CHAPTER 7 Ionic Compounds and Metals

BIG Idea Atoms in ionic compounds are held together by chemical bonds formed by the attraction of oppositely charged ions.

7.1 Ion Formation

MAIN Idea Ions are formed when atoms gain or lose valence electrons to achieve a stable octet electron configuration.

7.2 Ionic Bonds and Ionic Compounds

MAIN Idea Oppositely charged ions attract each other, forming electrically neutral ionic compounds.

7.3 Names and Formulas for Ionic Compounds

MAIN Idea In written names and formulas for ionic compounds, the cation appears first, followed by the anion.

7.4 Metallic Bonds and the Properties of Metals

MAIN Idea Metals form crystal lattices and can be modeled as cations surrounded by a "sea" of freely moving valence electrons.

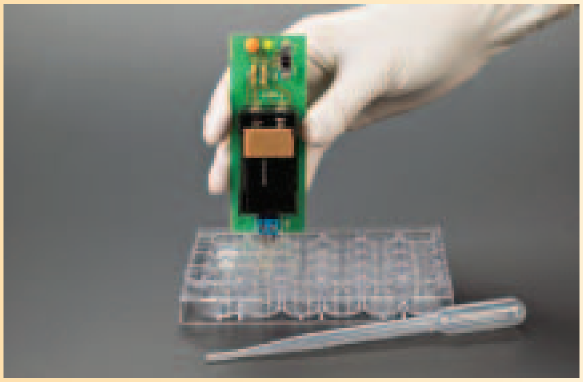
ChemFacts

- Scuba stands for **s**elf-**c**ontained **u**nderwater **b**reathing **a**pparatus.
- Most recreational scuba divers limit their dives to 40 m or less. The deepest scuba dive was to a depth of more than 300 m.
- Divers carry the air that they breathe in a tank, and must follow special procedures to avoid oxygen toxicity, nitrogen narcosis, and the bends.

LAUNCH Lab

What compounds conduct electricity in solution?

For a material to conduct an electric current, it must contain charged particles that can move throughout the substance. Electrical conductivity is a property of matter that tells you something about bonding.



Procedure

1. Read and complete the lab safety form.
2. Make a data table to record your observations.
3. Fill an open well in a well plate with **table salt (NaCl).**
4. Use a **disposable pipet** to transfer approximately 1 mL of **table salt (NaCl) solution** in an open well in the well plate.
5. Place the probes of a **conductivity tester** in the well plate containing the solid table salt. If the light is illuminated, the table salt conducts electricity. Repeat with the solution.
6. Repeat Steps 3 to 5 using **sugar ($C_{12}H_{22}O_{11}$)** instead of table salt.
7. Repeat Steps 3 to 5 using **distilled water** instead of tap water.

Analysis

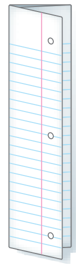
1. **Organize** Make a table listing the compounds and the results of the conductivity tests.
2. **Explain** your results.

Inquiry Create a model to describe how compounds that conduct electricity in solution differ from compounds that do not conduct electricity in solution.

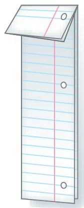
FOLDABLES™ Study Organizer

Ionic Compounds Make the following Foldable to to help you organize information about ionic compounds.

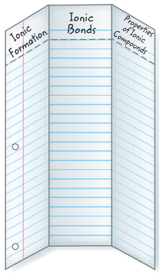
STEP 1 Fold a sheet of paper into thirds lengthwise.



STEP 2 Fold the top down about 2 cm.



STEP 3 Unfold and draw lines along all folds. Label the columns as follows: *Ion Formation*, *Ionic Bonds*, and *Properties of Ionic Compounds*.



FOLDABLES **Use this Foldable with Sections 7.1 and 7.2.** As you read these sections, record information about ionic compounds in the appropriate columns on your Foldable.

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Section 7.1

Objectives

- **Define** a chemical bond.
- **Describe** the formation of positive and negative ions.
- **Relate** ion formation to electron configuration.

Review Vocabulary

octet rule: atoms tend to gain, lose, or share electrons in order to acquire eight valence electrons

New Vocabulary

chemical bond
cation
anion

Ion Formation

MAIN Idea Ions are formed when atoms gain or lose valence electrons to achieve a stable octet electron configuration.

Real-World Reading Link Imagine that you and a group of friends go to a park to play soccer. There, you meet a larger group that also wants to play. To form even teams, one group loses members and the other group gains members. Atoms sometimes behave in a similar manner to form compounds.

Valence Electrons and Chemical Bonds

Imagine going on a scuba dive, diving below the ocean's surface and observing the awe-inspiring world below. You might explore the colorful and exotic organisms teeming around a coral reef, such as the one shown in **Figure 7.1.** The coral is formed from a compound called calcium carbonate, which is just one of thousands of compounds found on Earth. How do so many compounds form from the relatively few elements known to exist? The answer to this question involves the electron structure of atoms and the nature of the forces between atoms.

In previous chapters, you learned that elements within a group on the periodic table have similar properties. Many of these properties depend on the number of valence electrons the atom has. These valence electrons are involved in the formation of chemical bonds between two atoms. A **chemical bond** is the force that holds two atoms together. Chemical bonds can form by the attraction between the positive nucleus of one atom and the negative electrons of another atom, or by the attraction between positive ions and negative ions. This chapter discusses chemical bonds formed by ions, atoms that have acquired a positive or negative charge. In Chapter 8, you will learn about bonds that form from the sharing of electrons.

Figure 7.1 As carbon dioxide dissolves in ocean water, carbonate ions are produced. Coral polyps capture these carbonate ions, producing crystals of calcium carbonate, which they secrete as an exoskeleton. Over time, the coral reef forms. A coral reef is a complex habitat that supports coral, algae, mollusks, echinoderms, and a variety of fishes.

Concepts In Motion

Table 7.1 Electron-Dot Structures

Interactive Table Explore electron-dot structures at glencoe.com.

Group	1	2	13	14	15	16	17	18
Diagram	Li·	·Be·	·B·	·C·	·N·	·O:	:F:	:Ne:

Valence electrons Recall from Chapter 5 that an electron-dot structure is a type of diagram used to keep track of valence electrons. Electron-dot structures are especially helpful when used to illustrate the formation of chemical bonds. **Table 7.1** shows several examples of electron-dot structures. For example, carbon, with an electron configuration of $1s^22s^22p^2$, has four valence electrons in the second energy level. These valence electrons are represented by the four dots around the symbol C in the table.

Also, recall that ionization energy refers to how easily an atom loses an electron and that electron affinity indicates how much attraction an atom has for electrons. Noble gases, which have high ionization energies and low electron affinities, show a general lack of chemical reactivity. Other elements on the periodic table react with each other, forming numerous compounds. The difference in reactivity is directly related to the valence electrons.

The difference in reactivity involves the octet—the stable arrangement of eight valence electrons in the outer energy level. Unreactive noble gases have electron configurations that have a full outermost energy level. This level is filled with two electrons for helium ($1s^2$) and eight electrons for the other noble gases (ns^2np^6). Elements tend to react to acquire the stable electron structure of a noble gas.

Positive Ion Formation

A positive ion forms when an atom loses one or more valence electrons in order to attain a noble gas configuration. A positively charged ion is called a **cation.** To understand the formation of a positive ion, compare the electron configurations of the noble gas neon (atomic number 10) and the alkali metal sodium (atomic number 11).

Neon atom (Ne)	$1s^22s^22p^6$
Sodium atom (Na)	$1s^22s^22p^63s^1$

Note that the sodium atom has one 3s valence electron; it differs from the noble gas neon by that single valence electron. When sodium loses this outer valence electron, the resulting electron configuration is identical to that of neon. **Figure 7.2** shows how a sodium atom loses its valence electron to become a sodium cation.

By losing an electron, the sodium atom acquires the stable outer-electron configuration of neon. It is important to understand that although sodium now has the electron configuration of neon, it is not neon. It is a sodium ion with a single positive charge. The 11 protons that establish the character of sodium still remain within its nucleus.

Reading Check **Identify** the number of electrons in the outermost energy level that are associated with maximum stability.

FOLDABLES Incorporate information from this section into your Foldable.

Figure 7.2 In the formation of a positive ion, a neutral atom loses one or more valence electrons. The atom is neutral because it contains equal numbers of protons and electrons; the ion, however, contains more protons than electrons and has a positive charge.

Analyze ***Does the removal of an electron from a neutral atom require energy or release energy?***

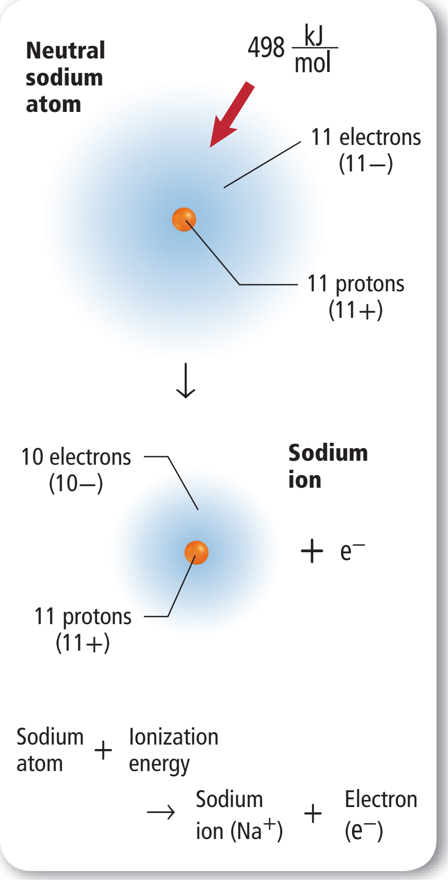


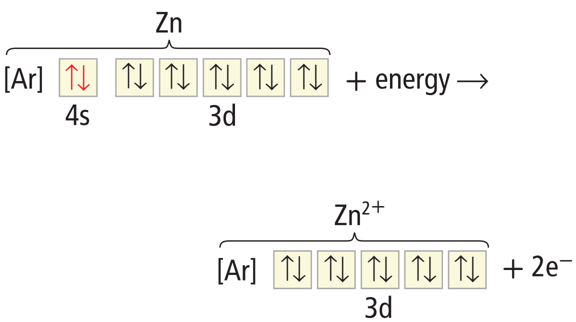
Table 7.2	Group 1, 2, and 13 Ions	
Group	**Configuration**	**Charge of Ion Formed**
1	[noble gas] ns^1	1+ when the s^1 electron is lost
2	[noble gas] ns^2	2+ when the s^2 electrons are lost
13	[noble gas] ns^2np^1	3+ when the s^2p^1 electrons are lost

Metal ions Metals atoms are reactive because they lose valence electrons easily. The group 1 and 2 metals are the most reactive metals on the periodic table. For example, potassium and magnesium, group 1 and 2 elements, respectively, form K^+ and Mg^{2+} ions. Some group 13 atoms also form ions. The ions formed by metal atoms in groups 1, 2, and 13 are summarized in **Table 7.2.**

Transition metal ions Recall that, in general, transition metals have an outer energy level of ns^2. Going from left to right across a period, atoms of each element fill an inner d sublevel. When forming positive ions, transition metals commonly lose their two valence electrons, forming 2+ ions. However, it is also possible for d electrons to be lost. Thus, transition metals also commonly form ions of 3+ or greater, depending on the number of d electrons in the electron structure. It is difficult to predict the number of electrons that will be lost. For example, iron (Fe) forms both Fe^{2+} and Fe^{3+} ions. A useful rule of thumb for these metals is that they form ions with a 2+ or a 3+ charge.

Pseudo-noble gas configurations Although the formation of an octet is the most stable electron configuration, other electron configurations can also provide some stability. For example, elements in groups 11–14 lose electrons to form an outer energy level containing full s, p, and d sublevels. These relatively stable electron arrangements are referred to as pseudo-noble gas configurations. In **Figure 7.3,** the zinc atom has the electron configuration of $1s^22s^22p^63s^23p^64s^23d^{10}$. When forming an ion, the zinc atom loses the two 4s electrons in the outer energy level, and the stable configuration of $1s^22s^22p^63s^23p^63d^{10}$ results in a pseudo-noble gas configuration.

Figure 7.3 When zinc reacts with iodine, the heat of the reaction causes solid iodine to sublimate into a purple vapor. At the bottom of the tube, ZnI_2 is formed containing Zn^{2+} ions with a pseudo-noble gas configuration.



When the two 4s valence electrons are lost, a stable pseudo-noble gas configuration consisting of filled s, p, and d sublevels is achieved. Note that the filled 3s and 3p orbitals exist as part of the [Ar] configuration.

Table 7.3	Group 15–17 Ions	
Group	Configuration	Charge of Ion Formed
15	[noble gas] ns^2np^3	3– when three electrons are gained
16	[noble gas] ns^2np^4	2– when two electrons are gained
17	[noble gas] ns^2np^5	1– when one electron is gained

Negative Ion Formation

Nonmetals, which are located on the right side of the periodic table, easily gain electrons to attain a stable outer electron configuration. Examine **Figure 7.4.** To attain a noble-gas configuration, chlorine gains one electron, forming an ion with a 1– charge. After gaining the electron, the chloride ion has the electron configuration of an argon atom.

Chlorine atom (Cl)	$1s^22s^22p^63s^23p^5$
Argon atom (Ar)	$1s^22s^22p^63s^23p^6$
Chloride ion (Cl^-)	$1s^22s^22p^63s^23p^6$

An **anion** is a negatively charged ion. To designate an anion, the ending *-ide* is added to the root name of the element. Thus, a chlorine atom becomes a chloride anion. What is the name of the nitrogen anion?

Nonmetal ions As shown in **Table 7.3,** nonmetals gain the number of electrons that, when added to their valence electrons, equals 8. For example, consider phosphorus, with five valence electrons. To form a stable octet, the atom gains three electrons and forms a phosphide ion with a 3– charge. Likewise, oxygen, with six valence electrons, gains two electrons and forms a oxide ion with a 2– charge.

Some nonmetals can lose or gain other numbers of electrons to form an octet. For example, in addition to gaining three electrons, phosphorus can lose five. However, in general, group 15 elements gain three electrons, group 16 elements gain two, and group 17 elements gain one to achieve an octet.

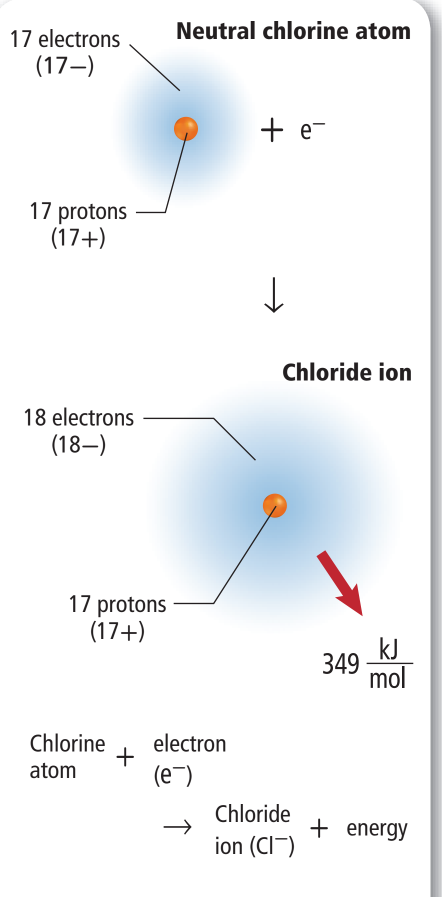


Figure 7.4 During the formation of the negative chloride ion, a neutral atom gains one or more electrons. The process releases 349 kJ/mol of energy.
Compare *How do the energy changes accompanying positive ion and negative ion formation compare?*

Section 7.1 Assessment

Section Summary

- A chemical bond is the force that holds two atoms together.
- Some atoms form ions to gain stability. This stable configuration involves a complete outer energy level, usually consisting of eight valence electrons.
- Ions are formed by the loss or gain of valence electrons.
- The number of protons remains unchanged during ion formation.

1. **MAIN Idea** **Compare** the stability of a lithium atom with that of its ion, Li^+.
2. **Describe** two different causes of the force of attraction in a chemical bond.
3. **Apply** Why are all of the elements in group 18 relatively unreactive, whereas those in group 17 are very reactive?
4. **Summarize** ionic bond formation by correctly pairing these terms: *cation*, *anion*, *electron gain*, and *electron loss*.
5. **Apply** Write out the electron configuration for each atom. Then, predict the change that must occur in each to achieve a noble-gas configuration.
   a. nitrogen **b.** sulfur **c.** barium **d.** lithium
6. **Model** Draw models to represent the formation of the positive calcium ion and the negative bromide ion.

Section 7.2

Objectives

- **Describe** the formation of ionic bonds and the structure of ionic compounds.
- **Generalize** about the strength of ionic bonds based on the physical properties of ionic compounds.
- **Categorize** ionic bond formation as exothermic or endothermic.

Review Vocabulary

compound: a chemical combination of two or more different elements

New Vocabulary

ionic bond
ionic compound
crystal lattice
electrolyte
lattice energy

Ionic Bonds and Ionic Compounds

MAIN Idea **Oppositely charged ions attract each other, forming electrically neutral ionic compounds.**

Real-World Reading Link Have you ever tried to separate sheets of plastic wrap that are stuck together? The hard-to-separate layers attract each other due to their oppositely charged surfaces.

Formation of an Ionic Bond

What do the reactions shown in **Figure 7.5** have in common? In both cases, elements react with each other to form a compound. **Figure 7.5a** shows the reaction between the elements sodium and chlorine. During this reaction, a sodium atom transfers its valence electron to a chlorine atom and becomes a positive ion. The chlorine atom accepts the electron into its outer energy level and becomes a negative ion. The oppositely charged ions attract each other, forming the compound sodium chloride. The electrostatic force that holds oppositely charged particles together in an ionic compound is referred to as an **ionic bond.** Compounds that contain ionic bonds are **ionic compounds.** If ionic bonds occur between metals and the nonmetal oxygen, oxides form. Most other ionic compounds are called salts.

Binary ionic compounds Thousands of compounds contain ionic bonds. Many ionic compounds are binary, which means that they contain only two different elements. Binary ionic compounds contain a metallic cation and a nonmetallic anion. Sodium chloride (NaCl) is a binary compound because it contains two different elements, sodium and chlorine. Magnesium oxide (MgO), the reaction product shown in **Figure 7.5b,** is also a binary ionic compound.

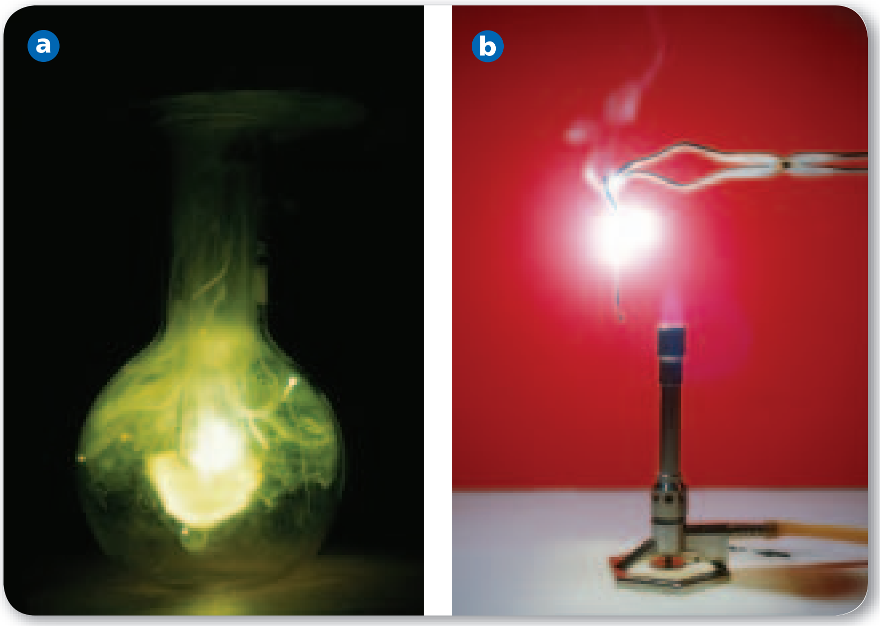


Figure 7.5 Each of these chemical reactions produces an ionic compound while releasing a large amount of energy. **a.** The reaction that occurs between elemental sodium and chlorine gas produces a white crystalline solid. **b.** When a ribbon of magnesium metal burns in air, it forms the ionic compound magnesium oxide.

Compound formation and charge What role does ionic charge play in the formation of ionic compounds? To answer this question, examine how calcium fluoride forms. Calcium has the electron configuration $[Ar]4s^2$, and needs to lose two electrons to attain the stable configuration of argon. Fluorine has the configuration $[He]2s^22p^5$, and must gain one electron to attain the stable configuration of neon. Because the number of electrons lost and gained must be equal, two fluorine atoms are needed to accept the two electrons lost from the calcium atom.

$$1\ \text{Ca}\ \cancel{\text{ion}}\left(\frac{2+}{\text{Ca}\ \cancel{\text{ion}}}\right) + 2\ \text{F}\ \cancel{\text{ions}}\left(\frac{1-}{\text{F}\ \cancel{\text{ion}}}\right) = (1)(2+) + (2)(1-) = 0$$

As you can see, the overall charge of one unit of calcium fluoride (CaF_2) is zero. **Table 7.4** summarizes several ways in which the formation of an ionic compound such as sodium chloride can be represented.

FOLDABLES Incorporate information from this section into your Foldable.

Concepts In Motion

Interactive Figure To see an animation of sodium chloride ionic bond formation, visit glencoe.com.

Table 7.4 Formation of Sodium Chloride

Chemical Equation

$$Na + Cl \longrightarrow Na^+ + Cl^- + \text{energy}$$

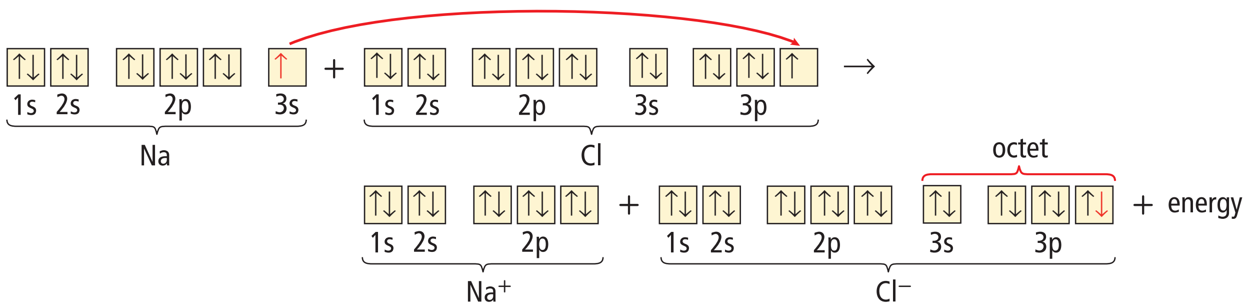
Electron Configurations

One electron is transferred.

$$\underbrace{[Ne]3s^1}_{Na} + \underbrace{[Ne]3s^23p^5}_{Cl} \longrightarrow \underbrace{[Ne]}_{Na^+} + \underbrace{[Ar]}_{Cl^-} + \text{energy}$$

Orbital Notation

One electron is transferred.

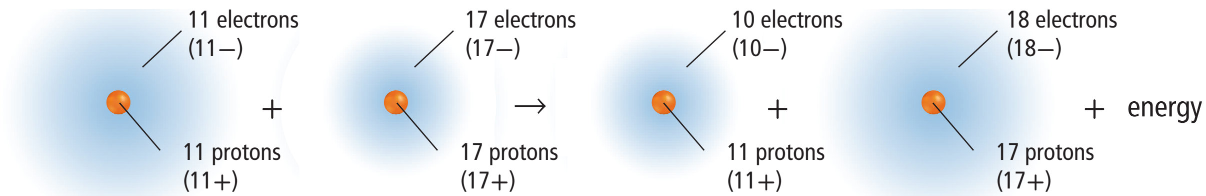


Electron-Dot Structures

One electron is transferred.

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

Atomic Models



Sodium atom Chlorine atom Sodium chloride

Next, consider aluminum oxide, the whitish coating that forms on aluminum chairs. To acquire a noble-gas configuration, each aluminum atom loses three electrons and each oxygen atom gains two electrons. Thus, three oxygen atoms are needed to accept the six electrons lost by two aluminum atoms. The neutral compound formed is aluminum oxide (Al_2O_3).

$$2\ \cancel{\text{Al ions}}\left(\frac{3+}{\cancel{\text{Al ion}}}\right) + 3\ \text{O}\ \cancel{\text{ions}}\left(\frac{2-}{\text{O}\ \cancel{\text{ion}}}\right) = 2(3+) + 3(2-) = 0$$

PRACTICE Problems

Extra Practice Page 979 and glencoe.com

Explain how an ionic compound forms from these elements.

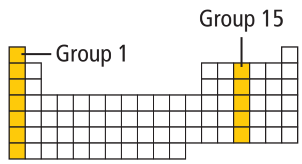
7. sodium and nitrogen

8. lithium and oxygen

9. strontium and fluorine

10. aluminum and sulfur

11. Challenge Explain how elements in the two groups shown on the periodic table at the right combine to form an ionic compound.



Properties of Ionic Compounds

The chemical bonds in a compound determine many of its properties. For ionic compounds, the ionic bonds produce unique physical structures, unlike those of other compounds. The physical structure of ionic compounds also contribute to their physical properties. These properties have been used in many applications, discussed in **Figure 7.6.**

Physical structure In an ionic compound, large numbers of positive ions and negative ions exist together in a ratio determined by the number of electrons transferred from the metal atom to the nonmetal atom. These ions are packed into a regular repeating pattern that balances the forces of attraction and repulsion between the ions.

Figure 7.6

Milestones in Ionic and Metallic Bonding

A series of discoveries helped scientists understand the properties of ionic and metallic substances—leading to the creation of new tools and materials.

1900 — 1910 — 1930

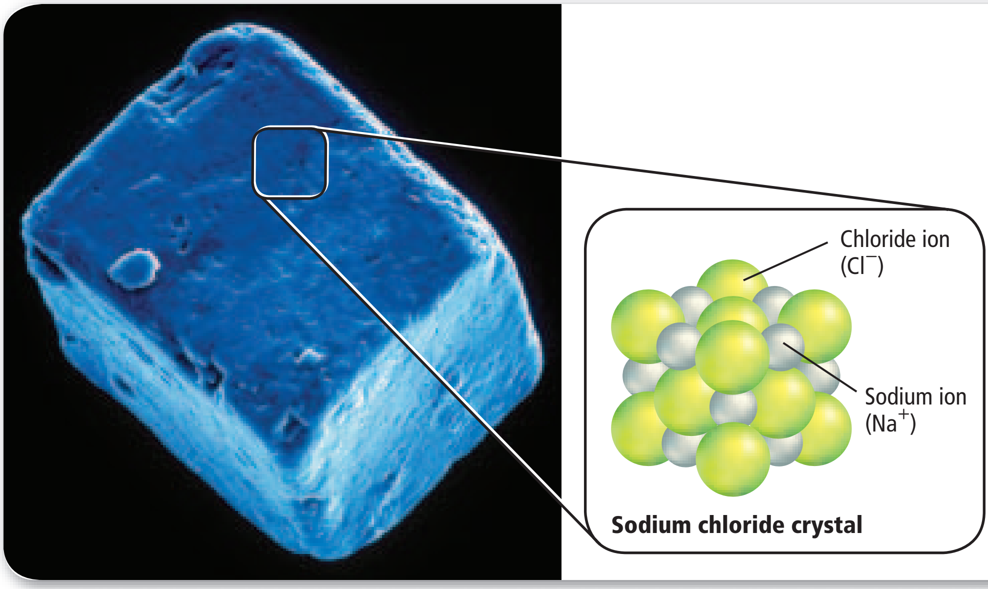
1897 J. J. Thomson speculates that electrons play a key role in chemical bonding.

1913 X-ray crystallography reveals sodium ions and chlorine ions in sodium chloride are arranged in regular geometric patterns.

1916 Gilbert Lewis proposes a bonding theory based on the interaction of electrons among atoms.

1932 The development of an electronegativity scale allows scientists to quantify the relative strength of attraction of each element for electrons.

CIRCA 1940 Metallurgists develop alloys that perform under extreme temperature, pressure, and centrifugal force. Such alloys are later used in jet engines and spacecraft.



■ **Figure 7.7** The structure of a sodium chloride crystal is highly ordered. When viewed with a scanning electron microscope, the cubic shape of sodium chloride crystals is visible.

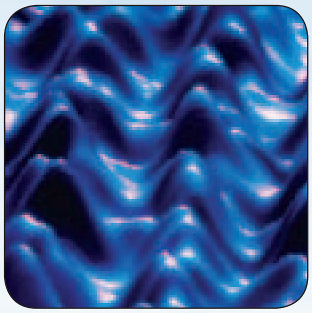
Interpret ***What is the ratio of sodium ions to chloride ions in the crystal?***

Examine the pattern of the ions in the sodium chloride crystal shown in **Figure 7.7.** Note the highly organized nature of an ionic crystal—the consistent spacing of the ions and the uniform pattern formed by them. Although the ion sizes are not the same, each sodium ion in the crystal is surrounded by six chloride ions, and each chloride ion is surrounded by six sodium ions. What shape would you expect a large crystal of this compound to be? As shown in **Figure 7.7,** the one-to-one ratio of sodium and chloride ions produces a highly ordered cubic crystal. As in all ionic compounds, in NaCl, no single unit consisting of only one sodium ion and one chloride ion is formed. Instead, large numbers of sodium ions and chloride ions exist together. If you can, obtain a magnifying lens and use it to examine some crystals of table salt (NaCl). What is the shape of these small salt crystals?

Reading Check **Explain** what determines the ratio of positive ions to negative ions in an ionic crystal.

1962 A nickel-titanium alloy with "shape memory" is discovered. The alloy reverts to its original shape after being deformed. Dental braces are one of many applications.

2004 Scientists develop a nickel-gadolinium alloy that absorbs radioactive neutrons emitted by nuclear waste. Applications include transport and storage of highly radioactive fuel.



1981 Invention of the scanning tunneling microscope allows researchers to study atomic-scale images in three dimensions.

Concepts in Motion

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Chemistry Online

■ **Figure 7.8** Aragonite ($CaCO_3$), barite ($BaSO_4$), and beryl ($Be_3Al_2Si_6O_{18}$) are examples of minerals that are ionic compounds. The ions that form them are bonded together in a crystal lattice. Differences in ion size and charge result in different ionic crystal shapes, a topic that will be discussed in Chapter 12.

The strong attractions among the positive ions and the negative ions in an ionic compound result in the formation of a crystal lattice. A **crystal lattice** is a three-dimensional geometric arrangement of particles. In a crystal lattice, each positive ion is surrounded by negative ions, and each negative ion is surrounded by positive ions. Ionic crystals vary in shape due to the sizes and relative numbers of the ions bonded, as shown by the minerals in **Figure 7.8.**

Connection to Earth Science The minerals shown in **Figure 7.8** are just a few of the types studied by mineralogists, scientists who study minerals. They make use of several classification schemes to organize the thousands of known minerals. Color, crystal structure, hardness, chemical, magnetic, and electric properties, and numerous other characteristics are used to classify minerals. The types of anions minerals contain can also be used to identify them. For example, more than one-third of all known minerals are silicates, which are minerals that contain an anion that is a combination of silicon and oxygen. Halides contain fluoride, chloride, bromide, or iodide ions. Other mineral classes include boron-containing anions known as borates and carbon-oxygen containing anions known as carbonates.

Reading Check **Identify** the mineral shown in **Figure 7.8** that is a silicate. Identify the mineral that is a carbonate.

Physical properties Melting point, boiling point, and hardness are physical properties of matter that depend on how strongly the particles that make up the matter are attracted to one another. Another property—the ability of a material to conduct electricity—depends on the availability of freely moving charged particles. Ions are charged particles, so whether they are free to move determines whether an ionic compound conducts electricity. In the solid state, the ions in an ionic compound are locked into fixed positions by strong attractive forces. As a result, ionic solids do not conduct electricity.

Table 7.5	Melting and Boiling Points of Some Ionic Compounds	
Compound	Melting Point (°C)	Boiling Point (°C)
NaI	660	1304
KBr	734	1435
NaBr	747	1390
$CaCl_2$	782	>1600
NaCl	801	1413
MgO	2852	3600

The situation changes dramatically, however, when an ionic solid melts to become a liquid or is dissolved in solution. The ions—previously locked in position—are now free to move and conduct an electric current. Both ionic compounds in solution and in the liquid state are excellent conductors of electricity. An ionic compound whose aqueous solution conducts an electric current is called an **electrolyte.** You will learn more about solutions of electrolytes in Chapter 14.

Because ionic bonds are relatively strong, ionic crystals require a large amount of energy to be broken apart. Thus, ionic crystals have high melting points and high boiling points, as shown in **Table 7.5.** Many crystals, including gemstones, have brilliant colors. These colors are due to the presence of transition metals in the crystal lattices.

Ionic crystals are also hard, rigid, brittle solids due to the strong attractive forces that hold the ions in place. When an external force is applied to the crystal—a force strong enough to overcome the attractive forces holding the ions in position within the crystal—the crystal cracks or breaks apart, as shown in **Figure 7.9.** The crystal breaks apart because the applied force repositions the like-charged ions next to each other; the resulting repulsive force breaks apart the crystal.

Vocabulary

Science usage v. Common usage

Conduct

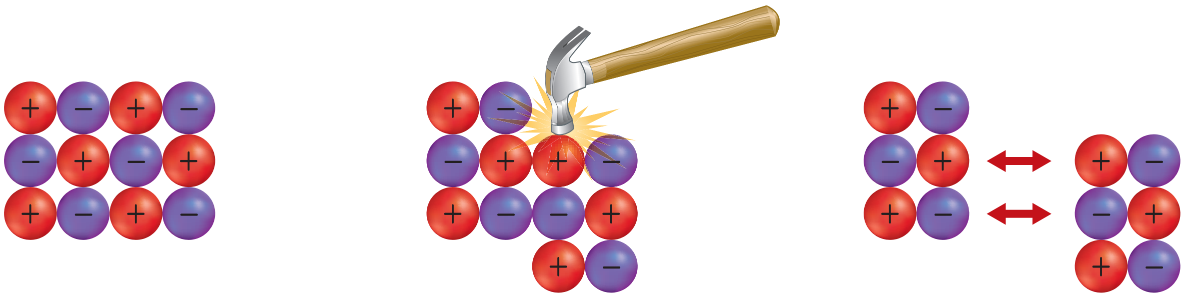
Science usage: the ability to transmit light, heat, sound, or electricity

The material did not conduct electricity well.

Common usage: to guide or lead

It was the manager's job to conduct the training session.

Figure 7.9 Strong attractive forces hold the ions in place until a force strong enough to overcome the attraction is applied.



Undisturbed ionic crystal

Before the force is applied, the crystal has a uniform pattern of ions.

Applied force realigns particles.

If the applied force is strong enough, it pushes the ions out of alignment.

Forces of repulsion break crystal apart.

A repulsive force created by nearby like-charged ions breaks apart the crystal.

Energy and the Ionic Bond

During every chemical reaction, energy is either absorbed or released. If energy is absorbed during a chemical reaction, the reaction is endothermic. If energy is released, it is exothermic.

The formation of ionic compounds from positive ions and negative ions is always exothermic. The attraction of the positive ion for the negative ions close to it forms a more stable system that is lower in energy than the individual ions. If the amount of energy released during bond formation is reabsorbed, the bonds holding the positive ions and negative ions together will break apart.

Lattice energy Because the ions in an ionic compound are arranged in a crystal lattice, the energy required to separate 1 mol of the ions of an ionic compound is referred to as the **lattice energy.** The strength of the forces holding ions in place is reflected by the lattice energy. The greater the lattice energy, the stronger the force of attraction.

Lattice energy is directly related to the size of the ions bonded. Smaller ions form compounds with more closely spaced ionic charges. Because the electrostatic force of attraction between opposite charges increases as the distance between the charges decreases, smaller ions produce stronger interionic attractions and greater lattice energies. For example, the lattice energy of a lithium compound is greater than that of a potassium compound containing the same anion because the lithium ion is smaller than the potassium ion.

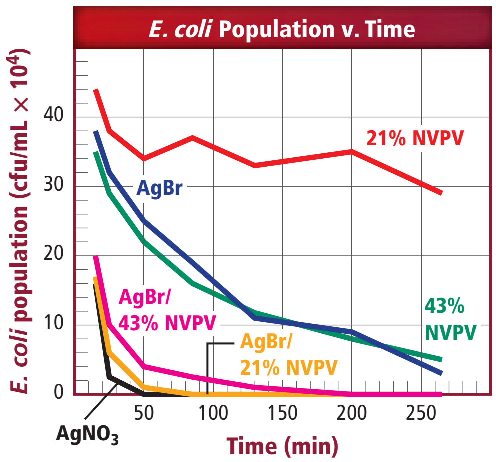
DATA ANALYSIS LAB

Based on Real Data*

Interpret Data

Can embedding nanoparticles of silver into a polymer give the polymer antimicrobial properties? Researchers tested the antimicrobial properties of a new composite material-- the polymer poly(4-vinyl-N-hexylpyridinium bromide), known as NPVP, which attracts cations. It is known that silver ions from silver bromide and silver nitrate exhibit antimicrobial activity. Silver bromide was embedded into the NPVP polymer. Scientists tested the antimicrobial properties of the composite material. Their results, illustrated in the graph, show the growth of *E. coli* bacteria over a period of approximately four hours. Each line represents the *E. coli* population in response to the introduction of a particular substance.

Data and Observations



Think Critically

1. **Interpret** Does the addition of silver bromide (AgBr) ions to NVPV improve the antimicrobial properties of the composite?
2. **Interpret** Which composite reduced the *E. coli* population to zero? How long does it take for each substance to reduce the bacteria population to zero?
3. **Conclude** Does a composite polymer containing NVPV and silver bromide show antimicrobial properties? Explain your answer.

*Data obtained from: Sambhy, V., et al. Published on the Web 7/7/2006. Silver Bromide Nanoparticle/Polymer Composites. *Journal of the American Chemical Society.*

Table 7.6 Lattice Energies of Some Ionic Compounds

Compound	Lattice Energy (kJ/mol)	Compound	Lattice Energy (kJ/mol)
KI	632	KF	808
KBr	671	AgCl	910
RbF	774	NaF	910
NaI	682	LiF	1030
NaBr	732	$SrCl_2$	2142
NaCl	769	MgO	3795

The value of lattice energy is also affected by the charge of the ion. The ionic bond formed from the attraction of ions with larger positive or negative charges generally has a greater lattice energy. The lattice energy of MgO is almost four times greater than that of NaF because the charge of the ions in MgO is greater than the charge of the ions in NaF. The lattice energy of $SrCl_2$ is between the lattice energies of MgO and NaF because $SrCl_2$ contains ions with both higher and lower charges.

Table 7.6 shows the lattice energies of some ionic compounds. Examine the lattice energies of RbF and KF. Because K^+ has a smaller ionic radius than Rb^+, KF has a greater lattice energy than RbF. This confirms that lattice energy is related to ion size. Notice the lattice energies of $SrCl_2$ and AgCl. How do they show the relationship between lattice energy and the charge of the ions involved?

Section 7.2 Assessment

Section Summary

- Ionic compounds contain ionic bonds formed by the attraction of oppositely charged ions.
- Ions in an ionic compound are arranged in a repeating pattern known as a crystal lattice.
- Ionic compound properties are related to ionic bond strength.
- Ionic compounds are electrolytes; they conduct an electric current in the liquid phase and in aqueous solution.
- Lattice energy is the energy needed to remove 1 mol of ions from its lattice.

12. MAIN Idea **Explain** how an ionic compound made up of charged particles can be electrically neutral.
13. **Describe** the energy change associated with ionic bond formation, and relate it to stability.
14. **Identify** three physical properties of ionic compounds that are associated with ionic bonds, and relate them to bond strength.
15. **Explain** how ions form bonds, and describe the structure of the resulting compound.
16. **Relate** lattice energy to ionic-bond strength.
17. **Apply** Use electron configurations, orbital notation, and electron-dot structures to represent the formation of an ionic compound from the metal strontium and the nonmetal chlorine.
18. **Design** a concept map that shows the relationships among ionic bond strength, physical properties of ionic compounds, lattice energy, and stability.

Section 7.3

Objectives

- **Relate** a formula unit of an ionic compound to its composition.
- **Write** formulas for ionic compounds and oxyanions.
- **Apply** naming conventions to ionic compounds and oxyanions.

Review Vocabulary

nonmetal: an element that is generally a gas or a dull, brittle solid and is a poor conductor of heat and electricity

New Vocabulary

formula unit
monatomic ion
oxidation number
polyatomic ion
oxyanion

Names and Formulas for Ionic Compounds

MAIN Idea In written names and formulas for ionic compounds, the cation appears first, followed by the anion.

Real-World Reading Link Although people have a wide range of names, most have both a first name and a last name. Ionic compound names are similar, in that they also consist of two parts.

Formulas for Ionic Compounds

Because chemists around the world need to be able to communicate with one another, they have developed a set of rules for naming compounds. Using this standardized naming system, you can write a chemical formula from a compound's name and name a compound given its chemical formula.

Recall that an ionic compound is made up of ions arranged in a repeating pattern. The chemical formula for an ionic compound, called a **formula unit,** represents the simplest ratio of the ions involved. For example, the formula unit of magnesium chloride is $MgCl_2$ because the magnesium and chloride ions exist in a 1:2 ratio. The overall charge of a formula unit is zero because the formula unit represents the entire crystal, which is electrically neutral. The formula unit for $MgCl_2$ contains one Mg^{2+} ion and two Cl^- ions, for a total charge of zero.

Monatomic ions Binary ionic compounds are composed of positively charged monatomic ions of a metal and negatively charged monatomic ions of a nonmetal. A **monatomic ion** is a one-atom ion, such as Mg^{2+} or Br^-. **Table 7.7** indicates the charges of common monatomic ions according to their location on the periodic table. What is the formula for the beryllium ion? The iodide ion? The nitride ion?

Transition metals, which are in groups 3 through 12, and metals in groups 13 and 14 are not included in **Table 7.7** because of the variance in ionic charges of atoms in the groups. Most transition metals and metals in groups 13 and 14 can form several different positive ions.

Table 7.7 Common Monatomic Ions

Group	Atoms that Commonly Form Ions	Charge of Ions
1	H, Li, Na, K, Rb, Cs	1+
2	Be, Mg, Ca, Sr, Ba	2+
15	N, P, As	3−
16	O, S, Se, Te	2−
17	F, Cl, Br, I	1−

Table 7.8	Monatomic Metal Ions
Group	**Common Ions**
3	Sc^{3+}, Y^{3+}, La^{3+}
4	Ti^{2+}, Ti^{3+}
5	V^{2+}, V^{3+}
6	Cr^{2+}, Cr^{3+}
7	Mn^{2+}, Mn^{3+}, Tc^{2+}
8	Fe^{2+}, Fe^{3+}
9	Co^{2+}, Co^{3+}
10	Ni^{2+}, Pd^{2+}, Pt^{2+}, Pt^{4+}
11	Cu^{+}, Cu^{2+}, Ag^{+}, Au^{+}, Au^{3+}
12	Zn^{2+}, Cd^{2+}, $Hg_2{}^{2+}$ Hg^{2+}
13	Al^{3+}, Ga^{2+}, Ga^{3+}, In^{+}, In^{2+}, In^{3+}, Tl^{+}, Tl^{3+}
14	Sn^{2+}, Sn^{4+}, Pb^{2+}, Pb^{4+}

Oxidation numbers The charge of a monatomic ion is known as its **oxidation number,** or oxidation state. As shown in **Table 7.8,** most transition metals and group 13 and 14 metals have more than one possible oxidation number. Note that the oxidation numbers given in **Table 7.8** are the most common ones, not the only ones possible.

The oxidation number of an element in an ionic compound equals the number of electrons transferred from the atom to form the ion. For example, a sodium atom transfers one electron to a chlorine atom to form sodium chloride. This results in Na^{+} and Cl^{-}. Thus, the oxidation number of sodium in the compound is 1+ because one electron was transferred from the sodium atom. Because an electron is transferred to the chlorine atom, its oxidation number is 1−.

Formulas for binary ionic compounds In the chemical formula for any ionic compound, the symbol of the cation is always written first, followed by the symbol of the anion. Subscripts, which are small numbers to the lower right of a symbol, represent the number of ions of each element in an ionic compound. If no subscript is written, it is assumed to be one. You can use oxidation numbers to write formulas for ionic compounds. Recall that ionic compounds have no charge. If you add the oxidation number of each ion multiplied by the number of these ions in a formula unit, the total must be zero.

Suppose you need to determine the formula for one formula unit of the compound that contains sodium and fluoride ions. Start by writing the symbol and charge for each ion: Na^{+} and F^{-}. The ratio of ions in a formula unit of the compound must show that the number of electrons lost by the metal equals the number of electrons gained by the nonmetal. This occurs when one sodium ion transfers one electron to the fluoride ion; the formula unit is NaF.

Reading Check **Relate** the charge of an ion to its oxidation number.

CAREERS IN CHEMISTRY

Food Scientist Have you ever thought about the science behind the food you eat? Food scientists are concerned about the effects of processing on the appearance, aroma, taste, and the vitamin and mineral content of food. They also develop and improve foods and beverages. Food scientists often maintain "tasting notebooks" as they learn the characteristics of individual and blended flavors. For more information on chemistry careers, visit glencoe.com.

VOCABULARY

ACADEMIC VOCABULARY

Transfer
to cause to pass from one to another
Carlos had to transfer to a new school when his parents moved to a new neighborhood.

EXAMPLE Problem 7.1

Formula for an Ionic Compound Determine the formula for the ionic compound formed from potassium and oxygen.

1 Analyze the Problem

You are given that potassium and oxygen ions form an ionic compound; the formula for the compound is the unknown. First, write out the symbol and oxidation number for each ion involved in the reaction. Potassium, from group 1, forms 1+ ions, and oxygen, from group 16, forms 2− ions.

$$K^{+} \qquad O^{2-}$$

Because the charges are not the same, you need to determine the subscripts to use to indicate the ratio of positive ions to negative ions.

2 Solve for the Unknown

A potassium atom loses one electron, while an oxygen atom gains two electrons. If combined in a one-to-one ratio, the number of electrons lost by potassium will not balance the number of electrons gained by oxygen. Thus, two potassium ions are needed for each oxide ion. The formula is **K_2O.**

3 Evaluate the Answer

The overall charge of the compound is zero.

$$2\ \cancel{\text{K ions}}\left(\frac{1+}{\cancel{\text{K ion}}}\right) + 1\ \cancel{\text{O ion}}\left(\frac{2-}{\cancel{\text{O ion}}}\right) = 2(1+) + 1(2-) = 0$$

Real-World Chemistry
Ionic Compounds

Mineral supplements To function properly, your body requires a daily intake of many different minerals. To ensure they are getting what they need, many people take a daily multivitamin and a mineral supplement. The minerals in these supplements come from a variety of ionic compounds. In fact, the majority of minerals found in mineral supplements come from ground-up rocks.

EXAMPLE Problem 7.2

Formula for an Ionic Compound Determine the formula for the compound formed from aluminum ions and sulfide ions.

1 Analyze the Problem

You are given that aluminum and sulfur form an ionic compound; the formula for the ionic compound is the unknown. First, determine the charges of each ion. Aluminum, from group 13, forms 3+ ions, and sulfur, from group 16, forms 2− ions.

$$Al^{3+} \qquad S^{2-}$$

Each aluminum atom loses three electrons, while each sulfur atom gains two electrons. The number of electrons lost must equal the number of electrons gained.

2 Solve for the Unknown

The smallest number that can be divided evenly by both 2 and 3 is 6. Therefore, six electrons are transferred. Three sulfur atoms accept the six electrons lost by two aluminum atoms. The correct formula, **Al_2S_3,** shows two aluminum ions bonded to three sulfur ions.

3 Evaluate the Answer

The overall charge of one formula unit of this compound is zero.

$$2\ \cancel{\text{Al ions}}\left(\frac{3+}{\cancel{\text{Al ion}}}\right) + 3\ \cancel{\text{S ions}}\left(\frac{2-}{\cancel{\text{S ion}}}\right) = 2(3+) + 3(2-) = 0$$

PRACTICE Problems

Extra Practice Page 979 and glencoe.com

Write formulas for the ionic compounds formed by the following ions.

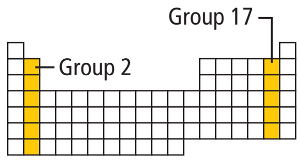
19. potassium and iodide

20. magnesium and chloride

21. aluminum and bromide

22. cesium and nitride

23. Challenge Write the general formula for the ionic compound formed by elements from the two groups shown on the periodic table at the right.



Formulas for polyatomic ionic compounds Many ionic compounds contain **polyatomic ions,** which are ions made up of more than one atom. **Table 7.9** and **Figure 7.10** list the formulas and charges of common polyatomic ions. Also, refer to **Table R-6** on page 970. A polyatomic ion acts as an individual ion in a compound and that its charge applies to the entire group of atoms. Thus, the formula for a polyatomic compound follows the same rules used for a binary compound.

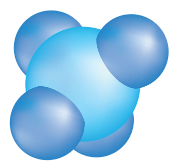
Because a polyatomic ion exists as a unit, never change subscripts of the atoms within the ion. If more than one polyatomic ion is needed, place parentheses around the ion and write the appropriate subscript outside the parentheses. For example, consider the compound formed from the ammonium ion (N_4^+) and the oxide ion (O^{2-}). To balance the charges, the compound must have two ammonium ions for each oxide ion. To add a subscript to ammonium, enclose it in parentheses, then add the subscript. The correct formula is $(NH_4)_2O$.

Table 7.9 Common Polyatomic Ions

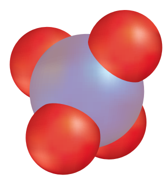
Ion	Name	Ion	Name
NH_4^+	ammonium	IO_4^-	periodate
NO_2^-	nitrite	$C_2H_3O_2^-$	acetate
NO_3^-	nitrate	$H_2PO_4^-$	dihydrogen phosphate
OH^-	hydroxide	CO_3^{2-}	carbonate
CN^-	cyanide	SO_3^{2-}	sulfite
MnO_4^-	permanganate	SO_4^{2-}	sulfate
HCO_3^-	hydrogen carbonate	$S_2O_3^{2-}$	thiosulfate
ClO^-	hypochlorite	O_2^{2-}	peroxide
ClO_2^-	chlorite	CrO_4^{2-}	chromate
ClO_3^-	chlorate	$Cr_2O_7^{2-}$	dichromate
ClO_4^-	perchlorate	HPO_4^{2-}	hydrogen phosphate
BrO_3^-	bromate	PO_4^{3-}	phosphate
IO_3^-	iodate	AsO_4^{3-}	arsenate

Figure 7.10 Ammonium and phosphate ions are polyatomic; that is, they are made up of more than one atom. Each polyatomic ion, however, acts as a single unit and has one charge.

Identify ***What are the charges of the ammonium ion and phosphate ion, respectively?***



Ammonium ion (NH_4^+)



Phosphate ion (PO_4^{3-})

EXAMPLE Problem 7.3

Formula for a Polyatomic Ionic Compound A compound formed by calcium ions and phosphate ions is often used in fertilizers. Write the compound's formula.

1 Analyze the Problem

You know that calcium and phosphate ions form an ionic compound; the formula for the compound is the unknown. First, write each ion along with its charge. Calcium, from group 2, forms 2+ ions, and the polyatomic phosphate acts as a single unit with a 3– charge.

$$Ca^{2+} \qquad PO_4^{3-}$$

Each calcium atom loses two electrons, while each polyatomic phosphate group gains three electrons. The number of electrons lost must equal the number of electrons gained.

2 Solve for the Unknown

The smallest number evenly divisible by both charges is 6. Thus, a total of six electrons are transferred. The negative charge from two phosphate ions equals the positive charge from three calcium ions. In the formula, place the polyatomic ion in parentheses and add a subscript to the outside. The correct formula for the compound is **$Ca_3(PO_4)_2$.**

3 Evaluate the Answer

The overall charge of one formula unit of calcium phosphate is zero.

$$3\ \text{Ca}\ \cancel{\text{ions}}\left(\frac{2+}{\text{Ca}\ \cancel{\text{ion}}}\right) + 2\ \text{PO}_4\ \cancel{\text{ions}}\left(\frac{3-}{\text{PO}_4\ \cancel{\text{ion}}}\right) = 3(2+) + 2(3-) = 0$$

PRACTICE Problems

Extra Practice Page 979 and glencoe.com

Write formulas for ionic compounds composed of the following ions.

24. sodium and nitrate

25. calcium and chlorate

26. aluminum and carbonate

27. Challenge Write the formula for an ionic compound formed by ions from a group 2 element and polyatomic ions composed of only carbon and oxygen.

Chemistry Online

Personal Tutor For an online tutorial on naming ionic compounds, visit glencoe.com.

Names for Ions and Ionic Compounds

Scientists use a systematic approach when naming ionic compounds. Because ionic compounds have both cations and anions, the naming system accounts for both of these ions.

Naming an oxyanion An **oxyanion** is a polyatomic ion composed of an element, usually a nonmetal, bonded to one or more oxygen atoms. More than one oxyanion exists for some nonmetals, such as nitrogen and sulfur. These ions are easily named using the rules in **Table 7.10.**

Table 7.10 Oxyanion Naming Conventions for Sulfur and Nitrogen

- Identify the ion with the greatest number of oxygen atoms. This ion is named using the root of the nonmetal and the suffix *-ate*.
- Identify the ion with fewer oxygen atoms. This ion is named using the root of the nonmetal and the suffix *-ite*.

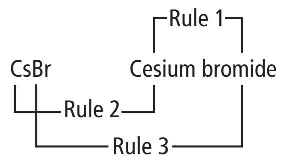
Examples:	NO_3^-	NO_2^-	SO_4^{2-}	SO_3^{2-}
	nitr*ate*	nitr*ite*	sulf*ate*	sulf*ite*

As shown in **Table 7.11,** chlorine forms four oxyanions that are named according to the number of oxygen atoms present. Names of similar oxyanions formed by other halogens follow the rules used for chlorine. For example, bromine forms the bromate ion (BrO_3^-), and iodine forms the periodate ion (IO_4^-) and the iodate ion (IO_3^-).

Naming ionic compounds Chemical nomenclature is a systematic way of naming compounds. Now that you are familiar with chemical formulas, you can use the following five rules to name ionic compounds.

1. Name the cation followed by the anion. Remember that the cation is always written first in the formula.
2. For monatomic cations, use the element name.
3. For monatomic anions, use the root of the element name plus the suffix *-ide*.

   Example:



4. To distinguish between multiple oxidation numbers of the same element, the name of the chemical formula must indicate the oxidation number of the cation. The oxidation number is written as a Roman numeral in parentheses after the name of the cation.

   Note: This rule applies to the transition metals and metals on the right side of the periodic table, which often have more than one oxidation number. See **Table 7.8.** It does not apply to group 1 and group 2 cations, as they have only one oxidation number.

   Examples:

   Fe^{2+} and O^{2-} ions form FeO, known as iron(II) oxide.

   Fe^{3+} and O^{2-} ions form Fe_2O_3, known as iron(III) oxide.

5. When the compound contains a polyatomic ion, simply name the cation followed by the name of the polyatomic ion.

   Examples:

   The name for NaOH is sodium hydroxide.

   The name for $(NH_4)_2S$ is ammonium sulfide.

Table 7.11 Oxyanion Naming Conventions for Chlorine

- The oxyanion with the greatest number of oxygen atoms is named using the prefix *per-*, the root of the nonmetal, and the suffix *-ate*.
- The oxyanion with one fewer oxygen atom is named using the root of the nonmetal and the suffix *-ate*.
- The oxyanion with two fewer oxygen atoms is named using the root of the nonmetal and the suffix *-ite*.
- The oxyanion with three fewer oxygen atoms is named using the prefix *hypo-*, the root of the nonmetal, and the suffix *-ite*.

Examples:

ClO_4^-	ClO_3^-
*per*chlor*ate*	chlor*ate*
ClO_2^-	ClO^-
chlor*ite*	*hypo*chlor*ite*

PRACTICE Problems

Extra Practice Page 979 and **glencoe.com**

Name the following compounds.

28. NaBr

29. $CaCl_2$

30. KOH

31. $Cu(NO_3)_2$

32. Ag_2CrO_4

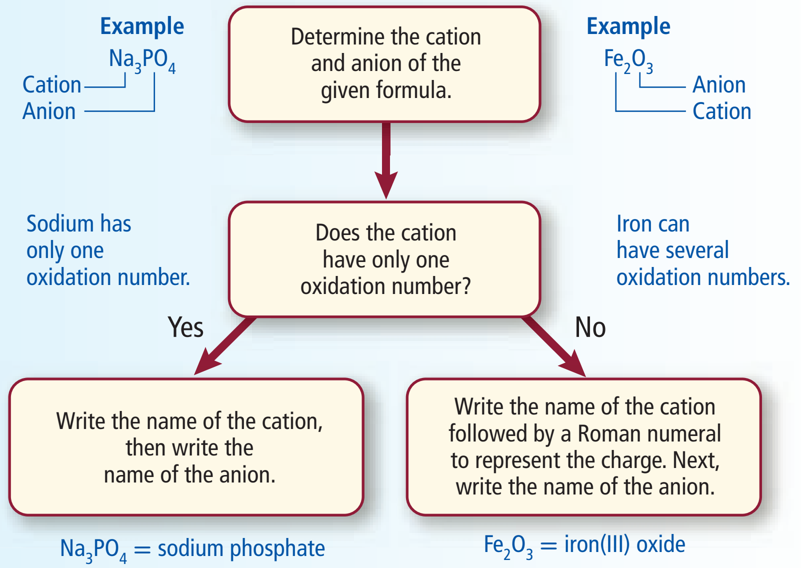
33. Challenge The ionic compound NH_4ClO_4 is a key reactant used in solid rocket boosters, such as those that power the Space Shuttle into orbit. Name this compound.

Problem-Solving Strategy
Naming Ionic Compounds

Naming ionic compounds is easy if you follow this naming-convention flowchart.

Apply the Strategy

Name the compounds KOH and Ag_2CrO_4 using this flowchart.



The Problem-Solving Strategy above reviews the steps used in naming ionic compounds if the formula is known. Naming ionic compounds is important in communicating the cation and anion present in a crystalline solid or aqueous solution. How might you change the diagram to help you write the formulas for ionic compounds if you know their names?

The ion-containing substances you have investigated so far have been ionic compounds. In the next section, you will learn how ions relate to the structure and properties of metals.

Section 7.3 Assessment

Section Summary

- A formula unit gives the ratio of cations to anions in the ionic compound.
- A monatomic ion is formed from one atom. The charge of a monatomic ion is its oxidation number.
- Roman numerals indicate the oxidation number of cations having multiple possible oxidation states.
- Polyatomic ions consist of more than one atom and act as a single unit.
- To indicate more than one polyatomic ion in a chemical formula, place parentheses around the polyatomic ion and use a subscript.

34. MAIN Idea **State** the order in which the ions associated with a compound composed of potassium and bromine would be written in the chemical formula and the compound name.

35. Describe the difference between a monatomic ion and a polyatomic ion, and give an example of each.

36. Apply Ion *X* has a charge of 2+, and ion *Y* has a charge of 1−. Write the formula unit of the compound formed from the ions.

37. State the name and formula for the compound formed from Mg and Cl.

38. Write the name and formula for the compound formed from sodium ions and nitrite ions.

39. Analyze What subscripts would you most likely use if the following substances formed an ionic compound?

a. an alkali metal and a halogen

b. an alkali metal and a nonmetal from group 16

c. an alkaline earth metal and a halogen

d. an alkaline earth metal and a nonmetal from group 16

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Section 7.4

Objectives

- **Describe** a metallic bond.
- **Relate** the electron sea model to the physical properties of metals.
- **Define** alloys, and categorize them into two basic types.

Review Vocabulary

physical property: a characteristic of matter that can be observed or measured without altering the sample's composition

New Vocabulary

electron sea model
delocalized electron
metallic bond
alloy

Metallic Bonds and the Properties of Metals

MAIN Idea Metals form crystal lattices and can be modeled as cations surrounded by a "sea" of freely moving valence electrons.

Real-World Reading Link Imagine a buoy in the ocean, bobbing by itself surrounded by a vast expanse of open water. Though the buoy stays in the same area, the ocean water freely flows past. In some ways, this description also applies to metallic atoms and their electrons.

Metallic Bonds

Although metals are not ionic, they share several properties with ionic compounds. The bonding in both metals and ionic compounds is based on the attraction of particles with unlike charges. Metals often form lattices in the solid state. These lattices are similar to the ionic crystal lattices discussed earlier. In such a lattice, 8 to 12 other metal atoms closely surround each metal atom.

A sea of electrons Although metal atoms always have at least one valence electron, they do not share these valence electrons with neighboring atoms, nor do they lose their valence electrons. Instead, within the crowded lattice, the outer energy levels of the metal atoms overlap. This unique arrangement is described by the electron sea model. The **electron sea model** proposes that all the metal atoms in a metallic solid contribute their valence electrons to form a "sea" of electrons. This sea of electron surrounds the metal cations in the lattice.

The electrons present in the outer energy levels of the bonding metallic atoms are not held by any specific atom and can move easily from one atom to the next. Because they are free to move, they are often referred to as **delocalized electrons.** When the atom's outer electrons move freely throughout the solid, a metallic cation is formed. Each such ion is bonded to all neighboring metal cations by the sea of valence electrons, as shown in **Figure 7.11.** A **metallic bond** is the attraction of a metallic cation for delocalized electrons.

Figure 7.11 The valence electrons in metals (shown as a blue cloud of minus signs) are evenly distributed among the metallic cations (shown in red). Attractions between positive cations and the negative "sea" hold the metal atoms together in a lattice.
Explain *Why are electrons in metals known as delocalized electrons?*

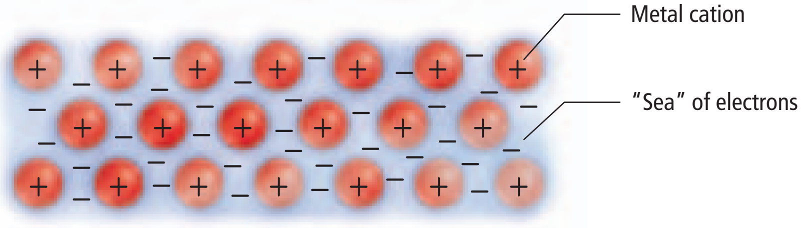


Table 7.12	Melting and Boiling Points	
Element	Melting Point (°C)	Boiling Point (°C)
Lithium	180	1347
Tin	232	2623
Aluminum	660	2467
Barium	727	1850
Silver	961	2155
Copper	1083	2570

Properties of metals The physical properties of metals can be explained by metallic bonding. These properties provide evidence of the strength of metallic bonds.

Melting and boiling points The melting points of metals vary greatly. Mercury is a liquid at room temperature, which makes it useful in scientific instruments such as thermometers and barometers. On the other hand, tungsten has a melting point of 3422°C. Lightbulb filaments are usually made from tungsten, as are certain spacecraft parts.

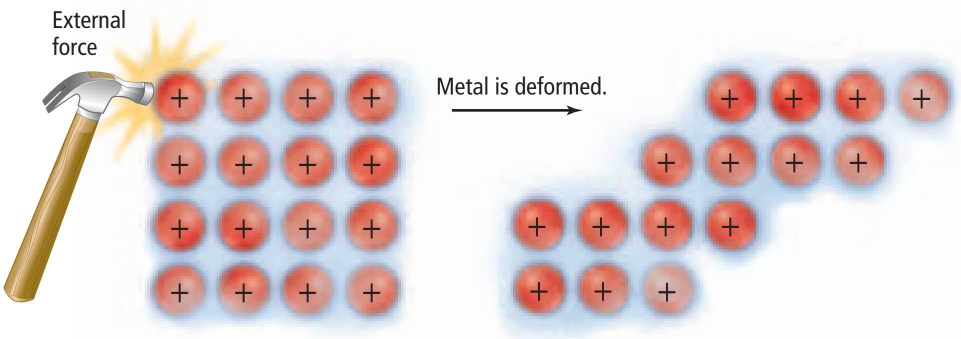
In general, metals have moderately high melting points and high boiling points, as shown in **Table 7.12.** The melting points are not as extreme as the boiling points because the cations and electrons are mobile in a metal. It does not take an extreme amount of energy for them to be able to move past each other. However, during boiling, atoms must be separated from the group of cations and electrons, which requires much more energy.

Malleability, ductility, and durability Metals are malleable, which means they can be hammered into sheets, and they are ductile, which means they can be drawn into wire. **Figure 7.12** shows how the mobile particles involved in metallic bonding can be pushed or pulled past each other. Metals are generally durable. Although metallic cations are mobile in a metal, they are strongly attracted to the electrons surrounding them and are not easily removed from the metal.

Thermal conductivity and electrical conductivity The movement of mobile electrons around positive metallic cations makes metals good conductors. The delocalized electrons move heat from one place to another much more quickly than the electrons in a material that does not contain mobile electrons. Mobile electrons easily move as part of an electric current when an electric potential is applied to a metal. These same delocalized electrons interact with light, absorbing and releasing photons, thereby creating the property of luster in metals.

Hardness and strength The mobile electrons in transition metals consist not only of the two outer s electrons but also of the inner d electrons. As the number of delocalized electrons increases, so do the properties of hardness and strength. For example, strong metallic bonds are found in transition metals such as chromium, iron, and nickel, whereas alkali metals are considered soft because they have only one delocalized electron, ns^1.

Reading Check **Contrast** the behavior of metals and ionic compounds when each is struck by a hammer.



■ **Figure 7.12** An applied force causes metal ions to move through delocalized electrons, making metals malleable and ductile.

Metal Alloys

Due to the nature of metallic bonds, it is relatively easy to introduce other elements into the metallic crystal, forming an alloy. An **alloy** is a mixture of elements that has metallic properties. Because of their unique blend of properties, alloys have a wide range of commercial applications. Stainless steel, brass, and cast iron are a few of the many useful alloys.

Properties of alloys The properties of alloys differ somewhat from the properties of the elements they contain. For example, steel is iron mixed with at least one other element. Some properties of iron are present, but steel has additional properties, such as increased strength. Some alloys vary in properties, depending on how they are manufactured. In the case of some metals, different properties can result based on heating and cooling.

VOCABULARY

WORD ORIGIN

Alloy
comes from the Latin word *alligare*, which means *to bind.*

MiniLab

Observe Properties

How do the properties of steel change when it is subjected to different types of heat treatment? For centuries, people have treated metals with heat to change their properties. The final properties of the metal depend on the temperature to which the metal is heated and the rate at which it cools.

Procedure

1. Read and complete the lab safety form.
2. Examine a property of spring steel by trying to bend open one of three **hairpins.** Record your observations.
3. Next, hold each end of the hairpin with a pair of **forceps.** Place the curved central loop portion of the hairpin in the top of the blue flame from a **laboratory burner.** When the metal turns red, pull the hairpin open to form a straight piece of metal. Allow it to cool as you record your observations. Repeat Step 3 for the remaining two hairpins.
   WARNING: ***Do not touch the hot metal. Do not hold your hand above the flame of the laboratory burner.***
4. To make softened steel, use a pair of forceps to hold all three hairpins vertically in the flame from the laboratory burner until the hairpins are glowing red all over. Slowly raise the three hairpins straight up and out of the flame so they cool slowly. Slow cooling results in the formation of large crystals.
5. After cooling, bend each of the three hairpins into the shape of the letter J. Record how the metal feels as you bend it.
6. To harden the steel, use the tongs to hold two of the bent hairpins in the flame until they are glowing red all over. Quickly plunge the hot metals into a **250-mL beaker** containing approximately 200 mL of **cold water.** Quick cooling causes the crystal size to be small.
7. Attempt to straighten one of the bends. Record your observations.
8. To temper the steel, use the tongs to hold the remaining hardened metal bend above the flame for a brief period of time. Slowly move the metal back and forth just above the flame until the gray metal turns to an iridescent blue-gray color. Do not allow the metal to become hot enough to glow red. Slowly cool the metal, and then try to unbend it using the end of your finger. Record your observations.

Analysis

1. **Analyze** your results, and identify the two types of steel that appear to have their properties combined in tempered steel.
2. **Hypothesize** how the different observed properties relate to crystal size.
3. **State** a use for spring steel that takes advantage of its unique properties.
4. **Infer** the advantages and disadvantages of using softened steel for body panels on automobiles.
5. **Apply** What is a major disadvantage of hardened steel? Do you think hardened steel would be wear-resistant and retain a sharpened edge? Explain your reasoning.

Figure 7.13 Bicycle frames are sometimes made of 3/2.5 titanium alloy, an alloy of titanium containing 3% aluminum and 2.5% vanadium.

Table 7.13 Commercial Alloys

Common Name	Composition	Uses
Alnico	Fe 50%, Al 20%, Ni 20%, Co 10%	magnets
Brass	Cu 67–90%, Zn 10–33%	plumbing, hardware, lighting
Bronze	Cu 70–95%, Zn 1–25%, Sn 1–18%	bearings, bells, medals
Cast iron	Fe 96–97%, C 3–4%	casting
Gold, 10-carat	Au 42%, Ag 12–20%, Cu 37.46%	jewelry
Lead shot	Pb 99.8%, As 0.2%	shotgun shells
Pewter	Sn 70–95%, Sb 5–15%, Pb 0–15%	tableware
Stainless steel	Fe 73–79%, Cr 14–18%, Ni 7–9%	instruments, sinks
Sterling silver	Ag 92.5%, Cu 7.5%	tableware, jewelry

Table 7.13 lists some commercially important alloys and their uses. An alloy of titanium and vanadium is used for the bicycle frame shown in **Figure 7.13.** Alloys such as this are classified into one of two basic types, substitutional alloys and interstitial alloys.

Substitutional alloys In a substitutional alloy, some of the atoms in the original metallic solid are replaced by other metals of similar atomic size. Sterling silver is an example of a substitutional alloy. In sterling silver, copper atoms replace some of the silver atoms in the metallic crystal. The resulting solid has properties of both silver and copper.

Interstitial alloys An interstitial alloy is formed when the small holes (interstices) in a metallic crystal are filled with smaller atoms. The best-known interstitial alloy is carbon steel. Holes in the iron crystal are filled with carbon atoms, and the physical properties of iron are changed. Iron is relatively soft and malleable. However, the presence of carbon makes the solid harder, stronger, and less ductile than pure iron.

Section 7.4 Assessment

Section Summary

- A metallic bond forms when metal cations attract freely moving, delocalized valence electrons.
- In the electron sea model, electrons move through the metallic crystal and are not held by any particular atom.
- The electron sea model explains the physical properties of metallic solids.
- Metal alloys are formed when a metal is mixed with one or more other elements.

40. MAIN Idea **Contrast** the structures of ionic compounds and metals.
41. **Explain** how the conductivity of electricity and the high boiling points of metals are explained by metallic bonding.
42. **Contrast** the cause of the attraction in ionic bonds and metallic bonds.
43. **Summarize** alloy types by correctly pairing these terms and phrases: *substitutional*, *interstitial*, *replaced*, and *filled in*.
44. **Design an experiment** that could be used to distinguish between a metallic solid and an ionic solid. Include at least two different methods for comparing the solids. Explain your reasoning.
45. **Model** Draw a model to represent the physical property of metals known as ductility, or the ability to be drawn into a wire. Base your drawing on the electron sea model shown in **Figure 7.11.**

Chemistry Online Self-Check Quiz glencoe.com

Everyday Chemistry

Killer Fashion

Shiny and colorful, costume jewelry can be inexpensive and fun. But is it safe? Usually the answer is yes. But some costume jewelry, particularly pieces made in developing countries, such as China and India, might pose a danger due to high levels of the toxic element lead (Pb).

Poisoned plumbing When lead gets wet, a certain amount of it dissolves, becoming lead (Pb^{2+}) ions. Inside the body, these ions can replace calcium (Ca^{2+}) ions. Other than their similar electric charges, lead and calcium are different (for one thing, lead ions are much heavier than calcium ions), and the presence of lead can cause learning disabilities, coma, or even death.

It might be surprising, then, to learn that lead was used by the Romans in, of all things, their water pipes! In fact, the symbol for lead—Pb—comes from the Latin word *plumbum,* which still appears in English as the root of the word *plumber,* one who works with pipes.

Toxic pottery While lead is not found in modern plumbing, it can still be found in other things. The pot shown in **Figure 1** was created with lead glaze and fired using traditional Mexican techniques to give it its distinctive black color. Glazes containing lead compounds can also create vibrant colors when fired under different conditions.

Figure 1 Lead compounds in pottery glaze give this pot its distinctive look.

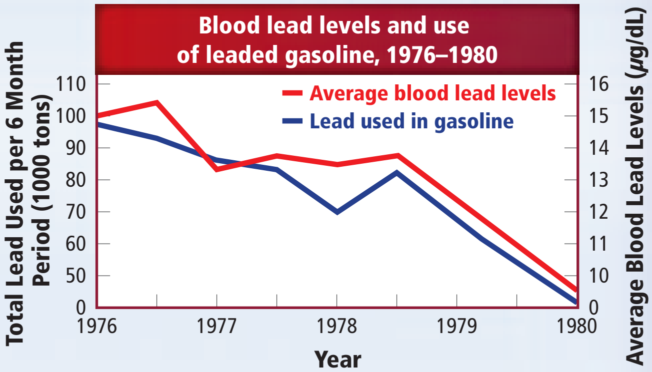


Figure 2 Lead levels in Americans' blood dropped as leaded gasoline was phased out.

A useful poison Before it was known to be highly toxic, lead had a number of applications beyond pottery and plumbing. Lead has been used in paint and even gasoline, where its presence reduced "knock"—the tendency of gasoline to explode at the wrong time within the engine block. In the 1970s, when leaded gasoline was phased out in the United States, blood lead levels dropped immediately (see **Figure 2**).

But other avenues, such as jewelry or toys manufactured in other countries, can still contain lead. A lead-rich piece of costume jewelry might rest harmlessly against the skin until the metal finds its way into the mouth of a curious child or a daydreaming teenager.

Chelation Children are particularly susceptible to lead poisoning, due to their smaller body sizes and rapid rates of development. In serious cases, a process called chelation therapy might be the only way to save the child's life. Chelation therapy reverses one important effect of lead poisioning, replacing toxic lead with beneficial calcium in the body.

WRITING in Chemistry

Sense of Danger Our sense of taste can detect certain toxins found naturally in plants. Research other modern toxins, such as lead and antifreeze, to find out why they don't elicit a negative response from our taste buds. For more information on green chemistry, visit glencoe.com.

CHEMLAB

SYNTHESIZE AN IONIC COMPOUND

Background: **You will form two compounds and test them to determine some of their properties. Based on your tests, you will decide whether the products are ionic compounds.**

Question: *Can the physical properties of a compound indicate that they have ionic bonds?*

Materials

magnesium ribbon (25 cm)
ring stand and ring
Bunsen burner
crucible tongs
100-mL beaker
conductivity tester
crucible
clay triangle
stirring rod
centigram balance
distilled water

Safety Precautions

WARNING: ***Do not look directly at the burning magnesium; the intensity of the light can damage your eyes. Avoid handling heated materials until they have cooled.***

Procedure

1. Read and complete the lab safety form.
2. Record all measurements in your data table.
3. Position the ring on the ring stand about 7 cm above the top of the Bunsen burner. Place the clay triangle on the ring.
4. Measure the mass of the clean, dry crucible.
5. Roll 25 cm of magnesium ribbon into a loose ball. Place it in the crucible. Measure the mass of the magnesium and crucible together.
6. Place the crucible on the triangle, and heat it with a hot flame (flame tip should be near the crucible).
7. Turn off the burner as soon as the magnesium ignites and begins to burn with a bright white light. Allow it to cool, and measure the mass of the magnesium product and the crucible.
8. Place the dry, solid product in the beaker.
9. Add 10 mL of distilled water to the beaker, and stir. Check the mixture with a conductivity tester.
10. **Cleanup and Disposal** Dispose of the product as directed by your teacher. Wash out the crucible with water. Return all lab equipment to its proper place.

Analyze and Conclude

1. **Analyze Data** Calculate the mass of the ribbon and the product. Record these masses in your table.
2. **Classify** the forms of energy released. What can you conclude about the stability of products?
3. **Infer** Does the magnesium react with the air?
4. **Predict** the ionic formulas for the two binary products formed, and write their names.
5. **Analyze and Conclude** The product of the magnesium-oxygen reaction is white, whereas the product of the magnesium-nitrogen reaction is yellow. Which compound makes up most of the product?
6. **Analyze and Conclude** Did the magnesium compounds conduct a current when in solution? Do these results verify that the compounds are ionic?
7. **Error Analysis** If the results show that the magnesium lost mass instead of gaining mass, cite possible sources of the error.

INQUIRY EXTENSION

Design an Experiment If the magnesium compounds conduct a current in solution, can you affect how well they conduct electricity? If they did not conduct a current, could they? Design an experiment to find out.

CHAPTER 7

Study Guide

BIG Idea Atoms in ionic compounds are held together by chemical bonds formed by the attraction of oppositely charged ions.

Section 7.1 Ion Formation

MAIN Idea Ions are formed when atoms gain or lose valence electrons to achieve a stable octet electron configuration.

Vocabulary

- anion (p. 209)
- cation (p. 207)
- chemical bond (p. 206)

Key Concepts

- A chemical bond is the force that holds two atoms together.
- Some atoms form ions to gain stability. This stable configuration involves a complete outer energy level, usually consisting of eight valence electrons.
- Ions are formed by the loss or gain of valence electrons.
- The number of protons remains unchanged during ion formation.

Section 7.2 Ionic Bonds and Ionic Compounds

MAIN Idea Oppositely charged ions attract each other, forming electrically neutral ionic compounds.

Vocabulary

- crystal lattice (p. 214)
- electrolyte (p. 215)
- ionic bond (p. 210)
- ionic compound (p. 210)
- lattice energy (p. 216)

Key Concepts

- Ionic compounds contain ionic bonds formed by the attraction of oppositely charged ions.
- Ions in an ionic compound are arranged in a repeating pattern known as a crystal lattice.
- Ionic compound properties are related to ionic bond strength.
- Ionic compounds are electrolytes; they conduct an electric current in the liquid phase and in aqueous solution.
- Lattice energy is the energy needed to remove 1 mol of ions from its lattice.

Section 7.3 Names and Formulas for Ionic Compounds

MAIN Idea In written names and formulas for ionic compounds, the cation appears first, followed by the anion.

Vocabulary

- formula unit (p. 218)
- monatomic ion (p. 218)
- oxidation number (p. 219)
- oxyanion (p. 222)
- polyatomic ion (p. 221)

Key Concepts

- A formula unit gives the ratio of cations to anions in the ionic compound.
- A monatomic ion is formed from one atom. The charge of a monatomic ion is its oxidation number.
- Roman numerals indicate the oxidation number of cations having multiple possible oxidation states.
- Polyatomic ions consist of more than one atom and act as a single unit.
- To indicate more than one polyatomic ion in a chemical formula, place parentheses around the polyatomic ion and use a subscript.

Section 7.4 Metallic Bonds and the Properties of Metals

MAIN Idea Metals form crystal lattices and can be modeled as cations surrounded by a "sea" of freely moving valence electrons.

Vocabulary

- alloy (p. 227)
- delocalized electron (p. 225)
- electron sea model (p. 225)
- metallic bond (p. 225)

Key Concepts

- A metallic bond forms when metal cations attract freely moving, delocalized valence electrons.
- In the electron sea model, electrons move through the metallic crystal and are not held by any particular atom.
- The electron sea model explains the physical properties of metallic solids.
- Metal alloys are formed when a metal is mixed with one or more other elements.

CHAPTER 7 Assessment

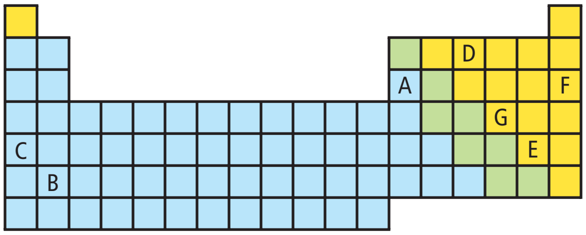
Section 7.1

Mastering Concepts

46. How do positive ions and negative ions form?

47. When do chemical bonds form?

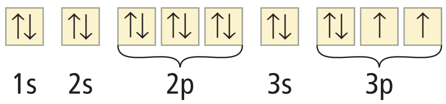
48. Why are halogens and alkali metals likely to form ions? Explain your answer.



■ **Figure 7.14**

49. The periodic table shown in **Figure 7.14** contains elements labeled *A–G*. For each labeled element, state the number of valence electrons and identify the ion that will form.

50. Discuss the importance of electron affinity and ionization energy in the formation of ions.



■ **Figure 7.15**

51. The orbital notation of sulfur is shown in **Figure 7.15.** Explain how sulfur forms its ion.

Mastering Problems

52. Give the number of valence electrons in an atom of each element.

a. cesium
b. rubidium
c. gallium
d. zinc
e. strontium

53. Explain why noble gases are not likely to form chemical bonds.

54. Discuss the formation of the barium ion.

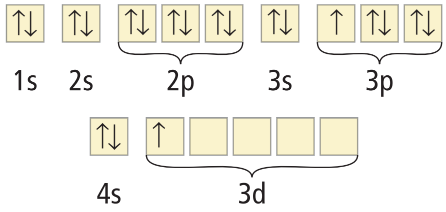
55. Explain how an anion of nitrogen forms.

56. The more reactive an atom, the higher its potential energy. Which atom has higher potential energy, neon or fluorine? Explain.

57. Explain how the iron atom can form both an iron 2+ ion and an iron 3+ ion.

58. Predict the reactivity of each atom based on its electron configuration.

a. potassium **b.** fluorine **c.** neon



■ **Figure 7.16**

59. Discuss the formation of a 3+ scandium ion using its orbital notation, shown in **Figure 7.16.**

Section 7.2

Mastering Concepts

60. What does the term *electrically neutral* mean when discussing ionic compounds?

61. Discuss the formation of ionic bonds.

62. Explain why potassium does not bond with neon to form a compound.

63. Briefly discuss three physical properties of ionic solids that are linked to ionic bonds.

64. Describe an ionic crystal, and explain why ionic crystals for different compounds might vary in shape.

65. How does lattice energy change with a change in the size of an ion?

66. In **Figure 7.14,** the element labeled *B* is barium, and the element labeled *E* is iodine. Explain why the compound formed between these elements will not be BaI.

Mastering Problems

67. Determine the ratio of cations to anions in each.

a. potassium chloride, a salt substitute
b. calcium fluoride, used in the steel industry
c. calcium oxide, used to remove sulfur dioxide from power-plant exhaust
d. strontium chloride, used in fireworks

68. Look at **Figure 7.14;** describe the ionic compound that form from the elements represented by C and D.

69. Discuss the formation of an ionic bond between zinc and oxygen.

70. Using orbital notation, diagram the formation of an ionic bond between aluminum and fluorine.

71. Using electron configurations, diagram the formation of an ionic bond between barium and nitrogen.

72. **Conductors** Under certain conditions, ionic compounds conduct an electric current. Describe these conditions, and explain why ionic compounds are not always used as conductors.

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73. Which compounds are not likely to occur: CaKr, Na_2S, $BaCl_3$, MgF? Explain your choices.

74. Use **Table 7.6** to determine which ionic compound has the highest melting point: MgO, KI, or AgCl. Explain your answer.

75. Which has the greater lattice energy, CsCl or KCl? K_2O or CaO? Explain your choices.

Section 7.3

Mastering Concepts

76. What information do you need to write a correct chemical formula to represent an ionic compound?

77. When are subscripts used in formulas for ionic compounds?

78. Discuss how an ionic compound is named.

79. Using oxidation numbers, explain why the formula NaF_2 is incorrect.

80. Explain what the name scandium(III) oxide means in terms of electrons lost and gained, and identify the correct formula.

Mastering Problems

81. Give the formula for each ionic compound.
- **a.** calcium iodide
- **b.** silver(I) bromide
- **c.** copper(II) chloride
- **d.** potassium periodate
- **e.** silver(I) acetate

82. Name each of the following ionic compounds.
- **a.** K_2O
- **b.** $CaCl_2$
- **c.** Mg_3N_2
- **d.** NaClO
- **e.** KNO_3

83. Complete **Table 7.14** by placing the symbols, formulas, and names in the blanks.

Table 7.14 Identifying Ionic Compounds

Cation	Anion	Name	Formula
		ammonium sulfate	
			PbF_2
		lithium bromide	
			Na_2CO_3
Mg^{2+}	PO_4^{3-}		

84. Chrome Chromium, a transition metal used in chrome plating, forms both the Cr^{2+} and Cr^{3+} ions. Write the formulas for the ionic compounds formed when each of these ions react with fluorine and oxygen ions.

85. Which are correct formulas for ionic compounds? For those that are not correct, give the correct formula and justify your answer.
- **a.** AlCl
- **b.** Na_3SO_4
- **c.** $BaOH_2$
- **d.** Fe_2O

86. Write the formulas for all of the ionic compounds that can be formed by combining each of the cations with each of the anions listed in **Table 7.15.** Name each compound formed.

Table 7.15 List of Cations and Anions

Cations	Anions
K^+	SO_3^{2-}
NH_4^+	I^-
Fe^{3+}	NO_3^-

Section 7.4

Mastering Concepts

87. Describe a metallic bond.

88. Briefly explain why metallic alloys are made.

89. Briefly describe how malleability and ductility of metals are explained by metallic bonding.

90. Compare and contrast the two types of metal alloys.

91. Explain how a metallic bond is similar to an ionic bond.

92. Brass Copper and zinc are used to form brass, an alloy. Briefly explain why these two metals form a substitutional alloy and not an interstitial alloy.

Mastering Problems

93. How is a metallic bond different from an ionic bond?

94. Silver Briefly explain why silver is a good conductor of electricity.

95. Steel Briefly explain why steel, an alloy of iron, is used to build the supporting structure of many buildings.

96. The melting point of beryllium is 1287°C, while that of lithium is 180°C. Explain the large difference in values.

97. Titanium has a boiling point of 3287°C, and copper has a boiling point of 2567°C. Explain why there is a difference in the boiling points of these two metals.

98. Alloys Describe the difference between the metal alloy sterling silver and carbon steel in terms of the types of alloys involved.

Mixed Review

99. Give the number of valence electrons for atoms of oxygen, sulfur, arsenic, phosphorus, and bromine.

100. Explain why calcium can form a Ca^{2+} ion but not a Ca^{3+} ion.

101. Which ionic compounds would have the greatest lattice energy: NaCl, KCl, or $MgCl_2$? Explain your answer.

102. Give the formula for each ionic compound.
- **a.** sodium sulfide
- **b.** iron(III) chloride
- **c.** sodium sulfate
- **d.** calcium phosphate
- **e.** zinc nitrate

103. Cobalt, a transition metal, forms both the Co^{2+} and Co^{3+} ions. Write the correct formulas, and give the name for the oxides formed by the two different ions.

104. Complete **Table 7.16.**

Table 7.16 Element, Electron, and Ion Data

Element	Valence Electrons	Ion Formed
Selenium		
Tin		
Iodine		
Argon		

105. Gold Briefly explain why gold can be used both in jewelry and as a conductor in electronic devices.

106. Discuss the formation of the nickel ion with a 2+ oxidation number.

107. Compare the oxyanions sulfate and sulfite.

108. Using electron-dot structures, diagram the formation of an ionic bond between potassium and iodine.

109. Magnesium forms both an oxide and a nitride when burned in air. Discuss the formation of magnesium oxide and magnesium nitride when magnesium atoms react with oxygen and nitrogen atoms.

110. An external force easily deforms sodium metal, while sodium chloride shatters when the same amount of force is applied. Why do these two solids behave so differently?

111. Name each ionic compound.
- **a.** CaO
- **b.** BaS
- **c.** $AlPO_4$
- **d.** $Ba(OH)_2$
- **e.** $Sr(NO_3)_2$

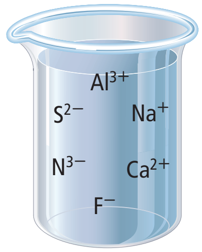
Think Critically

112. Design a concept map to explain the physical properties of both ionic compounds and metallic solids.

113. Predict which solid in each pair will have the higher melting point. Explain your answers.
- **a.** NaCl or CsCl
- **b.** Ag or Cu
- **c.** Na_2O or MgO

114. Compare and contrast cations and anions.

115. Observe and Infer Identify the mistakes in the incorrect formulas and formula names, and design a flowchart to prevent the mistakes.
- **a.** copper acetate
- **b.** Mg_2O_2
- **c.** Pb_2O_5
- **d.** disodium oxide
- **e.** Al_2SO_{43}



■ **Figure 7.17**

116. Apply Examine the ions in the beaker shown in **Figure 7.17.** Identify two compounds that could form using the available ions, and explain why this is possible.

117. Apply Praseodymium is a lanthanide element that reacts with hydrochloric acid, forming praseodymium(III) chloride. It also reacts with nitric acid, forming praseodymium(III) nitrate. Praseodymium has the electron configuration $[Xe]4f^36s^2$.
- **a.** Examine the electron configuration, and explain how praseodymium forms a 3+ ion.
- **b.** Write the correct formulas for both compounds formed by praseodymium.

118. Hypothesize Look at the locations of potassium and calcium on the periodic table. Form a hypothesis to explain why the melting point of calcium is considerably higher than the melting point of potassium.

119. Assess Explain why the term *delocalized* is an appropriate term for the electrons involved in metallic bonding.

120. Apply All uncharged atoms have valence electrons. Explain why elements such as iodine and sulfur do not have metallic bonds.

121. Analyze Explain why lattice energy is a negative quantity.

Challenge Problem

122. Ionic Compounds Chrysoberyl is a transparent or translucent mineral that is sometimes opalescent. It is composed of beryllium aluminum oxide, $BeAl_2O_4$. Identify the oxidation numbers of each of the ions found in this compound. Explain the formation of this ionic compound.

Cumulative Review

123. You are given a liquid of unknown density. The mass of a graduated cylinder containing 2.00 mL of the liquid is 34.68 g. The mass of the empty graduated cylinder is 30.00 g. Given this information, determine the density of the liquid. *(Chapter 2)*

124. In the laboratory, students used a balance and a graduated cylinder to collect the data shown in **Table 7.17.** Calculate the density of the sample. If the accepted value of this sample is 7.01 g/mL, calculate the percent error. *(Chapter 2)*

Table 7.17 Volume and Mass Data

Mass of sample	19.21 g
Volume of water alone	39.0 mL
Volume of water + sample	43.1 mL

125. A mercury atom drops in energy from 1.413×10^{-18} J to 1.069×10^{-18} J. *(Chapter 5)*

a. What is the energy of the photon emitted by the mercury atom?

b. What is the frequency of the photon emitted by the mercury atom?

c. What is the wavelength of the photon emitted by the mercury atom?

126. Which element has the greater ionization energy, chlorine or carbon? *(Chapter 6)*

127. Compare and contrast the ways in which metals and nonmetals form ions, and explain why they are different. *(Chapter 6)*

128. What are transition elements? *(Chapter 6)*

129. Write the symbol and name of the element that fits each description. *(Chapter 6)*

a. the second-lightest of the halogens

b. the metalloid with the lowest period number

c. the only group 16 element that is a gas at room temperature

d. the heaviest of the noble gases

e. the group 15 nonmetal that is a solid at room temperature

Additional Assessment

WRITING in Chemistry

130. Free Radicals Many researchers believe that free radicals are responsible for the effects of aging and cancer. Research free radicals, and write about the cause and what can be done to prevent free radicals.

131. Growing Crystals Crystals of ionic compounds can be easily grown in the laboratory setting. Research the growth of crystals, and design an experiment to grow a crystal in the laboratory.

DBQ Document-Based Questions

Oceans *As part of an analysis of the world's oceans, scientists summarized the ion-related data shown in* **Table 7.18.**

Data from: Royal Society of Chemistry, *All at sea? The chemistry of the oceans*.

Table 7.18 The Twelve Most-Common Ions in the Sea

Ion	Concentration (mg/dm^3)	% by mass (of total dissolved solids)
Cl^-	19,000	55.04
Na^+	10,500	30.42
SO_4^{2-}	2655	7.69
Mg^{2+}	1350	3.91
Ca^{2+}	400	1.16
K^+	380	1.10
CO_3^{2-}	140	0.41
Br^-	65	0.19
BO_3^{3-}	20	0.06
SiO_3^{2-}	8	0.02
Sr^{2+}	8	0.02
F^-	1	0.003

132. Identify the anions and cations listed in **Table 7.18.**

133. Create a bar graph of each ion's concentration. Explain why this is a difficult graph to draw.

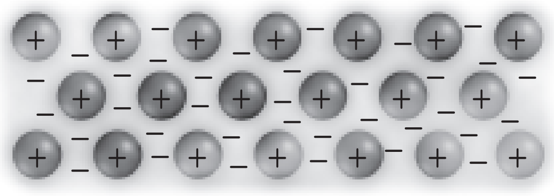
134. Sodium chloride is not the only ionic compound that forms from sea water. Identify four other compounds that could be formed that contain the sodium ion. Write both the formula and the name for each compound.

Cumulative

Standardized Test Practice

Multiple Choice

Use the figure below to answer Question 1.



1. Which description is supported by the model shown?
   - **A.** Metals are shiny, reflective substances.
   - **B.** Metals are excellent conductors of heat and electricity.
   - **C.** Ionic compounds are malleable compounds.
   - **D.** Ionic compounds are good conductors of electricity.

2. Which is NOT true of the Sc^{3+} ion?
   - **A.** It has the same electron configuration as Ar.
   - **B.** It is a scandium ion with three positive charges.
   - **C.** It is considered to be a different element than a neutral Sc atom.
   - **D.** It was formed by the removal of the valence electrons of Sc.

3. Of the salts below, which would require the most energy to break the ionic bonds?
   - **A.** $BaCl_2$
   - **B.** LiF
   - **C.** NaBr
   - **D.** KI

4. The high strength of its ionic bonds results in all of the following properties of NaCl EXCEPT
   - **A.** hard crystals.
   - **B.** high boiling point.
   - **C.** high melting point.
   - **D.** low solubility.

5. Which is the correct formula for the compound chromium (III) sulfate?
   - **A.** Cr_3SO_4
   - **B.** $Cr_2(SO_4)_3$
   - **C.** $Cr_3(SO_4)_2$
   - **D.** $Cr(SO_4)_3$

Use the table below to answer Questions 6–8.

Physical Properties of Selected Compounds

Compound	Bond Type	Melting Point (°C)	Boiling Point (°C)
F_2	Nonpolar covalent	−220	−188
CH_4	Nonpolar covalent	−183	−162
NH_3	Polar covalent	−78	−33
CH_3Cl	Polar covalent	−64	61
KBr	Ionic	730	1435
Cr_2O_3	Ionic	?	4000

6. A compound is discovered to have a melting point of −100°C. Which could be true of this compound?
   - **A.** It definitely has an ionic bond.
   - **B.** It definitely has a polar covalent bond.
   - **C.** It has either a polar covalent bond or a nonpolar covalent bond.
   - **D.** It has either a polar covalent bond or an ionic bond.

7. Which could NOT be the melting point of Cr_2O_3?
   - **A.** 2375°C
   - **B.** 950°C
   - **C.** 148°C
   - **D.** 3342°C

8. Which is supported by the data in the table?
   - **A.** Nonpolar covalent bonds have high boiling points.
   - **B.** Polar covalent bonds have high melting points.
   - **C.** Ionic bonds have low melting points.
   - **D.** Ionic bonds have high boiling points.

9. Which is the correct orbital diagram for the third and fourth principal energy levels of vanadium?
   - **A.** 3s: [↑↓] 3p: [↑↓][↑↓][↑↓] 4s: [↑↓] 3d: [↑↓][↑↓][ ][ ][ ]
   - **B.** 3s: [↑↓] 3p: [↑↓][↑↓][↑↓] 4s: [↑↓] 3d: [↑][↑][↑][ ][ ]
   - **C.** 3s: [↑↓] 3p: [↑↓][↑↓][↑↓] 4s: [↑↓] 3d: [↑↓][↑][ ][ ][ ]
   - **D.** 3s: [↑↓] 3p: [↑↓][↑↓][↑↓] 4s: [↑↓] 3d: [↑][↑↓][ ][ ][ ]

Short Answer

Use the table below to answer Questions 10–12.

Lutetium is a rare-earth element that can be used to speed up the chemical reactions involved in petroleum processing. It has two naturally occurring isotopes.

Isotope	Form of Decay	Percent Abundance
$^{175}_{71}Lu$	none	97.41
$^{176}_{71}Lu$	beta	2.59

10. Show the setup and calculate the average atomic mass of lutetium.

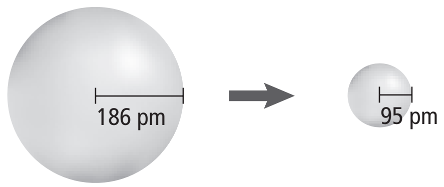
11. Identify the product when lutetium-176 goes through nuclear decay.

12. Compare the number of protons and neutrons in each of these isotopes.

Extended Response

13. Relate the change in atomic radius to the changes in atomic structure that occur across the periodic table.

Use the diagram below to answer Question 14.



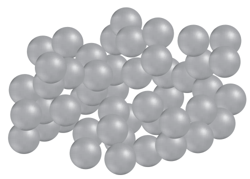
Sodium atom (Na) $[Ne]3s^1$

Sodium ion (Na^+) [Ne]

14. Relate the change in ionic radius to the changes in ion formation that occur across the periodic table.

SAT Subject Test: Chemistry

Use the diagram below to answer Question 15.



15. Which describes the state of matter shown?
- **A.** solid, because the particles are tightly packed against one another
- **B.** gas, because the particles are flowing past one another
- **C.** liquid, because the particles are able to move freely
- **D.** solid, because there is a regular pattern to the particles
- **E.** liquid, because the particles are flowing past one another

Use the list of elements below to answer Questions 16–20.

- **A.** sodium
- **B.** chromium
- **C.** boron
- **D.** argon
- **E.** chlorine

16. Which has its outermost electrons in an s-sublevel?

17. Which has seven valence electrons?

18. Which is a transition metal?

19. Which has an electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^5$?

20. Which is a noble gas?

NEED EXTRA HELP?

If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Review Section . . .	7.2	7.1	7.2	7.2	7.2	7.3	7.2	7.3	5.3	4.4	4.2	4.2	6.3	6.3	3.1	5.2	5.3	6.2	5.3	6.2