The Basics of Naming Chemical Compounds For Chemistry 134

Part II –Polyatomic Ions and the Oxoanions

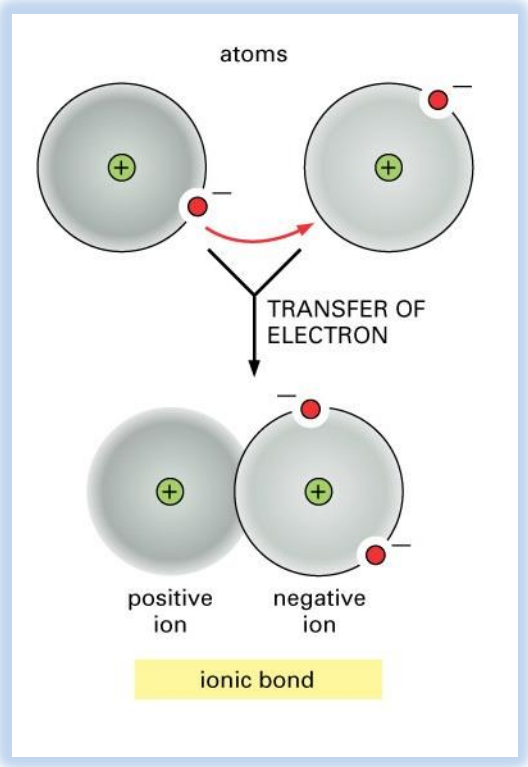
Goals and Objectives

After completing this module, you will be able to:

- Use **patterns** in the periodic table to help you remember the **polyatomic ions**.
- Write the **name** of a polyatomic ion, when given the formula.
- Write the **formula** for a polyatomic ion, when given the name.
- Apply the concepts from Part I of this series to **name compounds** that include polyatomic ions.

Ionic and Covalent Bonds

- In Part I, we discussed **ionic** bonds between metal and nonmetal ions.
- In Part II, we will also consider **covalent** bonds, generally formed between two **nonmetals**.



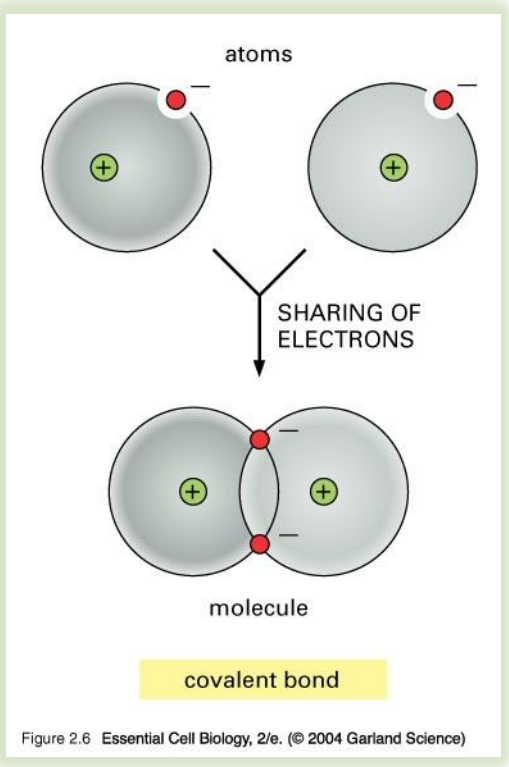
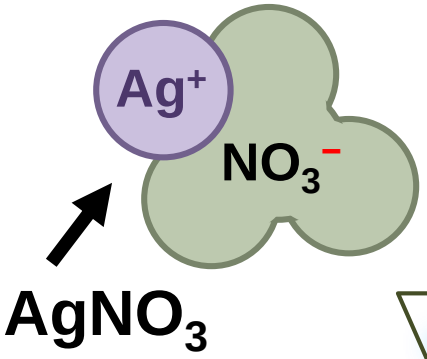


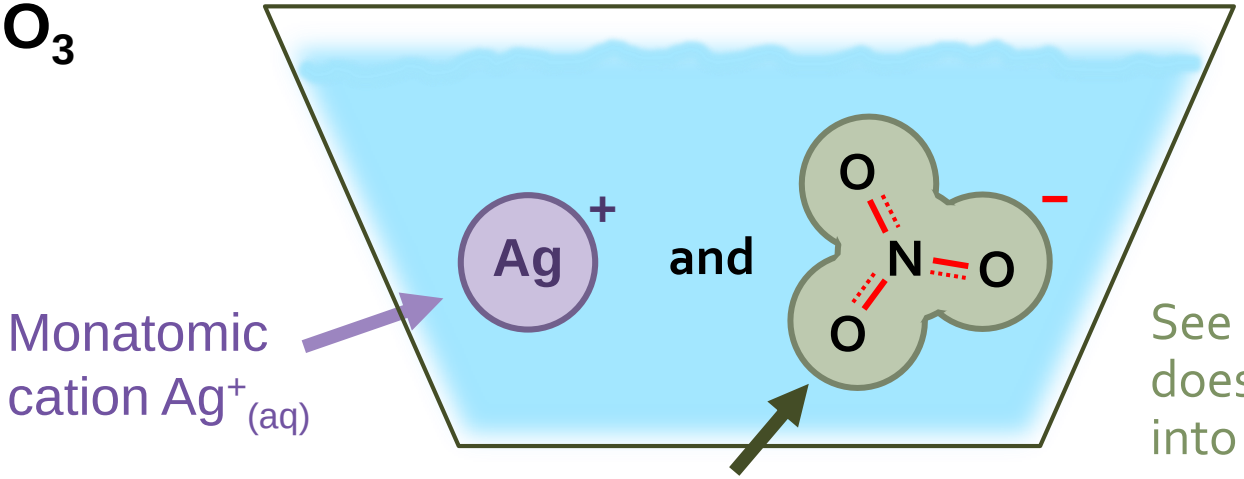
Figure 2.6 Essential Cell Biology, 2/e. (© 2004 Garland Science)

- In a **covalent** bond, electrons are **shared** between the atoms

Polyatomic Ions



Putting an $AgNO_3$ compound in water disrupts its **ionic** bond. It dissolves into:



See how NO_3^- doesn't separate into nitrogen and oxygen? These elements are still **covalently** bonded. That is why this is a polyatomic ion.

- Polyatomic ions are defined as elements **covalently** bonded together that carry charge as a unit.

Common Polyatomic Ions

Name	Formula	Name	Formula	Name	Formula
mercury(I) *(mercurous)*	Hg_2^{2+}	carbonate	CO_3^{2-}	arsenate	AsO_4^{3-}
		hydrogen carbonate	HCO_3^-	arsenite	AsO_3^{3-}
ammonium	NH_4^+				
		nitrate	NO_3^-	perchlorate	ClO_4^-
peroxide	O_2^{2-}	nitrite	NO_2^-	chlorate	ClO_3^-
				chlorite	ClO_2^-
hydroxide	OH^-	silicate	SiO_4^{4-}	hypochlorite	ClO^-
cyanide	CN^-	phosphate	PO_4^{3-}	bromate	BrO_3^-
thiocyanate	SCN^-	hydrogen phosphate	HPO_4^{2-}		
		dihydrogen phosphate	$H_2PO_4^-$	periodate	IO_4^-
formate	CHO_2^-	phosphite	PO_3^{3-}	iodate	IO_3^-
acetate	$C_2H_3O_2^-$				
oxalate	$C_2O_4^{2-}$	sulfate	SO_4^{2-}	chromate	CrO_4^{2-}
		hydrogen sulfate	HSO_4^-	dichromate	$Cr_2O_7^{2-}$
borate	BO_3^{3-}	sulfite	SO_3^{2-}		
		hydrogen sulfite	HSO_3^-	permanganate	MnO_4^-

While this looks like a lot, the following slides will discuss patterns that will help you remember these.

Polyatomic Ions: Module Outline

This module will:

- First present a small group of polyatomic **cations and anions** that have irregular names
- Next introduce the basics of **naming compounds** that include polyatomic ions
- Then tackle **oxoanions**, a large group of polyatomic ions. Including:
    - Oxoanions that follow a systematic pattern
    - Additional oxoanions that include hydrogen or transition metals
- Finally, work through more examples of naming compounds that include all these polyatomic ions.

Polyatomic Cations

There are only a couple of polyatomic **cations** you need to know:

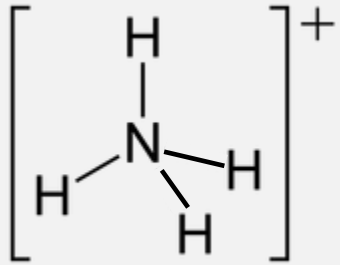
mercury(I)

Hg_2^{2+}

[Hg — Hg]$^{2+}$

ammonium

NH_4^+



Mercury(**I**) is a **polyatomic** ion. It is **two covalently bound** mercury atoms that share an **overall charge of 2+.** Each mercury **atom** has a **1+ charge.**

mercury(I) Hg^{1+} — Hg^{1+}

Mercury(**II**), in contrast, is a **monoatomic** ion. It is **one** mercury atom that has a **2+ charge**.

mercury(II) Hg^{2+}

Polyatomic Anions

You'll need to know the name and formula for these anions.

peroxide

O_2^{2-}

hydroxide

OH^-

cyanide

CN^-

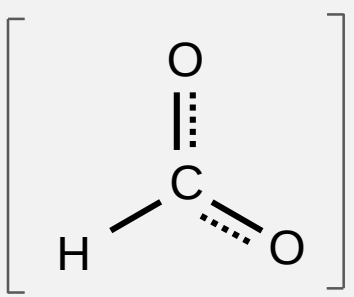
thiocyanate

SCN^-

formate

CHO_2^-

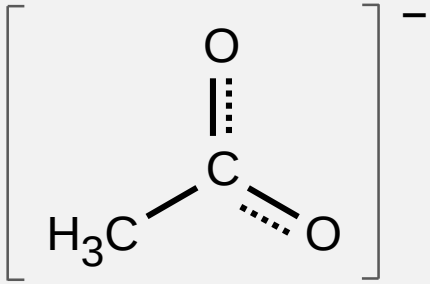
$(HCOO^-)$



acetate

$C_2H_3O_2^-$

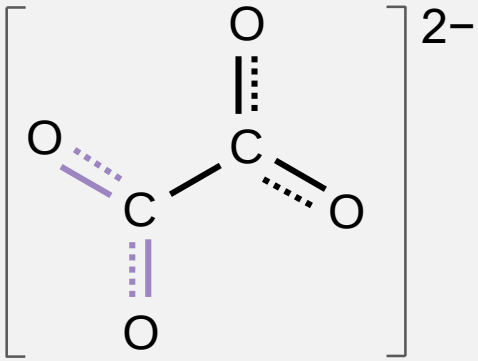
(CH_3COO^-)



oxalate

$C_2O_4^{2-}$

$(^-OOC\text{-}COO^-)$



You don't need to know the structures, they're only here to help you remember the formulas.

Naming Compounds Containing Polyatomic Ions

Use the rules from part I for naming ionic compounds. Wherever a polyatomic ion occurs, just use the name of the polyatomic ion.

1. First name the **cation**:
   Monoatomic: Name the element.
   Polyatomic: Name the polyatomic ion.
2. Name the **anion**:
   Monoatomic: Change the element's suffix to -ide.
   Polyatomic: Name the polyatomic ion.
3. When writing the chemical formula, write the symbol or formula of the cation first and then the symbol or formula of the anion.

Example:

KOH → Named as: potassium hydroxide

Practice Problem Set 1

Try it!

a) Write the name of NaCN

b) Write the formula for calcium acetate

And some trickier examples:

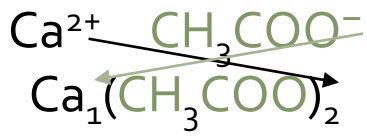
c) Write the name of H_2O_2

d) Write the formula for mercury(I) chloride

Practice Problem Set 1 Solutions

a) The ions in NaCN are Na^+ and CN^-, so it is named sodium cyanide.

b) Calcium acetate is calcium (Ca^{2+}) and acetate (CH_3COO^-).

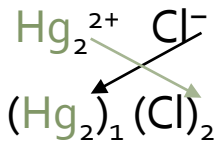


Use parentheses to enclose polyatomic ions when there is more than one of the ion in a compound.

The formula, with balanced charges, is $Ca(CH_3COO)_2$

c) H_2O_2 contains H^+ and O_2^{2-} ions, so it is hydrogen peroxide.

d) Mercury(I) chloride is mercury(I) (Hg_2^{2+}) and chloride (Cl^-).



The formula, with balanced charges, is Hg_2Cl_2

Note that the Hg_2Cl_2 and H_2O_2 formulas CANNOT be simplified further, since the Hg_2 and O_2 represent **covalently** bound **polyatomic** ions.

Polyatomic Ions: Oxoanions

Oxoanions are important polyatomic anions that contain oxygen.

While the list of oxoanions may look overwhelming, the next few slides will describe patterns in their names and formulas.

- The **most common** oxoanion for each element is named using the "-**ate**" suffix.
  - e.g. For NO_3^-, **nitr**ogen becomes **nitr**ate
- Many elements can form multiple oxoanions with varying numbers of oxygen atoms.
  - e.g. NO_3^- (nitrate) and NO_2^- (nitrite).

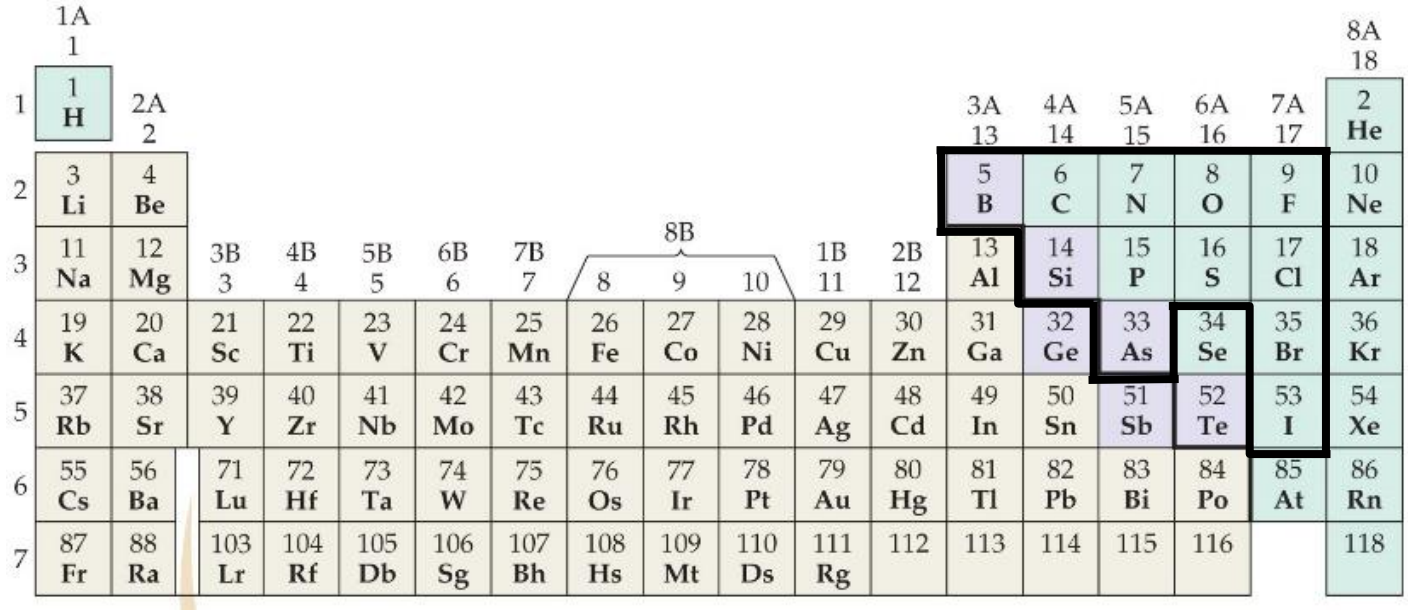
Oxoanions	
borate	BO_3^{3-}
carbonate	CO_3^{2-}
nitrate	NO_3^-
nitrite	NO_2^-
silicate	SiO_4^{4-}
phosphate	PO_4^{3-}
phosphite	PO_3^{3-}
sulfate	SO_4^{2-}
sulfite	SO_3^{2-}
arsenate	AsO_4^{3-}
arsenite	AsO_3^{3-}
perchlorate	ClO_4^-
chlorate	ClO_3^-
chlorite	ClO_2^-
hypochlorite	ClO^-
bromate	BrO_3^-
periodate	IO_4^-
iodate	IO_3^-

Remembering the "-ate" Oxoanions

We'll start by learning the **"-ate"** oxoanions of the highlighted elements (e.g. nitrate is NO_3^-).

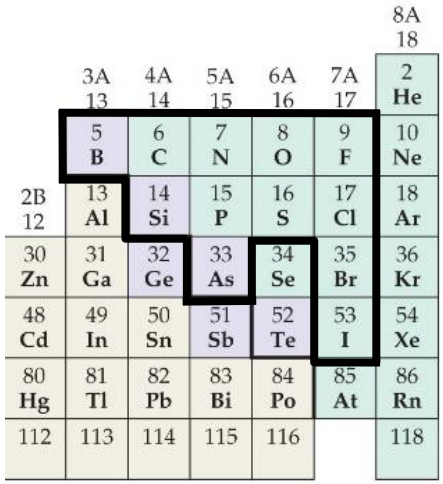
To remember the names and formulas of these ions, we will use the periodic table to see **patterns** in their:

- **charges** and
- **number of oxygen** atoms



Oxoanions — Patterns of **Charges**

3A 13	4A 14	5A 15	6A 16	7A 17
B BO_3^{3-} bor**ate**	C CO_3^{2-} carbon**ate**	N NO_3^{1-} nitr**ate**	O	F
	Si SiO_4^{4-} silic**ate**	P PO_4^{3-} phosph**ate**	S SO_4^{2-} sulf**ate**	Cl ClO_3^{1-} chlor**ate**
		As AsO_4^{3-} arsen**ate**		Br BrO_3^{1-} brom**ate**
				I IO_3^{1-} iod**ate**

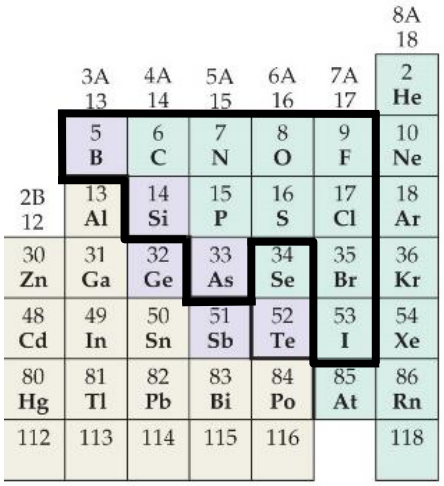


As you go **left** in the periodic table, the charge gets **more negative.**

"-ate" Oxoanions: Oxygen Atom Patterns

"-ate" ions with **3 oxygen atoms**

3A 13	4A 14	5A 15	6A 16	7A 17
B BO_3^{3-} bor**ate**	C CO_3^{2-} carbon**ate**	N NO_3^{1-} nitr**ate**	O	F
	Si SiO_4^{4-} silic**ate**	P PO_4^{3-} phosph**ate**	S SO_4^{2-} sulf**ate**	Cl ClO_3^- chlor**ate**
		As AsO_4^{3-} arsen**ate**		Br BrO_3^- brom**ate**
				I IO_3^- iod**ate**



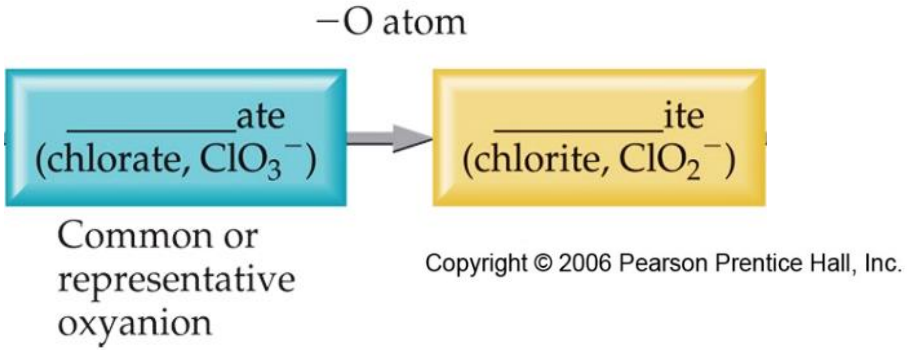
"-ate" ions with **4 oxygen atoms**

"-ate" ions with **3 oxygen atoms**

Naming Additional Oxoanions

Once you know the "-**ate**" oxoanion for each element, you can figure out the name or formula for any additional oxoanions the element forms.

- Many elements form an oxoanion with **one fewer oxygen atom** than the **–ate** ion. To name these oxoanions, we change the suffix to **–ite**.



sulf**ate** SO_4^{2-}

sulf**ite** SO_3^{2-}

Note: The **charge** remains the **same**, even though the number of oxygen atoms changes.

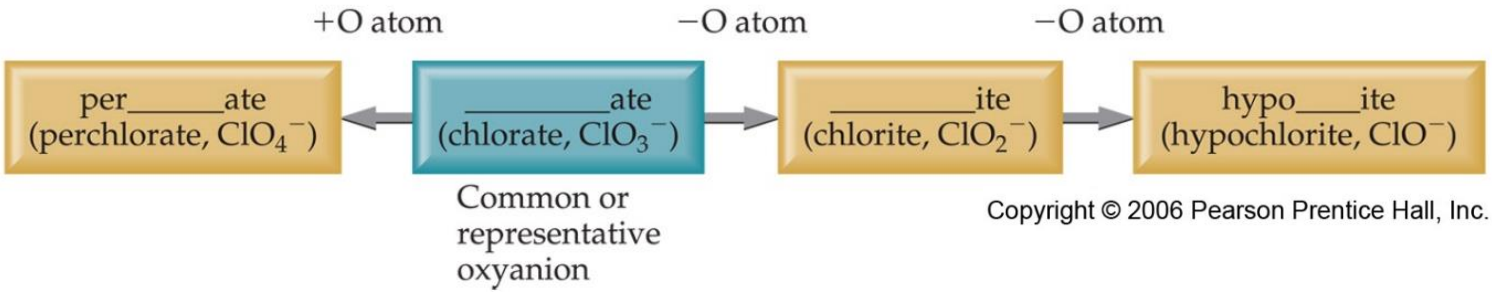
Naming Additional Oxoanions

The halogens Cl, Br, and I can form even more oxoanions:

- **1** oxygen **more** than **ate** → add prefix **per**
- **2** oxygens **less** than **ate** → change suffix to **ite** and add prefix **hypo**

period**ate**	IO_4^{1-}
iod**ate**	IO_3^{1-}

perchlor**ate**	ClO_4^{1-}
chlor**ate**	ClO_3^{1-}
chlor**ite**	ClO_2^{1-}
hypochlor**ite**	ClO^{1-}

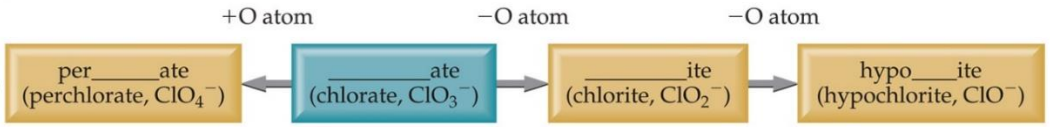


Note: The charge on the ions remains the same within each series.

Summary of Oxoanions

BO_3^{3-} borate	CO_3^{2-} carbonate	NO_3^{1-} nitrate NO_2^{1-} nitrite	O	F
	SiO_4^{4-} silicate	PO_4^{3-} phosphate PO_3^{3-} phosphite	SO_4^{2-} sulfate SO_3^{2-} sulfite	
		AsO_4^{3-} arsenate AsO_3^{3-} arsenite		BrO_3^{1-} bromate
				IO_4^{1-} periodate IO_3^{1-} iodate

ClO_4^{1-} perchlorate
ClO_3^{1-} chlorate
ClO_2^{1-} chlorite
ClO^{1-} hypochlorite



Oxoanions with Hydrogens

Some oxoanions can also include a hydrogen atom:

CO_3^{2-} carbonate + H^+ → HCO_3^- hydrogen carbonate *(or bicarbonate)*

Notice that the addition of one hydrogen reduces the negative charge by $1e$

For these anions, we just include the word "hydrogen" at the beginning of the name. (Dihydrogen for two hydrogen atoms.)

HCO_3^-	*hydrogen carbonate
HSO_4^-	hydrogen sulfate
HSO_3^-	hydrogen sulfite
HPO_4^{2-}	hydrogen phosphate
$H_2PO_4^{1-}$	dihydrogen phosphate

*Note : HCO_3^- is also known as bicarbonate, but the proper IUPAC name is hydrogen carbonate.

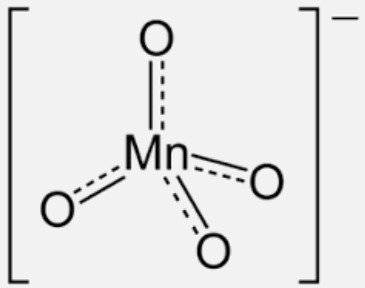
Transition Metal Oxoanions

Polyatomic oxoanions formed with transition metals **do not** follow the same naming patterns as the main-group oxoanions discussed previously.

- There are only a few transition metal oxoanions you need to know:

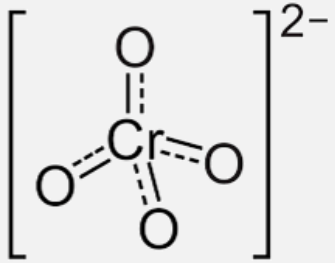
permanganate

MnO_4^-



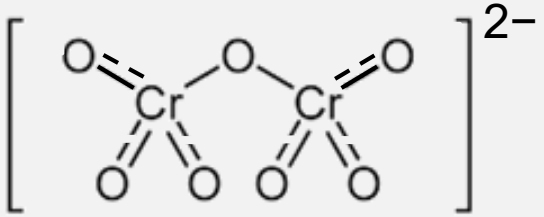
chromate

CrO_4^{2-}



dichromate

$Cr_2O_7^{2-}$



You don't need to know the structures, they're only here to help you remember the formulas.

Summary of Polyatomic Ions

Name	Formula	Name	Formula	Name	Formula
mercury(I) *(mercurous)*	Hg_2^{2+}	carbonate	CO_3^{2-}	arsenate	AsO_4^{3-}
		hydrogen carbonate	HCO_3^-	arsenite	AsO_3^{3-}
ammonium	NH_4^+				
		nitrate	NO_3^-	perchlorate	ClO_4^-
peroxide	O_2^{2-}	nitrite	NO_2^-	chlorate	ClO_3^-
				chlorite	ClO_2^-
hydroxide	OH^-	silicate	SiO_4^{4-}	hypochlorite	ClO^-
cyanide	CN^-	phosphate	PO_4^{3-}	bromate	BrO_3^-
thiocyanate	SCN^-	hydrogen phosphate	HPO_4^{2-}		
		dihydrogen phosphate	$H_2PO_4^-$	periodate	IO_4^-
formate	CHO_2^-	phosphite	PO_3^{3-}	iodate	IO_3^-
acetate	$C_2H_3O_2^-$				
oxalate	$C_2O_4^{2-}$	sulfate	SO_4^{2-}	chromate	CrO_4^{2-}
		hydrogen sulfate	HSO_4^-	dichromate	$Cr_2O_7^{2-}$
borate	BO_3^{3-}	sulfite	SO_3^{2-}		
		hydrogen sulfite	HSO_3^-	permanganate	MnO_4^-

You should now be able to use patterns in the periodic table to help you remember these polyatomic ions.

Practice Problem Set 2

Write the name or formula of the following compounds:

a) calcium carbonate _____

b) $Al(H_2PO_4)_3$ _____

c) ammonium dichromate _____

d) Hg_2SO_4 _____

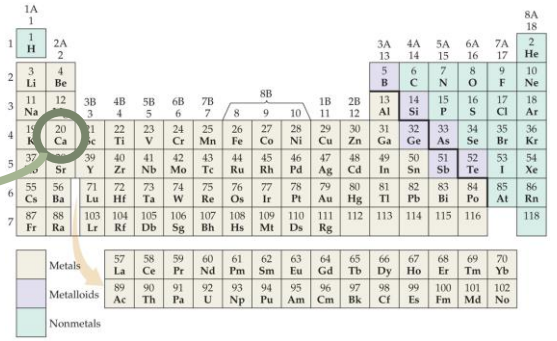
Practice Problem Set 2a Solution

Write the formula for calcium carbonate.

Step 1: Identify the cation.

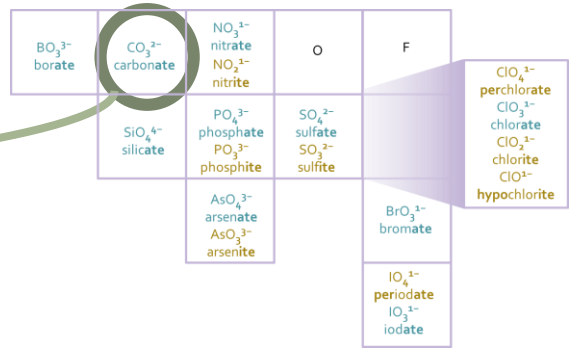
Since calcium is in Group 2, it will have a 2+ charge.

Ca^{2+}



Step 2: Identify the polyatomic anion.

CO_3^{2-}
carbonate



Step 3: Balance the charges.

Ca^{2+} CO_3^{2-}

$Ca_2(CO_3)_2$

Step 4: Simplify.

$\boxed{CaCO_3}$

Practice Problem Set 2b Solution

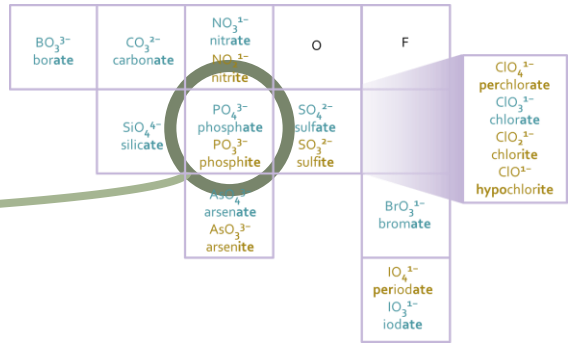
Write the name for $Al(H_2PO_4)_3$

Step 1: Name the cation.

Al^{3+} aluminum

Step 2: Identify the polyatomic ion.

PO_4^{3-}
phosphate



plus two hydrogen atoms:

$H_2PO_4^{-1}$ dihydrogen phosphate

Step 3: Write the compound name.

aluminum dihydrogen phosphate

Practice Problem Set 2c Solution

Write the formula for ammonium dichromate.

Step 1: Identify the polyatomic cation.

ammonium NH_4^+

Step 2: Identify the polyatomic anion.

dichromate $Cr_2O_7^{2-}$

Step 3: Balance the charges

Step 4: Simplify. $(NH_4)_{\mathbf{2}}(Cr_2O_7)_{\mathbf{1}}$

$\boxed{(NH_4)_2Cr_2O_7}$

Practice Problem Set 2d Solution

Write the name of Hg_2SO_4

Step 1: Identify the ions present.

Because mercury forms more than one cation, identify the anion first.

SO_4^{2-} sulfate

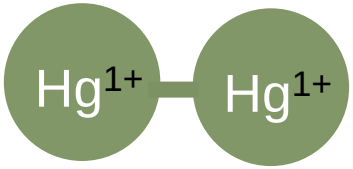
We know that there is one SO_4 ion that has a -2 charge.

Therefore the cation must have a +2 charge to make the compound neutral.

Note that the Hg_2 represents the **two covalently bound** mercury atoms

Hg_2^{2+} mercury (I)

mercury(I)



Step 2: Write the compound name.

mercury(I) sulfate
mercurous sulfate

More Examples - Ionic Compounds with Polyatomic Ions

Formula	Name of Cation	Name of Anion	Stock System	Classical System
$NiSO_4$	(Ni^{2+}) nickel(II), *nickelous*	sulfate(SO_4^{2-})	nickel(II) sulfate	*nickelous sulfate*
$Ni_2(SO_4)_3$	(Ni^{3+}) nickel(III), *nickelic*	sulfate(SO_4^{2-})	nickel(III) sulfate	*nickelic sulfate*
$(NH_4)_2HPO_4$	(NH_4^+), ammonium	hydrogen phosphate(HPO_4^{2-})	ammonium hydrogen phosphate	*ammonium hydrogen phosphate*
$Al(CH_3COO)_3$	Al^{3+}, aluminum	acetate(CH_3COO^-)	aluminum acetate	*aluminum acetate*
$Hg_2(NO_2)_2$	(Hg_2^{2+}) mercury(I), *mercurous*	nitrite(NO_2^-)	mercury(I) nitrite	*mercurous nitrite*
$Hg(NO_2)_2$	(Hg^{2+}) mercury(II) *mercuric*	nitrite(NO_2^-)	mercury(II) nitrite	*mercuric nitrite*

Exercise 1

Give the names or formulas of the following ionic compounds with polyatomic ions. If a compound can be named by both the Stock and the Classical systems, provide both names.

1. $CaSO_3$
2. $NaHCO_3$
3. $Hg_2(NO_3)_2$
4. $Hg(NO_2)_2$
5. $Cu(CH_3COO)_2$
6. $Ba(SCN)_2$
7. $Na_2Cr_2O_7$
8. calcium phosphate
9. cuprous sulfite
10. ammonium nitrite
11. ferrous dihydrogen phosphate
12. barium cyanide
13. potassium permanganate
14. plumbous carbonate

If you feel you have mastered the objectives of this module, please obtain a posttest from the Science Learning Center personnel.

If you don’t feel comfortable with polyatomic ions, please work through the module again, or request assistance from the SLC staff!

Exercise 1 - Key

Give the names or formulas of the following ionic compounds with polyatomic ions. If a compound can be named by both the Stock and the Classical systems, provide both names.

1. $CaSO_3$ — calcium sulfite
2. $NaHCO_3$ — sodium hydrogen carbonate or sodium bicarbonate
3. $Hg_2(NO_3)_2$ — mercurous/mercury(I) nitrate
4. $Hg(NO_2)_2$ — mercuric/mercury(II) nitrite
5. $Cu(CH_3COO)_2$ — cupric/copper(II) acetate
6. $Ba(SCN)_2$ — barium thiocyanate
7. $Na_2Cr_2O_7$ — sodium dichromate
8. calcium phosphate — $Ca_3(PO_4)_2$
9. cuprous sulfite — Cu_2SO_3
10. ammonium nitrite — NH_4NO_2
11. ferrous dihydrogen phosphate — $Fe(H_2PO_4)_2$
12. barium cyanide — $Ba(CN)_2$
13. potassium permanganate — $KMnO_4$
14. plumbous carbonate — $PbCO_3$