7.2

## 1 FOCUS

### Objectives

**7.2.1** **Explain** the electrical charge of an ionic compound.

**7.2.2** **Describe** three properties of ionic compounds.

## Guide for Reading

### Build Vocabulary L2

**Paraphrase** Have students skim through the section to locate the meanings of the vocabulary terms. Then have them paraphrase each definition.

### Reading Strategy L2

**Identify Main Ideas/Details** Have students identify the main idea of each paragraph of this section. Have them include these ideas in an outline of the section.

## 2 INSTRUCT

### *Connecting to Your World*

Have students examine the section-opening photograph and Figure 7.8. Discuss how the reactive (and poisonous) elements sodium metal and chlorine gas can combine to form harmless table salt. Ask, **What characteristics of sodium and chlorine atoms allow them to form the stable compound sodium chloride, also known as table salt?** *(Sodium atoms can lose an electron easily, and chlorine atoms can accept an electron easily. The resulting ions can combine with the other oppositely charged ions.)* Remind students that NaCl is an example of an ionic compound.

### Formation of Ionic Compounds

#### Discuss L2

Explain that the formation of positive ions and of negative ions are simultaneous and interdependent processes. An ionic compound is the result of the transfer of electrons from one set of atoms to another set of atoms. An ionic compound consists entirely of ions.



# 7.2 Ionic Bonds and Ionic Compounds

### Guide for Reading

**Key Concepts**
- What is the electrical charge of an ionic compound?
- What are three properties of ionic compounds?

**Vocabulary**

ionic compounds
ionic bonds
chemical formula
formula unit
coordination number

**Reading Strategy**

**Previewing** Before you read this section, rewrite the headings as *how*, *why*, and *what* questions about ionic compounds. As you read, write answers to the questions.

### *Connecting to Your World*

You have heard of harvesting crops such as wheat or rice—but salt? In many coastal countries that have warm, relatively dry climates, salt is produced by the evaporation of seawater. The salty water is channeled into a series of shallow ponds, where it becomes more concentrated as the water evaporates by exposure to the sun. When the saltwater is concentrated enough, it is diverted into a pan, on which the sodium chloride crystals deposit. Salt farmers then drain the pans and collect the salt into piles to dry. In this section, you will learn how cations and anions combine to form stable compounds such as sodium chloride.

## Formation of Ionic Compounds

Compounds composed of cations and anions are called **ionic compounds.** Ionic compounds are usually composed of metal cations and nonmetal anions. For example, sodium chloride, or table salt, is composed of sodium cations and chloride anions. **Although they are composed of ions, ionic compounds are electrically neutral.** The total positive charge of the cations equals the total negative charge of the anions.

**Ionic Bonds** Anions and cations have opposite charges and attract one another by means of electrostatic forces. The electrostatic forces that hold ions together in ionic compounds are called **ionic bonds.**

Sodium chloride provides a simple example of how ionic bonds are formed. Consider the reaction between a sodium atom and a chlorine atom. Sodium has a single valence electron that it can easily lose. (If the sodium atom loses its valence electron, it achieves the stable electron configuration of neon.) Chlorine has seven valence electrons and can easily gain one. (If the chlorine atom gains a valence electron, it achieves the stable electron configuration of argon.) When sodium and chlorine react to form a compound, the sodium atom gives its one valence electron to a chlorine atom. Thus sodium and chlorine atoms combine in a one-to-one ratio and both ions have stable octets.

$$\text{Na}\cdot + \cdot\ddot{\underset{..}{\text{Cl}}}: \longrightarrow \text{Na}^+ \quad :\ddot{\underset{..}{\text{Cl}}}:^-$$

$$1s^22s^22p^63s^1 \quad 1s^22s^22p^63s^23p^5 \qquad 1s^22s^22p^6\ (\text{octet}) \quad 1s^22s^22p^63s^23p^6\ (\text{octet})$$

$$\text{Ne}\ \ 1s^22s^22p^6\ (\text{octet}) \qquad \text{Ar}\ \ 1s^22s^22p^63s^23p^6\ (\text{octet})$$

Interactive Textbook

**Animation 8** Take an atomic-level look at the formation of KCl.

with ChemASAP



## Section Resources

### Print
- **Guided Reading and Study Workbook,** Section 7.2
- **Core Teaching Resources,** Section 7.2 Review, Interpreting Graphics
- **Transparencies,** T79–T81
- **Probeware Laboratory Manual,** Section 7.2

### Technology
- **Interactive Textbook with ChemASAP,** Animation 8, Simulation 5, Problem-Solving 7.12, Assessment 7.2
- **Go Online,** Section 7.2
- **Virtual Chemistry Lab,** Lab 2

Figure 7.7 shows aluminum and bromine reacting to form the compound aluminum bromide. Each aluminum atom has three valence electrons to lose. Each bromine atom has seven valence electrons and readily gains one additional electron. Therefore, when aluminum and bromine react, three bromine atoms combine with each aluminum atom.

**Formula Units** The ionic compound sodium chloride is composed of equal numbers of sodium cations ($Na^+$) and chloride anions ($Cl^-$). As you can see in Figure 7.8, the ions in solid sodium chloride are arranged in an orderly pattern. There are no single discrete units, only a continuous array of ions.

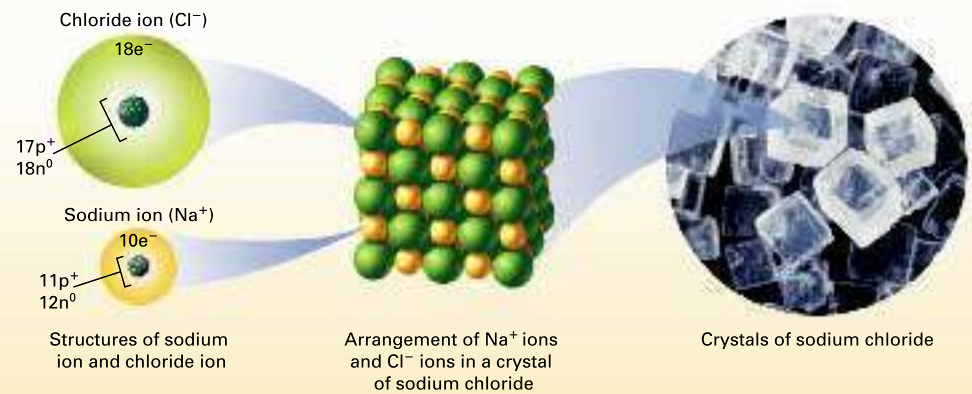
Chemists represent the composition of substances by writing chemical formulas. A **chemical formula** shows the kinds and numbers of atoms in the smallest representative unit of a substance. NaCl, for example, is the chemical formula for sodium chloride. Note, however, that the formula NaCl does not represent a single discrete unit. Because an ionic compound exists as a collection of positively and negatively charged ions arranged in repeating patterns, its chemical formula refers to a ratio known as a formula unit. A **formula unit** is the lowest whole-number ratio of ions in an ionic compound. For sodium chloride, the lowest whole-number ratio of the ions is 1:1 (one $Na^+$ to each $Cl^-$). Thus the formula unit for sodium chloride is NaCl. Although ionic charges are used to derive the correct formula, they are not shown when you write the formula unit of the compound.

The ionic compound magnesium chloride contains magnesium cations ($Mg^{2+}$) and chloride anions ($Cl^-$). In magnesium chloride, the ratio of magnesium cations to chloride anions is 1:2 (one $Mg^{2+}$ to two $Cl^-$). So its formula unit is $MgCl_2$. Because there are twice as many chloride anions (each with a 1− charge) as magnesium cations (each with a 2+ charge), the compound is electrically neutral. In aluminum bromide, described earlier, the ratio of aluminum cations to bromide ions is 1:3 (one $Al^{3+}$ to three $Br^-$ ions), so the formula unit is $AlBr_3$.

**Checkpoint** ***What is the formula unit for magnesium chloride?***


**Figure 7.7** Aluminum metal and the nonmetal bromine react to form an ionic solid, aluminum bromide.

**Figure 7.8** Sodium cations and chloride anions form a repeating three-dimensional array in sodium chloride (NaCl). **Inferring** ***How does the arrangement of ions in a sodium chloride crystal help explain why the compound is so stable?***






## Discuss L2

Ask, **Why are crystalline ionic compounds generally so rigid and brittle?** *(The crystal is rigid because it is held together by a specific three-dimensional array of relatively strong attractive forces between anions and cations, which is accompanied by minimal charge repulsion of like ions. The crystal is brittle because the attractive interactions are specifically arranged within the crystal structure. If this arrangement is disturbed, as it would be if the crystal were hit with a hammer, charge repulsion between ions of the same charge can force the crystal to fragment.)*

## Discuss L2

To assess students' prior knowledge about ionic bonds and crystals, ask, **What is an ionic bond?** *(an electical attraction between ions of opposite charge)* **How do a polyatomic ion and a monatomic ion differ?** *(A monatomic ion is an ion formed from a single atom; a polyatomic ion is a stable unit of two or more tightly bound atoms that carries a charge.)* **Why are crystals of different ionic compounds different shapes?** *(The shapes reflect different geometric arrangements of anions and cations with different sizes and charges.)*

## Differentiated Instruction

### English Learners L1

Encourage students to look up and define terms used to describe ionic compounds. Students should define terms such as *crystal* and *formula unit* in English and their native language. Emphasize how their strong bonding arrangement accounts for crystals having unique properties.

***Answers to...***

**Figure 7.8** Each ion in the arrangement is strongly attracted to its neighbors and repulsions are minimized.

**Checkpoint** $MgCl_2$

## CONCEPTUAL PROBLEM 7.2

**Answers**

**12. a.** KI

**b.** $Al_2O_3$

**13.** $CaCl_2$

**Practice Problems Plus** L2

Use electron dot structures to determine chemical formulas of the ionic compounds formed when the following elements combine:

**a. magnesium and chlorine** *($MgCl_2$)*

**b. aluminum and sulfur** *($Al_2S_3$)*

## Properties of Ionic Compounds

**CLASS Activity**

### "Hardness" of Water L2

**Purpose** Students detect the presence of ions in water samples.

**Materials** tap water samples, 10-mL graduated cylinder, potassium thiocyanate solution, dilute ethanoic acid, sodium oxalate solution, dropper

**Procedure** Water "hardness" is based on ions present in the water. Have students bring water samples from home to test for hardness. Test 2-mL samples as follows. Add three drops of potassium thiocyanate (KSCN) to the first sample. Add three drops of dilute ethanoic acid, $CH_3COOH$, and three drops of sodium oxalate, $Na_2C_2O_4$, to the second sample. Mix well.

**Expected Outcome** A red color from the iron(III) thiocyanate ion, $Fe(SCN)^{2+}$, indicates the presence of $Fe^{3+}$ ions. A white precipitate of calcium oxalate, $CaC_2O_4$, indicates the presence of $Ca^{2+}$ ions.

**Go Online** NSTA SCILINKS

Download a worksheet on **Ionic Compounds** to complete, and find additional teacher support on NSTA SciLinks.

## CONCEPTUAL PROBLEM 7.2

### Predicting Formulas of Ionic Compounds

The ionic compound formed from potassium and oxygen is used in ceramic glazes. Use electron dot structures to predict the formulas of the ionic compounds formed from the following elements.

**a.** potassium and oxygen **b.** magnesium and nitrogen

**1 Analyze** ***Identify the relevant concepts.***

Atoms of metals lose their valence electrons when forming an ionic compound. Atoms of nonmetals gain electrons. Enough atoms of each element must be used in the formula so that electrons lost equals electrons gained.

**2 Solve** ***Apply concepts to this situation.***

**a.** Start with the atoms.

$$K\cdot \quad \text{and} \quad \cdot\ddot{\underset{\cdot\cdot}{O}}:$$

In order to have a completely filled valence shell, oxygen must gain two electrons. These electrons come from two potassium atoms, each of which loses one electron.

$$\begin{matrix} K\cdot \\ K\cdot \end{matrix} + \cdot\ddot{\underset{\cdot\cdot}{O}}: \longrightarrow \begin{matrix} K^+ \\ K^+ \end{matrix} \; :\ddot{\underset{\cdot\cdot}{O}}:^{2-}$$

Electrons lost now equals electrons gained. The formula of the compound formed (potassium oxide) is $K_2O$.

**b.** Start with the atoms.

$$\dot{M}g\cdot \quad \text{and} \quad \cdot\dot{\underset{\cdot\cdot}{N}}:$$

Each nitrogen needs three electrons to have an octet, but each magnesium can lose only two electrons. Thus three magnesium atoms are needed for every two nitrogen atoms.

$$\begin{matrix} \dot{M}g \\ \dot{M}g \\ \dot{M}g \end{matrix} + \begin{matrix} \cdot\dot{\underset{\cdot\cdot}{N}}: \\ \cdot\dot{\underset{\cdot\cdot}{N}}: \end{matrix} \longrightarrow \begin{matrix} Mg^{2+} \\ Mg^{2+} \\ Mg^{2+} \end{matrix} \begin{matrix} :\ddot{\underset{\cdot\cdot}{N}}:^{3-} \\ :\ddot{\underset{\cdot\cdot}{N}}:^{3-} \end{matrix}$$

The formula of the compound formed (magnesium nitride) is $Mg_3N_2$.

### Practice Problems

**12.** Use electron dot structures to determine formulas of the ionic compounds formed when
**a.** potassium reacts with iodine.
**b.** aluminum reacts with oxygen.

**13.** What is the formula of the ionic compound composed of calcium cations and chloride anions?

**Interactive Textbook**

**Problem-Solving 7.12** Solve Problem 12 with the help of an interactive guided tutorial.

with ChemASAP

## Properties of Ionic Compounds

Figure 7.9 shows the striking beauty of the crystals of some ionic compounds. **Most ionic compounds are crystalline solids at room temperature.** The component ions in such crystals are arranged in repeating three-dimensional patterns. The composition of a crystal of sodium chloride is typical. In solid NaCl, each sodium ion is surrounded by six chloride ions, and each chloride ion is surrounded by six sodium ions. In this arrangement, each ion is attracted strongly to each of its neighbors and repulsions are minimized. The large attractive forces result in a very stable structure. This is reflected in the fact that NaCl has a melting point of about 800°C. **Ionic compounds generally have high melting points.**

**Go Online** NSTA SCILINKS

**For:** Links on Ionic Compounds
**Visit:** www.SciLinks.org
**Web Code:** cdn-1072



## Facts and Figures

### Do You Have "Soft" Water?

Explain that water hardness varies with location and source. Generally, water from groundwater sources is harder than water from surface sources. In the United States, most northeastern, southern, and north western states have predominantly soft water. Generally, hard water of varying degrees is found in the southwestern and midwestern states.

**Figure 7.9** The beauty of crystalline solids, such as these, comes from the orderly arrangement of their component ions.


Fluorite ($CaF_2$)


Grossularite ($Ca_3Al_2(SiO_4)_3$)

**Interactive Textbook**

**Simulation 5** Simulate the formation of ionic compounds at the atomic level.

with ChemASAP


Aragonite ($CaCO_3$)


Barite ($BaSO_4$) and calcite ($CaCO_3$)


Wulfenite ($PbMoO_4$)


Beryl ($BeAl_2(SiO_3)_6$)


Franklinite ($(Zn, Mn^{2+}, Fe^{2+})(Fe^{3+}, Mn^{3+})$)


Pyrite ($FeS_2$)


Hematite ($Fe_2O_3$)


Rutile ($TiO_2$)


Cinnabar (HgS)



## Differentiated Instruction

### Gifted and Talented L3

Have students research how minerals are categorized according to their ionic nature. Suggest that their written report include information concerning the physical properties of minerals and how these properties are used in mineral identification. Encourage students to include drawings, photos, or examples of minerals from each category.

**CLASS Activity**

### Types of Ionic Compounds L2

**Purpose** Students investigate properties of different classes of ionic compounds.

**Materials** library or Internet access

**Procedure** Divide the class into groups. Have each group choose a different class of ionic compounds to research and write about. For example, one group could work with oxides while another group worked with sulfides. Initially, each student should work alone to discover information such as where the compounds occur in nature, how they are produced, their physical and chemical properties, and any important uses. Finally, students in each group can pool their information to prepare a class display or report.

**Expected Outcome** Students will discover that different classes of ionic compounds share some properties with other ionic compounds and have some unique properties.

**CLASS Activity**

### Crystal Structures L2

**Purpose** Students observe different types of crystals.

**Materials** crystals of ionic compounds, watch glasses, magnifying glasses

**Safety** Use only nontoxic crystals. Remind students to not touch the crystals.

**Procedure** Pass around crystals of ionic compounds of various types in watch glasses. Have the students examine the crystals with magnifying glasses and write down their observations. Make a list of these observations and then discuss them in terms of the underlying ionic lattice structures.

**Expected Outcome** Students should observe the different geometries of different crystal structures.

**Quick LAB**

### Solutions Containing Ions L2

**Objective** After completing this activity, students will be able to:

- show that ions in solution conduct an electric current.

### Address Misconceptions

Students may think that the solutions contain only one ion. Clarify that each solution contains both cations and anions.

**Skills Focus** Observing, experimenting, concluding

**Prep Time** 20 minutes

**Materials** D-cell batteries, masking tape, 30-cm lengths of bell wire with ends scraped bare, clear plastic cups, distilled water, tap water, vinegar, sucrose, sodium chloride, baking soda, conductivity probe (optional)

**Class Time** 30 minutes

**Safety** Students should handle wires with caution. The wires may become hot during the activity.

**Expected Outcome** When ions are present in solution, the solution conducts an electric current.

#### Analyze and Conclude

1. Solutions of vinegar, sodium chloride, and baking soda (and maybe tap water) contain ions and therefore conduct electric current and produce bubbles.
2. Distilled water and sugar solution (and maybe tap water) do not contain ions and therefore do not conduct an electric current or produce bubbles.
3. Answers will vary but should indicate that a larger number of batteries will increase the current, which will, in turn, cause the rate at which the bubbles appear to increase.

### For Enrichment L3

Ask, **What gases form the bubbles you observe?** *(hydrogen and oxygen)* **What is the source of these gases?** *(water)* Have students collect the gases produced and check them for the presence of hydrogen and oxygen. Hydrogen will burn when a lit splint is placed in it, and a glowing split will begin to flame when placed in oxygen.

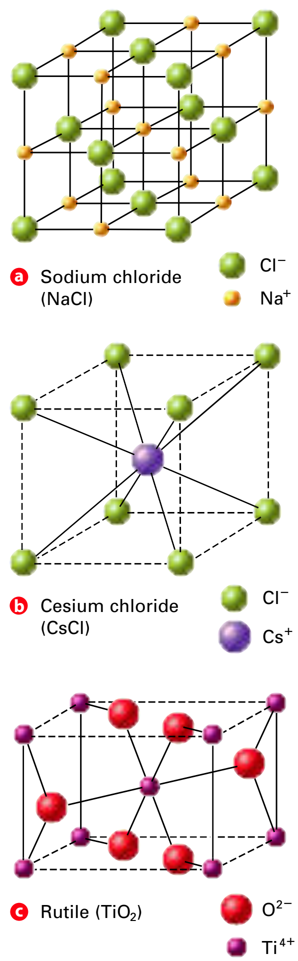



**Figure 7.10** Sodium chloride and cesium chloride form cubic crystals. **a** In NaCl, each ion has a coordination number of 6. **b** In CsCl, each ion has a coordination number of 8. **c** Titanium dioxide forms tetragonal crystals. In $TiO_2$, each $Ti^{4+}$ ion has a coordination number of 6, while each $O^{2-}$ ion has a coordination number of 3.

The **coordination number** of an ion is the number of ions of opposite charge that surround the ion in a crystal. Figure 7.10a shows the three-dimensional arrangement of ions in NaCl. Because each $Na^+$ ion is surrounded by six $Cl^-$ ions, $Na^+$ has a coordination number of 6. Each $Cl^-$ ion is surrounded by six $Na^+$ ions and also has a coordination number of 6. Cesium chloride (CsCl) has a formula unit that is similar to that of NaCl. As Figure 7.10b illustrates, both compounds have cubic crystals, but their internal crystal structures are different. Each $Cs^+$ ion is surrounded by eight $Cl^-$ ions, and each $Cl^-$ ion is surrounded by eight $Cs^+$ ions. The anion and cation in cesium chloride each have a coordination number of 8.

Figure 7.10c shows the crystalline form of titanium dioxide ($TiO_2$), also known as rutile. In this compound, the coordination number for the cation ($Ti^{4+}$) is 6. Each $Ti^{4+}$ ion is surrounded by six $O^{2-}$ ions. The coordination number of the anion ($O^{2-}$) is 3. Each $O^{2-}$ ion is surrounded by three $Ti^{4+}$ ions.

Another characteristic property of ionic compounds has to do with conductivity. **Ionic compounds can conduct an electric current when melted or dissolved in water.** As Figure 7.11 shows, when sodium chloride is melted, the orderly crystal structure breaks down. If a voltage is applied across this molten mass, cations migrate freely to one electrode and anions migrate to the other. This ion movement allows electricity to flow between the electrodes through an external wire. For a similar reason, ionic compounds also conduct electricity if they are dissolved in water. When dissolved, the ions are free to move about in the aqueous solution.

**Checkpoint** ***What is the coordination number of $Ti^{4+}$ in $TiO_2$?***

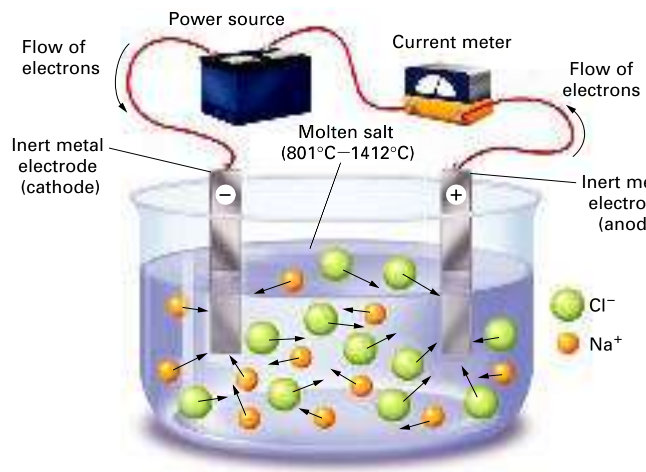



**Figure 7.11** When sodium chloride melts, the sodium and chloride ions are free to move throughout the molten salt. If a voltage is applied, positive sodium ions move to the negative electrode (the cathode), and negative chloride ions move to the positive electrode (the anode). **Predicting** ***What would happen if the voltage was applied across a solution of NaCl dissolved in water?***



### Differentiated Instruction

#### Gifted and Talented L3

Have students write the formulas for ionic compounds formed from selected pairs of cations and anions. Include various polyatomic cations and anions as well.

Examples:

1) $K^+$ and $S^{2-}$ *($K_2S$)*

2) $Ca^{2+}$ and $HCO^{3-}$ *($Ca(HCO_3)_2$)*

**Quick LAB**

## Solutions Containing Ions

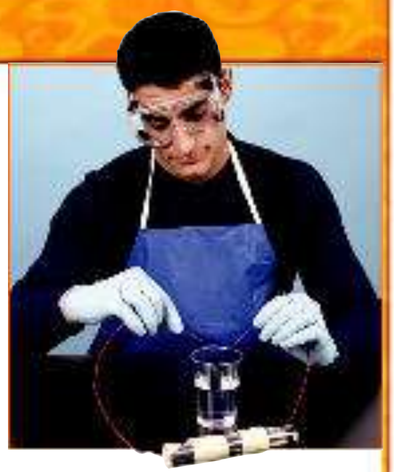
### Purpose
To show that ions in solution conduct an electric current.

### Materials
- 3 D-cell batteries
- masking tape
- 2 30-cm lengths of bell wire with ends scraped bare
- clear plastic cup
- distilled water
- tap water
- vinegar
- sucrose
- sodium chloride
- baking soda
- conductivity probe (optional)

### Procedure

*Probe version available in the Probeware Lab Manual.*

1. Tape the batteries together so the positive end of one touches the negative end of another. Tape the bare end of one wire to the positive terminal of the battery assembly and the bare end of the other wire to the negative terminal. **CAUTION** *Bare wire ends can be sharp and scratch skin. Handle with care.*
2. Half fill the cup with distilled water. Hold the bare ends of the wires close together in the water. Look for the production of bubbles. They are a sign that the solution conducts electric current.
3. Repeat Step 2 with tap water, vinegar, and concentrated solutions of sucrose, sodium chloride, and baking soda (sodium hydrogen carbonate).



### Analyze and Conclude
1. Which solutions produced bubbles of gas? Explain.
2. Which samples did not produce bubbles of gas? Explain.
3. Would you expect the same results if you used only one battery? If you used six batteries? Explain your answer.

## 7.2 Section Assessment

14. **Key Concept** How can you describe the electrical charge of an ionic compound?
15. **Key Concept** What properties characterize ionic compounds?
16. Define an ionic bond.
17. How can you represent the composition of an ionic compound?
18. Write the correct chemical formula for the compounds formed from each pair of ions.
    **a.** $K^+$, $S^{2-}$ **b.** $Ca^{2+}$, $O^{2-}$
    **c.** $Na^+$, $O^{2-}$ **d.** $Al^{3+}$, $N^{3-}$
19. Write formulas for each compound.
    **a.** barium chloride **b.** magnesium oxide
    **c.** lithium oxide **d.** calcium fluoride
20. Which pairs of elements are likely to form ionic compounds?
    **a.** Cl, Br **b.** Li, Cl
    **c.** K, He **d.** I, Na
21. Describe the arrangement of sodium ions and chloride ions in a crystal of sodium chloride.
22. Why do ionic compounds conduct electric current when they are melted or dissolved in water?

**Elements Handbook**

**Restoring Electrolytes** Read about restoring electrolytes on page R8. Write electron configurations for the two principal ions found in body fluids.

**Interactive Textbook**

**Assessment 7.2** Test yourself on the concepts in Section 7.2.

with ChemASAP



### Discuss L2
Point out that the rusting of iron is the production of iron oxide from iron metal and oxygen gas. Point out that $Fe^{3+}$ is a stable cation of Fe. (Students should know that $O^{2-}$ is the stable anion of O.) The compound formed from these ions is iron(III) oxide, or $Fe_2O_3$.

## 3 ASSESS

### Evaluate Understanding L2
Name ionic compounds and ask students to identify the cation, anion, and ratio of cations to anions in each compound.

### Reteach L1
Emphasize that an ionic solid is a collection of independent ions. There is no joining of individual particles to form molecules. Each ion "belongs" as much to one of its nearest neighbors as it belongs to any other. The arrangement in an ionic crystal is such that each ion is surrounded by ions of opposite charge, which produces a strong bonding force.

**Elements Handbook**

$Na^+$ $1s^22s^22p^6$
$K^+$ $1s^22s^22p^63s^23p^6$

**Interactive Textbook**

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 7.2.

with ChemASAP

## Section 7.2 Assessment

**14.** electrically neutral
**15.** usually solids at room temperature; have high melting points; conduct an electric current when melted or dissolved in water
**16.** electrostatic forces that hold ions together in an ionic compound
**17.** by writing its chemical formula
**18.** **a.** $K_2S$ **b.** CaO **c.** $Na_2O$ **d.** AlN
**19.** **a.** $BaCl_2$ **b.** MgO **c.** $Li_2O$ **d.** $CaF_2$
**20.** b and d
**21.** Acceptable answers should describe a solid containing positive sodium ions and negative chloride ions in an alternating, regular, and repeating three-dimensional pattern.
**22.** The ions are free to move.

***Answers to...***

**Figure 7.11** The solution would conduct an electric current; the $Na^+$ ions in solution would migrate to the negative electrode, and the $Cl^-$ ions in solution would migrate to the positive electrode.

**Checkpoint** $Ti^{4+}$ has a coordination number of 6 in $TiO_2$.

Small-Scale LAB

## Analysis of Anions and Cations L2

### Objective

After completing this activity, students will be able to:

- develop tests for various ions.
- use the tests to analyze unknown solutions.

**Skills Focus** Observing, drawing conclusions, designing experiments

**Prep Time** 40 minutes

**Materials** pencil, paper, ruler, reaction surface, medicine droppers, pipet, staples or solid Fe, solutions from Figures A & B.

| Solution | Preparation |
|---|---|
| 0.05*M* $AgNO_3$ | 2.1 g in 250 mL |
| 0.2*M* $Pb(NO_3)_2$ | 16.6 g in 250 mL |
| 0.2*M* $Na_2SO_4$ | 7.1 g in 250 mL |
| 0.1*M* $Na_3PO_4$ | 9.5 g $Na_3PO_4{\cdot}12H_2O$ in 250 mL |
| 0.5*M* NaOH | 20.0 g in 1.0 L |
| 0.1*M* KSCN | 2.4 g in 250 mL |
| 0.1*M* KI | 4.2 g in 250 mL |
| 0.5*M* $CaCl_2$ | 13.9 g in 250 mL |
| 0.1*M* $FeCl_3$ | 6.8 g $FeCl_3{\cdot}6H_2O$ in 25 mL of 1.0*M* NaCl; dilute to 250 mL |
| 1.0*M* HCl | 82 mL of 12*M* in 1.0 L |
| 1.0*M* $HNO_3$ | 63 mL of 15.8*M* in 1.0 L |

**CAUTION!** Always add acid to water carefully and slowly.

**Class Time** 40 minutes

**Expected Outcome** $Ag^+$ and $PO_4^{3-}$ form a yellow precipitate; Fe in HCl turns yellow with $NO_3^-$; $Pb^{2+}$ forms white precipitates with $SO_4^{2-}$ and $PO_4^{3-}$; $OH^-$ and $Ca^{2+}$ form a white product; KSCN and $Fe^{3+}$ form a red one.

### Analyze

1. Nitrate ion is the only ion that produces a yellow color with iron in the presence of acid.
2. $AgNO_3$ for $PO_4^{3-}$; Fe and HCl for $NO_3^-$; $Pb(NO_3)_2$ for $SO_4^{2-}$; NaOH for $Ca^{2+}$; and KSCN for $Fe^{3+}$.
3. No, neither of the solutions produced a visible product.

### You're the Chemist

1. Mix a drop of each unknown with one drop of each solution from figure A. Compare the results to those with known solutions.
2. Mix a drop of each unknown with one drop of both solutions from Figure B. Compare the results to those with known solutions.
3. Mix an unknown with one drop of each solution from Figures A and B and compare results.

### For Enrichment L3

Have students hypothesize about why none of the tests in the lab identified the potassium ion. Ask, **Why do you think potassium ions don't form precipitates with any of the anions used in the lab?** *(All potassium compounds are soluble in water.)* Have students read through the Quick Lab on page 142. Have them use this information to design an experiment that will provide a positive test for the potassium ion. The flame test for potassium produces a violet color.



Small-Scale LAB

## Analysis of Anions and Cations

### Purpose

To develop tests for various ions and use the tests to analyze unknown substances.

### Materials

- pencil
- ruler
- medicine droppers
- chemicals shown in Figures A and B
- paper
- reaction surface
- pipet

| | $Na_2SO_4$ ($SO_4^{2-}$) | $HNO_3$ ($NO_3^-$) | $Na_3PO_4$ ($PO_4^{3-}$) |
|---|---|---|---|
| $AgNO_3$ | X | X | X |
| HCl plus 1 piece of Fe(*s*) | X | X | X |
| $Pb(NO_3)_2$ | X | X | X |



**Figure A**
Anion Analysis

| | KI ($K^+$) | $CaCl_2$ ($Ca^{2+}$) | $FeCl_3$ ($Fe^{3+}$) |
|---|---|---|---|
| NaOH | X | X | X |
| KSCN | X | X | X |



**Figure B**
Cation Analysis

### Procedure

On one sheet of paper, draw grids similar to Figure A and Figure B. Draw similar grids on a second sheet of paper. Make each square 2 cm on each side. Place a reaction surface over the grids on one of the sheets of paper and add one drop of each solution or one piece of each solid as shown in Figures A and B. Stir each solution by blowing air through an empty pipet. Use the grids on the second sheet of paper as a data table to record your observations for each solution.

### Analyze

Using your experimental data, record the answers to the following questions below your data table.

1. Carefully examine the reaction of Fe(*s*) and HCl in the presence of $HNO_3$. What is unique about this reaction? How can you use it to identify nitrate ion?
2. Which solutions from Figure A are the best for identifying each anion? Which solutions from Figure B are the best for identifying each cation? Explain.
3. Can your experiments identify $K^+$ ions? Explain.

### You're the Chemist

The following small-scale activities allow you to develop your own procedures and analyze the results.

1. **Design It!** Obtain a set of unknown anion solutions from your teacher and design and carry out a series of tests that will identify each anion.
2. **Design It!** Obtain a set of unknown cation solutions from your teacher and design and carry out a series of tests that will identify each cation.
3. **Design It!** Obtain a set of unknown solid ionic compounds from your teacher. Design and carry out a series of tests that will identify each ion present.