth clean when they are brushed. Give names for (a) SnF_2; (b) Al_2O_3.

ANALYSIS First determine if the cation has a fixed or variable charge. To name an ionic compound that contains a cation that always has the same charge, name the cation and then the anion (using the suffix *-ide*). When the metal has a variable charge, use the overall anion charge to determine the charge on the cation. Then name the cation (using a Roman numeral or the suffix *-ous* or *-ic*), followed by the anion.

SOLUTION

a. SnF_2: Sn cations have variable charge so the overall anion charge determines the cation charge.

SnF_2 → 2 F^- anions ---→ The total negative charge is −2.

Sn must have a +2 charge to balance the −2 charge of the anions.

→ tin(II) or stannous → fluoride

Answer: tin(II) fluoride or stannous fluoride

b. Al_2O_3: Al has a fixed charge of +3. To name the compound, name the cation as the element (aluminum), and the anion by changing the ending of the element name to the suffix *-ide* (oxygen → oxide).

Al_2O_3 → aluminum, oxide **Answer:** aluminum oxide

HEALTH NOTE

Some toothpastes contain the ionic compounds SnF_2 as a source of fluoride and Al_2O_3 as an abrasive.

PROBLEM 3.19

Name each ionic compound.

a. $CrCl_3$
b. PbS
c. SnF_4
d. PbO_2
e. $FeBr_2$
f. $AuCl_3$

PROBLEM 3.20

Several copper salts are brightly colored. Give the name for each of the following ionic copper compounds.

a. Cu_2O (brown)
b. CuO (black)
c. CuCl (green)
d. $CuCl_2$ (blue)

PROBLEM 3.21

When iron rusts it forms Fe_2O_3. Name this product of air oxidation.

3.4E WRITING A FORMULA FROM THE NAME OF AN IONIC COMPOUND

Thus far, we have focused on assigning a name to a formula for an ionic compound. Writing a formula from a name is also a useful skill.

HOW TO Derive a Formula from the Name of an Ionic Compound

EXAMPLE **Write the formula for tin(IV) oxide.**

Step [1] **Identify the cation and the anion and determine their charges.**

- The name of the cation appears first, followed by the anion.
- For metals with variable charge, the Roman numeral gives the charge on the cation.

In this example, tin is the cation. The Roman numeral tells us that its charge is +4, making the cation Sn^{4+}. Oxide is the name of the oxygen anion, O^{2-} (Table 3.4).

Step [2] **Balance charges.**

- Use the charge on the cation to determine the number of ions of the anion needed to balance charge.

Sn^{4+} (cation) O^{2-} (anion) — Two −2 anions are needed for each +4 cation.

Step [3] **Write the formula with the cation first, and use subscripts to show the number of each ion needed to have zero overall charge.**

Answer: SnO_2

PROBLEM 3.22

Write the formula for each ionic compound.

a. calcium bromide
b. copper(I) iodide
c. ferric bromide
d. magnesium sulfide
e. chromium(II) chloride
f. sodium oxide

3.5 PHYSICAL PROPERTIES OF IONIC COMPOUNDS

Ionic compounds are crystalline solids composed of ions packed to maximize the interaction of the positive charge of the cations and negative charge of the anions. The relative size and charge of the ions determine the way they are packed in the crystal lattice. Ionic solids are held together by extremely strong interactions of the oppositely charged ions. How is this reflected in the melting point and boiling point of an ionic compound?

When a compound melts to form a liquid, energy is needed to overcome some of the attractive forces of the ordered solid, to form the less ordered liquid phase. Since an ionic compound is held together by very strong electrostatic interactions, it takes a great deal of energy to separate the ions from each other. As a result, **ionic compounds have very high melting points.** For example, the melting point of NaCl is 801 °C.

A great deal of energy is needed to overcome the attractive forces present in the liquid phase, too, to form ions that are far apart and very disorganized in the gas phase, so **ionic compounds have extremely high boiling points.** The boiling point of liquid NaCl is 1413 °C.

A great many ionic compounds are soluble in water. When an ionic compound dissolves in water, the ions are separated, and each anion and cation is surrounded by water molecules, as shown in Figure 3.4. The interaction of the water solvent with the ions provides the energy needed to overcome the strong ion–ion attractions of the crystalline lattice. We will learn much more about solubility in Chapter 8.

An **aqueous solution** contains a substance dissolved in liquid water.

When an ionic compound dissolves in water, the resulting aqueous solution conducts an electric current. This distinguishes ionic compounds from other compounds discussed in Chapter 4, some of which dissolve in water but do not form ions and therefore do not conduct electricity.

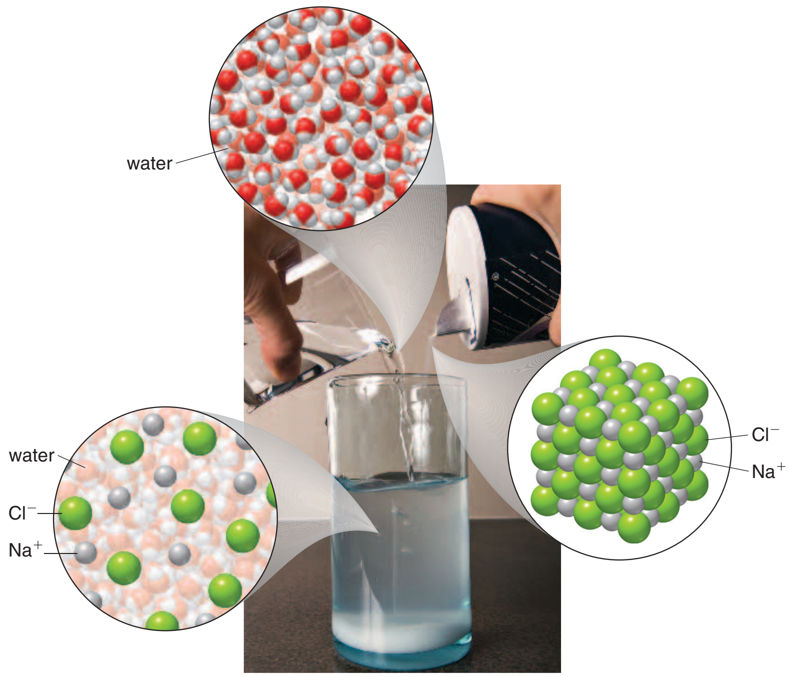
PROBLEM 3.23

List five physical properties of ionic compounds.

3.6 POLYATOMIC IONS

Sometimes ions are composed of more than one element. The ion bears a charge because the total number of electrons it contains is different from the total number of protons in the nuclei of all of the atoms.

FIGURE 3.4 Dissolving NaCl in Water



When NaCl dissolves in water, each Na^+ ion and each Cl^- ion is surrounded by water molecules. The interactions of these ions with water molecules provide the energy needed to break apart the ions of the crystal lattice.

- A *polyatomic ion* is a cation or anion that contains more than one atom.

The atoms in the polyatomic ion are held together by covalent bonds, but since the ion bears a charge, it bonds to other ions by ionic bonding. For example, calcium sulfate, $CaSO_4$, is composed of a calcium cation, Ca^{2+}, and the polyatomic anion sulfate, SO_4^{2-}. $CaSO_4$ is used to make plaster casts for broken bones.

We will encounter only two polyatomic cations: **H_3O^+, the hydronium ion,** which will play a key role in the acid–base chemistry discussed in Chapter 9, and **NH_4^+, the ammonium ion.**

In contrast, there are several common polyatomic anions, most of which contain a nonmetal like carbon, sulfur, or phosphorus, usually bonded to one or more oxygen atoms. Common examples include **carbonate (CO_3^{2-}), sulfate (SO_4^{2-}),** and **phosphate (PO_4^{3-}).** Table 3.5 lists the most common polyatomic anions.

The names of most polyatomic anions end in the suffix ***-ate.*** Exceptions to this generalization include hydroxide (^-OH) and cyanide (^-CN). Two other aspects of nomenclature are worthy of note.

- The suffix *-ite* is used for an anion that has one fewer oxygen atom than a similar anion named with the *-ate* ending. Thus, SO_4^{2-} is sulf*ate,* but SO_3^{2-} is sulf*ite.*
- When two anions differ in the presence of a hydrogen, the word *hydrogen* or the prefix *bi-* is added to the name of the anion. Thus, SO_4^{2-} is sulfate, but HSO_4^- is *hydrogen* sulfate or *bi*sulfate.

HEALTH NOTE

Spam, a canned meat widely consumed in Alaska, Hawaii, and other parts of the United States, contains the preservative sodium nitrite, $NaNO_2$. Sodium nitrite inhibits the growth of *Clostridium botulinum,* a bacterium responsible for a lethal form of food poisoning.

TABLE 3.5 Names of Common Polyatomic Anions

Nonmetal	Formula	Name
Carbon	$\mathbf{CO_3^{2-}}$	**Carbonate**
	HCO_3^-	Hydrogen carbonate or bicarbonate
	$CH_3CO_2^-$	Acetate
	^-CN	Cyanide
Nitrogen	$\mathbf{NO_3^-}$	**Nitrate**
	NO_2^-	Nitrite
Oxygen	$\mathbf{^-OH}$	**Hydroxide**
Phosphorus	$\mathbf{PO_4^{3-}}$	**Phosphate**
	HPO_4^{2-}	Hydrogen phosphate
	$H_2PO_4^-$	Dihydrogen phosphate
Sulfur	$\mathbf{SO_4^{2-}}$	**Sulfate**
	HSO_4^-	Hydrogen sulfate or bisulfate
	SO_3^{2-}	Sulfite
	HSO_3^-	Hydrogen sulfite or bisulfite

3.6A WRITING FORMULAS FOR IONIC COMPOUNDS WITH POLYATOMIC IONS

Writing the formula for an ionic compound with a polyatomic ion is no different than writing a formula for an ion with a single charged atom, so we follow the procedure outlined in Section 3.3A. When the cation and anion have the *same* charge, only *one* of each ion is needed for an overall charge of zero.

The charges are equal in magnitude, +1 and −1.

$$Na^+ \text{ (sodium)} + NO_2^- \text{ (nitrite)} \longrightarrow NaNO_2 \text{ (sodium nitrite)}$$

One of each ion is needed to balance charge.

The charges are equal in magnitude, +2 and −2.

$$Ba^{2+} \text{ (barium)} + SO_4^{2-} \text{ (sulfate)} \longrightarrow BaSO_4 \text{ (barium sulfate)}$$

One of each ion is needed to balance charge.

In a compound formed from ions of unequal charge, such as magnesium (Mg^{2+}) and hydroxide (^-OH), **the charges on the ions tell us how many of the *oppositely* charged ions are needed to balance the charge.**

The charges are not equal in magnitude, +2 and −1.

$$Mg^{2+} + {}^-OH \longrightarrow Mg(OH)_2$$

Two ^-OH anions are needed to balance charge.
Use parentheses around all atoms of the ion.
Use a subscript outside the parentheses.

Parentheses are used around the polyatomic ion, and a subscript indicates how many of each are needed to balance charge. The formula is written as $Mg(OH)_2$ *not* MgO_2H_2.

HEALTH NOTE

Barium sulfate is used to visualize the digestive system during an X-ray procedure.

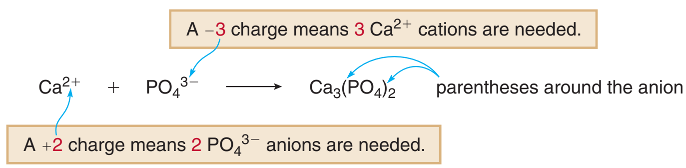
SAMPLE PROBLEM 3.8

A dietary supplement used to prevent and treat calcium deficiencies consists of an ionic compound formed from calcium and phosphate. What is its formula?

ANALYSIS

- Identify the cation and anion and determine the charges.
- When ions of equal charge combine, one of each is needed. When ions of unequal charge combine, use the ionic charges to determine the relative number of each ion.
- Write the formula with the cation first and then the anion, omitting charges. Use parentheses around polyatomic ions when more than one appears in the formula, and use subscripts to indicate the number of each ion.

SOLUTION The cation (Ca^{2+}) and anion (PO_4^{3-}) have different charges so the magnitude of the ionic charges determines the number of each ion giving an overall charge of zero.



Answer: Since three Ca^{2+} cations are needed for two PO_4^{3-} anions, the formula is $Ca_3(PO_4)_2$.

PROBLEM 3.24

Write the formula for the compound formed when the sulfate anion (SO_4^{2-}) combines with a cation from each of the following elements: (a) magnesium; (b) sodium; (c) nickel; (d) aluminum; (e) lithium.

PROBLEM 3.25

Write the formula of the ionic compound formed from each pair of cations and anions.

a. sodium and bicarbonate
b. potassium and nitrate
c. ammonium and sulfate
d. magnesium and phosphate
e. calcium and bisulfate
f. barium and hydroxide

PROBLEM 3.26

Write the formula for the compound formed when K^+ combines with each anion.

a. ^-OH
b. NO_2^-
c. SO_4^{2-}
d. HSO_3^-
e. PO_4^{3-}
f. ^-CN

3.6B NAMING IONIC COMPOUNDS WITH POLYATOMIC IONS

Naming ionic compounds derived from polyatomic anions follows the same procedures outlined in Sections 3.4C and 3.4D. There is no easy trick for remembering the names and structures of the anions listed in Table 3.5. The names of the anions in boldface type are especially common and should be committed to memory.

SAMPLE PROBLEM 3.9

Name each ionic compound: (a) $NaHCO_3$, the active ingredient in baking soda; (b) $Al_2(SO_4)_3$, an ingredient once used in antiperspirants, but no longer considered effective.

ANALYSIS First determine if the cation has a fixed or variable charge. To name an ionic compound that contains a cation that always has the same charge, name the cation and then the anion. When the metal has a variable charge, use the overall anion charge to determine the charge on the cation. Then name the cation (using a Roman numeral or the suffix *-ous* or *-ic*), followed by the anion.

SOLUTION

a. $NaHCO_3$: Sodium cations have a fixed charge of +1. The anion HCO_3^- is called bicarbonate or hydrogen carbonate.

Answer: sodium bicarbonate or sodium hydrogen carbonate

b. $Al_2(SO_4)_3$: Aluminum cations have a fixed charge of +3. The anion SO_4^{2-} is called sulfate.

Answer: aluminum sulfate

PROBLEM 3.27

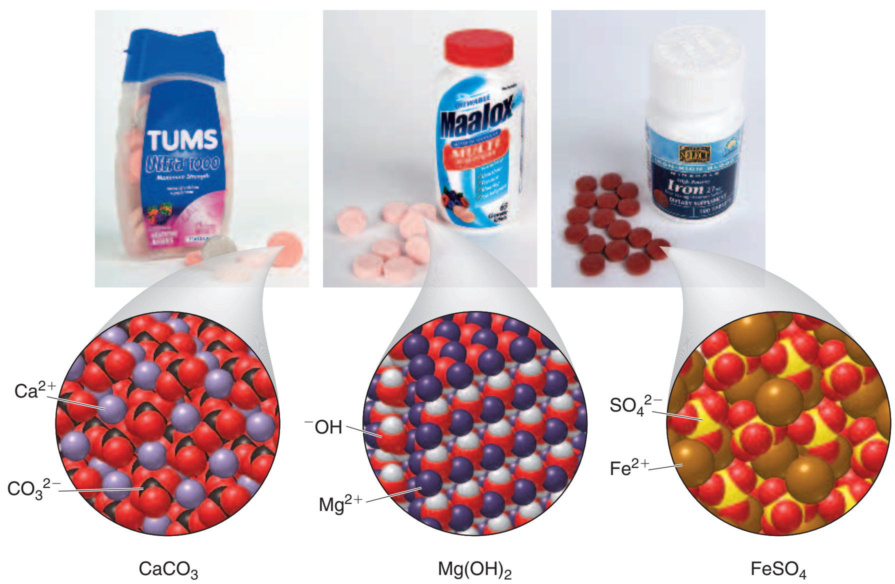
Name each compound.

a. Na_2CO_3
b. $Ca(OH)_2$
c. $Mg(NO_3)_2$
d. $Mn(CH_3CO_2)_2$
e. $Fe(HSO_3)_3$
f. $Mg_3(PO_4)_2$

3.6C FOCUS ON HEALTH & MEDICINE USEFUL IONIC COMPOUNDS

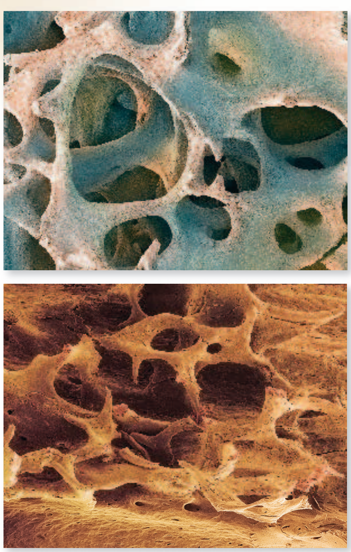
Ionic compounds are the active ingredients in several over-the-counter drugs. Examples include **calcium carbonate ($CaCO_3$),** the antacid in Tums; **magnesium hydroxide [$Mg(OH)_2$],** one of the active components in the antacids Maalox and milk of magnesia; and **iron(II) sulfate ($FeSO_4$),** an iron supplement used to treat anemia.

The shells of oysters and other mollusks are composed largely of calcium carbonate, $CaCO_3$.



Some ionic compounds are given as intravenous drugs. Bicarbonate (HCO_3^-) is an important polyatomic anion that controls the acid–base balance in the blood. When the blood becomes too acidic, sodium bicarbonate ($NaHCO_3$) is administered intravenously to decrease the acidity. Magnesium sulfate ($MgSO_4$), an over-the-counter laxative, is also given intravenously to prevent seizures caused by extremely high blood pressure associated with some pregnancies.

HEALTH NOTE



(top) Normal bone; (bottom) brittle bone due to osteoporosis. Osteoporosis results in a decrease in bone density, making bones brittle and easily fractured.

3.6D FOCUS ON HEALTH & MEDICINE TREATING OSTEOPOROSIS

Although much of the body is composed of compounds held together by covalent bonds, about 70% of bone is composed largely of a complex ionic solid with the formula $Ca_{10}(PO_4)_6(OH)_2$ called **hydroxyapatite.** Throughout an individual's life, hydroxyapatite is constantly broken down and rebuilt. In postmenopausal women, however, the rate of bone loss often becomes greater than bone synthesis, and bones get brittle and easily broken. This condition is called **osteoporosis.**

In recent years, some prescription drugs have proven effective in combating osteoporosis. Sodium alendronate, trade name Fosamax, increases bone density by decreasing the rate of bone loss. Fosamax is an ionic compound with the formula $Na(C_4H_{12}NO_7P_2)$. This compound contains a sodium cation, Na^+, and a polyatomic anion, $(C_4H_{12}NO_7P_2)^-$.

PROBLEM 3.28 Using the charges on the ions that compose hydroxyapatite, show that it has zero overall charge.

CHAPTER HIGHLIGHTS

KEY TERMS

Ammonium ion (3.6)
Anion (3.2)
Bonding (3.1)
Carbonate (3.6)
Cation (3.2)
Covalent bond (3.1)
Hydronium ion (3.6)
Hydroxide (3.6)
Ion (3.1)
Ionic bond (3.1)
Molecule (3.1)
Nomenclature (3.4)
Octet rule (3.2)
Phosphate (3.6)
Polyatomic ion (3.6)
Sulfate (3.6)

KEY CONCEPTS

❶ **What are the basic features of ionic and covalent bonds? (3.1)**

- Both ionic and covalent bonding follows one general rule: Elements gain, lose, or share electrons to attain the electronic configuration of the noble gas closest to them in the periodic table.
- Ionic bonds result from the transfer of electrons from one element to another. Ionic bonds form between a metal and a nonmetal. Ionic compounds consist of oppositely charged ions that feel a strong electrostatic attraction for each other.
- Covalent bonds result from the sharing of electrons between two atoms. Covalent bonds occur between two nonmetals, or when a metalloid combines with a nonmetal. Covalent bonding forms discrete molecules.

❷ **How can the periodic table be used to determine whether an atom forms a cation or an anion, and its resulting ionic charge? (3.2)**

- Metals form cations and nonmetals form anions.
- By gaining or losing one, two, or three electrons, an atom forms an ion with a completely filled outer shell of electrons.
- The charge on main group ions can be predicted from the position in the periodic table. For metals in groups 1A, 2A, and 3A, the group number = the charge on the cation. For nonmetals in groups 6A and 7A, the anion charge = 8 – (the group number).

❸ **What is the octet rule? (3.2)**

- Main group elements are especially stable when they possess an octet of electrons. Main group elements gain or lose one, two, or three electrons to form ions with eight outer shell electrons.

❹ **What determines the formula of an ionic compound? (3.3)**

- Cations and anions always form ionic compounds that have zero overall charge.
- Ionic compounds are written with the cation first, and then the anion, with subscripts to show how many of each are needed to have zero net charge.

❺ **How are ionic compounds named? (3.4)**

- Ionic compounds are always named with the name of the cation first.
- With cations having a fixed charge, the cation has the same name as its neutral element. The name of the anion usually ends in the suffix *-ide* if it is derived from a single atom or *-ate* (or *-ite*) if it is polyatomic.
- When the metal has a variable charge, use the overall anion charge to determine the charge on the cation. Then name the cation using a Roman numeral or the suffix *-ous* (for the ion with the smaller charge) or *-ic* (for the ion with the larger charge).

❻ **Describe the properties of ionic compounds. (3.5)**

- Ionic compounds are crystalline solids with the ions arranged to maximize the interactions of the oppositely charged ions.
- Ionic compounds have high melting points and boiling points.
- Most ionic compounds are soluble in water and their aqueous solutions conduct an electric current.

❼ **What are polyatomic ions and how are they named? (3.6)**

- Polyatomic ions are charged species that are composed of more than one element.
- The names for polyatomic cations end in the suffix *-onium*.
- Many polyatomic anions have names that end in the suffix *-ate*. The suffix *-ite* is used for an anion that has one fewer oxygen atom than a similar anion named with the *-ate* ending. When two anions differ in the presence of a hydrogen, the word *hydrogen* or the prefix *bi-* is added to the name of the anion.

❽ **List useful consumer products and drugs that are composed of ionic compounds.**

- Useful ionic compounds that contain alkali metal cations and halogen anions include KI (iodine supplement), NaF (source of fluoride in toothpaste), and KCl (potassium supplement). (3.3)
- Other products contain SnF_2 (fluoride source in toothpaste), Al_2O_3 (abrasive in toothpaste), and ZnO (sunblock agent). (3.4)
- Useful ionic compounds with polyatomic anions include $CaCO_3$ (antacid and calcium supplement), magnesium hydroxide (antacid), and $FeSO_4$ (iron supplement). (3.6)

PROBLEMS

Selected in-chapter and end-of-chapter problems have brief answers provided in Appendix B.

Ionic and Covalent Bonding

3.29 Which formulas represent ionic compounds and which represent covalent compounds?
a. CO_2 b. H_2SO_4 c. KF d. CH_5N

3.30 Which formulas represent ionic compounds and which represent covalent compounds?
a. C_3H_8 b. ClBr c. CuO d. CH_4O

3.31 Which pairs of elements are likely to form ionic bonds and which pairs are likely to form covalent bonds?
a. potassium and oxygen
b. sulfur and carbon
c. two bromine atoms
d. carbon and oxygen

3.32 Which pairs of elements are likely to form ionic bonds and which pairs are likely to form covalent bonds?
a. carbon and hydrogen
b. sodium and sulfur
c. hydrogen and oxygen
d. magnesium and bromine

3.33 Why do ionic bonds form between a metal and a nonmetal?

3.34 Is it proper to speak of sodium chloride molecules? Explain.

Ions

3.35 Write the ion symbol for an atom with the given number of protons and electrons.
a. four protons and two electrons
b. 22 protons and 20 electrons
c. 16 protons and 18 electrons
d. 13 protons and 10 electrons
e. 17 protons and 18 electrons
f. 20 protons and 18 electrons

3.36 How many protons and electrons are present in each ion?
a. K^+ b. S^{2-} c. Mn^{2+} d. Fe^{2+} e. Cs^+ f. I^-

3.37 What element fits each description?
a. a period 2 element that forms a +2 cation
b. an ion from group 7A with 18 electrons
c. a cation from group 1A with 36 electrons

3.38 What element fits each description?
a. a period 3 element that forms an ion with a –1 charge
b. an ion from group 2A with 36 electrons
c. an ion from group 6A with 18 electrons

3.39 Why do elements in group 6A gain electrons to form anions?

3.40 Why do elements in group 2A lose electrons to form cations?

3.41 Give the ion symbol for each ion.
a. sodium ion
b. selenide
c. manganese ion
d. gold(III)
e. stannic

3.42 Give the ion symbol for each ion.
a. barium ion
b. iron(II)
c. oxide
d. ferrous
e. lead(IV)

3.43 What noble gas has the same electronic configuration as each ion?
a. O^{2-} b. Mg^{2+} c. Al^{3+} d. S^{2-} e. F^- f. Be^{2+}

3.44 Give two cations and two anions that have the same electronic configuration as each noble gas: (a) neon; (b) argon.

3.45 How many electrons must be gained or lost by each element to achieve a noble gas configuration of electrons?
a. lithium b. iodine c. sulfur d. strontium

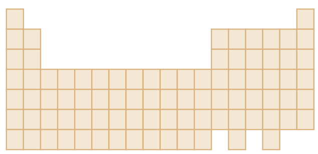
3.46 How many electrons must be gained or lost by each element to achieve a noble gas configuration of electrons?
a. cesium b. barium c. selenium d. aluminum

3.47 Which ions are likely to form? For those ions that are not likely to form, explain why this is so.
a. S^- b. S^{2-} c. S^{3-} d. Na^+ e. Na^{2+} f. Na^-

3.48 Which ions are likely to form? For those ions that are not likely to form, explain why this is so.
a. Mg^+ b. Mg^{2+} c. Mg^{3+} d. Cl^+ e. Cl^- f. Cl^{2-}

3.49 For each of the general electron-dot formulas for elements, give the following information: [1] the number of valence electrons; [2] the group number of the element; [3] how many electrons would be gained or lost to achieve a noble gas configuration; [4] the charge on the resulting ion; [5] an example of the element.
a. X· b. ·Q· c. ·Z̈· (with a pair of dots above and below) d. :Ä· (with a pair of dots above and below)

3.50 Label each of the following elements or regions in the periodic table.



a. a group that forms cations with a +2 charge
b. a group that forms anions with a –2 charge
c. a group that forms cations with a +1 charge
d. a group that forms anions with a –1 charge
e. elements that form ions with the same electronic configuration as Ne
f. elements that form ions with the same electronic configuration as He

3.51 Give the formula for each polyatomic ion.
a. sulfate c. hydrogen carbonate
b. ammonium d. cyanide

3.52 Give the formula for each polyatomic ion.
a. acetate c. dihydrogen phosphate
b. bisulfite d. hydronium

3.53 How many protons and electrons are contained in each polyatomic ion?
a. ^{-}OH b. H_3O^+ c. PO_4^{3-}

3.54 How many protons and electrons are contained in each polyatomic ion?
a. NH_4^+ b. ^{-}CN c. CO_3^{2-}

3.55 Why don't elements in group 4A readily form ions?

3.56 Do all isotopes of an element form the same type of ions? Explain.

3.57 Why isn't the octet rule followed by transition metals when they form cations?

3.58 Why don't the elements in group 8A form ions?

Ionic Compounds

3.59 How does the compound NaF illustrate the octet rule?

3.60 How does the compound LiF "violate" the octet rule?

3.61 Write the formula for the ionic compound formed from each pair of elements.
a. calcium and sulfur
b. aluminum and bromine
c. lithium and iodine
d. nickel and chlorine
e. sodium and selenium

3.62 Write the formula for the ionic compound formed from each pair of elements.
a. barium and bromine
b. aluminum and sulfur
c. manganese and chlorine
d. zinc and sulfur
e. magnesium and fluorine

3.63 Write the formula for the ionic compound formed from each cation and anion.
a. lithium and nitrite
b. calcium and acetate
c. sodium and bisulfite
d. manganese and phosphate
e. magnesium and hydrogen sulfite

3.64 Write the formula for the ionic compound formed from each cation and anion.
a. potassium and bicarbonate
b. magnesium and nitrate
c. lithium and carbonate
d. potassium and cyanide
e. ammonium and phosphate

3.65 Complete the following table by filling in the formula of the ionic compound derived from the cations on the left and each of the anions across the top.

	Br^-	^{-}OH	HCO_3^-	SO_3^{2-}	PO_4^{3-}
Na^+					
Co^{2+}					
Al^{3+}					

3.66 Complete the following table by filling in the formula of the ionic compound derived from the cations on the left and each of the anions across the top.

	I^-	^{-}CN	NO_3^-	SO_4^{2-}	HPO_4^{2-}
K^+					
Mg^{2+}					
Cr^{3+}					

3.67 Write the formula for the ionic compound formed from the bisulfate anion (HSO_4^-) and each cation: (a) K^+; (b) Ba^{2+}; (c) Al^{3+}; (d) Zn^{2+}.

3.68 Write the formula for the ionic compound formed from the sulfite anion (SO_3^{2-}) and each cation: (a) K^+; (b) Ba^{2+}; (c) Al^{3+}; (d) Zn^{2+}.

3.69 Write the formula for the ionic compound formed from the barium cation (Ba^{2+}) and each anion: (a) ^{-}CN; (b) PO_4^{3-}; (c) HPO_4^{2-}; (d) $H_2PO_4^-$.

3.70 Write the formula for the ionic compound formed from the iron(III) cation (Fe^{3+}) and each anion: (a) ^{-}CN; (b) PO_4^{3-}; (c) HPO_4^{2-}; (d) $H_2PO_4^-$.

Naming Ionic Compounds

3.71 Name each ionic compound.
a. Na_2O d. $AgCl$ f. $RbBr$
b. BaS e. $CoBr_2$ g. $PbBr_2$
c. PbS_2

3.72 Name each ionic compound.
a. KF d. SnO f. Li_2S
b. $ZnCl_2$ e. $AuBr_3$ g. $SnBr_4$
c. Cu_2S

3.73 Name each ionic compound.
a. $FeCl_2$ b. $FeBr_3$ c. FeS d. Fe_2S_3

3.74 Name each ionic compound.
a. $CrCl_2$ b. $CrBr_3$ c. CrO d. Cr_2O_3

3.75 Why is a Roman numeral needed in the name for $CuBr_2$ but not $CaBr_2$? Name both compounds.

3.76 Why is a Roman numeral needed in the name for PbO but not ZnO? Name both compounds.

3.77 Write formulas to illustrate the difference between each pair of compounds.
a. sodium sulfide and sodium sulfate
b. magnesium oxide and magnesium hydroxide
c. magnesium sulfate and magnesium bisulfate

3.78 Write formulas to illustrate the difference between each pair of compounds.
a. lithium sulfite and lithium sulfide
b. sodium carbonate and sodium hydrogen carbonate
c. calcium phosphate and calcium dihydrogen phosphate

3.79 Name each ionic compound.
a. NH_4Cl c. $Cu(NO_3)_2$ e. $Fe(NO_3)_2$
b. $PbSO_4$ d. $Ca(HCO_3)_2$

3.80 Name each ionic compound.
a. $(NH_4)_2SO_4$ c. $Cr(CH_3CO_2)_3$ e. $Ni_3(PO_4)_2$
b. NaH_2PO_4 d. $Sn(HPO_4)_2$

3.81 Write a formula from each name.
a. magnesium carbonate
b. nickel sulfate
c. copper(II) hydroxide
d. potassium hydrogen phosphate
e. gold(III) nitrate
f. lithium phosphate
g. aluminum bicarbonate
h. chromous cyanide

3.82 Write a formula from each name.
a. copper(I) sulfite
b. aluminum nitrate
c. tin(II) acetate
d. lead(IV) carbonate
e. zinc hydrogen phosphate
f. manganese dihydrogen phosphate
g. ammonium cyanide
h. iron(II) nitrate

3.83 Write the formula for the ionic compound formed from Pb^{4+} and each anion. Then name each compound.
a. ^{-}OH c. HCO_3^{-} e. PO_4^{3-}
b. SO_4^{2-} d. NO_3^{-} f. $CH_3CO_2^{-}$

3.84 Write the formula for the ionic compound formed from Fe^{3+} and each anion. Then name each compound.
a. ^{-}OH c. HPO_4^{2-} e. PO_4^{3-}
b. CO_3^{2-} d. NO_2^{-} f. $CH_3CO_2^{-}$

Properties of Ionic Compounds

3.85 Label each statement as "true" or "false." Correct any false statement to make it true.
a. Ionic compounds have high melting points.
b. Ionic compounds can be solid, liquid, or gas at room temperature.
c. Most ionic compounds are insoluble in water.
d. An ionic solid like sodium chloride consists of discrete pairs of sodium cations and chloride anions.

3.86 Label each statement as "true" or "false." Correct any false statement to make it true.
a. Ionic compounds have high boiling points.
b. The ions in a crystal lattice are arranged randomly and the overall charge is zero.
c. When an ionic compound dissolves in water, the solution conducts electricity.
d. In an ionic crystal, ions having like charges are arranged close to each other.

3.87 Why do ionic solids have high melting points?

3.88 Would you expect the gases in the atmosphere to be composed of ionic compounds or covalent molecules? Explain your choice.

3.89 Which compound has the highest melting point: NaCl, CH_4, or H_2SO_4?

3.90 Which compound or element has the lowest boiling point: Cl_2, KI, or LiF?

Applications

3.91 Zinc is an essential nutrient needed by many enzymes to maintain proper cellular function. Zinc is obtained in many dietary sources, including oysters, beans, nuts, whole grains, and sunflower seeds. (a) How many protons and electrons are found in a neutral zinc atom? (b) How many electrons and protons are found in the Zn^{2+} cation? (c) Write the electronic configuration of the element zinc, and suggest which electrons are lost to form the Zn^{2+} cation.

3.92 Wilson's disease is an inherited defect in copper metabolism in which copper accumulates in tissues, causing neurological problems and liver disease. The disease can be treated with compounds that bind to copper and thus remove it from the tissues. (a) How many protons and electrons are found in a neutral copper atom? (b) How many electrons and protons are found in the Cu^{+} cation? (c) How many electrons and protons are found in the Cu^{2+} cation? (d) Zinc acetate inhibits copper absorption and so it is used to treat Wilson's disease. What is the structure of zinc acetate?

3.93 Na^{+}, K^{+}, Ca^{2+}, and Mg^{2+} are the four major cations in the body. For each cation, give the following information: (a) the number of protons; (b) the number of electrons; (c) the noble gas that has the same electronic configuration; (d) its role in the body.

3.94 Unlike many ionic compounds, calcium carbonate is insoluble in water. What information contained in this chapter suggested that calcium carbonate is water insoluble?

3.95 Write the formula for silver nitrate, an antiseptic and germ killing agent.

3.96 Ammonium carbonate is the active ingredient in smelling salts. Write its formula.

3.97 $CaSO_3$ is used to preserve cider and fruit juices. Name this ionic compound.

3.98 Many ionic compounds are used as paint pigments. Name each of the following pigments.

a. CdS (yellow)
b. TiO_2 (white)
c. Cr_2O_3 (white)
d. $Mn_3(PO_4)_2$ (purple)

3.99 Ammonium nitrate is the most common source of the element nitrogen in fertilizers. When it is mixed with water, the solution gets cold, so it is used in instant cold packs. When mixed with diesel fuel it forms an explosive mixture that can be used as a bomb. Write the structure of ammonium nitrate.

3.100 Write the formula for sodium phosphate, a key ingredient in many commercial detergents.

CHALLENGE QUESTIONS

3.101 Energy bars contain ionic compounds that serve as a source of the trace elements that the body needs each day for proper cellular function. Answer the following questions about some of the ingredients in one commercial product.

a. Write the formulas for magnesium oxide and potassium iodide.
b. The ingredient $CaHPO_4$ is called dicalcium phosphate on the label. What name would you give to this ionic compound?
c. Give two different names for the ingredient $FePO_4$.
d. Sodium selenite is one ingredient. Selenite is a polyatomic anion that contains a selenium atom in place of the sulfur atom in sulfite. With this in mind, suggest a structure for sodium selenite.
e. Another ingredient is listed as chromium chloride. What is wrong with this name?

3.102 Some polyatomic anions contain a metal as part of the anion. For example, the anion dichromate has the structure $Cr_2O_7^{2-}$ and the anion permanganate has the structure MnO_4^{-}. Write the formula of the ionic compound formed from each of these anions and a potassium cation. Name each compound.