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

LESSON

22 Isn't It Ionic?

Polyatomic Ions

Think About It

So far, we have considered ionic compounds made of only two elements, a metal and a nonmetal. However, there are some ionic compounds that consist of more than two elements. For example, sodium hydroxide, NaOH, which is commonly found in drain cleaner, consists of one metal element and *two* nonmetal elements. You might wonder about the O and the H. Are they both ions?

What is a polyatomic ion?

To answer this question, you will explore

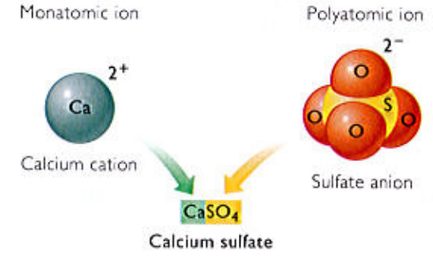
1. Polyatomic Ions
2. Predicting Chemical Formulas for Polyatomic Ions

Exploring the Topic

1 Polyatomic Ions

Some ionic compounds contain ions that consist of two or more elements. These ions are called **polyatomic ions.** In contrast, ions that have only one element are called **monatomic ions.** *Mono* means "one" and *poly* means "many." Calcium sulfate, $CaSO_4$, is an example of a compound made up of a monatomic ion and a polyatomic ion. The calcium ion is monatomic and the sulfate ion is polyatomic.

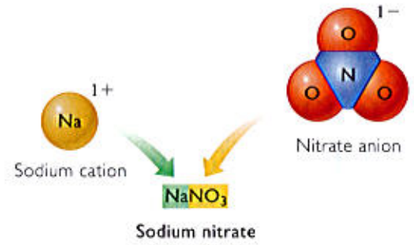
Polyatomic ion	Name
OH^-	hydroxide
NO_3^-	nitrate
CO_3^{2-}	carbonate
SO_4^{2-}	sulfate
PO_4^{3-}	phosphate
BrO_3^-	bromate
NH_4^+	ammonium



It is important to keep in mind that polyatomic ions are a *group* of atoms that stay together. In the above compound, the entire group of atoms has a negative charge.

Names of Polyatomic Ions

Ionic compounds with polyatomic ions have specific naming rules. Each polyatomic ion has its own name, as shown in the table. When naming a compound, you simply insert the polyatomic ion name at either the beginning or ending of the chemical name. The cation is first and the anion is second. For example, a compound that ends with NO_3 is a nitrate. $NaNO_3$ is called sodium *nitrate*, and $Ca(NO_3)_2$ is called calcium *nitrate*.



Sodium nitrate

Compound	Chemical formula
calcium sulfate	$CaSO_4$
magnesium hydroxide	$Mg(OH)_2$
sodium nitrate	$NaNO_3$
calcium nitrate	$Ca(NO_3)_2$
ammonium carbonate	$(NH_4)_2CO_3$

2 Predicting Chemical Formulas for Polyatomic Ions

Several chemical formulas with polyatomic ions are listed in the table. Notice that in some cases there are parentheses around the polyatomic ion, with a subscript after the second parenthesis. Why are the formulas written this way? How do you determine the subscript?

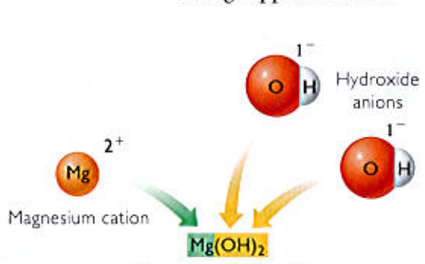
Recall that you can use the rule of zero charge to determine the chemical formulas associated with ionic compounds. For example, a single calcium ion combines with a single sulfate ion because the charges add up to zero:

$$Ca^{2+} + SO_4^{2-} \text{ becomes } CaSO_4\text{, calcium sulfate}$$

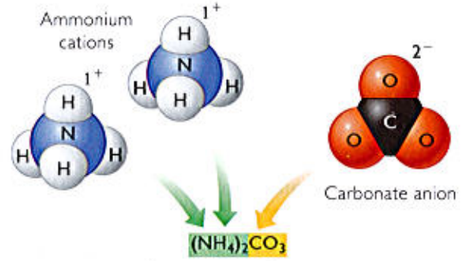
However, like simple ionic compounds, compounds with polyatomic ions do not always combine in a 1:1 ratio. When there is more than one of the same polyatomic ion in a formula, the ion is enclosed in parentheses and a subscript number indicates how many ions are in the compound. For example, a single calcium ion combines with *two* nitrate ions:

$$Ca^{2+} + NO_3^- + NO_3^- \text{ becomes } Ca(NO_3)_2\text{, calcium nitrate}$$

Below are two more examples of ionic compounds containing polyatomic ions. Each of these compounds consists of three ions. One compound has monatomic and polyatomic ions, while the other has only polyatomic ions. The rule of zero charge applies to both.



Magnesium hydroxide



Ammonium carbonate

Important to Know A polyatomic ion is treated as a unit. For example, the formula for calcium nitrate is written as $Ca(NO_3)_2$ with parentheses around NO_3. Notice that it is not written as CaN_2O_6. ◀

Key Terms

polyatomic ion
monatomic ion

Lesson Summary

What is a polyatomic ion?

Some ions are composed of more than one atom. These are called polyatomic ions. The entire cluster of atoms shares the charge on a polyatomic ion. If there are two or more polyatomic ions in a chemical formula, parentheses are placed around the ion and a subscript number indicates how many ions are present. To determine the formula of a compound with polyatomic ions, you can use the rule of zero charge. Each polyatomic ion has a unique name that is used when naming the compound it is in.

CONSUMER CONNECTION

Sodium hydroxide, or lye, has many uses. It is used to straighten or curl hair but, if left in too long, it can damage hair and skin.

EXERCISES

Reading Questions

1. What is a polyatomic ion?
2. How can you tell from a chemical formula if there is a polyatomic ion in a compound?

Reason and Apply

3. Write the name for each ionic compound listed here.
   a. NH_4Cl
   b. K_2SO_4
   c. $Al(OH)_3$
   d. $MgCO_3$
4. Write the chemical formula for each compound listed here.
   a. lithium sulfate
   b. potassium hydroxide
   c. magnesium nitrate
   d. ammonium sulfate
5. Sodium cyanide, NaCN, contains a cyanide ion. What is the charge on the cyanide ion?
6. Calcium phosphate, $Ca_3(PO_4)_2$, contains phosphate ions. What is the charge on a phosphate ion?
7. Which chemical formula does not represent a possible compound with sulfate, SO_4^{2-}? Explain your answer.
   A. Na_2SO_4 **B.** KSO_4 **C.** $Al_2(SO_4)_3$ **D.** $CaSO_4$

LESSON

23 Alchemy of Paint

Transition Metal Chemistry

Think About It

For thousands of years, human beings have expressed themselves through painting. Over time, people have discovered pigments with a wide variety of brilliant colors. The vast majority of paint pigments contain a transition metal cation.

What types of compounds are made from transition metals?

To answer this question, you will explore

1. Transition Metal Compounds
2. Charges on Transition Metal Cations

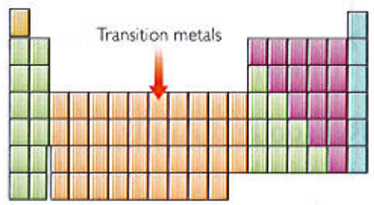
Exploring the Topic

1 Transition Metal Compounds

HISTORY CONNECTION

Ionic compounds containing transition metals were used to create ancient cave paintings. This cave painting is from Lascaux, France, and is approximately 17,000 years old.

The transition metals are named for their location in the middle of the periodic table. They consist of approximately 30 different elements. Many of the metals that we use in our daily life, such as copper, iron, nickel, silver, and gold, are located in this part of the periodic table.



Transition metal compounds tend to be brightly colored. Hence, they are commonly found as *pigments* to color paints. For example, red ochre is a pigment made from iron (III) oxide, Fe_2O_3. It is thought to be the first pigment ever used by human beings for creating art.

The ancient alchemists worked with the transition metals a great deal, mostly because these metals were closer in their properties to gold than to other metals. As a result, alchemists occasionally discovered paint pigments while trying to create gold.

The table on the next page lists various paint pigments that you can buy at an art store. Examine the data. Pay particular attention to the different charges on the transition metal cations.

Notice that the chemical names are a bit unusual. In the middle of each chemical name for a transition metal compound is a Roman numeral: I, II, III, or IV (meaning 1, 2, 3, or 4). This Roman numeral indicates what the charge is on the transition metal cation. Thus, cobalt (II) oxide has a +2 charge on the cobalt ion, and manganese (IV) carbonate has a +4 charge on the manganese ion.

HISTORY CONNECTION

There is an older naming system for the transition metal ionic compounds. In this system, Fe_2O_3 and FeO were called ferric oxide and ferrous oxide. The "-ic" ending indicated the higher ion charge and the "-ous" ending referred to the lower charge ion. So Co^{2-} was cobaltous and Co^{3-} was cobaltic.

FINE ART CONNECTION

Some paint pigments have more complicated chemical compositions than the compounds shown in the table. For example, the pigment Egyptian blue, shown below, is calcium copper silicate, with the formula $CaCuSi_4O_{10}$. There are three different cations and one type of anion.

Some Pigments Containing Ionic Compounds with Transition Metals

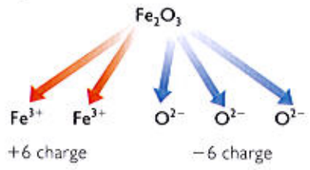
Color	Pigment name	Chemical name	Chemical formula	Cation	Anion
blue	cobalt blue	cobalt (II) oxide	CoO	Co^{2+}	O^{2-}
earth tone	red ochre	iron (III) oxide	Fe_2O_3	Fe^{3+}	O^{2-}
dark green	viridian	chromium (III) oxide	Cr_2O_3	Cr^{3+}	O^{2-}
brown	umber	manganese (IV) dioxide	MnO_2	Mn^{4+}	O^{2-}
blue-green	malachite	copper (II) carbonate	$CuCO_3$	Cu^{2+}	CO_3^{2-}
white	titanium white	titanium (IV) dioxide	TiO_2	Ti^{4+}	O^{2-}
red	cuprite	copper (I) oxide	Cu_2O	Cu^+	O^{2-}

Note that copper, Cu, has a charge of +1 in copper (I) oxide, Cu_2O, and a charge of +2 in copper (II) carbonate, $CuCO_3$.

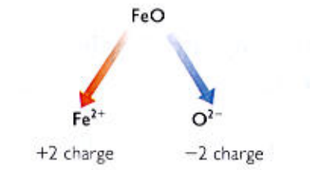
2 Charges on Transition Metal Cations

Recall that you can determine the charges on the main group metals and nonmetals from their positions on the periodic table. For example, all of the alkali metals, Group 1A, form cations with +1 charges. All of the halogens, Group 7A, form anions with −1 charges. However, you cannot simply determine the charge of a transition metal ion from its location on the periodic table. Instead, it is necessary to determine the charge of the ion from chemical formulas.

To determine the charges on transition metal cations, you use the charges on ions that you do know and apply the rule of zero charge. For example, iron combines with oxygen to form both Fe_2O_3 and FeO. Oxygen is a main group anion, so you can use the periodic table to determine that oxygen atoms form ions with a −2 charge. The rule of zero charge states that the charges on the ions in the compound should add up to zero. Working backward, you can determine the charge on the iron cations in each compound.



The charges on the three oxygen anions add up to −6. Each iron cation must have a charge of +3.



The charge on the single oxygen anion is −2. The iron cation must have a charge of +2.

These two different iron compounds are formally named iron (III) oxide and iron (II) oxide.

Important to Know Unlike the main group metals, most transition metals can form several ions with different charges. ◂

CONSUMER CONNECTION

Transition metal ions are responsible for colors in different-colored gem stones. For example, chromium ions, Cr^{3+}, are present in red ruby, green emerald, and pink topaz. Iron ions, Fe^{3+}, are present in citrine and yellow sapphire while Fe^{2+} ions make sapphires blue. The transition metals in crystals absorb certain colors of light while allowing other colors to pass through and be seen.

Example

Transition Metal Compounds

Determine the charge on the transition metal cation in each of the compounds given. Then name the compound.

a. Ag_2S **b.** $Fe(NO_3)_3$

Solution

You can determine the charge on each transition metal cation from the charges on the anions using the rule of zero charge.

a. Sulfur anions have a charge of −2. So each silver cation must have a charge of +1, Ag^+. The compound name is silver (I) sulfide.

b. The polyatomic ion is nitrate with a −1 charge. There are three nitrate ions, so the iron cation must have a charge of +3, Fe^{3+}. The compound name is iron (III) nitrate.

Lesson Summary

What types of compounds are made from transition metals?

Transition metals bond with nonmetal atoms to form ionic compounds. Unlike the main group atoms, most transition metals can have more than one ion charge. The best way to determine the charge on a transition metal cation is to work backward from the anion, whose charge is known. When naming ionic compounds, a Roman numeral is used to indicate the charge on the transition cation. Colorful paint pigments are frequently composed of transition metal compounds.

EXERCISES

Reading Questions

1. What does the Roman numeral in a chemical name indicate?
2. Explain how you determine the charge on a transition metal cation from the chemical formula.

Reason and Apply

3. Determine the charge on the transition metal cation in each of the compounds listed. Then name each compound.
   a. HgS **b.** $CuCO_3$ **c.** $NiCl_2$
   d. $Co(NO_3)_3$ **e.** $Cu(OH)_2$ **f.** $FeSO_4$
4. Write the cation and anion in each compound, then determine the correct chemical formula.
   a. copper (II) sulfide **b.** nickel (II) nitrate **c.** iron (II) carbonate
   d. cobalt (II) sulfate **e.** iron (III) carbonate **f.** chromium (VI) oxide
5. Cobalt violet is a paint pigment discovered in 1859. If the cation for this compound is Co^{2+} and the anion is PO_4^{3-}, what is the chemical formula?

LESSON

24 Shell Game

Electron Configurations

Think About It

Recall that the chemistry of the elements is closely related to the number of valence electrons in their atoms. The valence electrons are found in the outermost electron shell of an atom.

What does the periodic table indicate about the arrangements of electrons?

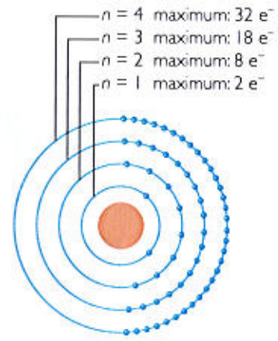
To answer this question, you will explore

1. Subshells in Atoms
2. Electron Configurations
3. Connecting the Periodic Table to Electron Arrangements
4. Noble Gas Shorthand

Exploring the Topic

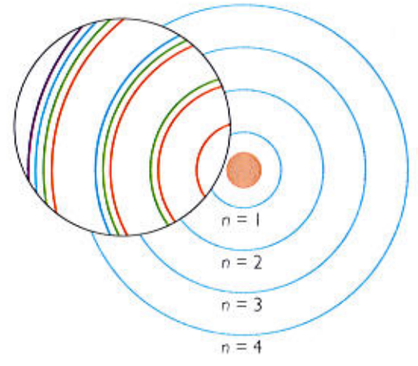
1 Subshells in Atoms

Electrons are arranged into shells numbered n = 1, 2, 3, and so on. The number of electron shells in an atom is the same as the number of the period where the element is located on the periodic table. Each shell has a maximum number of electrons. For instance, the n = 2 shell cannot have more than 8 electrons.



Each electron shell can have a maximum number of electrons.

Scientific evidence has led chemists to propose that electron shells are further divided into electron subshells. Imagine magnifying the basic atomic model and finding that each shell is composed of subshells. Notice that the number of subshells that a shell has is equal to n.



Electron shells are further divided into subshells.