# 5.7: Ionic Compounds Containing Polyatomic Ions

## Learning Objectives

- Write correct names and formulas for ionic compounds containing polyatomic ions.

Some ions consist of groups of atoms bonded together that carry an overall electric charge. Because these ions contain more than one atom, they are called polyatomic ions. Polyatomic ions have characteristic formulas, names, and charges that should be memorized. For example, the nitrate ion has one nitrogen atom and three oxygen atoms with an overall charge of 1−. The formula of the nitrate ion is written as $NO_3^-$. A list of the most common polyatomic ions appears in Table 5.7.1. Since these ions are regularly used throughout the rest of this text, it generally a good practice to memorize this list of ions.

## Table 5.7.1: The Most Common Polyatomic Ions

| Name | Formula |
|---|---|
| ammonium ion | $NH_4^+$ |
| acetate ion | $C_2H_3O_2^-$ |
| bicarbonate ion (hydrogen carbonate ion) | $HCO_3^-$ |
| carbonate ion | $CO_3^{2-}$ |
| chlorate ion | $ClO_3^-$ |
| cyanide ion | $CN^-$ |
| hydroxide ion | $OH^-$ |
| nitrate ion | $NO_3^-$ |
| phosphate ion | $PO_4^{3-}$ |
| sulfate ion | $SO_4^{2-}$ |

### Writing Formulas for Ionic Compounds Containing Polyatomic Ions

Writing formulas for ionic compounds containing polyatomic ions involves the same steps as for a binary ionic compound. The cation is written first in the chemical formula followed by the anion. Consider potassium nitrate. Potassium is located in Group IA of the periodic table, so it forms ions with a 1+ charge, $K^+$. As shown above in Table 5.7.1, the formula of the nitrate ion is $NO_3^-$. Since the charges of the two ions are already balanced, the formula for potassium nitrate may be written as $KNO_3$.

When more than one polyatomic ion is required to balance charge, the formula of the polyatomic ion is enclosed in parentheses followed by a subscript that indicates the quantity of that polyatomic ion required to balance the charge. This means that the formula of calcium nitrate is written as $Ca(NO_3)_2$, since calcium is located in Group IIA and forms ions with a 2+ charge, $Ca^{2+}$, and will require two nitrate ions, $NO_3^-$, to balance the charge of a single calcium ion.

It should be emphasized that enclosing a polyatomic ion in parentheses is only done when more than one is required to balance charge. Parentheses are not included when only one polyatomic ion is required to balance charge. That is why the formula of potassium nitrate is written as $KNO_3$ and *not* as $K(NO_3)$.

## ✅ Example 5.7.1: Writing Chemical Formulas

Write the chemical formulas for:

- copper(I) carbonate
- aluminum acetate

- magnesium hydroxide

**Solution**

| | copper(I) carbonate | | aluminum acetate | | magnesium hydroxide | |
|---|---|---|---|---|---|---|
| 1. Write the symbol and charge of the cation and the anion. | $Cu^+$ | $CO_3^{2-}$ | $Al^{3+}$ | $C_2H_3O_2^-$ | $Mg^{2+}$ | $OH^-$ |
| 2. Balance the charge of the cations and anions. | $Cu^+$<br>$Cu^+$ | $CO_3^{2-}$ | $Al^{3+}$ | $C_2H_3O_2^-$<br>$C_2H_3O_2^-$<br>$C_2H_3O_2^-$ | $Mg^{2+}$ | $OH^-$<br>$OH^-$ |
| 3. Explanation. | 2+ balances 2– | | 3+ balances 3– | | 2+ balances 2– | |
| 4. Write the final formula. Charges are left off. Subscripts of 1 are implied. | $Cu_2CO_3$ | | $Al(C_2H_3O_2)_3$ | | $Mg(OH)_2$ | |

## Writing Names for Ionic Compounds Containing Polyatomic Ions

The reverse process is used when writing names for ionic compounds containing polyatomic ions. Each ion is named in the order that they appear in the chemical formula. The most important part is to recognize that a polyatomic ion is present in the compound. $Na_3PO_4$ would be called sodium phosphate, since it contains the sodium ion, $Na^+$, and the phosphate ion, $PO_4^{3-}$. $Mg(ClO_3)_2$ would be called magnesium chlorate, since it contains the magnesium ion, $Mg^{2+}$, and the chlorate ion, $ClO_3^-$.

### ✅ Example 5.7.2: Writing Chemical Names

Write the name for each compound.

A. $(NH_4)_2S$
B. $FeSO_4$
C. $Fe_2(SO_4)_3$

**Solution**

A. $NH_4^+$ is the ammonium ion. S = sulfur. The root name of sulfur is *sulf-*. The nonmetal has a suffix of *-ide*. $(NH_4)_2S$ is ammonium sulfide.

B. $SO_4^{2-}$ is the sulfate ion. Fe is a transition element that forms ions with multiple charges. Since only one iron ion is needed to balance the charge of one sulfate ion, it must have a 2+ charge. An iron ion with a 2+ charge is called the iron(II) ion. $FeSO_4$ is iron(II) sulfate.

C. $SO_4^{2-}$ is the sulfate ion. Fe is a transition element that forms ions with multiple charges. Since two iron ions are needed to balance the charge of three sulfate ions, it must have a 3+ charge. An iron ion with a 3+ charge is called the iron(III) ion. $Fe_2(SO_4)_3$ is iron(III) sulfate.

## Oxyanions

You may have noticed that most of the polyatomic ions in Table 5.7.1 carry a negative charge and contain the element oxygen. Anions that contain the element oxygen are called **oxyanions**. Many oxyanions belong to a series where the number of oxygen atoms in the ion varies, as shown in Table 5.7.2.

### Table 5.7.2: Oxyanions Belonging to a Series

| Name | Formula |
|---|---|
| chlorate ion | $ClO_3^-$ |
| chlorite ion | $ClO_2^-$ |
| nitrate ion | $NO_3^-$ |
| nitrite ion | $NO_2^-$ |
| sulfate ion | $SO_4^{2-}$ |
| sulfite ion | $SO_3^{2-}$ |

Note that oxyanions may end with either an *-ate* or *-ite* suffix. In other words, if you encounter a compound (or polyatomic ion) that ends with *-ate* or *-ite*, it will *always* contain oxygen. To be clear, simply containing oxygen doesn't mean the compound will always end with an *-ate* or *-ite* suffix. We have seen examples of oxides, where oxygen is part of a binary compound such as lithium oxide, $Li_2O$, and hydroxides, where oxygen is part of the polyatomic ion $OH^-$.

When comparing oxyanions that end with *-ate* and *-ite*, the ion that ends with *-ate* will always have one more oxygen than the corresponding ion that ends with *-ite*. The ion in the series that ends with *-ate* is the one found in Table 5.7.1: The Most Common Polyatomic Ions. This is because the *-ate* form is more commonly found in nature than the *-ite* form. It is also the reason why memorizing the form that ends with *-ate* is recommended rather than the one that ends with *-ite*. Furthermore, if you learn the one that ends with *-ate*, the ion that ends with *-ite* can easily be obtained, since it always has one less oxygen than the *-ate* form.

It should also be pointed out that just because the *-ite* form always has one less oxygen than the *-ate* form doesn't mean that an *-ite* form is possible. Even though the carbonate ion, $CO_3^{2-}$, is quite common, there is no such thing as the carbonite ion. Some of you reading this might be saying right now, "Wait a minute! I remember hearing about carbonite in Star Wars!" That's true. However, Star Wars is science fiction and may have even been the reason for the choice of using the word carbonite...it doesn't really exist!

### ✅ Example 5.7.3

A. What is the formula of zinc sulfite?
B. Write the chemical name of $Sr(NO_2)_2$?
C. If the bromate ion has a formula of $BrO_3^-$, what is the formula of the bromite ion?

**Solution**

A. From Figure 5.5.1, Zn is one of the three transition elements that has a fixed charge. Zinc ions have a charge of 2+, $Zn^{2+}$. The formula of the sulfite ion is $SO_3^{2-}$, which has one less oxygen atom than the sulfate ion. The charge on $Zn^{2+}$ balances the charge on $SO_3^{2-}$, so the formula of zinc sulfite is $ZnSO_3$.

B. $Sr^{2+}$ is the formula of the strontium ion. $NO_2^-$ is the formula of the nitrite ion, which has one less oxygen than the nitrate ion. $Sr(NO_2)_2$ is strontium nitrite.

C. The *-ite* form always contains one less oxygen atom that the ion with an *-ate* suffix. If the bromate ion is $BrO_3^-$, then the bromite ion has a formula of $BrO_2^-$.

## Exercise 5.7.1

Write the formula for each:

A. silver cyanide
B. calcium bicarbonate
C. lithium chlorite
D. nickel(III) sulfate
E. phosphite ion

**Answer A**

AgCN

**Answer B**

$Ca(HCO_3)_2$

**Answer C**

$LiClO_2$

**Answer D**

$Ni_2(SO_4)_3$

**Answer E**

$PO_3^{3-}$

## Exercise 5.7.2

Write the name of each:

A. $Na_2SO_3$
B. $Cd(C_2H_3O_2)_2$
C. $(NH_4)_3PO_4$
D. KOH
E. $Pb(NO_3)_4$

**Answer A**

sodium sulfite

**Answer B**

cadmium acetate

**Answer C**

ammonium phosphate

**Answer D**

potassium hydroxide

**Answer E**

lead(IV) nitrate

## Additional Polyatomic Ions

There are many other polyatomic ions that may be encountered in this text besides the ones already listed. Table 5.7.3 is not an all-inclusive list of additional polyatomic ions that exist, but rather ions you may expect to see in this text. Ions are grouped together if they are a part of a series.

### Table 5.7.3: Additional Polyatomic Ions

| Name | Formula |
|---|---|
| hypochlorite ion | $ClO^-$ |
| perchlorate ion | $ClO_4^-$ |
| chromate ion | $CrO_4^{2-}$ |
| dichromate ion | $Cr_2O_7^{2-}$ |
| oxalate ion | $C_2O_4^{2-}$ |
| permanganate ion | $MnO_4^-$ |
| monohydrogen phosphate ion | $HPO_4^{2-}$ |
| dihydrogen phosphate ion | $H_2PO_4^-$ |
| bisulfate ion (hydrogen sulfate ion) | $HSO_4^-$ |
| bisulfite ion (hydrogen sulfite ion) | $HSO_3^-$ |

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