

Naming Ionic Compounds: Self-Study Assignment

You will have a QUIZ on the attached pages on _____ .

Your assignment is: READ the pages attached. WORK the examples in the lesson. Complete the pages as homework.

To work the examples,

- use a sheet of paper to cover below the ***** line,
- try the problem on your paper,
- then check your answer below the ***** line.

Start early. This assignment will require 2-4 hours of work outside of class.

Lesson 7B: Naming Ions

Prerequisites: Complete Module 6 and Lesson 7A before starting this lesson.

Pretest: If you think you know this topic, try several problems at the end of this lesson. If you complete them all correctly, you may skip the lesson.

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Ions

In ionic compounds, the constituent particles are *ions*, particles with an electrical charge.

In most first-year chemistry courses you will be asked to memorize the names and symbols for more than 50 frequently encountered ions. This task is simplified by the patterns for ion charges that are found in the periodic table. Learning these rules and patterns will help you to speak the language of chemistry.

Categories of Ions

- All ions are either positive or negative.
 - Positive ions are termed **cations** (pronounced KAT-eye-ons). The charges on positive ions can be 1+, 2+, 3+, or 4+.
 - Negative ions are termed **anions** (pronounced ANN-eye-ons). The charges on negative ions can be 1−, 2−, or 3−.
- All ions are either **monatomic** or **polyatomic**.
 - A monatomic ion is composed of a single atom.
Examples of monatomic ions are Na^+ , Al^{3+} , Cl^- , and S^{2-} .
 - A polyatomic ion is a particle that has two or more covalently bonded atoms and an overall electric charge.
Examples of polyatomic ions are OH^- , Hg_2^{2+} , NH_4^+ , and SO_4^{2-} .

Ions of Hydrogen

Hydrogen has unique characteristics. It is classified as a nonmetal, and in most of its compounds hydrogen bonds covalently. In compounds classified as acids, hydrogen can form H^+ ions (protons). When bonded to metal atoms, hydrogen behaves as a hydride ion (H^-).

The Structure and Charge of Metal Ions

More than 70% of the elements in the periodic table are metal atoms.

- Geologically, in the earth's crust, *most* metals are found as metal *ions*. When metal ions are found in rocks from which the ions can be extracted and converted to metals, the rocks have economic value and are termed **ores**.
 Famous exceptions to the “metals are found as ions” rule include the coinage metals: copper and silver, which may be found geologically both as ions or in their metallic, elemental form, and gold, which is always found in nature as a metal.
- In *reactions*, neutral metal atoms tend to *lose* electrons to form *positive* ions.
- In compounds that contain both metal and nonmetal atoms, the metal atoms nearly always behave as ions with a *positive* charge. The charge can be 1+, 2+, 3+, or 4+.
- With the exception of mercurous (Hg_2^{2+}) ion, all frequently encountered metal ions are monatomic: the ions are *single* metal atoms that have lost one or more electrons.

Examples of metal ions are Na^+ , Mg^{2+} , Al^{3+} , and Sn^{4+} .

All metals form at least one positive ion. Some frequently encountered metals form two stable ions. In many cases, the charge (or possible charges) on a metal ion can be predicted from the position of the metal in the periodic table.

In first-year chemistry, when you are asked to predict the charge on a metal atom, you will nearly always be allowed to consult a periodic table. Use a periodic table when learning the following rules for the charges on metal ions.

Metal Ions With One Charge

Metals in the *first two* columns of the periodic table form only *one* ion. The charge on that ion is easy to predict.

- All metals in column *one* (the alkali metals) form ions that are single atoms with a **1+** charge: Li^+ , Na^+ , K^+ , Rb^+ , Cs^+ , and Fr^+ .
- All metals in column *two* form ions that are single atoms with a **2+** charge: Be^{2+} , Mg^{2+} , Ca^{2+} , Sr^{2+} , Ba^{2+} , and Ra^{2+} .

The charges on metal ions in the remainder of the periodic table are more difficult to predict. Additional rules for predicting ion charge will be learned when electron configuration is studied in later parts of your course.

In order to solve problems initially, most courses require that the possible charges on certain metals to the right of column 2 in the periodic table be memorized. The rules below will help with that process.

Most metals to the right of the first two columns form two or more stable ions, but some form only one. The following rule should be memorized.

- Metals to the right of the first two columns that form only *one* stable ion include Ni^{2+} , Ag^+ , Zn^{2+} , Cd^{2+} , and Al^{3+} .

For help in remembering this group, note the position of these metals in the periodic table.

Naming Metal Ions

How a metal ion is named depends on whether the metal forms only one ion, or forms two or more ions.

1. If a metal forms only *one* stable ion, the ion name is the element name.

Examples: Na^+ is a sodium ion. Al^{3+} is an aluminum ion.

This rule applies to

- metal ions in columns one and two, plus
 - the additional five metal ions listed above, plus
 - additional ions that may be studied in later parts of first-year chemistry.
2. For metals that form *two* different positive ions, the **systematic name** (or *modern name*) of the ion is the element name followed by a roman numeral in parentheses that states the ion's positive charge.

Examples: Fe^{2+} is named iron(II) and Fe^{3+} is named iron(III)

3. For metals that form *two* different positive ions and were “known to the ancients” also have **common names** for their ions.

In common names, the lower charged ion uses the Latin root of the element name plus the suffix *-ous*. The higher-charged ion uses the Latin root plus the suffix *-ic*.

For metal ions, the systematic (roman numeral) names are preferred, but the common names are often encountered.

Most courses require that the names and symbols for the following ions, and perhaps others, be memorized.

Ion Symbol	Systematic Ion Name	Common Ion Name
Cu^+	copper(I)	cuprous
Cu^{2+}	copper(II)	cupric
Fe^{2+}	iron(II)	ferrous
Fe^{3+}	iron(III)	ferric
Sn^{2+}	tin(II)	stannous
Sn^{4+}	tin(IV)	stannic
Hg_2^{2+}	mercury(I)	mercurous
Hg^{2+}	mercury(II)	mercuric

Lead also forms two ions. Pb^{2+} is named lead(II), and Pb^{4+} is named lead(IV). The common names plumbous and plumbic are rarely used.

Note the exceptional name and structure of the mercury (I) ion. Mercury (I) is the only frequently encountered metal ion that is polyatomic: It has the structure of a diatomic ion with a 2+ charge. It is given the name mercury (I) matching the format of other metal ions, in part because it behaves in many respects as two loosely bonded +1 ions.

When to Include Roman Numerals In Systematic Names

When naming metal ions, the *rule* is: Do *not* use roman numerals in systematic names for metal ions that can form only *one* stable ion: ions for atoms in the first two columns, plus Ni^{2+} , Ag^+ , Zn^{2+} , Cd^{2+} , and Al^{3+} .

However, for ions of the transition metals, adding the roman numeral, such as using nickel(II) for Ni^{2+} , may be acceptable in your course.

Summary: Metal Ion Rules

- All metal ions are positive. Except for Hg_2^{2+} , all metal atoms are monatomic.
- In column one, all elements tend to form 1+ ions.
- In column two, all elements tend to form 2+ ions.
- For the metals to the right of column 2, five metals form only one ion: Ni^{2+} , Ag^+ , Zn^{2+} , Cd^{2+} , and Al^{3+} . Assume that the others form more than one ion.
- If a metal forms only one ion, the ion name is the element name.
- If a metal forms **more** than one ion, the systematic ion name is the element name followed by a roman numeral in parentheses showing the positive charge of the ion.

Flashcards: Using the flashcard steps in Lesson 2C, make cards for any of these that you cannot answer from memory.

One-way cards (with notch)

Back Side -- Answers

cation	positive ion
anion	negative ion
Monatomic ion	one atom with a charge
Polyatomic ion	2 or more bonded atoms with an overall charge
All metal ions (except mercurous) are	Monatomic – contain only one atom
The charge on a metal ion is always	positive
Column one ions have what charge?	+1
Column two ions have what charge?	+2
When is () in <i>ion</i> name needed?	In systematic names, if the metal forms more than one kind of positive ion
In systematic names for metal ions, which do <i>not</i> need (roman numerals) to show their charge?	Columns 1 and 2, plus Ni^{2+} , Ag^+ , Zn^{2+} , Cd^{2+} , and Al^{3+}

Practice A: Use a periodic table. Memorize the rules, ion symbols, and names in the section above *before* doing the problems. On multi-part questions, save a few parts for your next study session.

- Add a charge to show the symbol for the stable ion that these elements form.
 - Ba
 - Al
 - Rb
 - Na
 - Zn
 - Ag
- Write the symbols for these ions.
 - Cadmium ion
 - Lithium ion
 - Hydride ion
 - Calcium ion
- Which ions in Problems 1 and 2 are anions?
- Write the name and symbol for a polyatomic metal ion often encountered.
- Fill in the blanks.

Ion Symbol	Systematic Ion Name	Common Ion Name
		Stannic
		Cupric
	Iron(III)	
	Copper(I)	
Fe^{2+}		

Monatomic Anions

Nine monatomic anions are often encountered in first-year chemistry. Their names and symbols should be memorized.

- One is H^- (hydride).
- Four are halides (the -1 ions of halogens): fluoride, chloride, bromide, and iodide (F^- , Cl^- , Br^- , and I^-).
- Two are in tall column 6A: oxide (O^{2-}) and sulfide (S^{2-}).
- Two are in tall column 5A: nitride (N^{3-}), and phosphide (P^{3-}).

For monatomic anions, the name is the root of the element name followed by *-ide*.

For monatomic ions, the position of the element in the periodic table predicts the charge.

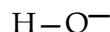
Group	1A	2A	Transition Metals	3A	4A	5A	6A	7A	8A	
Family Name	Alkali Metals						N Family	O Family	Halogens	Noble Gases
Charge on Monatomic ion	1 +	2 +			3 + (or 1+)		3 –	2 –	1 –	None

Polyatomic Ions

A polyatomic ion is a particle that both has two or more atoms held together by covalent bonds and has an overall electrical charge. In polyatomic ions, the total number of protons and electrons in the particle is not equal.

An example of a polyatomic ion is the hydroxide ion, OH^- . One way to form this ion is to start with a neutral water molecule $\text{H}-\text{O}-\text{H}$, which has $1+8+1 = 10$ protons and 10 balancing electrons, and take away an H^+ ion (which has one proton and no electrons).

The result is a particle composed of two atoms with a total of 9 protons and 10 electrons. Overall, the particle has a negative charge. The negative charge behaves as if it is attached to the oxygen. A structural formula for the hydroxide ion is



Polyatomic ions will be considered in more detail when studying the three-dimensional structure of particles. At this point, our interest is the *ratios* in which ions combine. For that purpose, it may help to think of a monatomic ion as a charge that has one atom attached, and a polyatomic ion as a charge with several atoms attached.

Polyatomic Cations

Three polyatomic cations with names and symbols that should be memorized are the NH_4^+ (ammonium), H_3O^+ (hydronium), and Hg_2^{2+} (mercury(I) or mercurous) ions.

Oxyanions

Polyatomic ions with negative charges that contain non-metals and oxygen are termed **oxyanions**.

Oxyanions are often part of a *series* of ions that has one *common* atom and the same charge, but different numbers of oxygen atoms.

Example: Nitrate ion = NO_3^- , nitrite ion = NO_2^-

The names and symbols for most oxyanions can be determined from the following rules.

Oxyanion Naming System

1. When an atom has *two* oxyanions that have the same charge, the ion with more oxygens is named *root-ate*, and the ion with one fewer oxygen atoms is *root-ite*.

Example: Sulfate is SO_4^{2-} . Sulfite is SO_3^{2-}

2. If an atom has *more* than two oxyanions with the same charge, the
- *per-root-ate* ion has X oxygen atoms;
 - *root-ate* ion has one fewer oxygens;
 - *root-ite* ion has 2 fewer oxygens;
 - *hypo-root-ite* ion has 3 fewer oxygens.

Example: Memorize that the ClO_4^- ion is named *perchlorate*. Then,

- ClO_3^- is **chlorate**;
- ClO_2^- is **chlorite**;
- ClO^- is **hypochlorite**.

To simplify naming these ions, memorize the formula for *one* ion in a series, then write out the rest by logic as needed. With practice, this naming process will become automatic.

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Memorizing the Ion Names and Formulas

In most courses, you will be asked to memorize the names and formulas for a list of frequently encountered ions. Even if it is not required, doing so will speed your work and improve your understanding of chemistry.

The following set of flashcards is information that you will rely on heavily for the remainder of the year. You may want to use a unique card color to identify these as the *ion* cards, or add the word *ion* for clarity after each ion name.

Your course may not require that you know the “latin” names for the metal ions that have more than one possible charge, but learning those names and charges will help you to recall what charges are likely to be found on those metal ions.

Make and learn these flashcards on 3" by 5" index cards

CH_3COO^-	acetate
CN^-	cyanide
OH^-	hydroxide
NO_3^-	nitrate
MnO_4^-	permanganate
CO_3^{2-}	carbonate
HCO_3^-	hydrogen carbonate
CrO_4^{2-}	chromate
$\text{Cr}_2\text{O}_7^{2-}$	dichromate
PO_4^{3-}	phosphate
SO_4^{2-}	sulfate
SO_3^{2-}	sulfite
Na^+	sodium ion
K^+	potassium ion
Al^{3+}	aluminum ion
F^-	fluoride
Cl^-	chloride
Br^-	bromide
I^-	iodide
Ca^{2+}	calcium ion
Ba^{2+}	barium ion

Cu^+	cuprous
Cu^{2+}	cupric
Fe^{2+}	ferrous
Fe^{3+}	ferric
Sn^{2+}	stannous
Sn^{4+}	stannic
Hg_2^{2+}	mercurous or mercury (I)
Hg^{2+}	mercuric
O^{2-}	oxide
S^{2-}	sulfide
N^{3-}	nitride
P^{3-}	phosphide
ClO_4^-	perchlorate
ClO_3^-	chlorate
ClO_2^-	chlorite
ClO^-	hypochlorite
H^+	hydrogen ion
H^-	hydride
Mg^{2+}	magnesium ion
NH_4^+	ammonium
H_3O^+	hydronium

* * * * *

Practice B: Learn the rules and run the flashcards for the ion names and symbols in the section above, *then* try these problems. Work in your notebook. Repeat these again after a few days of flashcard practice.

1. In this chart of ions, from memory, add *charges, names, and ion formulas*.

Symbol	Ion name
	acetate
CN	
	silver
	hydroxide
Al	
ClO ₄	
	nitrate
	sodium
F	

CO ₃	
	radium
MnO ₄	
CrO ₄	
K	
	dichromate
PO ₄	
	sulfate
	sulfide
Ba	

2. Circle the **polyatomic** ion symbols in the left column of Problem 1 above.
3. If NO₃⁻ is a nitrate ion, what is the symbol for a nitrite ion?
4. Complete this table for the series of oxyanions containing bromine.

Ion name	Ion Symbol
Per_____	_____
_____	BrO ₃ ⁻
Bromite	_____
Hypo_____	_____

ANSWERS

Practice A

1. a. Ba²⁺ b. Al³⁺ c. Rb⁺ d. Na⁺ e. Zn²⁺ f. Ag⁺
2. a. Cd²⁺ b. Li⁺ c. H⁻ d. Ca²⁺ 3. Only the hydride ion (H⁻). 4. Hg₂²⁺

5.

Ion Symbol	Systematic Ion Name	Common Name
Sn⁴⁺	tin(IV)	stannic
Cu²⁺	copper(II)	cupric
Fe³⁺	iron(III)	ferric
Cu⁺	copper(I)	cuprous
Fe ²⁺	iron(II)	ferrous

Practice B

1,2.

Symbol	Ion name
CH₃COO⁻	acetate
CN ⁻	cyanide
Ag⁺	silver
OH⁻	hydroxide
Al ³⁺	aluminum
ClO ₄ ⁻	perchlorate
NO₃⁻	nitrate
Na⁺	sodium
F ⁻	fluorine

CO ₃ ²⁻	carbonate
Ra²⁺	radium
MnO ₄ ⁻	permanganate
CrO ₄ ²⁻	chromate
K ⁺	potassium
Cr ₂ O ₇ ²⁻	dichromate
PO ₄ ³⁻	phosphate
SO ₄ ²⁻	sulfate
S ²⁻	sulfide
Ba ²⁺	barium

3. **NO₂⁻**

4.

Ion name	Ion Symbol
Per br omate	BrO₄⁻
Brom ate	BrO ₃ ⁻
Bromite	BrO₂⁻
Hypobromite	BrO⁻

Lesson 7C: Names and Formulas for Ionic Compounds

Pretest: Using a periodic table, if you get these right 100%, you may skip the lesson. Answers are at the end of the lesson.

1. Name $\text{Pb}_3(\text{PO}_4)_2$ 2. Write formulas for a. tin(IV) chlorate b. radium nitrate.

* * * * *

Ionic Compounds: Fundamentals

Positive and negative ions combine to form ionic compounds. Ionic compounds must have both positive and negative ions.

There is only *one ratio* possible for the ions in a compound. The ions must combine in a ratio that results in electrical neutrality. This means that the *charges* in any ionic substance must *balance*. The overall charge of any stable combination of ions must be zero.

Names and Formulas

The composition of an ionic compound can be expressed in three ways.

- In a **name**; Example: ammonium phosphate
- As a **solid** formula; Example: $(\text{NH}_4)_3\text{PO}_4$
- As balanced, **separated ions**. Example: $3 \text{NH}_4^+ + 1 \text{PO}_4^{3-}$

As a part of solving many upcoming chemistry problems, given one of these expressions, you will need to be able to write the other two.

Ionic compounds can initially be confusing because their names and solid formulas do not clearly identify the *charges* on the ions. The key to writing a correct name and solid formula is to first write the *separated-ions* formula that shows the number and the formulas of the ions in the combination, including their charges.

For ionic compounds, the fundamental rules for writing names and formulas are:

- Always write the *separated-ions* formula *first*, and
- Add *coefficients* that balance the *charges*.

Balancing Separated Ions

In all combinations of ions, whether in solids, melted, or dissolved in water, the total charges on the ions must balance: the total number of positive charges must equal the total number of negative charges, so that the overall charge is *zero*.

In problems, you will often be asked to determine the *ratios* that balance the charges. The way to find those ratios is to write a balanced *separated-ions* formula for the compound. Let's learn the method with an example.

- Q.** Find the ratio that balances the charges when S^{2-} and Na^+ combine.

Try this problem using these steps, *then* check your answer below.

Step 1: Write the symbols for the two ions in the compound, with their charges, separated by a + sign. It is preferred to put the positive ion first.

Step 2: **Coefficients** are numbers written in *front* of ion or particle symbols. In all ion combinations,

(Coefficient *times* charge of cation) must equal (coefficient *times* charge of anion).

Write the whole-number coefficients in front of the ion formulas that *make* the positive and negative charges balance.

In balancing, you *cannot* change the symbol or the stated charge of an ion. The only change allowed is to add coefficients in front of the particle symbols.

Step 3: Reduce the coefficients to the *lowest* whole-number ratios.

* * * * *

Answer **Step 1:** $\text{Na}^+ + \text{S}^{2-}$

Step 2: $2 \text{Na}^+ + 1 \text{S}^{2-}$ This is the *separated*-ions formula.

The coefficients that balance the charges show the ratios in which the ions must exist in the compound.

Step 3: 2 and 1 are the lowest whole-number ratios.

There *must* be *two* sodium ions for every *one* sulfide ion. Why? For the charges, (2 times $1+ = 2+$) balances (1 times $2- = 2-$). In ion combinations, the ions are always present in ratios so that the total positive and negative *charges* balance.

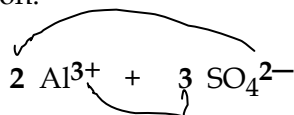
Only one set of coefficient *ratios* will balance the charges. The coefficients identify the ratios in which the ions are found in the compound.

Try another. Cover the answer below, then try this question using the steps above.

Q. Add coefficients so that the charges balance: $\underline{\quad} \text{Al}^{3+} + \underline{\quad} \text{SO}_4^{2-}$

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Answer: An easy way to find the coefficients is to make the coefficient of each ion equal to the *number of charges* of the *other* ion.



For these ions, (2 times $+3 = +6$) balances (3 times $-2 = -6$). In an ionic compound, the total positives and total negatives must balance.

However, when balancing charge when using this method, you must often adjust the coefficients so that the *final* coefficients are the *lowest* whole-number ratios.

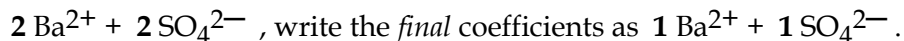
Try this problem.

Q. Add proper coefficients: $\underline{\quad} \text{Ba}^{2+} + \underline{\quad} \text{SO}_4^{2-}$

* * * * *

Answer

If balancing produces a ratio of



When balancing ions, make the coefficients the *lowest whole-number ratios*.

Practice A: Add lowest-whole-number coefficients to make these separated ions balanced for charge. After every two, check your answers at the end of the lesson.

- | | |
|--|--|
| 1. ___ Na^+ + ___ Cl^- | 5. ___ NH_4^+ + ___ CH_3COO^- |
| 2. ___ Ca^{2+} + ___ Br^- | 6. ___ In^{3+} + ___ CO_3^{2-} |
| 3. ___ Mg^{2+} + ___ SO_4^{2-} | 7. ___ Al^{3+} + ___ PO_4^{3-} |
| 4. ___ Cl^- + ___ Al^{3+} | 8. ___ HPO_4^{2-} + ___ In^{3+} |

Writing the Separated Ions from Names

To write the separated ions from the *name* of an ionic compound, use these steps.

Step 1: Write the symbols for the two named ions, with their charges, separated by a + sign. The first word in the name is always the positive ion.

Step 2: Add lowest-whole-number coefficients to balance the charges.

Try those the steps on this problem:

Q. Write a balanced separated-ions formula for aluminum carbonate.

* * * * *

Answer: Step 1: Aluminum carbonate \rightarrow $\text{Al}^{3+} + \text{CO}_3^{2-}$

Step 2: Aluminum carbonate \rightarrow $2 \text{Al}^{3+} + 3 \text{CO}_3^{2-}$

The separated-ions formula shows clearly what the name does not. In aluminum carbonate, there must be 2 aluminum ions for every 3 carbonate ions.

When writing separated ions, write the charge *high*, the subscript *low*, and the coefficient at the *same* level as the symbol.

Practice B

If you have not done so today, run your ion flashcards one more time. Then write balanced separated-ions formula for the ionic compounds below. You may use a periodic table, but otherwise write the ion formulas from memory. Check answers as you go.

- Sodium hydroxide \rightarrow
- Aluminum chloride \rightarrow

3. Rubidium sulfite →
4. Ferric nitrate →
5. Lead(II) phosphate →
6. Calcium chlorate →

Writing Solid Formulas From Names

In ionic solid formulas, charges are hidden, but charges must balance. The key to writing a correct solid formula is to write the balanced *separated*-ions first, so that you can see and balance the charges.

To write a *solid* formula from the name of an ionic compound, use these steps.

1. Based on the name, write the *separated* ions. Add lowest whole number coefficients to balance charge. Then, to the right, draw an arrow → .
 2. After the →, write the two ion symbols, positive ion first, with a small space between them. Include any *subscripts* that are part of the ion symbol, but *no* charges or coefficients.
 3. For the ion symbols written after the arrow, **put parentheses ()** around a **polyatomic ion** if its coefficient in the *separated*-ions formula is more than 1.
 4. Add *subscripts* after each symbol on the right. The subscript will be the same as the coefficient in front of that ion in the *separated*-ions formula.
- Omit subscripts of 1. For polyatomic ions, write the coefficients as subscripts *outside* and *after* the parentheses.

Apply those four steps to this example.

Q. Write the solid formula for potassium sulfide.

* * * * *

Answer

- 1: Write the *separated*-ions formula first. For potassium sulfide: $2 \text{K}^+ + 1 \text{S}^{2-}$
- 2: Re-write the symbols without coefficients or charges. $2 \text{K}^+ + 1 \text{S}^{2-} \rightarrow \text{K S}$
- 3: Since both K and S ions are monatomic, add no parentheses.
- 4: The K coefficient becomes a solid formula subscript: $2 \text{K}^+ + 1 \text{S}^{2-} \rightarrow \text{K}_2\text{S}$

The sulfide subscript of one is omitted as understood.

The *solid* formula for potassium sulfide is **K₂S**.

* * * * *

Try another using the same steps.

Q. Write the solid formula for magnesium phosphate.

★ ★ ★ ★ ★

Answer

1: Write the balanced separated ions. Magnesium phosphate $\rightarrow 3 \text{Mg}^{2+} + 2 \text{PO}_4^{3-}$

2: Write symbols without coefficients or charges. $3 \text{Mg}^{2+} + 2 \text{PO}_4^{3-} \rightarrow \text{Mg PO}_4$

3: Since Mg^{2+} is *monatomic* (just one atom), it is not placed in parentheses.

Phosphate is *both polyatomic and* we need >1 , so add (). $\text{Mg (PO}_4)$

4: The separated coefficient of the Mg ion becomes its solid subscript. $\text{Mg}_3(\text{PO}_4)$

The phosphate ion's separated coefficient becomes its solid subscript. $\text{Mg}_3(\text{PO}_4)_2$

$\text{Mg}_3(\text{PO}_4)_2$ is the *solid* formula for magnesium phosphate.

Recite the *3-P's rule* for ionic-solid formulas until it is memorized.

➤ **Put parentheses around polyatomic ions -- if you need more than one.**

Practice C: As you go, check the answers at the end of the lesson. You may want to do half of the lettered parts today, and the rest during your next study session.

1. Circle the polyatomic ions.

a. Na^+ b. NH_4^+ c. CH_3COO^- d. Ca^{2+} e. OH^-

2. When do you need parentheses? Write the rule from memory.

3. Write solid formulas for these ion combinations.

a. $2 \text{K}^+ + 1 \text{CrO}_4^{2-} \rightarrow$

b. $2 \text{NH}_4^+ + 1 \text{S}^{2-} \rightarrow$

c. $1 \text{SO}_3^{2-} + 1 \text{Sr}^{2+} \rightarrow$

4. Balance these separated ions for charge, then write solid formulas.

a. $\text{Cs}^+ + \text{N}^{3-} \rightarrow$

b. $\text{Cr}_2\text{O}_7^{2-} + \text{Ca}^{2+} \rightarrow$

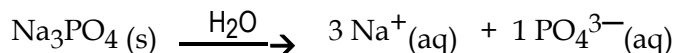
c. $\text{Sn}^{4+} + \text{SO}_4^{2-} \rightarrow$

5. From these names, write the separated-ions formula, then the solid formula.
 - a. Ammonium sulfite →
 - b. Potassium permanganate →
 - c. Calcium hypochlorite →
 - d. Sodium hydrogen carbonate →
6. Write the solid formula.
 - a. Stannous fluoride →
 - b. Calcium hydroxide →
 - c. Radium acetate →

Writing Separated Ions From Solid Formulas

When placed in water, all ionic solids dissolve to *some* extent. The dissolved ions separate and move about in the solution.

This dissolving process can be represented by a chemical equation that has a solid on the left and the separated ions on the right. For example, when solid sodium phosphate dissolves in water, the equation is



The (s) is an abbreviation for *solid*, and (aq) is an abbreviation for **aqueous**, which means “dissolved in water.”

An equation for ion separation must balance atoms, balance charge, and result in the correct formulas for the ions that are actually found in the solution.

In equations for an ionic solid separating into its ions, some subscripts in the solid formula become coefficients in the separated ions, but others do not. In the equation above, the subscript 3 became a coefficient, but the subscripts 1 and 4 did not. To correctly separate solid formulas into ions, you must be able to recognize the ions inside the solid formula.

Cover the answer below, try this example, then check the answer for tips that will make this process easier. When needed, read a part of the answer for a hint, then try again.

Q. Write the equation for the ionic solid Cu_2CO_3 separating into its ions.

* * * * *

Answer: Follow these steps in going from a solid formula to separated ions.

Step 1: Decide the *negative* ion's charge and coefficient first.

The first ion in a solid formula is always the positive ion, but many metal ions can have two possible positive charges. Most negative ions only have one likely charge, and that charge will identify the positive ion's charge, so do the negative ion first.

In Cu_2CO_3 , the negative ion is CO_3 , which always has a $2-$ charge.

This step temporarily splits the solid formula into Cu_2 and 1CO_3^{2-} .

Step 2: Decide the positive ion's charge and coefficients.

Given Cu_2 and CO_3^{2-} , the positive ion or ions must include **2** copper atoms *and* must have a total **2+** charge to balance the charge of CO_3^{2-} .

So Cu_2 , in the separated-ions formula, must be *either* 1Cu_2^{2+} *or* 2Cu^+ .

Both possibilities balance atoms and charge. Which is correct? Recall that

All *metal* ions are *monatomic* (except Hg_2^{2+} (mercury(I) ion)).

This means that Cu^+ must be the ion that forms, since Cu_2^{2+} is polyatomic.

Because most metal ions are monatomic, a solid formula with a metal ion will separate



You also know that Cu^+ is the copper(I) ion that was previously memorized because it is frequently encountered. Both rules lead us to predict that the equation for ion separation is



Copper can also be a Cu^{2+} ion, but in the formula above, there is only one carbonate, and carbonate always has a $2-$ charge. Two Cu^{2+} ions cannot balance the single carbonate.

Step 3: Check. Make sure that the charges balance. Make sure that the number of atoms of each kind is the same on both sides. The equation must also make sense going backwards, from the separated to the solid formula.

Try another.

Q2. Write the equation for the ionic solid $(\text{NH}_4)_2\text{S}$ dissolving to form ions.

* * * * *

Answer

- In a solid formula, parentheses are placed around polyatomic ions. When you write the separated ions, a subscript after parentheses *always* becomes the polyatomic ion's *coefficient*.

You would therefore split the formula $(\text{NH}_4)_2\text{S} \rightarrow 2 \text{NH}_4 + 1 \text{S}$

- Assign the charges that these ions prefer. $(\text{NH}_4)_2\text{S} \rightarrow 2 \text{NH}_4^+ + 1 \text{S}^{2-}$
- Check. In the separated formula, do the charges balance?

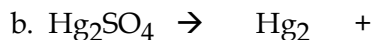
Going backwards, do the separated ions combine to give the solid formula?

Keep up your practice, for 15-20 minutes a day, with your *ion* name and formula flashcards (Lesson 7B). Identifying ions without consulting a table will be essential in the complex problems ahead.

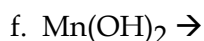
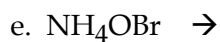
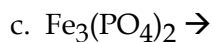
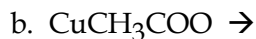
Practice D

If you have not done so today, run your ion flashcards in both directions, then try these. To take advantage of the “spacing effect” (Lesson 2C), do half of the lettered parts below today, and the rest during your next study session.

1. Finish balancing by adding ions, coefficients, and charges.



2. Write equations for these ionic solids separating into ions.



Naming Ionic Compounds

From a solid or a separated-ions formula, writing the *name* is easy.

- Step 1: Write the separated-ions formula.
 Step 2: Write the *name* of the positive ion in the formula.
 Step 3: Write the name of the negative ion.

That's it! In ionic compounds, the name ignores the number of ions inside. Simply name the ions in the compound, with the positive ion named first. Try this problem.

Q. What is the name of K_2CO_3 ?

* * * * *

Answer

$K_2CO_3 \rightarrow 2 K^+ + 1 CO_3^{2-}$; the name is potassium carbonate.

With time, you will be able to convert solid formulas to compound names without writing the separated ions, but the only way to develop this accurate intuition is by practice.

Practice E: If you are unsure of an answer, check it before continuing.

- Return to Practice D and name each compound.
- In Practice C, Problems 3 and 4, name each compound.
- Would CBr_4 be named carbon bromide or carbon tetrabromide? Why?
- Name these ionic and covalent compounds. Try half today and half during your next study session.

a. $CaBr_2$	b. NCl_3	c. NaH	d. $CuCl_2$
e. $RbClO_4$	f. KOI	g. Li_3P	h. PbO
i. NH_4BrO_2	j. SO_2	k. $CaSO_3$	l. P_4S_3

Flashcards: Add these to your collection.

One-way cards (with notch)

Back Side -- Answers

What must be true in all ionic substances?	Total + charges = total – charges Must be electrically neutral
Numbers you add to balance separated ions	coefficients
To understand ionic compounds:	Write the <i>separated-ion</i> formulas
When are parentheses needed in formulas?	In <i>solid</i> formulas, put parentheses around polyatomic ions -- <i>if you need >1</i>
In separated-ion formulas, what do the coefficients tell you?	The ratio in which the ions must be present to balance atoms and charge

* * * * *

Practice F: Combining Ions Worksheet

Fill in the blanks. Do half today and the rest during your next study session. Check answers at the end of the lesson.

Ionic Compound NAME	SEPARATED Ions	SOLID Formula
<ul style="list-style-type: none"> Name by ion names Must be two or more words Put name of + ion first 	<ul style="list-style-type: none"> Charges must show Charges must balance Charges may flow Coefficients tell ratio of ions 	<ul style="list-style-type: none"> Positive ion first Charges balance, but don't show Put () around polyatomic ions IF you need >1
Sodium chloride	$1 \text{ Na}^+ + 1 \text{ Cl}^-$	NaCl
	$2 \text{ Al}^{3+} + 3 \text{ SO}_3^{2-}$	$\text{Al}_2(\text{SO}_3)_3$
Lithium carbonate		
Potassium hydroxide		
	$__ \text{ Ag}^+ + __ \text{ NO}_3^-$	
	$__ \text{ NH}_4^+ + __ \text{ SO}_4^{2-}$	
		FeBr ₂
		Fe ₂ (SO ₄) ₃
Cuprous chloride		
Tin(II) fluoride		
	$__ \text{ Al}^{3+} + __ \text{ Cr}_2\text{O}_7^{2-}$	
		K ₂ CrO ₄
		CaCO ₃
Aluminum phosphate		

ANSWERS

Pretest: 1. Lead(II) phosphate 2a. $\text{Sn}(\text{ClO}_3)_4$ 2b. $\text{Ra}(\text{NO}_3)_2$

Practice A

- | | | |
|--|--|---|
| 1. $1 \text{ Na}^+ + 1 \text{ Cl}^-$ | 4. $3 \text{ Cl}^- + 1 \text{ Al}^{3+}$ | 7. $1 \text{ Al}^{3+} + 1 \text{ PO}_4^{3-}$ |
| 2. $1 \text{ Ca}^{2+} + 2 \text{ Br}^-$ | 5. $1 \text{ NH}_4^+ + 1 \text{ CH}_3\text{COO}^-$ | 8. $3 \text{ HPO}_4^{2-} + 2 \text{ In}^{3+}$ |
| 3. $1 \text{ Mg}^{2+} + 1 \text{ SO}_4^{2-}$ | 6. $2 \text{ In}^{3+} + 3 \text{ CO}_3^{2-}$ | |

Practice B

- | | |
|--|---|
| 1. Sodium hydroxide $\rightarrow 1 \text{ Na}^+ + 1 \text{ OH}^-$ | 4. Ferric nitrate $\rightarrow 1 \text{ Fe}^{3+} + 3 \text{ NO}_3^-$ |
| 2. Aluminum chloride $\rightarrow 1 \text{ Al}^{3+} + 3 \text{ Cl}^-$ | 5. Lead(II) phosphate $\rightarrow 3 \text{ Pb}^{2+} + 2 \text{ PO}_4^{3-}$ |
| 3. Rubidium sulfite $\rightarrow 2 \text{ Rb}^+ + 1 \text{ SO}_3^{2-}$ | 6. Calcium Chlorate $\rightarrow 1 \text{ Ca}^{2+} + 2 \text{ ClO}_3^-$ |

Practice C

- The polyatomic ions: b. NH_4^+ c. CH_3COO^- e. OH^-
 - For ionic solid formulas, put parentheses around polyatomic ions IF you need more than one.
- | | |
|---|---|
| 3a. $2 \text{ K}^+ + 1 \text{ CrO}_4^{2-} \rightarrow \text{K}_2\text{CrO}_4$ | 4a. $3 \text{ Cs}^+ + 1 \text{ N}^{3-} \rightarrow \text{Cs}_3\text{N}$ |
| 3b. $2 \text{ NH}_4^+ + 1 \text{ S}^{2-} \rightarrow (\text{NH}_4)_2\text{S}$ | 4b. $1 \text{ Cr}_2\text{O}_7^{2-} + 1 \text{ Ca}^{2+} \rightarrow \text{CaCr}_2\text{O}_7$ |
| 3c. $1 \text{ SO}_3^{2-} + 1 \text{ Sr}^{2+} \rightarrow \text{SrSO}_3$ | 4c. $1 \text{ Sn}^{4+} + 2 \text{ SO}_4^{2-} \rightarrow \text{Sn}(\text{SO}_4)_2$ |
| 5a. $2 \text{ NH}_4^+ + 1 \text{ SO}_3^{2-} \rightarrow (\text{NH}_4)_2\text{SO}_3$ | 5c. $1 \text{ Ca}^{2+} + 2 \text{ OCl}^- \rightarrow \text{Ca}(\text{ClO})_2$ |
| 5b. $1 \text{ K}^+ + 1 \text{ MnO}_4^- \rightarrow \text{KMnO}_4$ | 5d. $1 \text{ Na}^+ + 1 \text{ HCO}_3^- \rightarrow \text{NaHCO}_3$ |
- Write balanced, separated ions first to help with the solid formula.
 - Stannous fluoride $\rightarrow 1 \text{ Sn}^{2+} + 2 \text{ F}^- \rightarrow \text{SnF}_2$
 - Calcium hydroxide $\rightarrow 1 \text{ Ca}^{2+} + 2 \text{ OH}^- \rightarrow \text{Ca}(\text{OH})_2$
 - Radium acetate $\rightarrow 1 \text{ Ra}^{2+} + 2 \text{ CH}_3\text{COO}^- \rightarrow \text{Ra}(\text{CH}_3\text{COO})_2$

Practice D and E

- $\text{PbCO}_3 \rightarrow 1 \text{ Pb}^{2+} + 1 \text{ CO}_3^{2-}$ (Lead(II) carbonate)
 - $\text{Hg}_2\text{SO}_4 \rightarrow 1 \text{ Hg}_2^{2+} + 1 \text{ SO}_4^{2-}$ (Mercurous sulfate or Mercury(I) sulfate)
- $\text{KOH} \rightarrow 1 \text{ K}^+ + 1 \text{ OH}^-$ (Potassium hydroxide)
 - $\text{CuCH}_3\text{COO} \rightarrow 1 \text{ Cu}^+ + 1 \text{ CH}_3\text{COO}^-$ (Copper(I) acetate or cuprous acetate)
 - $\text{Fe}_3(\text{PO}_4)_2 \rightarrow 3 \text{ Fe}^{2+} + 2 \text{ PO}_4^{3-}$ (Iron(II) phosphate or ferrous phosphate)
 - $\text{Ag}_2\text{CO}_3 \rightarrow 2 \text{ Ag}^+ + 1 \text{ CO}_3^{2-}$ (Silver carbonate)
 - $\text{NH}_4\text{OBr} \rightarrow 1 \text{ NH}_4^+ + 1 \text{ BrO}^-$ (Ammonium hypobromite)
 - $\text{Mn}(\text{OH})_2 \rightarrow 1 \text{ Mn}^{2+} + 2 \text{ OH}^-$ (Manganese hydroxide)

- E2. C3a. Potassium chromate C3b. Ammonium sulfide C3c. Strontium sulfite
 C4a. Cesium nitride C4b. Calcium dichromate C4c. Tin(IV) sulfate *or* stannic sulfate
- E3: Carbon tetrabromide. Carbon is a nonmetal, so the compound is covalent (see Lesson 7A). Use *di-*, *tri-* prefixes in the names of *covalent* compounds. Practice recognizing the symbols of the nonmetals.
- E4. a. Calcium bromide b. Nitrogen trichloride c. Sodium hydride
 c. Copper(II) chloride or cupric chloride e. Rubidium perchlorate f. Potassium hypoiodite
 g. Lithium phosphide h. Lead(II) oxide i. Ammonium bromite j. Sulfur dioxide
 k. Calcium sulfite l. Tetraphosphorous trisulfide

Practice F

Ionic Compound NAME	SEPARATED Ions	SOLID Formula
Sodium chloride	$1 \text{ Na}^+ + 1 \text{ Cl}^-$	NaCl
Aluminum sulfite	$2 \text{ Al}^{3+} + 3 \text{ SO}_3^{2-}$	$\text{Al}_2(\text{SO}_3)_3$
Lithium carbonate	$2 \text{ Li}^+ + \text{CO}_3^{2-}$	Li_2CO_3
Potassium hydroxide	$1 \text{ K}^+ + 1 \text{ OH}^-$	KOH
Silver nitrate	$1 \text{ Ag}^+ + 1 \text{ NO}_3^-$	AgNO_3
Ammonium sulfate	$2 \text{ NH}_4^+ + 1 \text{ SO}_4^{2-}$	$(\text{NH}_4)_2\text{SO}_4$
Iron(II) bromide/Ferrous bromide	$1 \text{ Fe}^{2+} + 2 \text{ Br}^-$	FeBr_2
Iron(III) sulfate/Ferric sulfate	$2 \text{ Fe}^{3+} + 3 \text{ SO}_4^{2-}$	$\text{Fe}_2(\text{SO}_4)_3$
Cuprous chloride	$1 \text{ Cu}^+ + 1 \text{ Cl}^-$	CuCl
Tin(II) fluoride	$1 \text{ Sn}^{2+} + 2 \text{ F}^-$	SnF_2
Aluminum dichromate	$2 \text{ Al}^{3+} + 3 \text{ Cr}_2\text{O}_7^{2-}$	$\text{Al}_2(\text{Cr}_2\text{O}_7)_3$
Potassium chromate	$2 \text{ K}^+ + \text{CrO}_4^{2-}$	K_2CrO_4
Calcium carbonate	$1 \text{ Ca}^{2+} + 1 \text{ CO}_3^{2-}$	CaCO_3
Aluminum phosphate	$1 \text{ Al}^{3+} + 1 \text{ PO}_4^{3-}$	AlPO_4