4.6: Ionic Compounds: Formulas and Names

Key Concept Video **Naming Ionic Compounds**

In Section 4.5, we deduced the formula for a simple ionic compound from the Lewis symbols of its constituent atoms. Because ionic compounds must be charge-neutral, we can also deduce the formula from the charges of the ions. In this section, we examine how to write a formula for an ionic compound based on the charges of the constituent ions and how to systematically name ionic compounds. The process of naming compounds is called *nomenclature*.

Writing Formulas for Ionic Compounds

Because ionic compounds are charge-neutral and because many elements form only one type of ion with a predictable charge (see Figure 3.12), we can deduce the formulas for many ionic compounds from their constituent elements. For example, we know that the formula for the ionic compound composed of potassium and fluorine must be KF because, in compounds, K always forms 1+ cations and F always forms 1− anions. In order for the compound to be charge-neutral, it must contain one K^+ cation to every one F^- anion. The formula for the ionic compound composed of *magnesium* and fluorine, in contrast, is MgF_2 because Mg always forms 2+ cations and F always forms 1− anions. In order for this compound to be charge-neutral, it must contain one Mg^{2+} cation for every two F^- anions.

Summarizing Ionic Compound Formulas:

- Ionic compounds always contain positive and negative ions.
- In a chemical formula, the sum of the charges of the positive ions (cations) must equal the sum of the charges of the negative ions (anions).
- The formula of an ionic compound reflects the smallest whole-number ratio of ions.

To write the formula for an ionic compound, follow the procedure in the left column in the following examples. Examples of how to apply the procedure are provided in the center and right columns.

Example 4.3 Writing Formulas for Ionic Compounds

PROCEDURE FOR Writing Formulas for Ionic Compounds

Write the formula for the ionic compound that forms between aluminum and oxygen.

1. Write the symbol for the metal cation and its charge followed by the symbol for the nonmetal anion and its charge. Determine charges from the element's group number in the periodic table (refer to Figure 3.12).

$$Al^{3+} \quad O^{2-}$$

2. Adjust the subscript on each cation and anion to balance the overall charge.

$$\begin{array}{ccc} Al^{3+} & & O^{2-} \\ & \downarrow & \\ & Al_2O_3 & \end{array}$$

3. Check to make sure the sum of the charges of the cations equals the sum of the charges of the anions.

cations: $2(3+) = 6+$
anions : $3(2-) = 6-$
The charges cancel.

FOR PRACTICE 4.3 Write the formula for the compound formed between potassium and sulfur.

Example 4.4 Writing Formulas for Ionic Compounds

PROCEDURE FOR Writing Formulas for Ionic Compounds

Write the formula for the ionic compound that forms between calcium and oxygen.

1. Write the symbol for the metal cation and its charge followed by the symbol for the nonmetal anion and its charge. Determine charges from the element's group number in the periodic table (refer to Figure 3.12).

$$Ca^{2+} \quad O^{2-}$$

2. Adjust the subscript on each cation and anion to balance the overall charge.

$$Ca^{2+} \qquad O^{2-}$$
$$\downarrow$$
$$CaO$$

3. Check to make sure the sum of the charges of the cations equals the sum of the charges of the anions.

cations: 2+
anions: 2–
The charges cancel.

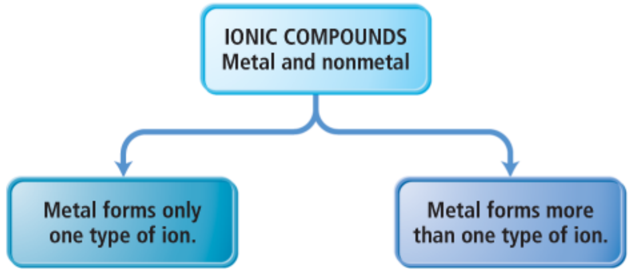
FOR PRACTICE 4.4 Write the formula for the compound formed between aluminum and nitrogen.

Interactive Worked Example 4.3 **Writing Formulas for Ionic Compounds**

Naming Ionic Compounds

Some ionic compounds—such as NaCl (table salt) and $NaHCO_3$ (baking soda)—have **common names**, which are nicknames of sorts learned by familiarity. Chemists have also developed **systematic names** for different types of compounds including ionic ones. Even if you are not familiar with a compound, you can determine its systematic name from its chemical formula. Conversely, you can deduce the formula of a compound from its systematic name.

The first step in naming an ionic compound is identifying it as one. Remember, *ionic compounds are usually composed of metals and nonmetals*; any time we see a metal and one or more nonmetals together in a chemical formula, we assume that it is an ionic compound. We categorize ionic compounds into two types, depending on the metal in the compound. The first type contains a metal whose charge is invariant from one compound to another. In other words, whenever the metal in this first type of compound forms an ion, the ion always has the same charge.

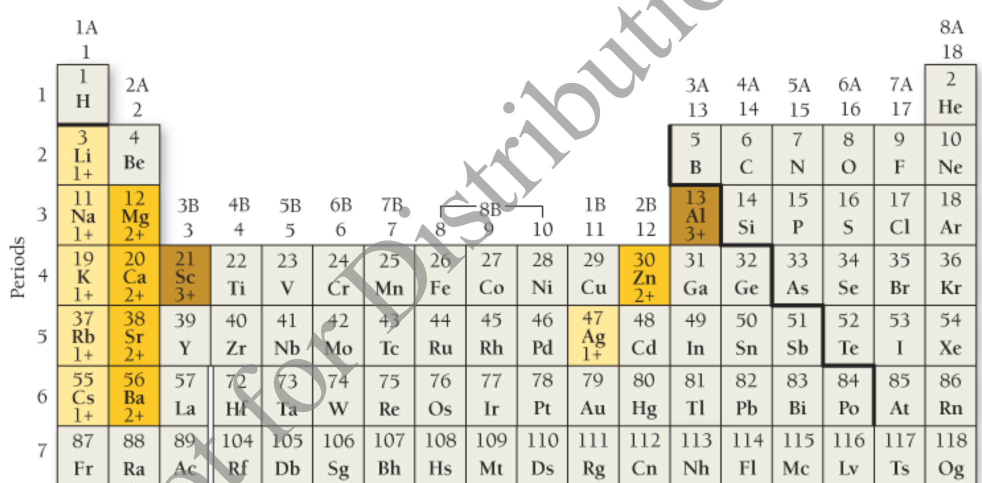


Since the charge of the metal ion in this first type of ionic compound is always the same, we don't need to specify its charge in the name of the compound. Sodium, for instance, has a 1+ charge in all of its compounds. Figure 4.6 lists some examples of these types of metals; we can infer the charges of most of these metals from their group number in the periodic table. This figure includes all of the metals in Figure 3.12 (which are all main-group metals) and three additional metals, which are transition metals. The charges of the transition metals cannot be inferred from their group number.

Figure 4.6 **Metals with Invariant Charges**

The metals highlighted in this table form cations with the same charges in all of their compounds. (Note that silver sometimes forms compounds with other charges, but these are rare.)

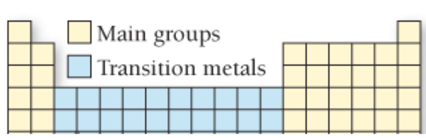
Metals Whose Charge Is Invariant from One Compound to Another



The second type of ionic compound contains a metal ion with a charge that can differ in different compounds. In other words, the metal in this second type of ionic compound can form more than one type of cation (depending on the compound). Therefore, we must specify its charge for a given compound. Iron, for instance, forms a 2+ cation in some of its compounds and a 3+ cation in others. These metals are usually *transition metals* (Figure 4.7). However, some transition metals, such as Zn and Ag, form cations with the same charge in all of their compounds (as shown in Figure 4.6), and some main-group metals, such as Pb and Sn, form more than one type of cation.

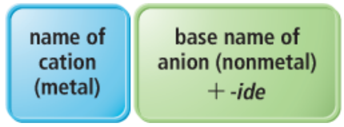
Figure 4.7 **Transition Metals**

Metals that can have different charges in different compounds are usually (but not always) transition metals.



Naming Binary Ionic Compounds Containing a Metal That Forms Only One Type of Cation

Binary compounds contain only two different elements. The names of binary ionic compounds take the form:



For example, the name for KCl consists of the name of the cation, *potassium*, followed by the base name of the anion, *chlor*, with the ending *-ide*. Its full name is *potassium chloride*:

KCl potassium chloride

The name for CaO consists of the name of the cation, *calcium*, followed by the base name of the anion, *ox*, with the ending *-ide*. Its full name is *calcium oxide*:

CaO calcium oxide

The base names for various nonmetals and their most common charges in ionic compounds are shown in Table 4.2.

Table 4.2 **Some Common Monoatomic Anions**

Nonmetal	Symbol for Ion	Base Name	Anion Name
Fluorine	F^-	Fluor	Fluoride
Chlorine	Cl^-	Chlor	Chloride
Bromine	Br^-	Brom	Bromide
Iodine	I^-	Iod	Iodide
Oxygen	O^{2-}	Ox	Oxide
Sulfur	S^{2-}	Sulf	Sulfide
Nitrogen	N^{3-}	Nitr	Nitride
Phosphorus	P^{3-}	Phosph	Phosphide

Example 4.5 Naming Ionic Compounds Containing a Metal That Forms Only One Type of Cation

Name the compound $CaBr_2$.

SOLUTION

The cation is *calcium*. The anion is from bromine, which becomes *bromide*. The correct name is *calcium bromide*.

FOR PRACTICE 4.5 Name the compound Ag_3N.

FOR MORE PRACTICE 4.5 Write the formula for rubidium sulfide.

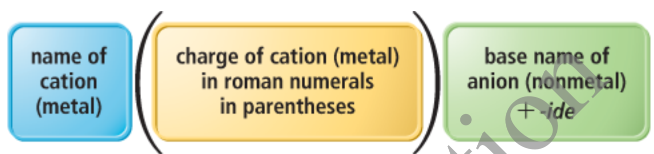
Naming Binary Ionic Compounds Containing a Metal That Forms More Than One Type of Cation

For these metals, the name of the cation is followed by a roman numeral (in parentheses), which indicates the charge of the metal in that particular compound. For example, we distinguish between Fe^{2+} and Fe^{3+} as follows:

$$\begin{array}{ll} Fe^{2+} & \text{iron (II)} \\ Fe^{3+} & \text{iron (III)} \end{array}$$

> Note that there is no space between the name of the cation and the parenthetical number indicating its charge.

The full names for compounds containing metals that form more than one kind of cation have the form:



We can determine the charge of the metal cation by inference from the sum of the charges of the nonmetal anions—remember that the sum of all the charges in the compound must be zero. Table 4.3 shows some of the metals that form more than one type of cation and their most common charges. For example, in $CrBr_3$, the charge of chromium must be 3+ in order for the compound to be charge-neutral with three Br^- anions. The cation is named:

$$Cr^{3+} \quad \text{chromium (III)}$$

The full name of the compound is:

$$CrBr_3 \quad \text{chromium(III) bromide}$$

Similarly, in CuO, the charge of copper must be 2+ in order for the compound to be charge-neutral with one O^{2-} anion. The cation is therefore:

$$Cu^{2+} \quad \text{copper (II)}$$

The full name of the compound is:

$$CuO \quad \text{copper (II) oxide}$$

Table 4.3 Some Metals That Form Cations with Different Charges

Metal	Ion	Name	Older Name*
Chromium	Cr^{2+}	Chromium(II)	Chromous
	Cr^{3+}	Chromium(III)	Chromic
Iron	Fe^{2+}	Iron(II)	Ferrous
	Fe^{3+}	Iron(III)	Ferric
Cobalt	Co^{2+}	Cobalt(II)	Cobaltous

	Co^{3+}	Cobalt(III)	Cobaltic
Copper	Cu^{+}	Copper(I)	Cuprous
	Cu^{2+}	Copper(II)	Cupric
Tin	Sn^{2+}	Tin(II)	Stannous
	Sn^{4+}	Tin(IV)	Stannic
Mercury	Hg_2^{2+}	Mercury(I)	Mercurous
	Hg^{2+}	Mercury(II)	Mercuric
Lead	Pb^{2+}	Lead(II)	Plumbous
	Pb^{4+}	Lead(IV)	Plumbic

*An older naming system substitutes the names found in this column for the name of the metal and its charge. Under this system, chromium(II) oxide is named chromous oxide. In this system, the suffix *-ous* indicates the ion with the lesser charge, and *-ic* indicates the ion with the greater charge. We will *not* use the older system in this text.

Example 4.6 Naming Ionic Compounds Containing a Metal That Forms More Than One Type of Cation

Name the compound $PbCl_4$.

SOLUTION

The charge on Pb must be 4+ for the compound to be charge-neutral with 4 Cl^- anions. The name for $PbCl_4$ is the name of the cation, *lead*, followed by the charge of the cation in parentheses *(IV)*, and the base name of the anion, *chlor*, with the ending *-ide*. The full name is *lead(IV) chloride*.

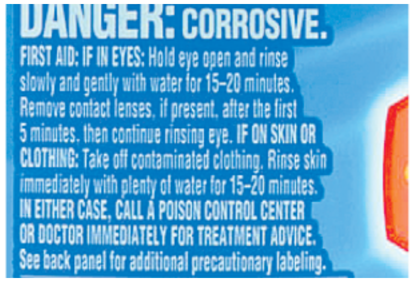
$PbCl_4$ lead(IV) chloride

FOR PRACTICE 4.6 Name the compound FeS.

FOR MORE PRACTICE 4.6 Write the formula for ruthenium(IV) oxide.

Naming Ionic Compounds Containing Polyatomic Ions

Many common ionic compounds contain ions that are themselves composed of a group of covalently bonded atoms with an overall charge. For example, the active ingredient in household bleach is sodium hypochlorite, which acts to chemically alter color-causing molecules in clothes (bleaching action) and to kill bacteria (disinfection). Hypochlorite is a **polyatomic ion**—an ion composed of two or more atoms—with the formula ClO^-. Note that the charge on the hypochlorite ion is a property of the whole ion, not just the oxygen atom; this is true for all polyatomic ions. The hypochlorite ion is a unit in other compounds as well (such as KClO and $Mg(ClO)_2$). Other common compounds that contain polyatomic ions include sodium bicarbonate ($NaHCO_3$), also known as baking soda, sodium nitrite ($NaNO_2$), an inhibitor of bacterial growth in packaged meats, and calcium carbonate ($CaCO_3$), the active ingredient in antacids such as Tums™.



Polyatomic ions are common in household products such as bleach, which contains sodium hypochlorite (NaClO).

Conceptual Connection 4.4 Polyatomic Ions

We name ionic compounds that contain a polyatomic ion in the same way that we name other ionic compounds, except that we incorporate the name of the polyatomic ion whenever it occurs. Table 4.4 lists common polyatomic ions and their formulas. For example, $NaNO_2$ is named according to its cation, Na^+, *sodium*, and its polyatomic anion, NO_2^-, *nitrite*. Its full name is *sodium nitrite*.

$NaNO_2$ sodium nitrite

Table 4.4 Some Common Polyatomic Ions

Name	Formula	Name	Formula
Acetate	$C_2H_3O_2^-$	Hypochlorite	ClO^-
Carbonate	CO_3^{2-}	Chlorite	ClO_2^-
Hydrogen carbonate (or bicarbonate)	HCO_3^-	Chlorate	ClO_3^-
Hydroxide	OH^-	Perchlorate	ClO_4^-
Nitrite	NO_2^-	Permanganate	MnO_4^-
Nitrate	NO_3^-	Sulfite	SO_3^{2-}
Chromate	CrO_4^{2-}	Hydrogen sulfite (or bisulfite)	HSO_3^-
Dichromate	$Cr_2O_7^{2-}$	Sulfate	SO_4^{2-}
Phosphate	PO_4^{3-}	Hydrogen sulfate (or bisulfate)	HSO_4^-
Hydrogen phosphate	HPO_4^{2-}	Cyanide	CN^-
Dihydrogen phosphate	$H_2PO_4^-$	Peroxide	O_2^{2-}
Ammonium	NH_4^+		

We name $FeSO_4$ according to its cation, *iron*, its charge *(II)*, and its polyatomic ion *sulfate*. Its full name is *iron(II) sulfate*.

$FeSO_4$ iron(II) sulfate

If the compound contains both a polyatomic cation and a polyatomic anion, we use the names of both polyatomic ions. For example, NH_4NO_3 is *ammonium nitrate*.

NH_4NO_3 ammonium nitrate

You should be able to recognize polyatomic ions in a chemical formula, so become familiar with the ions listed in Table 4.4. Most common polyatomic ions are **oxyanions**, anions containing oxygen and another element. Notice that when a series of oxyanions contains different numbers of oxygen atoms, we name them systematically according to the number of oxygen atoms in the ion. If there are only two ions in the series, the one with more oxygen atoms has the ending *-ate* and the one with fewer oxygen atoms has the ending *-ite*. For example, NO_3^- is *nitrate* and NO_2^- is *nitrite*.

NO_3^- nitr*ate*
NO_2^- nitr*ite*

If there are more than two ions in the series, we use the prefixes *hypo-*, meaning *less than*, and *per-*, meaning *more than*. So ClO^- is hypochlorite—less oxygen than chlorite, and ClO_4^- is perchlorate—more oxygen than chlorate.

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

Other halides (halogen ions) form similar series with similar names. Thus, IO_3^- is called iodate and BrO_3^- is called bromate.

Example 4.7 Naming Ionic Compounds That Contain a Polyatomic Ion

Name the compound $Li_2Cr_2O_7$.

SOLUTION

The name for $Li_2Cr_2O_7$ is the name of the cation, *lithium*, followed by the name of the polyatomic ion, *dichromate*. Its full name is *lithium dichromate*.

$Li_2Cr_2O_7$ lithium dichromate

FOR PRACTICE 4.7 Name the compound $Sn(ClO_3)_2$.

FOR MORE PRACTICE 4.7 Write the formula for cobalt(II) phosphate.

Hydrated Ionic Compounds

Some ionic compounds—called **hydrates**—contain a specific number of water molecules associated with each formula unit. For example, the formula for Epsom salts is $MgSO_4 \cdot 7H_2O$, and its systematic name is magnesium sulfate heptahydrate. The seven H_2O molecules associated with the formula unit are *waters of hydration*. Waters of hydration can usually be removed by heating the compound. Figure 4.8 shows a sample of cobalt(II) chloride hexahydrate ($CoCl_2 \cdot 6H_2O$) before and after heating. The hydrate is pink and the anhydrous salt (the salt without any associated water molecules) is bluish/purple. We name hydrates like we name other ionic compounds, but we give them the additional name "*prefix*hydrate," where the *prefix* indicates the number of water molecules associated with each formula unit.

Figure 4.8 Hydrates

Cobalt(II) chloride hexahydrate is pink. Heating the compound removes the waters of hydration, leaving the bluish/purple anhydrous cobalt(II) chloride.

$CoCl_2 \cdot 6H_2O$ $CoCl_2$

> Common hydrate prefixes
>
> $\text{hemi} = 1/2$
>
> $\text{mono} = 1$
>
> $\text{di} = 2$
>
> $\text{tri} = 3$
>
> $\text{tetra} = 4$
>
> $\text{penta} = 5$
>
> $\text{hexa} = 6$
>
> $\text{hepta} = 7$
>
> $\text{octa} = 8$

Other common hydrated ionic compounds and their names are as follows:

$CaSO_4 \cdot \frac{1}{2}H_2O$	calcium sulfate hemihydrate
$BaCl_2 \cdot 6H_2O$	barium chloride hexahydrate
$CuSO_4 \cdot 5H_2O$	copper(II) sulfate pentahydrate