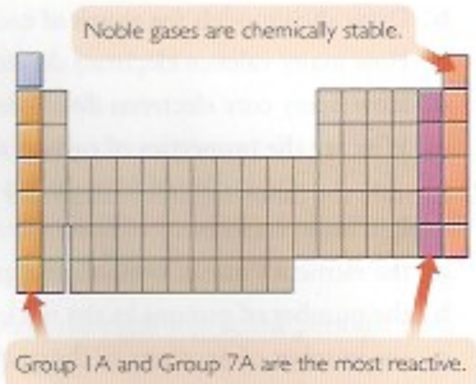
LESSON

19 Noble Gas Envy

Ions

Think About It

Some atoms are more chemically stable than others. In other words, they don't readily combine with other atoms to form new compounds. The noble gases are considered the most chemically stable atoms on the periodic table. The most reactive elements are located just before and just after the noble gases, in Groups 1A and 7A. Perhaps the electron arrangements of these atoms are related to their reactivity.



How is chemical stability related to the arrangements of electrons in atoms?

To answer this question, you will explore

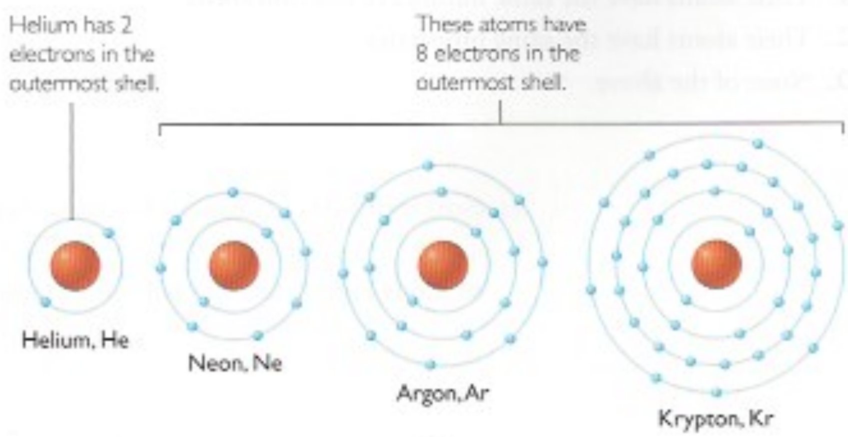
1. Noble Gases
2. Noble Gas Envy
3. Patterns in Ion Charges

Exploring the Topic

1 Noble Gases

Some elements are chemically stable, or rarely react with other elements. Others are reactive and combine readily with other elements to form compounds. What makes some elements chemically stable and others reactive?

Noble gases are the most chemically stable elements. Shell models for the noble gas elements helium, He, neon, Ne, argon, Ar, and krypton, Kr, are shown below. Take a moment to compare the valence electrons of each.



INDUSTRY CONNECTION

Noble gases are so stable that they rarely form compounds. At one time it was thought that they *never* formed compounds with other atoms. But in 1962 a British scientist, Neil Bartlett, created xenon hexafluoroplatinate, a yellow solid, by accident. Chemists have not yet been able to create any compounds with either helium or neon.

Helium has two valence electrons, which is the maximum for the first shell. The remaining noble gases each have eight valence electrons. The stability of the noble gases is due to the number of valence electrons they have.

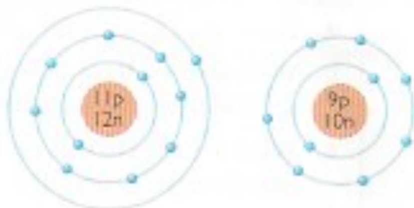
> **BIG IDEA** Noble gases are chemically stable. This is because they have a full outer shell.

❷ Noble Gas Envy

INDUSTRY CONNECTION

Sodium and chlorine are both highly reactive. In elemental form, sodium is a soft, silvery metal, and chlorine is a greenish poisonous gas. However, they are never found in elemental form in nature. Frequently, they are found as sodium chloride, which is used as table salt.

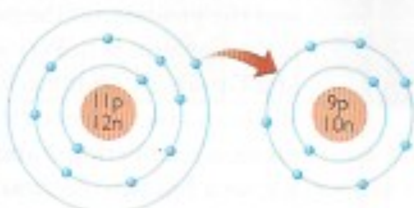
Consider two highly reactive elements, sodium, Na, and fluorine, F. The outer shell of a fluorine atom, F, has seven electrons. This is just one short of the eight electrons that neon, Ne, has in its outer shell. The outer shell of a sodium atom, Na, has one electron. This is just one more electron than neon has in its valence shell.



Sodium, Na
1 valence electron

Fluorine, F
7 valence electrons

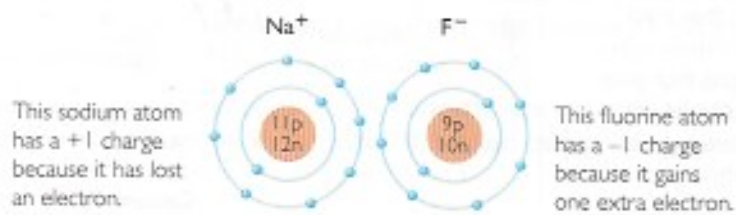
Now examine what happens to these two atoms when they combine to form a compound. Sodium, Na, gives one electron to fluorine, F.



Sodium, Na
1 valence electron

Fluorine, F
7 valence electrons

Now both atoms have an electron arrangement like that of neon, Ne.



Sodium fluoride, NaF

Both ions now have an electron arrangement like the noble gas neon. They form an ionic compound, NaF.

The movement of an electron from one atom to the other alters the balance of charges on both atoms. Fluorine now has more electrons than protons. Sodium has more protons than electrons. The atoms are now called **ions** because they possess a charge. The sodium ion has a charge of +1 and its symbol is written as Na^+. The fluorine ion has a charge of −1 and its symbol is written as F^-. Because

Na^+ and F^- have opposite charges, they attract one another. So the movement of an electron from one atom to the other forms a new compound, sodium fluoride, NaF. As a result of this electron transfer, sodium atoms are now bonded to fluorine atoms.

Important to Know When an atom loses or gains electrons, the result is a charge on the atom. The rest of the atom stays the same, and the identity of the element does not change. ◂

Example

Calcium Oxide, CaO

Consider the compound calcium oxide, CaO.

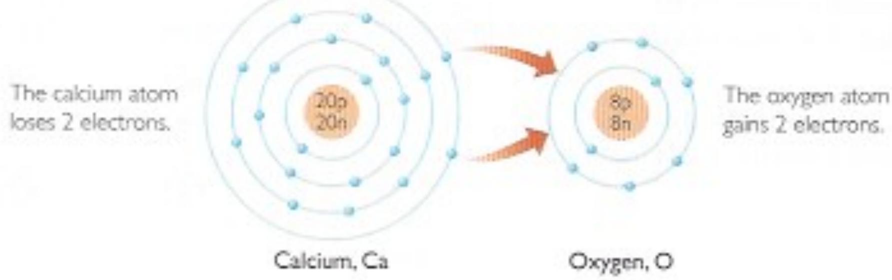
a. Draw shell models for calcium, Ca, and oxygen, O.

b. With arrows, show how electrons can be transferred so that each atom has the same electron arrangement as that of a noble gas.

c. What are the charges on the calcium, Ca, and oxygen, O, ions after electrons have been transferred?

Solution

a. You can draw a shell model for a neutral atom, an atom that has no charge, using the element number and the position on the periodic table. Calcium is in Period 4 and Group 2A, so it has four shells and two valence electrons. Oxygen is in Period 2 and Group 6A, so it has two electron shells and six valence electrons.



b. If calcium transfers two electrons to oxygen, they will both have noble gas electron configurations. The electron arrangement of oxygen now resembles that of neon, Ne. The electron arrangement of calcium now resembles that of argon, Ar.

c. Because calcium has lost two electrons, it now has more protons than electrons, giving it a +2 charge. The ion can be written as Ca^{2+}. Oxygen has gained 2 electrons, so its charge is −2. Its ion can be written as O^{2-}.

CONSUMER CONNECTION

Neon signs contain neon gas. When electricity is run through the gas, the electrons get excited. When they come back down to their normal energy level, they emit red light. Real neon signs glow red. Signs that glow other colors are usually made of colored glass and filled with argon.

In the calcium and oxygen example, each ion has an electron arrangement that is identical to that of a noble gas. It is reasonable to assume that there is some advantage to having this sort of electron arrangement.

Noble gases are very stable the way they are, without reacting or exchanging any electrons with other elements. Apparently, other atoms can achieve some of the stability of the noble gases by exchanging electrons and becoming ions.

3 Patterns in Ion Charges

When atoms lose or gain electrons they become ions, with negative or positive charges. Below is a portion of the periodic table with the various charges on the ions filled in. In every case, the ion that forms has an electron arrangement identical to the noble gas it is nearest to in the table.

Take a moment to examine the table. What patterns do you notice?

Ion Charges on Main Group Elements

1A	2A	3A	4A	5A	6A	7A	8A
1+							
1 H^+							2 He
	2+	3+	4+ (or 4−)	3−	2−	1−	
3 Li^+	4 Be^{2+}	5 B^{3+}	6 C^{4+}	7 N^{3-}	8 O^{2-}	9 F^-	10 Ne
11 Na^+	12 Mg^{2+}	13 Al^{3+}	14 Si^{4+}	15 P^{3-}	16 S^{2-}	17 Cl^-	18 Ar
19 K^+	20 Ca^{2+}	31 Ga^{3+}	32 Ge^{4+}	33 As^{3-}	34 Se^{2-}	35 Br^-	36 Kr

Notice that the elements on the left of the table, which are mostly metals, tend to form ions with a positive charge. Ions with a positive charge are also called **cations.** The valence shells of these atoms have fewer electrons in them than those of the elements on the right. Thus, it is easier for these elements to form compounds by giving up these few electrons.

On the other hand, the elements on the right of the table, which are mostly nonmetals, tend to form ions with a negative charge. Ions with a negative charge are called **anions.**

For the first four groups of the periodic table, the ion charge is the same as the group number. For Groups 5A through 7A, the ion charge is negative and goes from −3 to −1.

Key Terms
ion
cation
anion

Lesson Summary

How is chemical stability related to the arrangements of electrons in atoms?

Noble gases have particularly stable atoms. This is attributed to their electron arrangements. Helium has two electrons, which is the maximum for the first shell. The remaining noble gases all have eight electrons in their outermost shells. Other atoms on the periodic table are more reactive than the noble gases. However, they reach greater chemical stability by gaining or losing valence electrons. The goal is to end up with an electron arrangement similar to that of a noble gas. Atoms do this by combining with other atoms to form new compounds. When atoms lose or gain electrons the atom becomes an ion, with a charge. Ions with a positive charge are called cations. Ions with a negative charge are called anions.

EXERCISES

Reading Questions

1. Explain the difference between an anion and a cation.
2. Explain what is meant by noble gas envy.

1,2,6,12,15

Reason and Apply

3. How many electrons, protons, and neutrons does Li^{+} have?
4. Give two similarities and two differences between Cl and Cl^{-}.
5. Give two similarities and two differences between Be and Be^{2+}.
6. Which noble gas is closest to magnesium, Mg, on the periodic table? What must happen to a magnesium atom in order for it to have an electron arrangement similar to that of a noble gas?
7. Which noble gas is closest to sulfur, S, on the periodic table? What must happen to a sulfur atom in order for it to have an electron arrangement similar to that of a noble gas?
8. List four ions that have the same number of electrons as neon, Ne.
9. List four ions that have the same number of electrons as argon, Ar.
10. What charge would an arsenic, As, ion have?
11. What is the symbol of an ion with 22 protons, 24 neutrons, and 18 electrons?
12. When chlorine gains an electron to become a chloride ion with a −1 charge, it ends up with the electron arrangement of argon. Why doesn't it become an argon atom?
13. Explain why the elements on the right side of the periodic table gain electrons instead of losing them.
14. What periodic patterns do you notice for the charges on the ions?
15. Which of these ions have the correct charge? Choose all that apply.

    A. Na^{2+} **B.** Li^{+} **C.** Al^{4+} **D.** Ca^{2+} **E.** Ga^{3+}
16. Which of these ions have the same number of electrons as S^{2-}? Choose all that apply.

    A. Cl^{-} **B.** Ca^{2+} **C.** Na^{+} **D.** O^{2-} **E.** P^{3-}

LESSON

20 Getting Connected

Ionic Compounds

Think About It

Sodium and chlorine atoms combine to form sodium chloride, NaCl, when sodium transfers a valence electron to chlorine. There are no other compounds that form between sodium and chlorine. For example, $NaCl_4$ and Na_3Cl are not possible compounds. Why is NaCl the compound that forms rather than $NaCl_4$ or Na_3Cl?

How can valence electrons be used to predict chemical formulas?

To answer this question, you will explore

1. Ionic Compounds
2. The Rule of Zero Charge
3. More Complex Ionic Compounds

Exploring the Topic

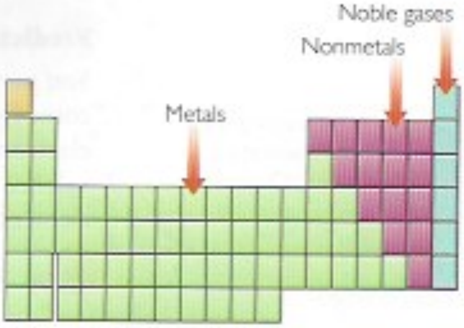
1 Ionic Compounds

There are millions of different compounds on the planet. Each one is a result of a unique combination of atoms. Thus, each one has a unique chemical formula. However, some combinations of atoms are simply not possible. Valence electrons are the key to figuring out chemical formulas and to determining which compounds are possible.

Compounds Between Metals and Nonmetals

Atoms combine with other atoms in order to achieve the stability of the noble gases. One way to accomplish this is for atoms to transfer valence electrons to other atoms. When atoms gain or lose electrons, the resulting atoms are no longer neutral. They become ions with charges. The compounds that form in this way are called **ionic compounds.** Ionic compounds, like the noble gases, are very stable.

Ionic compounds form between metal atoms and nonmetal atoms. The metal atoms, on the left side of the periodic table, tend to give up electrons and become cations, which have positive charges. The nonmetal atoms, on the right side of the periodic table, tend to accept electrons and become anions, which have negative charges. Because the cation and anion have opposite charges, they are strongly attracted to one another.



BIG IDEA Ionic compounds form when valence electrons are transferred between atoms.

CONSUMER CONNECTION

All ionic compounds form crystals. If you look at grains of table salt with a magnifying glass, you will see that the pieces are shaped like tiny boxes.

Formulas of Simple Ionic Compounds

The tables below contain data on three simple ionic compounds. These compounds are all composed of a metal atom and a nonmetal atom in a 1:1 ratio. Pay particular attention to the total charge and the number of valence electrons on each of the atoms that combine.

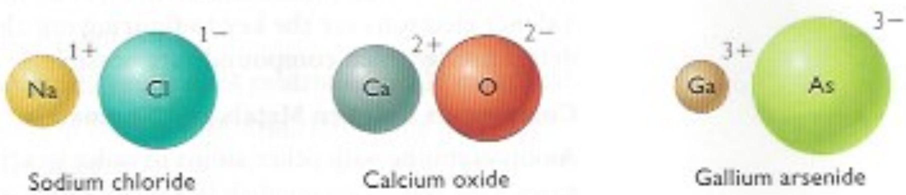
Some Ionic Compounds

Compound	Metal	Cation	Number of valence electrons	Nonmetal	Anion	Number of valence electrons
NaCl	Na	Na^{+}	1	Cl	Cl^{-}	7
CaO	Ca	Ca^{2+}	2	O	O^{2-}	6
GaAs	Ga	Ga^{3+}	3	As	As^{3-}	5

Note that in each case, the charge on the cation is equal and opposite to the charge on the anion.

2 The Rule of Zero Charge

You can see there is a distinct pattern to the ions that form in ionic compounds. Every time a metal atom and a nonmetal atom bond, they form a compound with an overall zero charge. This is known as the **rule of zero charge.**



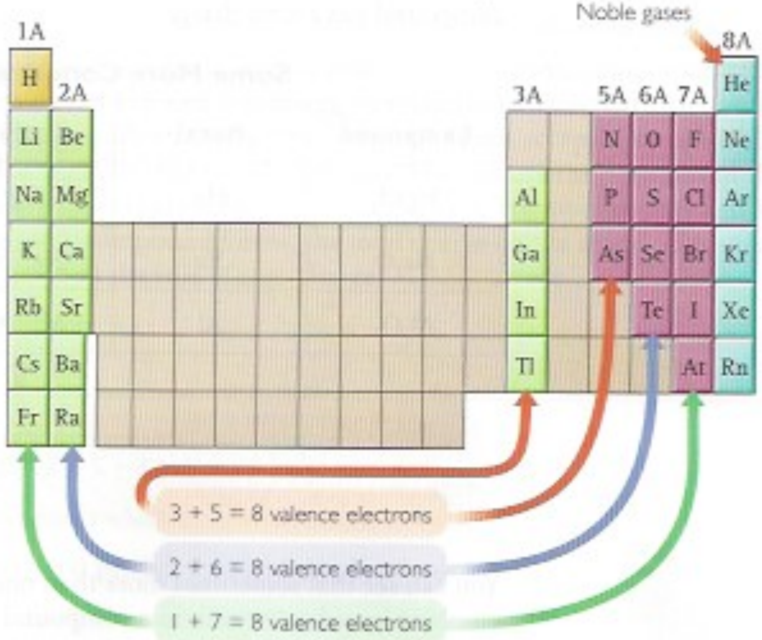
Notice how the ions in each compound add up to zero.

The charges on the metal cations and nonmetal anions add up to zero. The rule of zero charge is useful in predicting the chemical formulas for ionic compounds, which form between a metal and a nonmetal.

Predicting Ionic Bonding Using the Periodic Table

You may have noticed that the atoms that combine to form ionic compounds come from very predictable places on the periodic table. Sodium, with one valence electron, can combine with chlorine, or fluorine, or bromine, each with seven valence electrons. In fact, any Group 1A elements can combine with any Group 7A elements to form ionic compounds.

Valence Electrons in Main Group Elements



The drawing illustrates how you can use the periodic table to decide which atoms will combine in a 1:1 ratio to form an ionic compound. There are dozens of possible combinations. For example, an atom in Group 3A can form a compound with an atom in Group 5A.

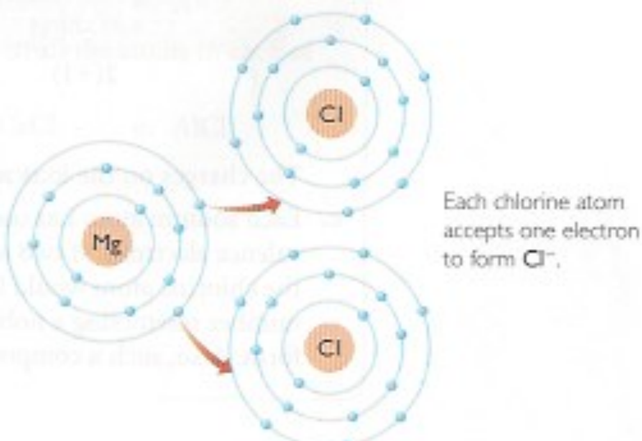
Important to Know The atoms in Group 4A can either transfer or accept electrons. ◂

❸ More Complex Ionic Compounds

All of the compounds discussed in this lesson so far have a metal to nonmetal ratio of 1:1. However, it is also possible to have compounds with different ratios. For example, one magnesium atom can combine with two chlorine atoms to form magnesium chloride, $MgCl_2$. Before bonding, each magnesium atom has two valence electrons. These two electrons are transferred to two different chlorine atoms, each of which needs one more electron to have the same number of electrons as the noble gas argon, Ar.

CONSUMER CONNECTION

Energy drinks help replace necessary ions, known as electrolytes, in your body.



Mg^{2+} + Cl^- + Cl^- produces $MgCl_2$ with zero charge.

Notice in this table that the atoms combine in such a way that the resulting compound has a zero charge.

Some More Complex Ionic Compounds

Compound	Metal	Cations	Nonmetal	Anions
$MgCl_2$	Mg	Mg^{2+}	Cl	Cl^- Cl^-
Na_2O	Na	Na^+ Na^+	O	O^{2-}
Al_2O_3	Al	Al^{3+} Al^{3+}	O	O^{2-} O^{2-} O^{2-}

Note that the charges on cations are equal and opposite to charges on anions. For example for aluminum oxide, $+3 + 3 - 2 - 2 - 2 = 0$. The total charge on the five atoms in the compound adds up to zero.

You can see that sometimes more than one atom of a particular element must combine in order to result in a compound with a zero charge. Thus, ionic compounds in ratios of 1:2, 2:1, or even 2:3 may result.

Example

Sodium Sulfide

The chemical formula for sodium sulfide is Na_2S.

a. What is the charge on each sodium ion, Na? On each sulfur ion, S?

b. Show that the charges on the ions add up to zero.

c. Is Na_2Cl a possible ionic compound? Why or why not?

Solution

a. Sodium, Na, is in Group 1A and has one valence electron. Sodium atoms give up one electron to have a charge of +1. Sulfur, S, is in Group 6A and has six valence electrons. Sulfur atoms gain two electrons to have a charge of −2.

b. Check the charge on the compound:

Two sodium cations, each with a +1 charge: $2(+1)$ + One sulfur anion with a −2 charge: (-2)

$$(+2) + (-2) = 0$$

The charges on the ions add up to zero, as they should.

c. Each sodium atom has one valence electron and each chlorine atom has seven valence electrons. If two sodium atoms gave up electrons to one chlorine atom, the chlorine atom would have nine valence electrons, which is not a stable number resembling a noble gas. So Na_2Cl is not a compound that is likely to form. Also, such a compound would not have a neutral charge.

Key Terms

ionic compound
rule of zero charge

Lesson Summary

How can valence electrons be used to predict chemical formulas?

Metal atoms and nonmetal atoms combine to form ionic compounds through electron transfer. The metal atoms give up electrons. They form ions with a positive charge, called cations. The nonmetal atoms accept electrons and form ions with a negative charge, called anions. You can use the positions of the elements on the periodic table to predict the ionic compounds they can form. When an ionic compound forms, the total charge on the atoms adds up to zero. This is known as the rule of zero charge.

EXERCISES

Reading Questions

1. How can you use valence electrons to predict which ionic compounds will form?
2. How does the rule of zero charge help you predict the formula of an ionic compound?

Reason and Apply

2, 3, 5, 7

3. Lithium nitride has the formula Li_3N.
   a. What is the charge on the lithium ion?
   b. What is the charge on the nitrogen ion?
   c. Show that the charges on the ions add up to zero.
   d. What is the total number of valence electrons in all the atoms in Li_3N?
4. Aluminum arsenide has the formula AlAs.
   a. What is the charge on the aluminum ion?
   b. What is the charge on the arsenic ion?
   c. Show that the charges on the ions add up to zero.
   d. What is the total number of valence electrons in all the atoms in AlAs?
5. For each of the compounds below, show that the charges on the ions add up to zero.
   a. KBr b. CaO c. Li_2O d. $CaCl_2$ e. $AlCl_3$
6. What are the total numbers of valence electrons in all the atoms in each of the compounds below?
   a. KBr b. CaO c. Li_2O d. $CaCl_2$ e. $AlCl_3$
7. Explain why the following compounds do not form.
   a. $NaCl_2$ b. CaCl c. AlO

LESSON

21 Salty Eights

Formulas for Ionic Compounds

Think About It

There are at least 50 common metal elements. These combine with over 15 nonmetal elements to make a wide variety of ionic compounds. The task of predicting compounds might seem complex given the number of possible ways to combine a metal and a nonmetal. However, if you know how many valence electrons each atom has, you can reliably predict which ionic compounds can be made.

How can you predict chemical formulas and name ionic compounds?

To answer this question, you will explore

1. Predicting Chemical Formulas
2. Naming Ionic Compounds

Exploring the Topic

1 Predicting Chemical Formulas

An ionic compound that is made up of only one kind of metal atom and one kind of nonmetal atom is known as a *salt*. Table salt, NaCl, is the most familiar example. To predict formulas for salt compounds, follow these guidelines:

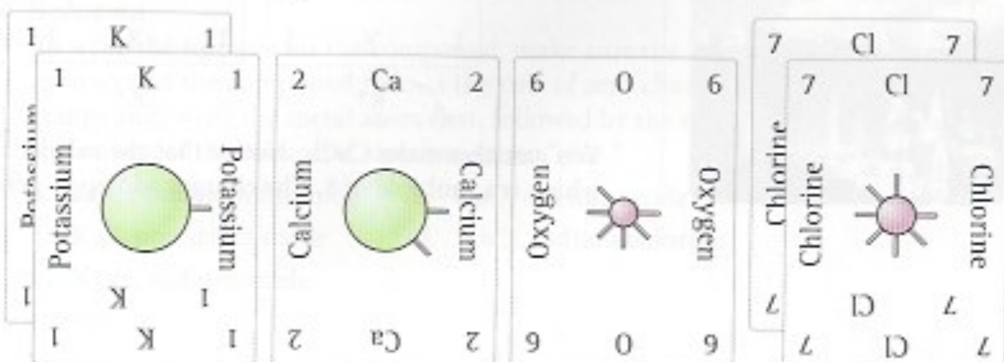
- Make sure you are combining two different elements—a metal and a nonmetal.
- No matter how many atoms you use, the total number of valence electrons must add up to 8, 16, 24, or another multiple of 8.
- Make sure that the charges on the metal cations and nonmetal anions in your ionic compound add up to zero (rule of zero charge).

This process applies only to the main group elements. Ionic compounds using transition elements are covered in Lesson 23: Alchemy of Paint.

Example 1

Practice Writing Chemical Formulas

Each of these cards represents an atom.



a. Which atoms are metals and which are nonmetals? How can you tell?

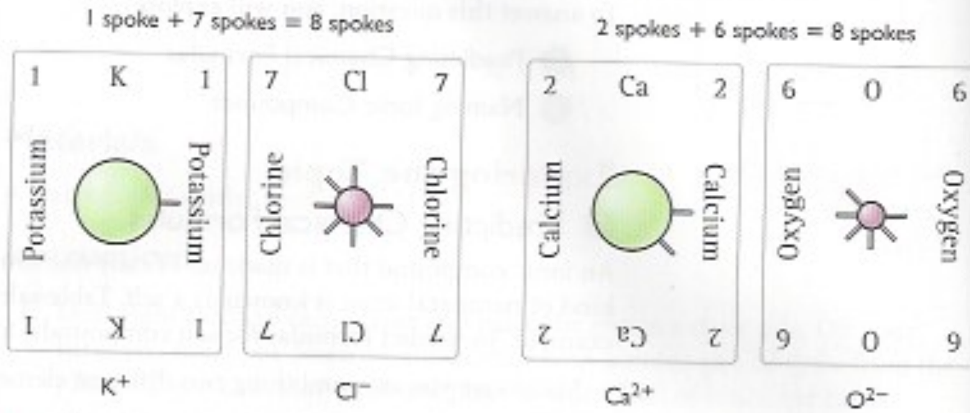
b. What ionic compounds can you make from two of these cards?

c. What ionic compounds could you make from three cards but only two different elements?

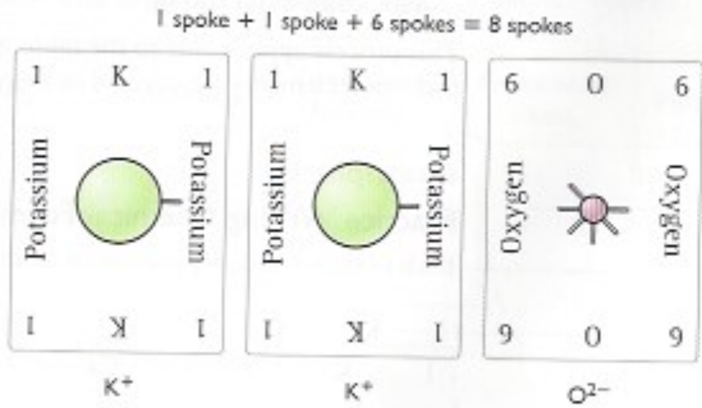
Solution

a. The atoms from the left side of the periodic table, with fewer valence electrons, are the metals. Thus, potassium, K, and calcium, Ca, are metal atoms. The atoms from the right side of the periodic table, which have closer to eight valence electrons, are the nonmetals. These include oxygen, O, and chlorine, Cl.

b. Look at the number of spokes on each card. The number of spokes represents the number of valence electrons. To create ionic compounds, combine a metal with a nonmetal. The number of spokes must add up to 8. Two ionic compounds are possible with these cards. These are shown here.



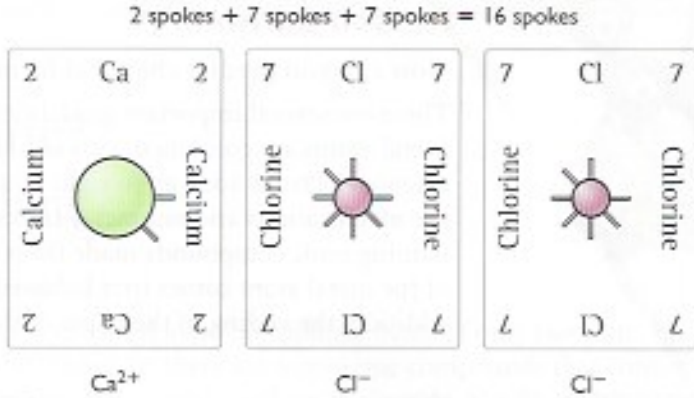
c. If two atoms with one valence electron combine with one atom with six valence electrons, the result is eight valence electrons. One possible compound is shown.



You can also make $CaCl_2$. Notice that the valence electrons add up to 16, which is a multiple of 8. The charges add up to zero.

HISTORY CONNECTION

Salt has been a valuable trade item since ancient times. For thousands of years—before refrigeration—humans depended largely on salt as a preservative for foods, especially meats and butter. The wealth of a city, country, or individual could often be linked to the amount of salt possessed or stored. Thus, people who are "worth their salt" are considered worthwhile and valuable. Salzburg, Germany, shown here, is named for its many salt mines, which contributed to its great wealth.



ENVIRONMENTAL CONNECTION

Calcium chloride and magnesium chloride are often used to remove ice on slick winter roadways in the United States. Unfortunately, this practice may have a negative effect on wildlife, causing salt poisoning in some birds, and upsetting the salt balance in lakes and rivers.

2 Naming Ionic Compounds

When naming salt compounds, the name of the metal comes first, followed by the name of the nonmetal atom. However, the name of the nonmetal atom is altered slightly by replacing the last part of the word with the letters "-ide." Here is a list of ionic compounds with their names. Take a moment to examine them.

Compound	Name	Compound	Name
NaCl	sodium chlor**ide**	Al_2O_3	aluminum ox**ide**
MgF_2	magnesium fluor**ide**	GaP	gallium phosph**ide**
Li_2S	lithium sulf**ide**		

So in ionic compounds, sulfur becomes sulfide, nitrogen becomes nitride, and bromine becomes bromide.

Notice that the chemical name for ionic compounds does not have anything to do with the subscript numbers in the chemical formula. For example, $MgCl_2$ is simply magnesium chloride, *not* magnesium dichloride.

INDUSTRY CONNECTION

Potassium bromide is currently in use as an anti-seizure medication for dogs and cats with epilepsy.

Example 2

Naming Compounds

Write the chemical formula and name for the compound created from each pair of elements.

a. potassium and bromine
b. oxygen and calcium
c. oxygen and potassium
d. sodium and chlorine
e. sodium and oxygen

Solution

To write the formula for the compound, make sure the atoms are in the correct ratio so that the compound follows the rule of zero charge. To name the compound, write the metal atom first, followed by the nonmetal atom. Change the ending of the nonmetal atom's name to "-ide."

a. KBr, potassium bromide
b. CaO, calcium oxide
c. K_2O, potassium oxide
d. NaCl, sodium chloride
e. Na_2O, sodium oxide

Lesson Summary

How can you predict chemical formulas and name ionic compounds?

There are several important guidelines to follow in creating ionic compounds. Metal atoms are combined with nonmetal atoms. Next, the total number of valence electrons adds up to eight or a multiple of eight. Finally, the charges on the metal cations and nonmetal anions in ionic compounds add up to zero. When naming ionic compounds made from two different types of elements, the name of the metal atom comes first followed by the name of the nonmetal atom. In addition, the ending of the name of the nonmetal atom is changed to "-ide."

EXERCISES

Reading Questions

1. Explain how to use the periodic table to determine the charges on ions.
2. Explain how to use the periodic table to determine the correct formulas for ionic compounds.

1, 3, 7, 8

Reason and Apply

3. Is each compound possible? Explain your thinking.

   a. LiCl b. $LiCl_2$ c. MgCl d. $MgCl_2$ e. $AlCl_3$

4. Give examples of six ionic compounds with a metal to nonmetal ratio of 1:1. Specify the total number of valence electrons for each compound. Name each compound.
5. Give examples of three ionic compounds with a metal to nonmetal ratio of 2:1. Specify the total number of valence electrons for each compound. Name each compound.
6. Give examples of three ionic compounds with a metal to nonmetal ratio of 1:2. Specify the total number of valence electrons for each compound. Name each compound.
7. Predict the formulas for ionic compounds between the following metal and nonmetal elements. Name each compound.

   a. Al and Br b. Al and S c. Al and As

   d. Na and S e. Ca and S f. Ga and S

8. For each compound, write the cation and anion with the appropriate charge. Then write the chemical formula for each compound.

   Example: sodium fluoride, Na^+, F^-, NaF

   a. magnesium oxide
   b. rubidium bromide
   c. strontium iodide
   d. beryllium fluoride
   e. aluminum chloride
   f. lead sulfide